WORLD SUSTAINABLE BUILDING 2014
BARCELONA CONFERENCE

Sustainable Building: RESULTS
Are we moving as quickly as we should?
It's up to us!

CONFERENCE PROCEEDINGS
VOLUME 2

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The Conference was organised by GBCe (Green Building Council España), co-promoted by iiSBE, UNEP-SBCI, CIB and FIDIC, and counted on the participation of World GBC*.

This volume gathers papers from the Conference area "Creating New Resources", presented at World SB14 Barcelona on the morning of day 2 of the Conference. All the papers in this volume were double blind peer reviewed by the Scientific Committee of World SB14 Barcelona.

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***iiSBE:** International Initiative for a Sustainable Built Enviroment
UNEP-SBCI: United Nations Environment Programme - Sustainable Buildings and Climate Initiative
CIB: Conseil International de Batîment
FIDIC: International Federation of Consulting Engineers
World GBC: World Green Building Council

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Session 47:

Is embodied energy in materials the barrier to achieve ZEB? If so, how can we overcome it?

Chairperson:

Tenorio, José Antonio

Responsable de la Unidad de Calidad en la Construcción. Instituto de Ciencias de la Construcción Eduardo Torroja. CSIC

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Sustainability and Building Materials within BNB[1] – Evaluation, Tools and Database

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Abstract: *Due to the growing activities in the field of sustainable construction the consideration of possible environmental and health relevant impacts of building materials gains in importance. Wihtin the German assessment system for sustainable construction for federal buildings (BNB), building materials are not evaluated as such but in the context of their application within the building regarding all relevant requirements, e. g. ecological, economical and technical.*

The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) offers different tools for the evaluation of these aspects. Within this paper the environmental impact of building materials on ground water, air pollution or soil is regarded, and also health relevant aspects. The website WECOBIS is intended for planners and architects and provides a tool for selecting suitable building materials regarding environmental and health relevant issues. WECOBIS is provided by BMUB in cooperation with the Bavarian Chamber of Architects (ByAK). It is maintained by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), a research Institution under the portfolio of BMUB.

Life cycle assessment and its tools within BNB are explained in another paper of this conference; see "Life Cycle Assessment within BNB - Online Tool eLCA and building materials database ÖKOBAU.DAT" [1].

Sustainability, Building Materials, Life Cycle Assessment, WECOBIS, Health,Environment

Introduction

Due to growing activities in the field of sustainable construction the consideration of possible environmental and health relevant impacts of building materials gains in importance. Even the European Construction Products Regulation (CPR) addresses now sustainability aspects and resource efficiency. Due to these developments it is often asked for so-called ecological or sustainable building materials. The philosophy of BNB is not to evaluate building materials as such but in the context of their application within the building regarding all relevant aspects, i.e. ecological, economical and technical requirements. Hence, building materials are regarded within different sustainability criteria.

In a former paper of SB 13 the philosophy of evaluating building materials within BNB was explained [2]. In another paper of this conference life cycle assessment within BNB is explained [1]. Hence, within this paper the environmental impact of building materials or its contents on ground water, air pollution or soil is regarded, and also health relevant aspects.

[1] BNB – German assessment system for sustainable construction for federal buildings

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BMUB offers different tools for the evaluation of these aspects. The website WECOBIS (www.wecobis.de) provides a meaningful help which provides free and comprehensive information on environmental and health-relevant aspects of building materials for different life cycle phases.

Within myWECOBIS selected information of WECOBIS can be organised for individual projects and individual documents can be added. Also, help for (public) tendering which takes into account specific environmental aspects are given by WECOBIS.

Product specific information is organized in a specific tool, also used within BNB, which complies with WECOBIS.

WECOBIS – structure and content

WECOBIS is intended for planners and architects. With WECOBIS the German federal government offers comprehensive basis information on building materials, which is not product or producer specific. A team of experts from Universities, or other specialised scientific Institutions and also practical experience contributes and continuously revises the contents of WECOBIS. Furthermore, a scientific committee gives advice on strategic development of contents, cooperation, research projects, and the like.

WECOBIS provides, in a very structured way, helpful information for selecting suitable building materials and products regarding environmental and health relevant issues (Fig. 1). Typically, in the planning stage, the user can find out if there are possible health and evironmental aspects for the considered material/product group which could be relevant within the different life cycle stages.

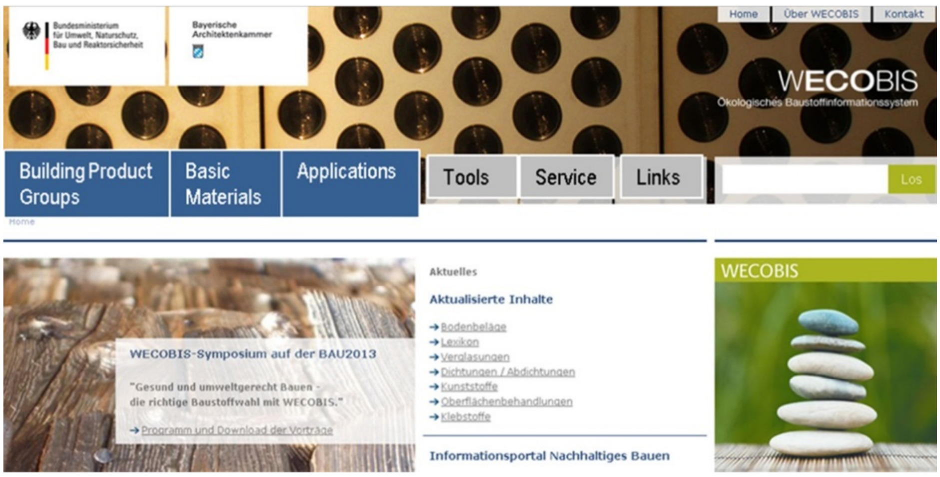

Figure 1: WECOBIS. German web based information system for health and environmental aspects of building products. ***www.wecobis.de***

The following material groups are considered:

- **Building product groups**, i.e. wallcladdig / flooring / insulation / seals / timber and derived timber products / adhesives / solid construction materials / mortar and screed / surface treatment materials / glazing;
- **Basic construction material**, i.e. binder / aggregates / plastic / metal.

These main material groups comprise further sub-groups, which finally lead to a "data sheet" of a more specific material group. For example, for the main group adhesives the following sub-groups are given: dispersions / epoxies / pastes / solvents / polyurethane. These data sheets are structured in two basic information blocks, i.e. technical information and life cycle, with subsequent detailed information on the following subjects:

- **Technical information**, i.e. general / tendering / marks and labels / technical specification / literature
- **Life cycle**, i.e. raw materials / production / construction / use / re-use

Users can choose amongst 190 different data sheets. As an example, Fig. 2 shows information within the block 'life cycle' for the life cycle stage 'raw material', for PVC-flooring.

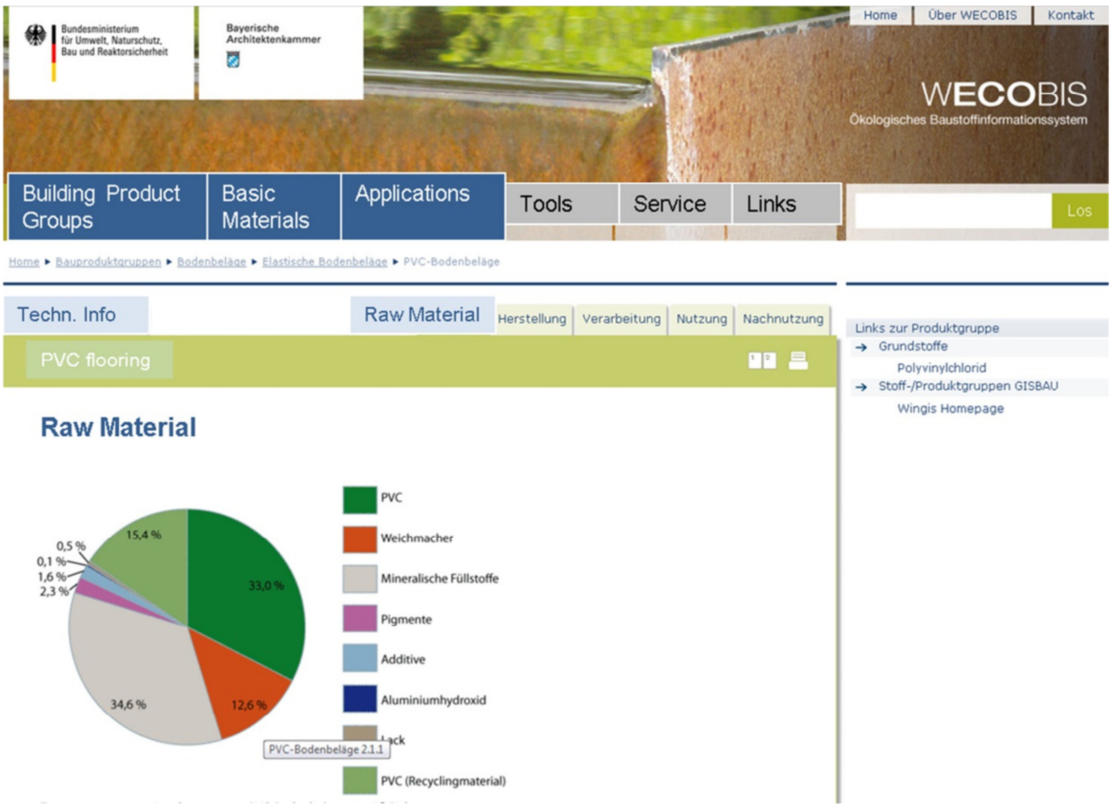

Figure 2: Screenshot – Life cycle / raw materials (PVC-flooring)

As userfriendliness is one of the important aspects of WECOBIS, a multiscreen view allows a direct comparison of two data sheets (Fig. 3). With this help, it is easy to find out if two different products groups imply the same health risks or not.

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Figure 3: WECOBIS multiscreen with comparison of two product group datasheets (insulation EPS and XPS)

WECOBIS will inform the user about which products are in the market and which relevant health and environmental aspects are relevant for different life cycle stages. The user will also find out, that here might be a wide range of products, some with more or less significant impacts. Further links show where more detailed and also product specific information can be found. Hence, WECOBIS is an important tool with basic information for decisions within the planning processes. Still, it does not replace the planners task to inform himself and finally decide about the produtcs to be used for construction. It shows which information is relevant within a product group, at which life cycle phase, which aspects might be relevant and where detailed information is to be found.

myWECOBIS for planning processes

WECOBIS does not only offer comprehensive information in a structured and userfriendly way, it furthermore offers a planning tool for real planning and construction projects. In myWECOBIS (Fig. 4) the user can organize information found in WECOBIS in such a way, that for chosen materials and construction elements (which individually can be created) information can be collected in the given scheme of technical and life cycle information with its sub-groups. In a very helpful way, individual comments, fotos or other documents, e. g. product specific documents, can be uploaded and filed. Certain templates, appropriate for BNB evalutations, will be given. Anyhow, within the templates one can structure the projects in reference to a building project or construction elements. An output of myWECOBIS can be a zip.file and/or a report (pdf.file), useful for project meetings and other working progress (Fig. 4).

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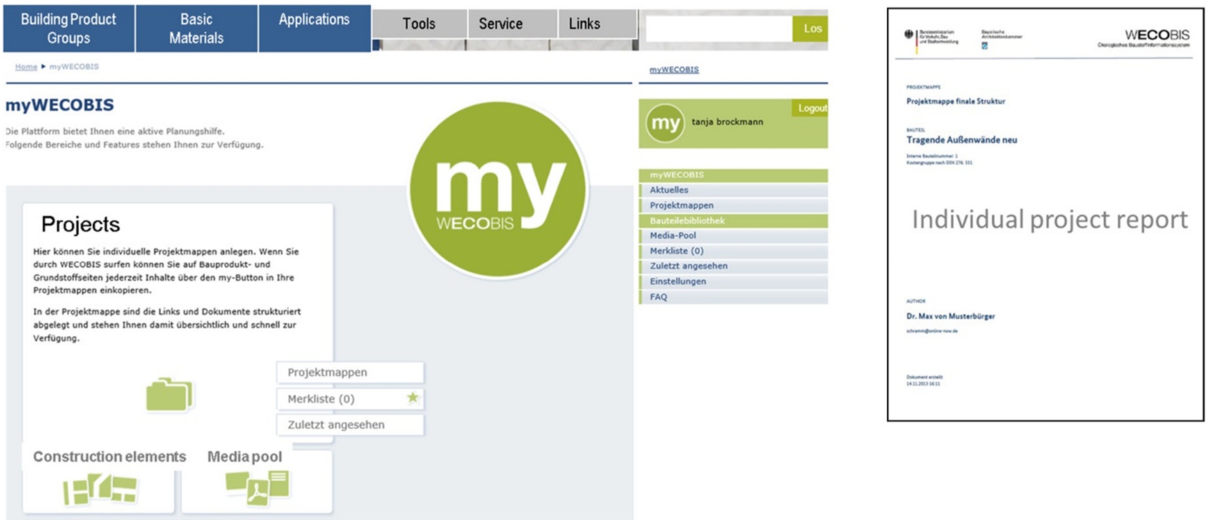

Figure 4: MyWECOBIS – homepage (left); report as output of myWECOBIS (right)

Help for planning and tendering

For the practical process of planning and building a construction the contents of public and private tendering can be decisive. The idea of sustainable building is established by now in general. Nevertheless, even though the application of BNB to federal buildings is compulsory (by several decrees issued by BMUB), it is still not brought into praxis in a satisfying way. Especially, in the context of sustainable buildings in (public) tendering the idea of using building materials which are suitable regarding health and environmental impacts (for example hazardous ingredients, possible emissions relevant for different life cycle stages) is not well integrated in the processes yet. Often, the planners or institutions responsible for tenderings stick to used procedures and have in mind well-known products only. Often, there is a lack of knowledge about building products, their impacts on health and environment and evaluation. Sometimes, it is not even known which aspects might be relevant and regarded within a tendering. Here, WECOBIS offers a good help with many tables for each product group which shows which product groups are suitable with respect to the different quality standards within BNB (especially sustainability criterion 'Risks to the local environment' 1.1.6). These tables show, which copound within different product groups might be relevant regarding different applications as well as life cycle stages. Furthermore, other tables show if there are alternative products within a product group. All these information is a good help, to inform and alert about possible impacts, but the planner will not find complete formulated tenderings and templates – it will still be the planner's responsibility to evaluate and choose bulding products in the complex context of the building, regarding all relevant sustainability aspects, as ecological, economical and technical aspects.

All described features above are useful in general for everybody planning and choosing building materials for constructions. Furthermore, WECOBIS gives information especially relevant for BNB. Building materials are evaluated within several sustainability criteria. Important global environmental contributions which cause e.g. global warming, smog,

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eutrophication, acid rain, are calculated by LCA using ÖKOBAU.DAT. Hence, WECOBIS offers links to relevant webpages for environmental products declarations or to ÖKOBAU.DAT.

Further sustainability criteria of BNB are related to ‘dismantling, separation, and utilisation’ (4.1.4) and ‘indoor air quality’ (3.1.3). In its data sheets WECOBIS gives as much information as possible directly related to these sustainability criteria as evaluated within BNB. Tables are provided showing which product groups may fulfill different quality levels of BNB.

The criterion ‘risks to the local environment’ (1.1.6) is of high importance for the suitable choice of builing materials when a construction is certified according to BNB (Fig. 5). But what does the reduction of ‘risks to the local environment’ mean for a BNB planning processes? On one hand side, a sustainable planning must give answers about the deposition of substances of very high concern, dangerous substances, voltaile organic compounds from products, mobile heavy metals, biocides and refrigerant fluids with halogenated hydrocarbons.

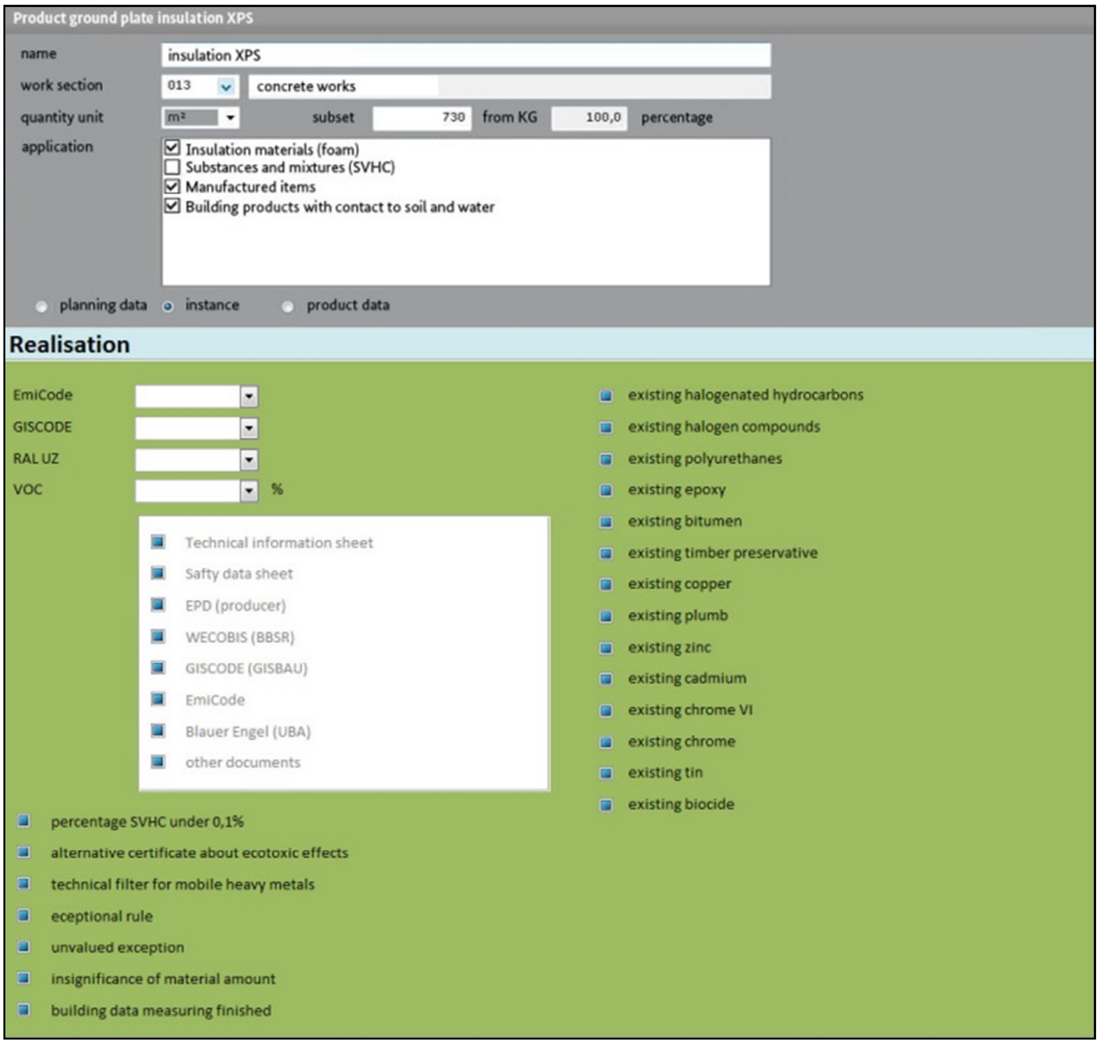

Figure 5: Software tool for estimations in BNB criterion 1.1.6 Risk for the local environment

All these dangerous substances are adressed in european directives and regulations (e.g. REACH, CLP) or national documents, but a comprehensible assessment method is needed. As a consequense of the different discussions, the BBSR has designed a prototype of software - the BNB_1_1_6-Tool - for an estimation of defined quality levels for risks to the local environment (Fig. 5).

Summary

Within BNB the choice of building materials has a significant influence on the evaluation of the building regarding sustainability. Building products are not assessed as individual products, but looked at within the context of the entire building. The properties of building products play a role in all areas of sustainability: Ecological Quality (life cycle assessment, environment, and health), Economic Quality (life cycle costs), Socio-Cultural Quality (e.g., indoor air quality), Technical Quality and Process Quality. The German federal government requires sustainable constructions and hence, offers a comprehensive certification scheme with many useful evaluation tools. All these are free of charge and offered to the public, and hence may be used for any projects. Life cycle assessment and its tools are described in [1]. Regarding local environmental and health relevant impacts the website WECOBIS offers a very well structured and comprehensive basis of information on building materials. It allows organising and structuring information for individual projects in myWECOBIS and furthermore gives userfriendly help for tendering and planning processes. The information is directly linked to BNB criteria, but is also relevant for any interested user.

In summary, it can be seen that the German government acts as antetype to plan and construct its buildings in a mostly sustainable way.

[1] Brockmann, T.; Kusche, O.; Rössig, S. (2014). *Life Cycle Assessment within BNB - Online Tool eLCA and building materials database ÖKOBAU.DAT*. SB 14, Barcelona.

[2] Brockmann, T. (2013). *Ecological Aspects of Building Materials within BNB (Assessment System for Sustainable Buildings for Federal Buildings)*, SB 13 Munich.

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Design strategies for low embodied energy and greenhouse gases in buildings: analyses of the IEA Annex 57 case studies

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Abstract:
This paper introduces the IEA Annex 57 case study method, consisting of a format for describing individual case studies and an evaluation matrix covering all case studies. Sample case studies are used to illustrate the method and the evaluation matrix through a first preliminary analysis. In compiling and evaluation existing, transparent case studies we have taken a stakeholder perspective. By so doing it is intended to identify fordecision makers the key issues affecting EE/EC in buildings. Analysis in this paper focuses on one of the six case study themes, building design strategies for EE/EC mitigation and references cases covering e.g. material selection, building shape, construction stage strategies and strategies to handle the trade-off between embodied and operational impacts in net-zero emission building design.

Design strategies, embodied energy, embodied greenhouse gases, case studies, IEA Annex 57, LCA, buildings

Introduction

Participants from nearly 20 countries world-wide are working on IEA Annex 57 '*Evaluation of Embodied Energy and Carbon Dioxide Emissions for Building Construction*. The annex aims to provide stakeholders with detailed information as well as guidelines on calculation methodologies, databases and methods for design and construction of buildings with low embodied energy (EE) and embodied greenhouse gas emissions (EC).

So far, environmental strategies and policies for the built environment have mainly focused on energy use and environmental impact from the use of buildings. However, the interest in other building life cycle stages has recently increased substantially. The development of passive or net-zero energy/emissions buildings, amongst others, imply a trend-shift in overall life cycle impacts from operational energy to impacts embodied in building material and construction, see e.g. [1, 2]. A growing share of embodied impacts calls for a new focus in energy and climate change mitigation.

One of the methods used by Annex 57 is the compilation and evaluation of case studies, with the aim of pointing decision makers at the key issues which influence the reduction of EE/EC in buildings. This paper introduces the Annex 57 case study method, consisting of a format for describing individual case studies and an evaluation matrix covering all case studies. Example case studies are used to illustrate the method and the evaluation matrix, through a first preliminary analysis. The analysis focus on a few specific measures falling within one of the themes of the case studies, *strategies for reduced EE/EC* in buildings.

Definitions and clarifications

The term *embodied* has been used in different ways in literature and with varying system boundaries in LCA case studies. Chosen boundaries may include only the product stage A1-3, both the product and construction stage A1-5 or even including end-of-life stage C1-4 with reference to the modules in EN 15978 [3]. In a forthcoming report, Annex 57 will provide recommendations on the definition of EE and EC in terms of included life-cycle stages. In the meantime, sample case studies discussed in this paper also use slightly different system boundaries in terms covered life-cycle stages.

Case study method

To provide a comprehensive and transparent analysis, a case study matrix was set up consisting of six themes and a number of stakeholder-types , Table 1. The themes allow a thorough analysis of different perspectives regarding EE/EC of buildings. Partners of Annex 57 and external partners were invited to submit case studies targeting one or more themes and stakeholders. The division of case studies by stakeholder interest was to contribute to development of practice by addressing issues of concern to different groups of actors.

Table 1. Themes and targeted stakeholders of the Annex 57 case study matrix, showing case studies analysed in this paper.

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Themes / Targeted stakeholders	National gov./policy	Local gov./planning	Designers/ consultants	Developers/ contractors	Clients/owners	Manufacturers
1. Strategies for reduced EE/EC	UK2, 9	UK2,4, 9 SE1	DK1-2 NO1 SE1-2 UK2-5,7,9 CH1-2 KO3 AT1-2	UK2-5, 9	SE1-2 UK4	DK1 NO1 K3
2. Significance of different factors over the full life cycle						
3. Impacts of calculation method and system boundaries						
4. Reduction strategies, significant factors and calculation of EE/EC for building components and construction materials						
5. Reduction strategies, significant factors and calculation of EE/EC for building sector at national level						
6. Integration of EE/EC calculations in decision making processes						

The six themes are as follows:

1. Strategies for reduced EE/EC. The theme involves in particular calculations case studies showing the potential for reducing the embodied impact of buildings through different design strategies, such as the selection of construction materials, flexibility and design for recyclability.

2. Significance of different factors over the full life cycle. Case studies typically including full life cycle impact calculations of buildings, displaying for example the significance of different life cycle stages/processes or significance of different building elements with regard to contributions to the whole life cycle impact.

3. Impacts of calculation method and system boundaries. This theme also typically include LCA case studies of buildings. However, the perspective is rather how methodological choices may affect calculation results and conclusions regarding significant contributors, such as the ones discussed under theme 2. Examples of important methodological choices in relation to EE/EC include length of the reference study period, completeness of building data, future energy scenarios, and source of data.

4. Reduction strategies, significant factors and calculation of EE/EC for building components and construction materials. Case studies with the building component and/or material as the object of study. This is to enable a discussion concerning EE/EC reduction strategies at building component level such as traditional materials vs. emerging state of the art materials or improved production processes for concrete products etc.

5. Reduction strategies, significant factors and calculation of EE/EC for building sector at national level. Case studies illustrating implications regarding EE/EC at the national level and

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may concern national strategies for reduction of EE/EC or calculations of EE/EC at national level, etc.

6. Integration of EE/EC calculations in decision making processes. Case studies which mainly address decision making processes to provide examples of how EE/EC calculations were integrated into the building design process or e.g. to provide real-life examples of ways to promote life cycle considerations by different stakeholders.

A case study template, incorporating a structure for details of calculation procedures, data used, system boundaries, etc. was designed to be used for all case studies, to promote better documentation and transparency. A case study call was launched in June 2013 and to date we have received 20 completed templates and an additional 50 offers of case studies to be analysed and included in the case study report of the Annex 57.

Case study evaluation matrix

The case studies are organised into an *evaluation matrix* based on themes and stakeholders as in Table 1, but also on additional detailed information, such as building type, location and key issues. Table 2 shows the more detailed (preliminary) evaluation matrix focusing on theme 1 case studies studied in this paper. The evaluation matrix facilitates for interested stakeholders to find relevant case studies for specific questions of interest to them. Most of the cases found in Table 2 include new buildings complying with energy standards in national building Codes or to passive house standard. However, to find examples of refurbishment and very high energy standard projects, like plusenergy or NZEB concepts, may also be of interest to stakeholders (see separate columns in Table 2).

Table 2. Preliminary case study evaluation matrix –exemplified by Theme 1 case studies studied in this paper.

Project type Strategies / measures	Residential – multifamliy	Residential – single family	Office	School		Refurbished building	NZEB
Choice of materials for load bearing structure	SE1-2 UK7,UK9 AT2 CH1-2	NO1 UK5	DK1	UK4		AT1 UK2	NO1
Use of recycled materials	SE2	DK2	KO3				
Choice of material type in facades	AT2	UK5		UK4		AT1	
Building shape	SE2 CH2						
Use of local materials	CH1			UK7			
Construction process	UK3	UK5		UK4			
On-site energy production	AT2	UK2				AT1 UK2	NO1

Table 3. Brief description of case studies included in the paper. NO=Norway, DK=Denmark, SE=Sweden, UK=United Kingdom, AT=Austria, CH=Switzerland, KO=South Korea. References in bracket.

No	Description

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NO1 [4]	Zero emission (GHGs) concept single family building
DK1 [5]	LCA of a new headquarter office building with loadbearing structure in concrete
DK2 [6]	Exploratory comparative LCA of single family building with load bearing structure of shipping containers compared with a standard masonry building
SE1 [7]	LCA in early design of new, quite typical, multifamily building with load bearing structure in timber compared with concrete
SE2 [8]	LCA in early design of a new multifamily building complying with Nordic passive house standard comparing load-bearing structure (2 timber alternatives and one concrete), building form (square and rectangular) and use of recycled aluminium in roof
UK2 [9]	Simple renovation of terraced single family buildings
UK3 [10]	Investigation of energy use and carbon emissions, water and waste during the construction stage of 11 housing developments
UK4 [11]	New build near-passivhaus standard school building in the UK, constructed of timber and low carbon materials
UK5 [12]	EC and EE analyses up to end of construction of new build social housing, comparing a timber clad timber framed house with a brick clad timber-framed and a standard UK brick and block construction.
UK7 [13]	A comparison of two alternative structural designs for a school sports hall – steel framed with blockwork walls, and cross-laminated timber.
UK 9 [14]	A simplified analysis of EC/EE for a cross-laminated timber eight-storey residential building in London produced by the developers in order to demonstrate the potential carbón savings
KO3 [15]	LCA study of four-storey concrete/steel office building using slag-based concrete, re-used steel and a high proportion of renewable energy for operation. Compared with a reference building.
AT1 [16]	Plusenergy, refurbishment of multifamily building; Optimisation strategies for reaching plus-energy standard by the use of prefabricated wood elements for refurbishment
AT2	Passive house with plus-energy concept, new multi-family residential building; Prefabrication technology of wood housing (cross laminated timber) for wall- and floor elements.
CH1[17]	Multifamily building, hybrid construction (mainly made of wood, with concrete elements as thermal mass); utilization of local wood products.
CH2[17]	Multifamily building, massive construction (mainly made of reinforced concrete, masonry and steel); high insulation standard (25-35 cm).

Case study examples illustrating the use of the evaluation matrix

In this section, we illustrate how the evaluation matrix (as elaborated in general in Table 1 and in detail in Table 2) can be used to find cases providing information of interest to different stakeholders. In addition, results regarding design and construction strategies for low EE/EC are discussed based on an initial analysis of the cases in Table 3.

Cases illustrating individual design and construction strategies

As shown in Table 1, there are a considerable number of Theme 1 case studies that provide information of interest for *building designers and consultants*. As seen in Table 2, a majority of these consider the selection of load-bearing structure. Initial analysis of the case studies suggests that concrete is likely the most significant single material in terms of its contribution

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to EE/EC. This is understandably so for cases with concrete loadbearing structures, e.g. DK1. Meanwhile, since it is used in foundations even for timber buildings concrete also produces a significant impact also in timber alternatives like in UK5 and AT2. The case studies show therefore that mitigating EE/EC due to concrete is a major cross-cutting issue where design strategies may contribute. The choice of load-bearing structure is one key design strategy and Tables 2-3 provide five cases where the use of timber is compared with non-timber solutions. Initial analysis of these cases shows that four of the studies (SE1-2, UK5, UK9) demonstrate a clear advantage for timber structures in terms of EC and EE (where considered). The other study (UK7) shows a slight advantage for the steel structure in terms of EE and a slight advantage for timber in terms of EC. This latter study also considers impacts from end-of-life treatment (assuming combustion for wood and recycling for steel). Taking this into consideration timber is shown to be preferable over the lifetime for both EE and EC. However the assumptions made for end-of-life treatment may be contentious. The comparison presented here suggests that it is important to further analyse system boundaries and assumptions in the case studies to provide clearer advice to practitioners. For a variety of reasons, the use of timber is very rare in high-rise buildings. Therefore the case UK9 is particularly interesting since it presents the use of cross-laminated timber in an eight-storey building.

Use of recycled materials as mitigation strategy is for example dealt with in KO3, a standard high-rise steel/concrete office building where steel beams and plates were reused and slag was mixed with concrete. Data shows that these measures combined to reduce EC by 25 % compared with a reference case. Meanwhile, the case DK2 takes an exploratory approach with the very concept “Upcycle”, where materials to the extent considered possible are recycled or reused. This approach reduced EC by over 80 % and EE by nearly 70 % compared to a reference masonry house. Though small in terms of mass, SE2 showed that using recycled as opposed to primary aluminium as a roofing material could reduce EC by as much as 9 %.

Meanwhile UK5 compares the use of a wooden vs. brick façade, finding EC and EE to be higher by as much as 30 % and 40 % respectively for the brick alternative. In CH1-2 it was observed that the material for the main construction in combination with the insulation materials cover a major part of the overall EC/EE for the building’s whole lifetime.

Further building-level cases give examples of other strategies. For example SE2 considers two different floor plans for multifamily residential buildings. The findings show that the EC follows the ratio between floor area and building surface area fairly closely. This yields a reduction of around 5 % between a rectangular and square floor plan in this case.

Finally, the case studies UK3-5 in contrast to most other cases within Theme 1, include a focus on the construction stage and are thus of particular interest for contractors. UK3 presents the energy, carbon, water and waste of the construction stage of 11 housing developments in the UK, showing a large variation in the impact of these developments. One important variable affecting the carbon emissions is the type of energy used and whether construction takes place during the heating season. Other aspects that seem to contribute to the variation include building form and extent of off-site prefabrication of building elements (in particular UK5) since this, in turn, affects the construction waste volumes.

Net Zero Emission Building (NZEB) design strategies

As seen in Table 2, a few case studies target NZEB buildings. Again, these case studies target primarily designers who can get useful insights into key challenges regarding building design to reduce and balance the EE/EC with the energy produced on-site. The Norwegian case study NO1 presents the development of an NZEB conceptual design and investigates whether it was possible to achieve NZEB by counterbalancing emissions from the energy used for operation and EC from materials with those from on-site renewables in the cold climate conditions of Norway. The main result shows that the criteria for zero emissions in operation is easily met, however, it was found that the use of roof mounted PV production is critical to counterbalance emissions from both operation and materials. Firstly, it was found that the available roof area for PV is insufficient to generate enough electricity. Secondly, the PV panels were accountable for a significant part of the total EC in this case. Thus, the case study illustrates that the efficiency as well as production technology of the PV panels is a crucial challenge in achieving a NZEB building.

In this sense, this case study is also clearly relevant to the stakeholder manufacturers (as seen in Table 2). Other key challenges for manufacturers identified in the case study include mitigating impacts from main EC contributors which was the load-bearing structure and foundation (where concrete dominates) and insulating elements (where EPS and glass wool are used).

The Austrian AT1 case study is also focusing NZEB solutions but is instead an example of a refurbishment of an existing multifamily building to a plusenergy solution. Similarly, the goal of the project was to achieve an operational plus-energy solution without including the embodied energy and emissions to reach net plus-energy after refurbishment. Like in the Norwegian case study, an integrated energy concept with local energy production (HVAC, solar thermal panels, PV, etc.), has been essential to accomplish the plus-energy solution. Key contributors to EE/EC in the refurbishment include the new façade modules (despite the use of timber frame construction) and the installation of new HVAC system. Thus design solutions focussing on these systems need to be worked out to further reduce the total energy use and GWP.

Concluding remarks

Case studies are just what they are, case studies. Conclusions drawn from individual cases are not always relevant in other contexts. In addition, the calculation methodology, system boundaries and the data used have important impacts on the conclusions drawn from individual cases. The value of the compilation structure and presentation of Annex 57 is that heterogeneity of objects of study and methodological choices made between all of the gathered cases becomes transparent and accessible for a wide range of stakeholders and where

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cross-cutting themes can be identified and discussed. The case study catalogue can thus for instance be utilised by designers as a reference for and an overview of good design strategies with regard to reducing a building's environmental impact over its entire lifetime.

Issues developed in the forthcoming IEA Annex 57 case study report include case studies illustrating additional design strategies, for example design for recyclability, design for low maintenance need and design for a long life time. In addition, case studies will be provided from other parts of the world, thus highlighting contextual issues such as local construction practices, use of traditional materials, climatic contexts, etc. Using a systematic case study method as described in this paper will enable this compilation and analysis of case studies concerning EE/EC to provide a useful, comprehensive source for better understanding of different perspectives on EE/EC of use for a wide range of stakeholders.

References

[1] Brown NWO, Olsson S, Malmqvist T. Embodied greenhouse gas emissions from refurbishment of residential building stock to achieve a 50 % operational energy reduction. Build Environ. 2014; in press, accepted manuscript.
[2] Karimpour M, Belusko M, Xing K, Bruno F. Minimising the life cycle energy of buildings: Review and analysis. Build Environ. 2014;73:106-14.
[3] European Committee for Standardisation. EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method. 2011.
[4] Dokka TH HWAA-M, Mellegård S., Georges L, Time B., Haase M., Lien A.G. . A zero emission concept analysis of a single family house. The Research Centre on Zero Emission Buildings (ZEB), Norwegian University of Science and Technology; 2013 (in press).
[5] Nygaard Rasmussen F. Certification of sustainable buildings in a life cycle assessment perspective: Technical University of Denmark; 2012.
[6] Sander E. Reduction of environmental impact of building production by material upcycling: Technical University of Denmark; 2012.
[7] Glaumann M. Enslic case study Sollentuna 2, Sweden. 2010.
[8] Brown NWO. Basic Energy and Global Warming Potential Calculations at an Early Stage in the Development of Residential Properties. Sustainability in Energy and Buildings, SEB'12. Stockholm, Sweden: Springer; 2013.
[9] Sahagun D. Embodied Carbon and Energy in Residential Refurbishment- A Case Study: University of Cambridge; 2011.
[10] Willmott Dixon, Moncaster A, Cook S, Symons K. Case study of the construction stage of 11 housing developments in the UK. 2013.
[11] Gavotsis E. The way forward for practical measurement and reduction of embodied energy and carbon in UK buildings: The case study of St Faith's School: University of Cambridge; 2013.
[12] Monahan J, Powell JC. An embodied carbon and energy analysis of modern methods of construction in housing A case study using a lifecycle assessment framework. Energ Buildings. 2011;43:179-88.
[13] Vukotic L, Fenner RA, Symons K. Assessing embodied energy of building structural elements. Proceedings Of The Institution Of Civil Engineers Engineering Sustainability2010. p. 147-58.

ISBN: 978-84-697-1815-5

[14] Darby H, Elmualim AA, Kelly F. A case study to investigate the life cycle carbon emissions and carbon storage capacity of a cross laminated timber, multi-storey residential building. Sustainable Building Conference, SB13. Munich, Germany2013.
[15] Korea Institute of Construction Technology. The study on GHG reduction and LCA on POSCO GREEN Building, RIST. 2012.

[16] Passer A, Kreiner H, Halder T, Höfler K, E80^3 - A PLUS ENERGY BUILDING CONCEPT FOR EXISTING BUILDINGS, Sustainable Building Conference, SB13 Munich, Germany2013.

[17]John, V. (2012) Derivation of reliable simplification strategies for the comparative LCA of individual and "typical" newly built Swiss apartment buildings. ETH Zurich, Zurich. DOI: http://dx.doi.org/10.3929/ethz-a-007607252.

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Assessment of embodied impacts – Incorporation of the approaches of IEA Annex 57 into the overall context of environmental performance assessment

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Abstract: After decades of focusing exclusively on the use phase, life cycle approaches get more and more attention in design and decision making in the building sector. In this sense, the assessment of embodied impacts is currently in focus as part of the impacts analysed within a life cycle assessment. Such discussions are no longer only part of the scientific debate, but they have now found their way into practice to assist in variant comparisons and investment decisions. Additionally, the availability of data and the development of tools provide new possibilities. Therefore, it is discussed, how the embodied impacts assessment can be part of a comprehensive assessment of the environmental performance, how the indicators and system boundaries can be defined and which actors follow already specific approaches. Results are presented that were developed by the authors as a preliminary work on the currently ongoing project IEA Annex 57.

Embodied environmental impacts, greenhouse gas emissions, embodied energy, cumulative energy demand, environmental performance

Introduction

The efforts undertaken to implement sustainable development principles in the construction and real estate industry have led in recent years to various activities. These include, among others, the further development of design methods and tools, the development and testing of net zero building (NZB) concepts, the use of innovative products and technologies, the development and application of methods of life cycle analysis, the ongoing standardization for sustainability assessment of buildings or the development and application of systems for describing and certifying the sustainability of buildings.

One current trend is the description and assessment of embodied impacts of buildings, representing the energy and mass flows as well as emissions resulting from all the processes related to the production of construction products and the creation, maintenance and end-of-life of the building. This trend has its roots in experiences and results mainly from the 1970's and 80's [1]. Questions concerning the further development, standardization and application of principles related to the description, assessment and influence of the embodied impacts, are the subject of the currently ongoing project, IEA Annex 57 "Evaluation of Embodied Energy

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& Embodied Green House Gas Emissions for Building Construction", in which the authors actively participate.

The various stakeholders/actors involved in the building process have different perspectives on embodied impacts and need to cope with diverse problems within their daily decision-making situations. Some actors (building designers etc.) may have lot of experience for the embodied impacts due to the requirements of sustainable design. On the other hand, some others (e.g. investors) might have limited knowledge of these issues. The discussion of this topic was driven by the increased demand for sustainability assessment of buildings and green public procurement. This fact is also reflected in the literature, where these issues are being integrated more and more into the procurement and practice in comparison to the past.

In this context, it is important to provide a uniform basis for the description and assessment of embodied impacts and place them within the context of environmental performance assessment. In this sense, the objective of this paper is to provide an overview by discussing the following questions:

a) *How are embodied impacts described in the existing life cycle oriented standards (e.g., ISO/TC 59/SC 17, CEN TC 350 etc) and initiatives to assess the cumulative energy demand and carbon footprint?*
b) *Are embodied impacts considered in the design and sustainability assessment?*
c) *What is the current state of data availability, data supply and data quality in selected regions (including Europe, Asia, America)?*
d) *How can and should the transparency and traceability of results related to embodied impacts be improved?*
e) *What is the status of the application by selected groups of actors and what recommendations can be developed?*

Embodied impacts as part of environmental performance assessment

There is a demand to reduce the environmental impacts related to the energy consumption and greenhouse gas emissions (GHG) coming from the building material production, as well as construction, refurbishment and demolition of buildings. These elements make up the "embodied energy" and "embodied GHG emissions" of the building. Within a whole lifecycle approach to dealing with buildings, embodied energy and embodied GHG emissions data can be either used as single indicators, or addressed as part of a wider set of environmental impact indicators. Life Cycle Assessment (LCA) is a methodology used to measure and assess all significant environmental impacts associated with a product, system or service, over its entire life cycle, from extraction of raw materials, through processing, manufacturing, transportation, and use, to eventual disposal or recycling. Therefore, it covers a broad range of environmental issues. Within the context of LCA embodied GHG emissions would normally be expressed as part of the environmental impact category climate change or global warming potential (GWP) and embodied energy would be expressed as a part of the cumulative energy consumption, alongside other environmental indicators (e.g. acidification, eutrophication, etc.). An LCA should be always carried out in accordance with the standards ISO 14040:2006 and ISO 14044:2006.

Considering the current standardization activities also the sustainability assessment of buildings should be based on life cycle thinking. Thus, the current standards elaborated by the ISO TC59 /SC 17 at an international level, and the CEN TC 350 working group at a European level, require Life Cycle Assessments (LCA) to be carried out in the course of a environmental performance assessment as part of sustainability assessment. Within this group of standards the ones including the assessment of embodied energy and embodied GHG emissions in buildings are ISO 21929-1:2011 and EN 15978:2011, while ISO 14025:2006, ISO 21930:2007, and EN 15804:2012 are the ones to be used for calculating the impacts at construction product level and defining environmental product declarations (EPD) based on product category rules (PCR). These standards include a long list of indicators, some of them used for describing environmental impacts and others for describing resource use.

However, some building practitioners and decision makers choose to focus on a single issue rather than a long list of environmental impacts. This single issue is climate change and a great deal of attention has focused on measuring this specific impact using "carbon footprint", as being an easy to understand indicator among stakeholders coming mainly from real estate industry. Different methodologies have begun to emerge to measure a carbon footprint, either at an organisational level or a product level, in a standardised way. Examples include the ISO/TS 14067:2013, Greenhouse Gas Protocol, or the BSI PAS 2050 specific to UK. In this case, "embodied carbon" can be considered as a partial carbon footprint.

Therefore, there are both international and European standards for the assessment of energy consumption and GHG emissions of buildings. The same applies to the production of standardized data and information for construction products. In this regard, these standards can also be applied for determining "embodied energy" as part of the cumulative primary energy demand, and "embodied GHG emissions" as part of the total GWP or carbon footprint. In particular, the uniform basis for the development and publication of environmental product declarations (EPDs) has contributed significantly to the improvement of the data availability for construction products related to "embodied energy" and "embodied GHG emissions". IEA EBC Annex 57 considers both "embodied energy" and "embodied GHG emissions" as important indicators that provide the different stakeholders with useful information to be incorporated into their decision making, as well as a first step into the subject of energy resource use and associated effects on the environment caused by the manufacture, construction and use of buildings. However, for giving a complete picture of the life cycle environmental impacts of a building, these two indicators must be supplemented by others and be part of a full life cycle assessment.

Consideration of embodied impacts in design and sustainability assessment
Architects are increasingly interested in reducing the environmental impacts of the buildings they design. Additionally, they are increasingly concerned about the embodied impacts, due

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to the increasing number of NZB, comparing to previous years when they were only concerned for operational impact of buildings. A larger segment of this group of actors and other decision makers procuring new buildings are choosing to use sustainability assessment systems as a tool to support decision making in this direction. In this field, a rapid movement from qualitative to predominantly quantitative approaches is observed, as well as an elevation of the importance of Life Cycle Assessment (LCA) in an attempt to comply with the recent standardization activities.

For example, some of the existing certification systems already consider LCA for their assessment criteria (e.g. LEED v4 , GreenStar , etc.), while many of them (e.g. CASBEE) are still focused on operational energy use and associated environmental impact ignoring the issue of embodied energy and embodied GHG emissions (table 1). One of the reasons for this might be the lack of available data. Nowadays, there are freely available national databases, among others, that can provide detailed life cycle data on environmental impact and energy for building products and systems. These national databases can be easily integrated into the respective national sustainability assessment systems. Specifically, the newly released versions of US LEED and Australian Green Star integrate LCA for building product level only, while the German BNB/ DGNB and the Swiss SNBS for the whole building. In addition, in Switzerland also design goals for embodied energy have been formulated [2].

	Production + construction	Operational	Renovation	End-of-Life
BREEAM (UK)		**		
BEAM Plus (China)	*	**		
LEED (USA)	***	**		
CASBEE (Japan)		***		
DGNB/ BNB (Germany)	***	***	***	***
SNBS (Switzerland)	***	***	***	***
SBToolCZ (Czech Republic)	***	***	***	
Green Mark (Singapore)		**		
Green Star (Australia)	***	**		

* qualitative assessment of Global Warming Potential
** both qualitative and quantitative assessment of Global Warming Potential
*** quantitative assessment of Global Warming Potential

Table 1. Coverage of assessment of global warming potential along the building life cycle by selected building sustainability assessment systems as an example.

Data availability

The most important prerequisite for the assessment of embodied impacts of a building is that there is an availability and accessibility of LCI data of building materials. Nowadays, the availability of environmental product declarations (EPD's) for construction products, as well as the provision of accessible databases and tools can be considered as a progress towards this direction. For example, there are already comprehensive collections of construction product related EPDs from different countries that can be found catalogued on the web, such as the International EPD system [3], the IBU in Germany [4], or the Green Book Live in UK [5]. In case EPDs are not available, information can be derived from general life cycle databases. For example, Ecoinvent [6], ICE [7] and Ökobau.dat [8] in Europe, BPLCI [9] and AusLCI [10] in Australia and CLCD [11] in China are some good examples.

However, the availability of life cycle inventory data is more limited in Asia or America than it is in Europe, where LCA is practiced more widely. The deficiency in present databases in such countries leads to collection of data from other sources, such as product manufacturers (first party data, instead of third-party data). Another possibility for closing data gaps offers the I-O analysis [12]. The lack of readily available data makes the task of conducting LCA difficult for the architect or even for an LCA practitioner [13]. Also the assessment of the quality of the data set to be used is very important. For example, the report of GHG Protocol "*Product Life Cycle and Accounting and Reporting Standard*" lists important questions to use when selecting a database. Also a quality control of the secondary data chosen from the selected databases is necessary and can be achieved through the use of various quality indicators [14]. The analysis and evaluation of all these issues are part of the activities of the authors. Further information will be available on the website of Annex 57 (www.annex57.org).

Transparency and traceability of results

In many cases, the results of various embodied impact assessments cannot be directly compared with each other, as they might be based on different methodologies, assumption, boundaries, and calculation principles. Particularly it is even more difficult to compare the results when this information is not transparent or is only partially transparent. Especially in relation to the selection and application of indicators and system boundaries, there are still various views and approaches. One of the key tasks of IEA Annex 57 is to develop specific recommendations aiming at providing more transparency and traceability regarding different parameters influencing the results. One consistent way of defining the system boundary in terms of the included life cycle stages is by referring to the stages described in EN 15804:2012 and EN 15978:2011 (figure 1). The authors recommend that, where possible, embodied impacts from all life cycle stages should be considered (Cradle to Grave) for the building level. As a sub-information, the system boundary "Cradle to Handover" should be used. This can be also a minimum requirement, as it represents the initial embodied impacts of the building. Benefits and loads beyond the system boundary may be reported. If so, they shall always be reported separately.

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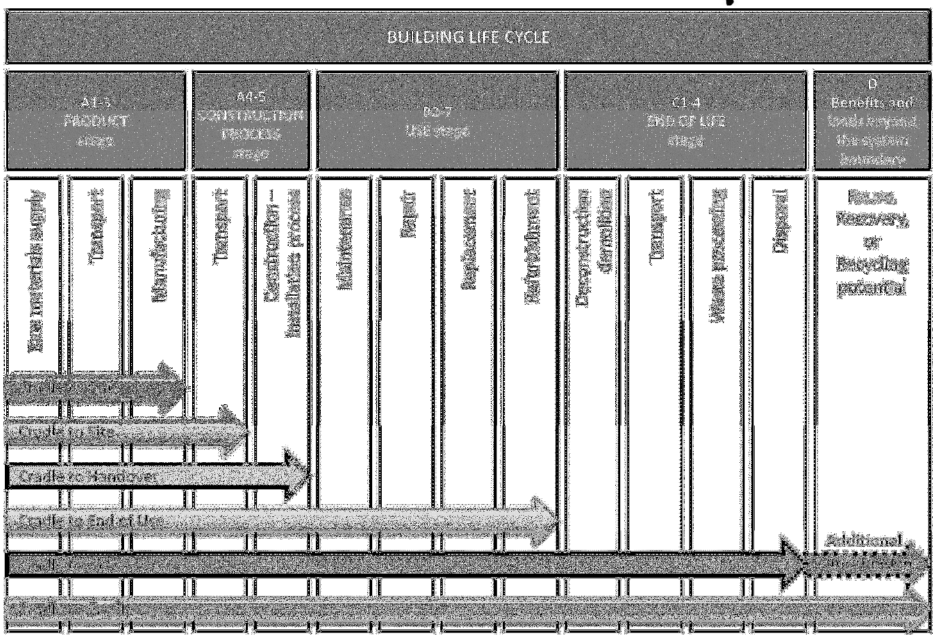

Figure 1. Illustration of the building life cycle stages in a modular structure (adapted from EN 15978:2011) and the various system boundary types. The system boundaries recommended by Annex 57 are highlighted.

The authors recommend the use of three different indicators for the quantification of embodied impacts: a) the consumption of primary energy non-renewable in MJ, b) the consumption of primary energy total (renewable + non-renewable) in MJ and finally c) the greenhouse gas emissions in kgCO_2eq. However, this alone is not sufficient to guarantee comparability of results. Additional information on the character and scope of each indicator is required, as for example information on the different sources of energy included in the first two recommended indicators, or the different GHG emissions included in the kgCO_2eq. For this purpose, specific tables have been developed by the authors to provide a detailed description of the definition and system boundaries of each recommended indicator. Specifically, the tables include the following information: (1) name of the indicator inside Annex 57, (2) also known as (different names used in literature), (3) name in LCIA (4) metric (5) target (6) definition (7) system boundaries (8) included modules in detail, and (9) unit. Furthermore, a specific reporting template has been designed providing the minimum documentation requirements for case studies in order for them to be comparable. Besides the database and data used for a case study, also the building components and products included, their service life, the method of materials quantification used, the reference study period and the different scenarios and assumptions made are considered important requirements, among others, that should be transparently documented.

Recommendations for selected groups of actors

To further improve the situation, the following recommendations are made by the authors:

- *The architects should discuss intensively the topic as well as the use of tools and databases.*

- *The methods of Life Cycle Analysis should be integrated into the education and training of designers in a more effective manner. It should be explained to them that they do not have to perform an LCA in the narrow sense, but rather just to combine information from the materials quantification with information from databases and interpret the result.*
- *The scientists should evaluate and publish more case studies. There is a need for the development of reference values and benchmarks.*
- *The industry should develop and publish EPD's in parallel with the development of new products.*
- *In the area of standardization, there is still a need on clear - adapted to the needs of the construction industry - definitions and system boundaries;*
- *The developers of sustainability rating systems should integrate LCA based methods and benchmarks. The consideration of embodied impacts is a good starting point.*
- *The description and assessment of embodied impacts requires the determination and listing of the type and quantity of materials needed for the building construction. This information can be re-used for the building file.*
- *Procurement (e.g. green public procurement) and funding programmes should incorporate more than ever before embodied impacts considerations.*

Summary and conclusions

Nowadays, the current international and European standards form the basis for a quantitative assessment of embodied energy and embodied GHG emissions. At the same time, the increasing integration of LCA into sustainability assessment systems and building labels, such as DGNB, SNBS or Green Star, helps to spread life cycle thinking even more among investors and architects. The consideration of embodied impacts in terms of energy and GHG emissions in the design and decision making process is the first step towards this direction. This is also propelled by the current availability and accessibility of appropriate data and the development of EPD’s. Comparing to the past the assessment of embodied impacts is now less time and cost intensive as a lot of information is already collected and stored in national databases worldwide. Besides data availability, transparency and traceability of the assessment results are important in order to ensure comparability of the results. This leads to the establishment of new requirements for all stakeholders in the construction industry to secure, on the one hand, the information flow and, on the other hand, the inclusion of embodied impacts in their decisions.

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References

[1] Haseltine, B. A. (1975). Comparison of Energy Requirements for Building Materials and Structures. *The structural engineer*, 53(9): 357-365. Retrieved from www.istructe.org/

[2] Morrow, J. K., & Smith-Morrow, J. A. (2008). Switzerland and the 2000 Watt Society. *Sustainability: The Journal of Record*, 1(1): 32-33. doi:10.1089/SUS.2008.9992

[3] IES (The International EPD System). www.environdec.com/. Accessed May 2014

[4] IBU (Institut Bauen und Umwelt e.V.) www.construction-environment.com/hp2/Institut-Bauen-und-Umwelt-e-V.htm. Accessed May 2014

[5] GBL (Green Book Live). http://www.greenbooklive.com/. Accessed May 2014

[6] Ecoinvent Swiss Center for Life Cycle Inventories. www.ecoinvent.ch/. Accessed May 2014

[7] Hammond, G., & Jones, C. (2010). *Inventory of Carbon and Energy (ICE).* Bath. University of Bath

[8] Ökobau.dat (2013). www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html. Accessed May 2014

[9] BPLCI (Building Products Life Cycle Inventory). www.bpic.asn.au/LCI. Accessed May 2014

[10] AusLCI. http://alcas.asn.au/AusLCI/. Accessed May 2014

[11] CLCD (Chinese Life Cycle Data). www.itke.com.cn. Accessed May 2014

[12] Casler, S., & Wilbur, S. (1984). Energy input–output analysis: a simple guide. *Resources and Energy,* 6: 187–201, doi: 10.1016/j.bbr.2011.03.031.

[13] Bayer, C., Gamble, M., Gentry, R., & Joshi, S. (2010). *AIA Guide to Building Life Cycle Assessment in Practice*. Washington. The American Institute of Architects

[14] World Resources Institute (2011). *Greenhouse Gas Protocol. Product Life Cycle and Accounting and Reporting Standard*. USA

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Introduction of Annex 57 - Evaluation of Embodied Energy and Carbon Dioxide Emissions for Construction Worldwide

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Abstract: *Annex 57 deals with methods for evaluating embodied energy and the CO_2 emissions of buildings, in order to find better design and construction solutions of buildings with less embodied energy and CO_2 emissions. The CO_2 emissions due to building construction and operation in Japan, estimated by an Input-Output (IO) analysis, are shown. An estimation of the total CO_2 emissions in various countries and the corresponding fractions of embodied CO_2 due to building construction and public works are shown as a result of analysis of world IO tables. Total embodied CO_2 due to building construction and civil engineering is estimated to be 20.3% of the total worldwide CO_2 emissions. In particular, fractions of embodied energy are higher in developing countries and often exceed the building operation energy. The embodied energy differs among countries depending on the building design, the energy intensity of materials, and the quantity of materials used in the building. The embodied CO_2 per capita among the countries is also shown.*

Keywords: Embodied energy/CO_2 emissions, IO analysis, International comparison

1. Scope

The evaluation of energy consumption and related CO_2 emissions resulting from the use of buildings is becoming more accurate and is being applied in the design of more energy efficient building envelopes, systems and regulations. This means that the weight of the energy consumption and CO_2 emissions caused by stages other than the use of the buildings is becoming larger, and their estimation methods will be more important in the future. It can be said now is the time to further study the scientific basis of embodied energy and CO_2 emissions (EEC) for building construction by organizing the new Annex and international team in IEA EBC.

Annex 57 (2011-2016) deals with methods for evaluating the embodied energy (EE) and embodied CO_2 (EC) emissions of buildings in order to develop guidelines, which contribute to practitioners' further understanding of the evaluation methods and to helping them find better design and construction solutions of buildings with less embodied energy and CO_2 emissions.

2. Details of Annex 57 research

Annex 57 consists of 5 Subtasks. ST1 deals with the decision making process regarding EEC. ST2 involves collating the existing literature and identifying the contents to be studied in Annex 57. ST3 finalizes a calculation method and its characteristics in creating an EEC database, as well as proposes a method for calculating EEC in buildings. ST4 compiles

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methods for reducing EEC and their effects based mainly on case studies. ST5 is a task associated with promotion and diffusion. Deliverables include the Annex 57 report, Guidelines (for building designers, policy makers, manufacturers, education) and Digest book.

3. Input/output analysis for EEC for building construction

This paper aims to understand the values of EEC for building construction and civil engineering in individual countries and to identify the research objective of Annex 57 in a quantitative manner. Generally, the calculation of EEC for buildings uses a database in compliance with the ISO. EEC of a building is the total value of an EEC database for individual materials (e.c. MJ/t, kg-CO_2/t) multiplied by their quantities used (e.c. t, m^3). However, the Input/output analysis is more practical when calculating EEC due to construction in countries worldwide. This paper provides a method for calculating EC for construction in individual countries according to the Input/Output analysis and its calculation results.

4. Input /Output analysis in Japan

4.1 Methodology

The embodied energy/CO_2 is obtained from the analysis of IO (input/output) tables [1]. The IO tables of Japan consist of 401 industrial sectors. The domestic output **X** of each industrial sector can be calculated by Leontief inversion with domestic consumption expenditure $\mathbf{F}_{(D)}$, as follows:

$$\mathbf{X} = \{\mathbf{I}-(\mathbf{I}-\mathbf{M})\mathbf{A}\}^{-1}\{(\mathbf{I}-\mathbf{M})\mathbf{F}_{(D)}+\mathbf{F}_{(E)}\} \quad \cdots\cdots (1)$$

X: Domestic output (yen/year) $\mathbf{F}_{(D)}$: Domestic consumption expenditure (yen/year)
$\{\mathbf{I}-(\mathbf{I}-\mathbf{M})\mathbf{A}\}^{-1}$: Leontief competitive import-type inverse matrix (-) **I**: Unit matrix (-)
M: Import coefficient diagonal matrix, $m_i=M_i/C_i$, m_i: Import coefficient (-)
C_i: Domestic consumption expenditure for i product (yen/year)
M_i: Import of i product (yen/year) $\mathbf{F}_{(E)}$: Export (yen/year)
A: Activity (Input coefficient) (-)

Since the energy consumption and total domestic output data in each industrial sector is published, the energy intensity E_i (MJ/Yen) for each industrial sector can be derived. The total ultimate energy consumption E_F with final influences can be expressed with X_i and Ei as follows:

$$E_F = \sum_{i=1}^{n} X_i \times E_i \quad \ldots\ldots\ldots\ldots\ldots(2)$$

n: Number of industrial sectors in the country E_i: Energy intensity (MJ/Yen)
X_i: Domestic output in industrial sector (Yen) E_F: Total ultimate energy consumption (MJ)

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Total ultimate CO_2 emissions, C_F can be obtained in the same way as E_F by substituting CO_2 intensity Ec (kg-CO_2/Yen) for E_i (MJ/Yen). E_F (C_F) means EE (EC) when X_i is calculation result with $\mathbf{F}_{(D)}$ for construction.

4.2 Embodied CO_2 emissions in Japan

The total annual CO_2 emissions in Japan, where the corresponding fractions of embodied CO_2 due to building construction and civil engineering, and the CO_2 emissions due to building operation are estimated by the Input-Output analysis are shown in Fig 1. Embodied CO_2 is 19.2% and the operation of buildings is 23.2% of the total CO_2 emissions in Japan.

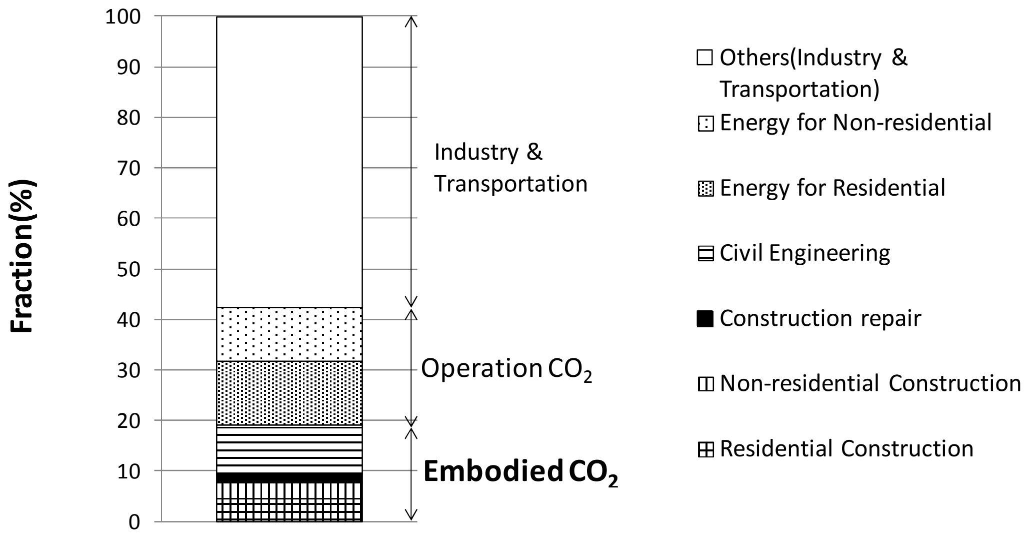

Fig. 1 Fraction of embodied CO_2 due to building construction and operation in Japan, 2005

(Total CO_2 emissions in Japan, 2005: 1.29Billion t-CO_2)

5. Worldwide Input/output (IO) analysis

5.1 Data source

The Symmetry IO table and the SNA table for 40 major countries around the world from 1995 to 2009 are made available to the public [2]. The number of industrial sectors in the Symmetry IO table is 35. The SNA-use matrix is a table listing the amounts of input in terms of 59 commodities corresponding to 35 sectors. The units used in the table are currencies in individual countries and the United States dollar. A database that shows changes in CO_2 emissions across the ages in each country due to gas fuels, liquid fuels, solid fuels and cement production is also publicly available [3].

5.2 Calculation method and the result

(1) Create Leontief inversion of the Symmetry matrix
(2) Calculate X_{ti} and X_{ci}, the domestic total output (X_{ti}) of 35 sectors by entering the total domestic consumption expenditure, and the domestic output (X_{ci}) by entering the domestic consumption expenditure for construction industry in the inversion

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(3) According to the SNA-use matrix, calculate the amount of input from the coal and lignite sector and the crude petroleum and natural gas sector for 35 sectors, from which we will obtain UC_{ti} and UP_{ti} corresponding to X_{ti}, as well as UC_{ci} and UP_{ci} corresponding to X_{ci}.

UC_{ti}, UP_{ti}: Input from coal/lignite sector and crude petroleum/natural gas sector for X_{ti}
UC_{ci}, UP_{ci}: Input from coal/lignite sector and crude petroleum/natural gas sector for X_{ci}

(4) CF obtained in the following formula serves as EC originating from fossil fuels consumed due to construction demand, assuming that CO_2 emissions are proportional to the amount of input.

$$CF=\Sigma UC_{ci}/\Sigma UC_{ti}\times CCE+\Sigma UP_{ci}/\Sigma UP_{ti}\times CPE \quad \cdots\cdots (3)$$

CF: EC (t-CO_2) originating from fossil fuels required due to construction demand
CCE: CO_2 emissions (t-CO_2) originating from coal and lignite
CPE: CO_2 emissions (t-CO_2) originating from crude petroleum and natural gas

In the Symmetry matrix in most countries, figures of import/domestic demand in terms of coke, refined petroleum and nuclear fuel input for 35 sectors are fixed at a certain value in all types of industry.

(5) The CO_2 emissions from cement are calculated in the same manner as that of fossil fuels, assuming that it will be proportional to other non-metallic mineral products, the value of which is used as CC originating from cement production. EC due to construction is expressed as CF+CC (t-CO_2).

Table 1 shows a comparison/contrast of CO_2 intensities in Japan between industrial sectors in the 401 industrial sector IO table and those in the 35 industrial IO table. In terms of iron/steel and non-ferrous metals having a wide range of items, hot rolled steel in the 401 sector table does not correspond to basic metals and fabricated metal. However, EC per ton of iron/steel is approximately the same value in the two tables.

Table 1 Comparison of CO_2 intensities between 401 and 35 industrial sector IO tables of Japan

IO in Japan (401 Sectors)		World IO (35 Sectors)	
Industrial sector	CO2 Intensity (kg－CO2/Million JPY)		Industrial sector
Timber	769	1788	Wood and products of wood and cork
Plywood	1594		
Wooden furniture and fixtures	1402		
High functionality resins	5975	6242	Chemicals and chemical products
Plastic products	4763		
Sheet glass and safety glass	2999	7279	Other non-metallic minerals
Glass fiber and glass fiber products	5732		
Cement products	7985		
Hot rolled steel	22135	6757	Basic metals and fabricated metal
Steel pipes and tubes	13374		
Other iron or steel products	5329		
Copper	1756		
Aluminum(inc. regenerated aluminum)	1308		
Boilers	2057	1814	Machinery
Refrigerators and air conditioning apparatus	1970		
Residential construction(wooden)	1707	3395	Construction
Non residential construction(non-wooden)	2704		
Public construction for roads	3451		
Road freight transport service	3132	2700	Inland transport

6. Worldwide EC

6.1 Fraction of worldwide EC

An estimation of the total CO_2 emissions in various countries and the corresponding fractions of embodied CO_2 due to building construction and public works are shown as a result of analysis of world IO tables in Fig. 2. In particular, fractions of embodied energy are higher in developing countries and often exceed the building operation energy. The embodied energy differs among countries depending on the building design, the energy intensity of materials, and the quantity of materials used in the building.

Among the various countries, EC in China is exceptionally high, accounting for a substantial fraction of the entire CO_2 emissions. Regarding EC, though it is certainly important to reduce the current EC, we could also consider means of greatly reducing the future EC by slightly increasing the current one. For example, we could reduce EC substantially in the future by strengthening the current building structure in order to double the durability performance.

Some of the phenomena generally observed in Asian countries include the situation in which CO_2 emissions shoot up and the fraction of EC also increases as the country becomes industrialized. Since there are many countries falling into such category, it would be effective in reducing CO_2 emissions to take appropriate measures in the initial stage of industrialization and sustain the EC reduction efforts into the future.

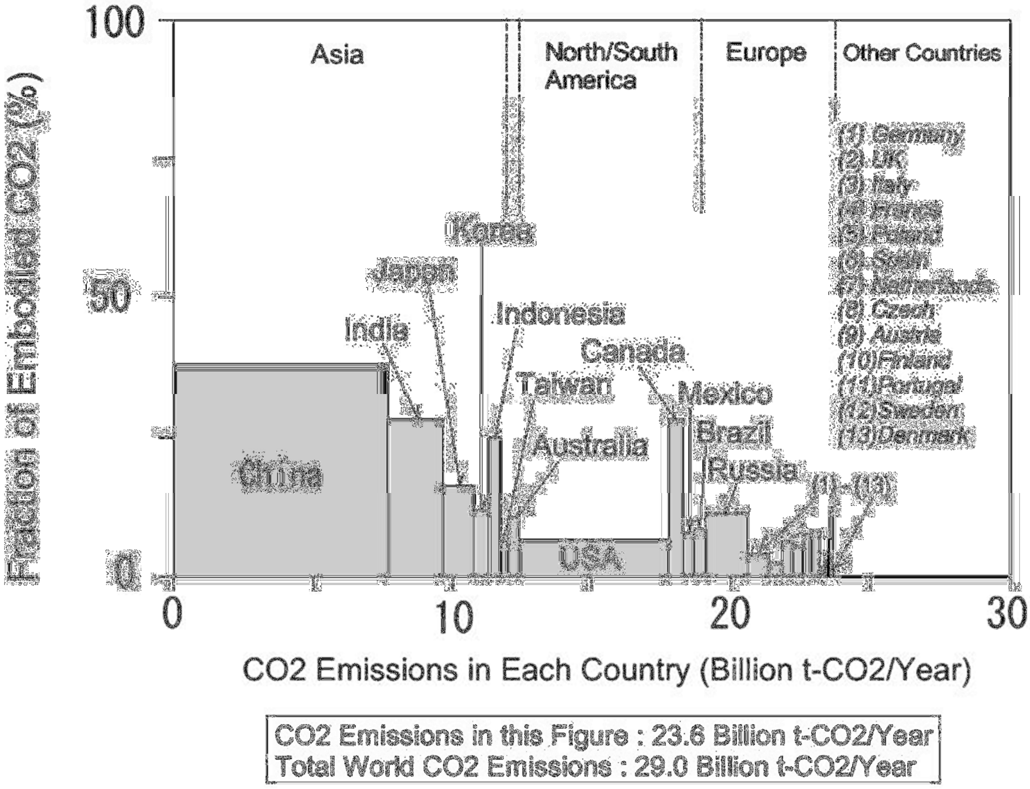

Fig. 2 Total CO_2 emissions in each country and the fraction of embodied CO_2

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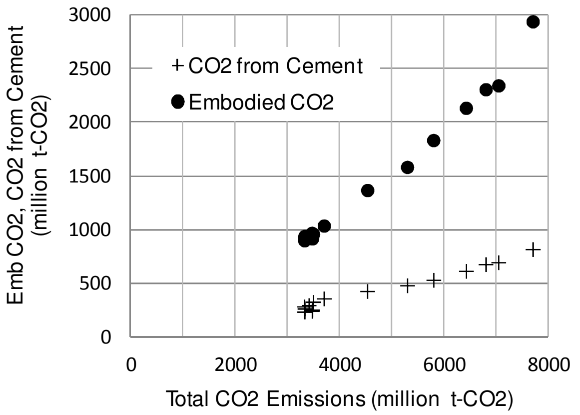
6.2 Annual change of EC and CO_2 emissions from cement production

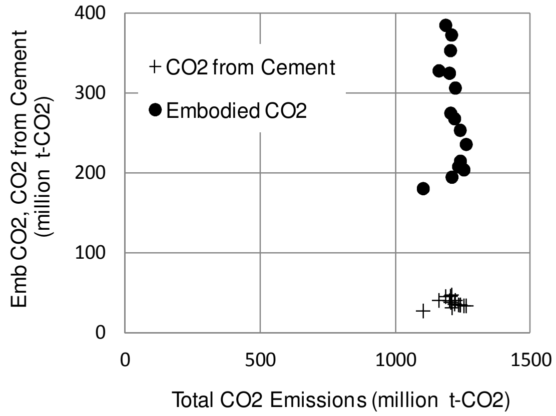
Cement and iron/steel used as structural materials in building construction and civil engineering account for a large fraction of EC. Figure 3 shows the annual EC due to construction and CO_2 emissions from cement production [3].

In China, EC due to construction and CO_2 emissions from cement production have been increasing every year at a constant rate. The CO_2 emissions from cement production in Japan are generally fixed, whereas EC has been on the decrease year by year.

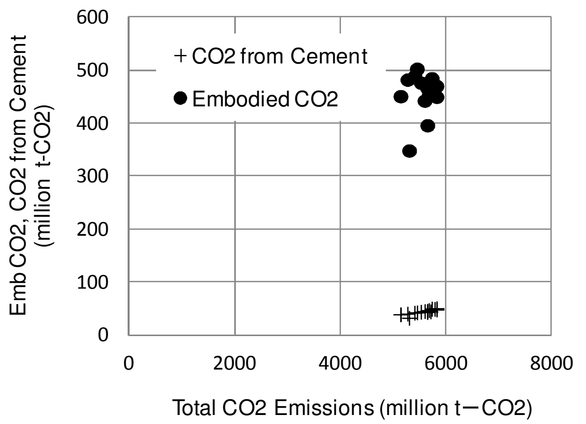
In the USA, the CO_2 emissions from cement production are low compared to EC, whereas it is relatively high in Germany. We can assume that this is due to the difference between building structures and the amount of cement consumed per floor space. Further, by the nature of the IO calculation, as cement products are allotted in proportion to other non-metallic mineral products, in some cases, it may be allotted more to other industrial sectors in the calculation.



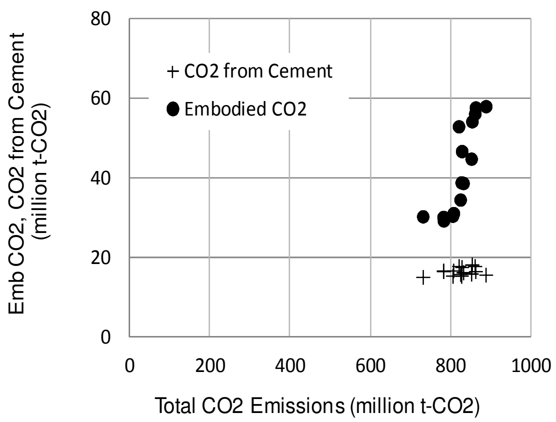
(1)China, 1995-2009



(2) Japan, 1995-2009



(3) USA, 1995-2009



(4) Germany, 1995-2009

Fig. 3 Relationship between EC for construction and CO_2 emissions from cement production

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6.3 EC per capita

Figure 4 shows the comparison of EC from construction per capita among individual countries. EC values are high in Asia (0.5～2t-CO_2/Person), the USA (1.1t-CO_2/Person) and Australia (1.9t-CO_2/Person), whereas EC from construction per capita in Europe is low (0.2～0.7 t-CO_2/Person). The large value in Canada (4.4 t-CO_2/Person) is due to the fact that the fraction of EC to the entire CO_2 emissions is as high as 28.4%, as well as a large amount of energy is consumed directly by the construction sector.

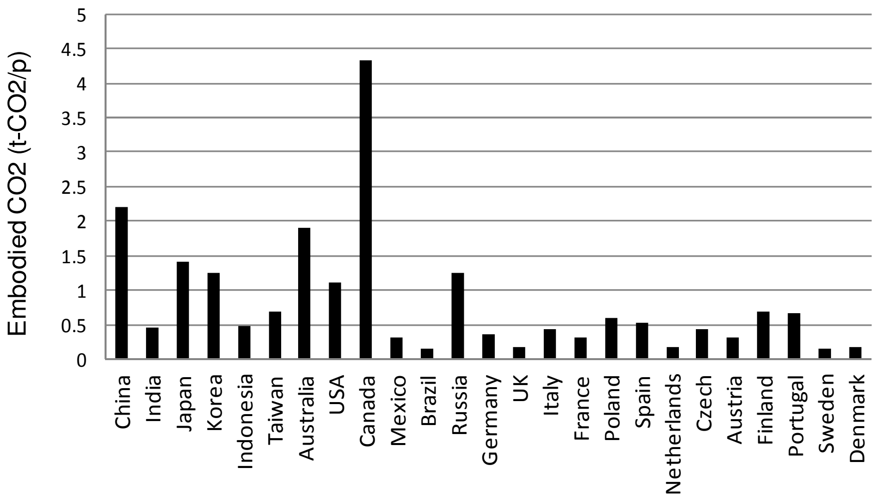

Fig. 4 Embodied CO_2 due to construction per capita, 2009

7. Conclusion

This research calculates EC in Japan and other countries throughout the world according to the IO analysis, in order to quantify the fraction of EC that accounts for the entire CO_2 emissions. We summarize our conclusion as follows:

1) According to the 401 industrial sector IO table in Japan, EC from construction accounts for 19.2% of the entire CO_2 emissions, and the CO_2 emissions from building operation is 23.2%.

2) According to the calculation result of EC from construction in individual countries based on the World IO table, EC accounts for 20.3% of the entire CO_2 emissions on average worldwide. EC is high in Asian countries ranging from 10% to 38%. EC in the USA and European counties is lower, accounting for 6.6% and around 5% to 10%, respectively.

3) Calculation results of EC per capita in individual countries indicate that it is 0.5～2t-CO_2/Person in Asia and the USA, and 0.2～0.7 t-CO_2/Person in Europe.

References

[1] Ministry of Internal Affairs and Communications (2009), 2005 Input and Output Table, Research Institute of Economy, Trade and Industry
[2] Marcel Timmer, The World Input-Output Database (WIOD), www.wiod.org/publications/source_docs/WIOD_sources.pdf
[3] T. Boden, G. Marland, B. Andres: National CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2010, http://cdiac.ornl.gov/ftp/ndp030/nation.1751_2010.ems

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Session 48:

What role can renewable materials play in sustainable construction?

Chairperson:

Laudy, Sander Cornelius
Architect, B01 Arquitectes

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Bamboo Reinforcement – A Sustainable Alternative to Steel

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Abstract: *Researchers at the Future Cities Laboratory Singapore/ETH Zurich achieved the liaison of both the superior physical properties of the bamboo fiber and the extraordinary mechanical properties of polymer resins in a new green and sustainable material technology. The team investigates the potential of high-performance bamboo fiber composite materials to replace steel reinforcements in structural concrete applications. The technology as such is to be considered low-tech with injected high-tech knowledge and components in order to up-scale and install it in developing territories. With their fast growing urbanization rates, these areas overlap with the global natural habitat of bamboo, rendering bamboo an affordable and locally available natural resource for a future construction industry. The herein presented newly developed fiber composite materials might revolutionize this industry. In this sense, the research at the Future Cities Laboratory Singapore/ETH Zurich aims to offer a local solution on urban sustainability within a global frame.*

Bamboo, Concrete, Reinforcement, Composite Materials

Introduction

According to the UN Population Division Report 2013([i]) the world's population will increase by 1.8 billion people until 2050. Regarding the question, which parts of the world will have to cope with the highest growth rates, the UN predicts the utmost population increase for developing territories – mainly in Africa and South East Asia. What's more, these territories will not only gain inhabitants but simultaneously experience a rise of urban population. Such ever-growing urbanization, on the other hand, comes along with a huge demand for building materials. Due to traditional construction ideologies, it is in particular cement, steel, glass and aluminum consumption, which shoots up in parallel with urbanization rates. Hence, growing economies within the developing nations entail a huge demand for these materials, which must mainly be imported due to the lack of resources, production knowledge or the necessary industry. Not surprisingly, nearly 90 % of the worldwide shares for concrete demand are ascribed to emerging and developing countries.([ii]) For Ethiopia, for instance, which according to the Economist is the fastest growing nation in Africa today([iii]), cement, steel, glass and machinery add up to the majority of its trade deficit. Such dependence on trade markets, which are mainly dictated by the developed world results in an exploitative north-south relationship and puts entire nations into huge trading shortfalls. In this regard, we ask ourselves what are the possible solutions to the problematic issues, which emerge from an exponentially growing population with an ever-increasing demand for building materials. The answer to this question requires the reshaping of traditional western ideologies imposed on the construction sector in the developing world to more innovative and local resources-oriented approaches.

Hence, considering that most developing countries are located within the tropical climate zone and this coincides to be the natural habitat of bamboo – one of the strongest naturally growing materials – it is not far fetched to contemplate its potential for the local building and construction sector. Therefore, we aim to benefit from bamboo's fast growth, its unrivaled capability to store CO_2, its superior mechanical strength and renewability and activate all these features in a new innovative material technology that delivers a lighter, stronger and cheaper material alternative to steel that does not corrode. However, above all, bamboo is growing exactly there, where it can substantially unfold its potential by far more than simply as a building material. Providing these territories a technology to produce an alternative construction material and with it liberate themselves from the current conditions of heavy steel import creates social equity. Even more: the usual one-way directions of global material flows could be reversed into a South-North relationship. A high-performance bamboo-based material helps to establish local value chains, which could in turn strengthen rural-urban linkages and establish alternative technologies based on renewable resources as their key industries. All these factors drive our motivation for the development of this new material technology. As of now, we are able to produce a fibrous material, in which the inherent mechanical properties of certain bamboo species are retained, and then process it into a high-strength composite material. In this publication, we describe the fabrication and mechanical properties of the composite material as well as its performance in reinforcing concrete applications.

Mechanical Properties of Gigantochloa Apus Bamboo

Due to local availability and proximity to Singapore we chose the Indonesian bamboo genus *Gigantochloa Apus* or *Tali Putih*([iv]) as the raw material for the production of our composite. After five to six years, the *Tali Putih* species reaches its full strength capacity, which makes it suitable for high load capacity applications. For this study, we chose 5-year-old bamboos which represent an average distribution of the bottom and middle parts of the entire culm. Tensile specimens out of raw bamboo have been prepared and tested to verify its inherent tensile strength. With an average tensile capacity of the entire culm including nodes – in contrast to solely single fibers – of 363 MPa this bamboo species is particularly suitable for reinforcing applications. Another important material property for building and construction applications is the modulus of elasticity (MOE), which has been determined to values between 19.4 and 22.6 GPa and is higher than many other bamboo species.([v]) No significant variation of both the tensile strength and MOE could be found for the different parts of the culm which points to a rather homogenous distribution of the fibers. The density of *Gigantochloa Apus* is 0.6 g/cm^3.([vi])

Bamboo Composite Material – Fabrication and Properties

In order to exploit these remarkable mechanical properties for building and construction applications it is crucial to preserve the inherent natural strength of the bamboo fibers and

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protect these from environmental impacts such as moisture, fungi and insects. One way to achieve this goal is to process the raw bamboo with the help of thermoset polymer resins and pressure into a composite material with controlled and durable properties.

Our approach involves a processing method for raw bamboo, which entirely relinquishes chemical substances and purely mechanically delivers long bamboo fiber bundles. Thereby, the inherent material properties of the natural bamboo fibers are preserved, which has been proven by achieving equal tensile strengths of the processed fiber bundles as for the natural raw material. After obtaining the raw material, it is dried to reduce the moisture content. The dried bamboo fiber bundles are then bewetted with the resin and placed in the mold of a press. In particular, we look into resin compositions, which utilize naturally sourced ingredients obtained from waste industry. Together with the environmental benefits of bamboo as a raw material and the relatively low operating temperatures of our hot press the production of our composite material (Figure 1) turns out to be CO_2 negative.

Figure 1. Left – High-tensile strength composite material as produced at the Future Cities Laboratory in Singapore. Right – Tensile test specimens after failure.

The obtained composite samples are subsequently prepared into various shapes in accordance with the corresponding standards (ASTM) for testing their mechanical properties. By creating a closed feedback loop between fabrication, analysis and modification we are able to quickly react on the parameters which control the mechanical properties of our composite – the raw material processing, the production process, the resin composition – and control them to achieve optimal material features with respect to the application in concrete. Hence, presently the tensile strength of our prototype surpasses 400 MPa with a MOE of nearly 50 GPa. The compressive strength is in the range of 100 to 120 MPa and the bending strength nearly 200 MPa. Our method protects the bamboo from moisture absorption, fungi and insect attacks as well as renders the material corrosion-free, which is due to the distinct synergy between resin and fibers (Figure 2).

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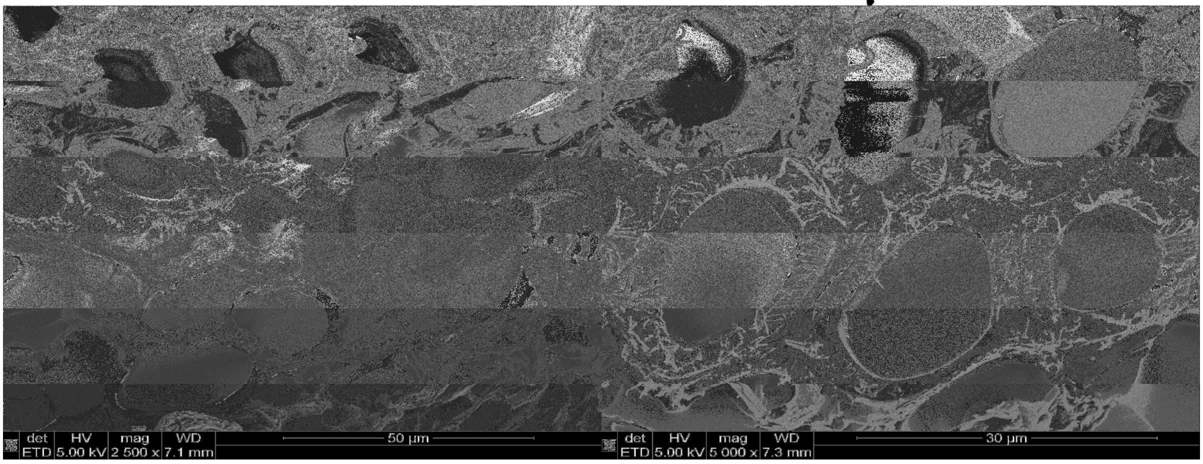

Figure 2. Scanning electron microscopy images of the resin-filled vascular bundles of the bamboo composite material. The smooth surfaced structures represent the resin.

Bamboo Reinforced Concrete – Application and Analysis

After the fabrication of the first proof-of-concept high-tensile specimens of our bamboo composite material the next logical step was the analysis of the reinforcing qualities for concrete applications. Similar approaches have already been attempted decades ago. Early applications of raw bamboo as concrete reinforcement go back to 1914 when when Prof. Chow tested small diameter bamboo culms and splits as a reinforcement material for concrete applications at the MIT in Boston([vii]). Later on, during the 1950s Prof. Glenn conducted major extensive research on natural bamboo as reinforcement in concrete structures at the Clemson Agricultural College of South Carolina([7]). The tensile capacity of bamboo made its application in concrete in principle feasible but drawbacks such as water absorption, low modulus of elasiticity and thermal expansion obstructed a longterm usage. With time, the exposure of bamboo – a natural material – to the concrete matrix results in water absorption from the concrete, leading to a progressive degradation and excessive swelling. The swelling causes internal pressure that builds up inside the concrete and ultimately leads to internal cracks. These cracks propagate in the concrete medium and eventually result in concrete spalling and failure of the structural system.

Unlike raw bamboo, our composite material is waterproof and therefore capable of standing tensile loads in long-term conditions without the problems of swelling, shrinkage and insect or fungi attacks. This chemical resistance makes it suitable for exterior and concrete applications – especially in regions with natural bamboo occurrence.

Concrete Beams – Preparation

To evaluate the mechanical properties of bamboo composite reinforced concrete, four beams were cast using grade 50 MPa concrete due to its common usage in Singapore (Table 1). The tension reinforcement is made from the bamboo composite material. Further, shear reinforcement for flexure was used in the shear span at close spacing of 70 mm center to center distance. The middle part of the beam (140 mm) contained neither compression nor

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shear reinforcement. This design approach guarantees that the compressive zone of the concrete is not preventing the tension reinforcement from absorbing the loads and yielding under flexural strain. Therefore, already before the concrete begins to crush, the bamboo composite reinfrocements will be activated and bear the tension force. As a result, the estimation of tensile forces on the bamboo composite reinfrocmeents becomes straightforward and can be simply calculated from the experimental parameters.

Table 1. Mix proporation for concrete beams

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
400	750	1100	140

Bamboo Reinforcement – Structure

The bamboo composite material in this study was produced out of Gigantochloa Apus bamboo (see above). Before using it as a concrete as reinforcement, the tensile properties of dogbone-shaped samples were measured according to ASTM D7031. The average tensile strength of the utilized material along the fiber direction was in range of 330 to 380MPa, which was comparable to the tensile properties of the raw bamboo culm (363MPa). The reinforcement length was chosen to to guarantee sufficient concrete coverage at both ends of the beam and also to provide additional mechanical anchorage between the composite reinforcement and the concrete matrix. The bars were cut into dogbone shapes as well with square sections.

Testing and Results

The experimental test set up and the instrumentation are shown in Figure 3. Four point bending tests were chosen to study the flexural properites of the concrete beams reinforced with the bamboo composite bars. A universal testing machine (UTM) with a load capaicy of 100 kN was employed and the load was applied at a constant rate of 1 mm/min. The deflection at the center was measured with a dispalacement gauge. The beams were tested until rupture.

Throughout the tests, the first cracks were marked immediately after their formation and the propagation was followed on the exterior surface of the entire beam. It also has been observed that rupture occurred in the mid span of the beam and in the tension bars. Figure 4 shows the crack patterns within the concrete beams and the rupture of the bamboo composite bars. Importantly, the fact that the bamboo composite reinforcements failed in the mid span of the beam indicates that the tension force was taken by the bamboo composite reinforcements before concrete matrix failure, which has been expected. Thus, the maximum load recorded during the tests is an estimate for the actual tensile capacity of the bamboo composite reinforcements in the concrete beam.

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The maximum load recorded during the test was 29 kN, based on the American Concrete Institute design code for structural concrete design corresponds to a value of 310 MPa in design strength. Given the fact that our bamboo composite reinforcement has a modulus of elasticity of not more than 50 GPa such strength is above the expected values for such a flexible reinforcing material. Furthermore, it nearly matches the inherent tensile capacity of the separately tested bars, which hints to efficient load transfer and activation within the concrete matrix. The slight differences between both values could be attributed to the differences in design codes and safety factors for steel reinforced concrete and bamboo composite reinforced concrete. Due to the lack of a design code for the new bamboo composite reinforcement, the material safety factors need to be adjusted to obtain more accurate values. Corresponding design codes are currently being developed at the AFCL in Singapore, as well.

A visual inspection of the tested samples did not reveal any signs of debonding between our material and the concrete environment (Figure 4) which demonstrates an efficient bonding between the composite and the concrete matrix. Moreover, a careful examination of the two ends of the beams did not reveal any slippage throughout the test, which proves a good mechanical friction during bending due to the dogbone shape of the bars. Summarizing, the newly developed and tested bamboo composite reinforcement showed efficient load bearing capacity and bonding throughout our tests, which shows its advantage in comparison with many other alternative reinforcing materials.

Figure 3. four point flexural strength test set-up

Figure 4. crack patterns of the concrete beam and rupture of bamboo composite reinfrocements

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Conclusions

Achieving the successfull activation of the remarkable mechanical strength of a renewable resource in the form of a sustainable composite material, which can be successfully applied as a reinforcement system for structural concrete, does not only come along with huge environmental benefits (e.g. the reduction of carbon footprints) but has an immense socio-economic impact. Considering the fact that the herein presented reinforcement system can actually be produced within those territories, which are less developed but expect the highest demand for building materials within the next decades, the true asset is not a new sustainable material technology but the creation of social equity. An emerging local industry would be able to satisfy the building material demand and, in addition, create new value chains for the rising economies in the developing world. Hence, the true innovation of this research is not the creation and application of a new material that can serve as an alternative to steel in terms of mechanical properties but – most importantly – also as an alternative in view of global socio-economic aspects.

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Lignin based Sandwich System for load bearing insulation

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Abstract: *Polymer foams have proved to be an excellent „warm shell“for buildings for years. Generally the foam is based on petrochemical resources. It is used for external wall insulation and not employed for additional functions.A Sandwich build of rigid laminates and a quite shear resistant polymer foam core results in an extraordinary stiff element. This provides thermal insulation and forms an independent load carrying structure. The sustainability of the sandwich structure can be raised by combining materials from renewable resources. The sandwich system currently developed, in cooperation with our partner from industries C3 Technologies, consists of lignin based foams of varying density and natural fibre reinforced laminates. The lignin is produced from beech-wood via the organosolv-process. Afterwards it is chemically integrated into the phenolic resin. The proportion of lignin in the resin can be varied from 10% up to 40%. This poses a quite prospective idea since using lignin means using nature's own synthesis instead of artificial petrochemical processes for resin production and thus reducing the energy needed for resin production. The worldwide availability of lignin is estimated up to about 20 billion tons per year, this is a sufficient raw material base for a prospering lignin based bioeconomy. This means that up to 80% of the material for the described sandwich elements may be bio-based and sustainable.*

Keywords: sandwich; biofoam; load bearing insulation; lignin based resin

Introduction

Man has always sought materials that can be used to implement his ideas and to satisfy his requirements. The development of construction engineering is therefore closely linked with the development of construction materials. Fibre-reinforced plastics were first used in their own right as a class of construction materials in the construction industry in the middle of the 20th century. They made it possible to construct plane load-bearing structures and lightweight sandwich structures, dream-like structures with thin walls spanning wide stretches and floral and crystal structures, providing us with a novel type of housing and protection from the environment. Fibre-reinforced plastics are a multifaceted class of construction materials as the most diverse types of fibres as well as thousands of combinations of plastics together provide high-performance materials. Plastics are currently undergoing a period of transition. Oil is no longer the sole means of producing plastics: also natural products are now undergoing chemical processes and are being offered as bioplastics. Natural fibres are now fulfilling other roles apart from their traditional use as textile fabrics in the clothing and carpet industries. The construction system development which is presented in this paper is on the one hand based of the combination of a new material composite and on the other hand of existing achievements in the field of lightweight construction using sandwich systems.

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Design & architecture

The development of construction engineering is closely linked with the development of construction materials. Fibre-reinforced plastics first used in their own right as a class of construction materials in the construction industry in the middle of the 20th century. They made it possible to construct plane load-bearing structures and lightweight sandwich structures, dream-like structures with thin walls spanning wide stretches and floral and crystal structures, providing us with a novel type of housing and protection from the environment. The essential advantage of sandwich panels is the high bending stiffness and strength to weight ratio. Furthermore the insulating quality with relatively low weight and low raw material consumption in connection with efficient industrial manufacturing methods brings a benefit compared to conventional materials. Sandwich construction is not currently used in the private house building market, yet. This is mainly caused by the use of steel facings which are not accepted by the end user. Even markets in emerging and developing countries could not be penetrated by the steel sandwich construction for buildings because they are particularly used at high ambient humidity and tend to rapid rusting. The Company C3 Technologies filled this “gap“ with the manufacturing of “green“ high-tech composite materials. The layers of the C3 sandwich panels primarily consist of renewable and regionally available agricultural raw materials which are not in competition with the food industry. Furthermore they offer the possibility of material production independent from oil and high-energy processes which can be produced worldwide in an industrial way by an innovative mobile production line. During the last two years three prototypes have been developed for structural applications in which the recent developments have been implemented and verified in practice. A revolutionary modular building system was developed based on C3 composite monocoque structure in close collaboration with the renowned architectural office Florian Busch Architects (Tokyo). The sandwich elements of single basic modules are bonded together by gluing to a compact unity (figure 1). The Design offers an excellent impact resistance against natural disasters like earthquake or cyclones. The modules have the dimension of a 20 ft. sea container for maximum flexibility in logistics. The low number of different basic modules allows a high degree of industrial prefabrication and flexibility with a wide range of combinations.

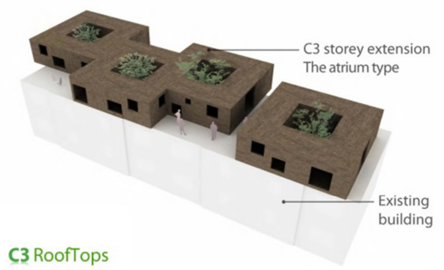

Figure 1: Housing modules as monocoque structures based on standardised glued sandwich panels

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The raw material - beech wood

The question of the appropriate raw material for sandwich elements is a major challenge for the use of renewable materials under a bio-based economy. Because they need to be available in sufficient quantities and don't compete with the food industry. Through the ongoing ecological forest conversion over many years, the hardwood volume medium to long term are increased in Germany. Especially the thin and poor-quality wood can be used as a potential raw material for chemical processing. The following figure shows the development of the hardwood volume in the last decades and the natural distribution of the raw material hardwood (BUND Naturschutz).

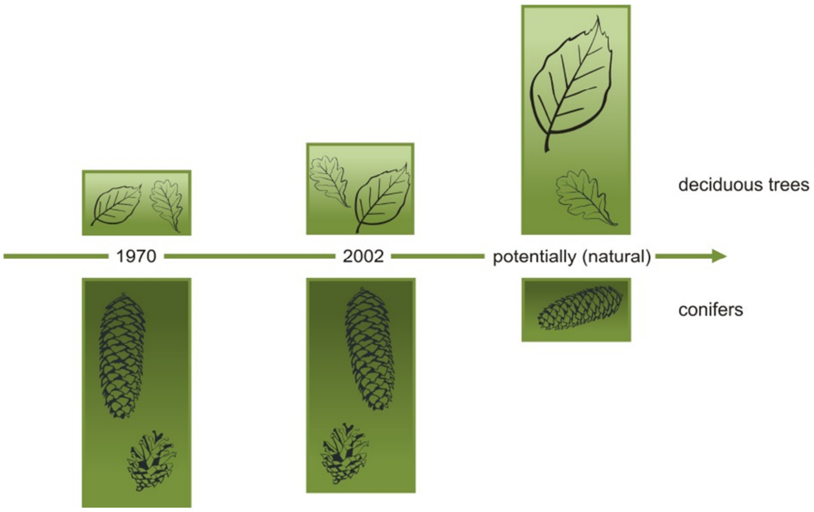

Figure 2: Development of the hardwood volume in the last decades and the natural distribution of the raw material hardwood

The main tree species in the future are beech and oak. They represents about three quarter of the hardwood stock. The beech is used as a starting material for the production of reinforcement fibers and as a source for the production of phenolic lignin macromolecule.

The resin

As a basic resin for the skins and the foam a phenolic resin system on the basis of lignin has been developed. The lignin is produced from beech-wood by the use of the organosolv-process. The digestion of the wood and the fractionation is carried out at 170-200 °C and a pressure of 20 - 35 bar over a period of 4 h in an ethanol/water mixture. The organosolv lignin was selected as a raw material because it is characterized by a small molecular weight. Furthermore it is sulfur-free and high reactive. Afterwards the lignin is chemically integrated into the phenolic resin. This poses a quite prospective idea since using lignin means using nature's own synthesis instead of artificial petrochemical processes for resin production and thus reducing the energy needed for resin production. The obtained resin systems P10 (10% lignin content) and P20 (20% lignin) can be provide in industry standard quantities. Due to the low viscosity (Hoppler viscosity at 20 ° C: 140 mPas P10, P20 328 mPas) the resin systems are easy to process and can be used for the impregnation of fibers, nonwoven and woven fabrics to build laminates and also as a basic for foams.

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The Laminat

Laminates are manufactured for the strong and stiff skins of sandwich elements. Natural fibres are impregnated with the resin systems and bonded as a nonwoven fabric. Afterwards dried and pressed to thin laminates for this purpose. The compression takes place at temperatures between 140 °C and 170 °C. The main focus in the selection of raw materials was on the material beech wood. The produced laminates are used as skin-material for the sandwich systems and take over tasks such as fire protection and impact resistance. Because of their mechanical properties (young's-modulus (4200 ± 480) MPa und strength (30 ± 2)MPa under tension load), the laminates in combination with the foam core increases significant the stiffness of the sandwich element. Furthermore the pressing process of the laminates enables a variety of design options. Additional subsequent coating and thus a further step can be omitted (figure 3).

Figure 3: Design options for the laminates during the manufacturing process. From left to right: Embossing | Printing | Laminating

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Manufacturing of Lignin-based Phenolic Foam

A Lignin-based aqueous dispersion of phenolic resin is used for the production of foams. The solid content of the resin is about 55% by weight at a density of 1.2 g/cm³ and the lignin content between 10% and 20% by weight. During the crosslinking reaction by polycondensation phenolic resins show a tendency of frothing due to the release of water. Therefore, no additional foaming agent is required, whereby the foaming can be performed material and cost optimized. However this process must be controlled for the systematic adjustment of the material properties. The morphology and structural properties of the foam depends on the water content in the basic resin-material, aggregates such as beech wood fibres and stabilization agents, and the lignin content of 10 % to 20 % by weight. For an optimized process the phenolic resin is dried before foaming. With a low residual moisture content of 10% by weight, the lignin-based phenolic resin has a very high expansion force at temperature of 150 °C and normal air pressure. Simultaneously the viscosity of the resin is decreased by heating. This induces an almost complete degassing of the phenolic resin. If the reaction volume is pressurized, the size of the foam pores can be controlled. Higher pressure up to 250 bar countervails the expansion of the water and the foam pores are finer and more stable. In addition, the water evaporates at higher temperature. The stabilization agent thickens the resin and gives it a certain higher viscosity, which counteracts the liquefaction when heated. Additionally the foam pores are stabilized at higher water contents in the resin. By means of this method, densities between 100-600 g/cm³ are adjustable. The morphologies of the foams are determined by computed tomography (CT) (figure 4). Important morphological parameters are determined from the CT scans data by using a cell-reconstruction program. The reconstruction occurs in a homogeneous region of the sample at 727 cells, boundary cells are not included in the reconstruction. The average cell diameter is (0.69 ± 0.11) mm. The foam almost consists of closed-cells, which is ideally suited for thermal insulation.

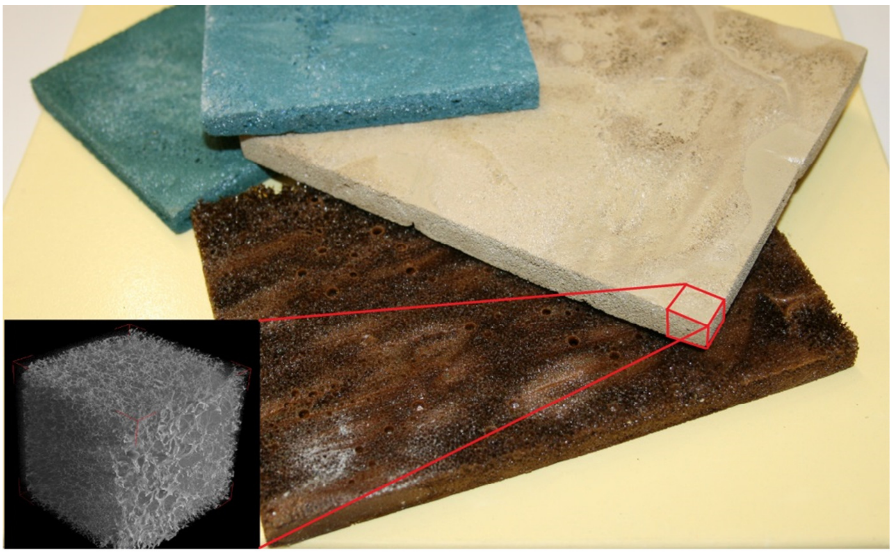

Figure 4: Lignin-based foams made with different densities and colours. Details of computer tomography of a small-scale foam sample. The colouring of the foams is the result of lignin, titanium dioxide and blue pigment.

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The Sandwich

The consolidation of the Sandwich structure can be done in two ways. In the classical case the skins are bonded to the foam under a certain pressure and temperature. In the second case as a more innovative process, the foam expands intrinsic in a tool. One laminate is fixed at the bottom and a second one via corresponding spacers above the cavity. The appropriate prepared lignin-based resin is filled into the cavity and afterwards the tool is closed. The foaming starts after adjusting the process parameters of pressure and temperature. An additional bonding of the skins is not necessary because there occurs a bonded connection of the laminates during foaming. On laboratory scale sandwich panels with a dimension of 300 x 300 x 80 mm³ and on industrial scale elements with the geometry of 2500 x 1200 x 100 mm ³ can be produced. The industrial production can be carried out either continuously or batchwise. The elements produced by intrinsic foaming can be used without any further treatment and do not need to be tempered subsequently. The elements produced in this way are suitable for the usage in interior design as well as supporting structures for exterior and ceiling elements. Therefore sample elements with a dimension of 2500 x 1200 x 100 mm ³ did not fail until a load of 13 tons at a buckling test (figure 5).

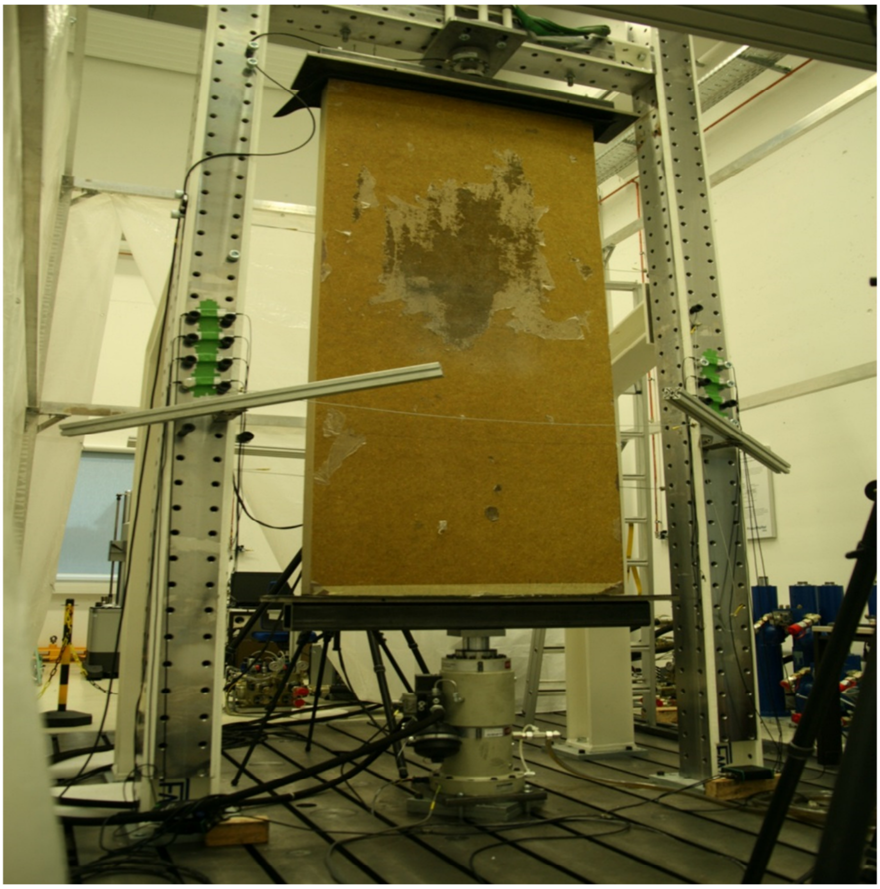

Figure 5: To determine the structural behaviour of the sandwich panels (dimensions 2500 x 1000 x 100 mm³) under realistic conditions, a comprehensive mechanical characterization of the parts was performed. For example, the structural behaviour of a wall panel was characterized in a buckling test. This was carried out on a servo-hydraulic test facility using a 400 kN-test cylinder.

The principle manufacturing process is shown in the following figure. The sandwich product is based to a significant fraction on the raw material beech wood. The prospective on a large scale implemented cleavage of lignin to monomers until 2020 opens the way to a purely on hardwood based processing technology, almost completely independent from petrochemical sources.

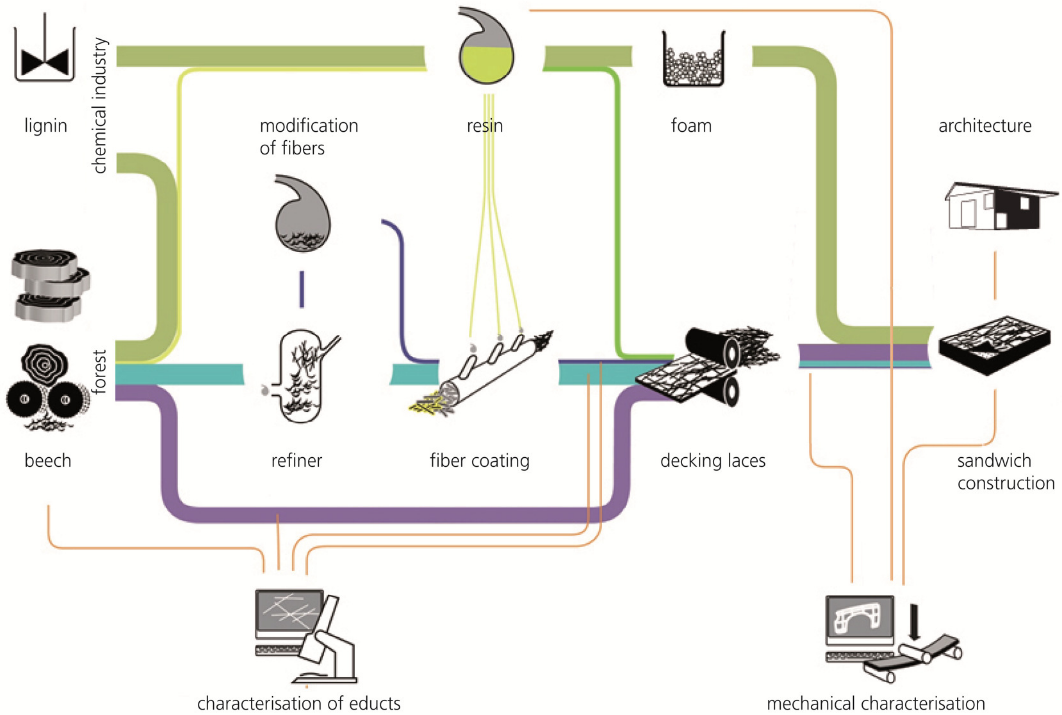

Figure 6: Manufacturing process from beechwood to a highly thermally insulating biosandwich

Summary

The compact construction method can be implemented with the sandwich system presented here which comprises natural fibres reinforced skins with a foam core of lignin-based phenolic resin. By the choice of suitable raw materials and their combination in the sandwich ideal structures for respective applications are created. The lignin-based resin matrix provides on the one hand sufficient fire resistance for the entire sandwich itself and on the other hand a high performance thermal insulation. Also rely on local resources for the laminates by the selection of fibres and their ratio of mixture in the natural-fibre-fleeces. By manipulating the composition of the various fibres in the fleece the mechanical properties can additionally influenced according to the usage. Depending on the pressing technology, the fibre-resin-ratio and the kind of fleece the elastic modulus of the laminates can be adjusted in a wide range to fit to the particular application like external or internal walls.

Funding

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Applicability of a vapor-open wooden building envelope for subtropical regions in global context

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Abstract: *The subtropical regions are of interest of our time as it includes both developing and developed regions. The applicability of a vapor-open wooden building envelope to those regions was evaluated in terms of the longevity of the wood fiber insulation layer and its life time cost. Atlanta, New York City, Shanghai and Sydney were selected as representing cities with different economic set-ups. Transient heat and moisture transfer simulation and life time cost analysis of the envelope was carried out. It was shown that regions with lower humidity load from exterior in the summer and higher electricity price such as New York City have high potential to apply the system. In order to even further promote such an envelope system in the regions with lower electricity price and higher humidity load, it is required to employ materials with lower price and higher moisture sorption capacity.*

Subtropical climate, Vapor-open building envelope, Durability, Optimization, Local economy

1. Introduction

The rapid economic development and urbanization in subtropical regions is a major issue with regard to the reduction of GHG emission and the mitigation to global warming. As the construction industry plays a significant role, there is a need for innovations on building technologies in those regions [1]. From the view point of building physics, such a climatic condition is very challenging because it results in both heating and cooling demands in buildings. This means that the direction of moisture flux due to the gradient of vapor pressure between exterior and interior changes throughout the year. Meanwhile it is crucial to take into account that there is an enormous socio-cultural diversity and different economic situations among the regions, which needs to be thoroughly taken into account when applying and developing new technologies to and for these regions.

The authors have developed a vapor-open wooden building envelope system and the optimization method of its insulation layer for central Japan, which has typical subtropical climate conditions with hot-humid summer and dry-cold winter, and evaluated its sustainability aspect from environmental, economic and building physics perspective with a sound consideration of the local socio-cultural context [2] [3] [4]. In the present study, the system was applied to other regions with similar climatic conditions: Atlanta (USA), New York City (USA), Shanghai (China) and Sydney (Australia). The analysis focused on the climatic conditions to evaluate the durability of the building as well as the economic feasibility considering the life span of the insulation layer. Comparing the minimum insulation thickness to avoid moisture related damages inside the wall and the economically optimal insulation thickness, the applicability of the system to those regions was evaluated.

2. Vapor-open wooden building envelope for subtropical regions

The interest of energy efficiency is growing in subtropical regions because of the high growth rate in the urbanizing areas in these regions. From the view point of building physics, such a climatic condition is very challenging because of both heating and cooling demands. The humid subtropical climate is difined by Köppen-Geiger Climate classification [5] as Cfa and Cwa which has the following climate characteristics: The mean temperature of the coldest month is between 0°C and 18°C and that of the warmest month is above 22°C (Cfa and Cwa has wet and dry winter respectively). It should be noted that in terms of heating demand, the winter condition covers too wide range (the regions with significant heating demand and minor heating demand are mixed). Figure 1 shows such regions all over the world.

Figure 1 Subtropical regions all over the world

Considering this issue, a new building envelope system was developed within the research team led by the authors. This envelope system mainly consists of major layers with natural materials, namely the external insulation layer with wood fiber board, the structural layer with cross laminated wooden panel and the interior finishing layer with the composite of wood and clay. The illustration of the envelope system and the materials for each layer is shown in Figure 2. The basic design philosophy of this system is that the envelope consists of hygroscopic materials with moderate vapor permeability. This system allows the moisture flux to move through the wall in both directions. By defining the appropriate thickness to each layer, it is possible to avoid moisture related problems inside the wall by humidity buffering.

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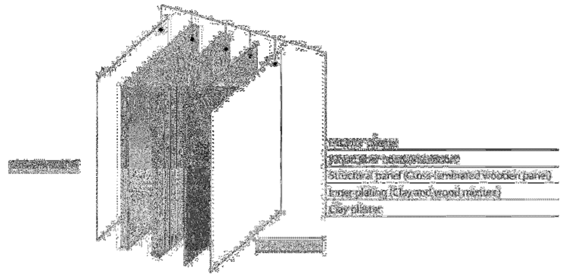

Figure 2 Layered structure of the vapor-open envelope for subtropical regions

3. Selection of the cities

In order to investigate a wider range of regions within the similar climatic condition, the following cities were chosen; Atlanta in USA (Cfa, significant temperature difference between summer and winter (rather warm), developed region), New York City in USA (Cfa, significant temperature difference between summer and winter (rather cold), developed region), Shanghai in China (Cfa, moderate temperature difference between summer and winter, developing region) and Sydney (Cfa, small temperature difference between summer and winter, developed region). The climatic data of each city was cited from an online database [6].

4. Minimum insulation thickness to ensure the longecity of the envelope

In order to evaluate the longevity of the building envelope under the climatic conditions of the selected cities, transient heat and moisture transfer simulation was carried out by using WUFI® 2D-3 [7]. Within this program, the basic heat and mass transfer is modeled by equation (1) and (2). Those are solved simultaneously and the temperature and relative humidity across the building component assembly is calculated [8].

$$\frac{dH}{d\theta}\cdot\frac{\partial\theta}{\partial t}=\nabla\cdot(\lambda\nabla\theta)+h_v\nabla\cdot\left(\delta_p\nabla(\varphi p_{sat})\right) \quad (1)$$

$$\frac{dw}{d\varphi}\cdot\frac{\partial\varphi}{\partial t}=\nabla\cdot\left(D_\varphi\nabla\varphi+\delta_p\nabla(\varphi p_{sat})\right) \quad (2)$$

Where $dH/d\theta$ (J/m^3K) is heat storage capacity of the material, $dw/d\varphi$ (kg/m^3) is its moisture storage capacity of the building material, λ (W/mK) is its thermal conductivity, D_φ (kg/ms) is its liquid transport coefficient, δ_p (kg/msPa) is its water vapor permeability, h_v (J/kg) is evaporation enthalpy of water, p_{sat} (Pa) is water vapor saturation pressure, θ (°C) is temperature and φ (-) is relative humidity.

The input for material properties and parameters concerning cerface transfer and rainwater were given in accordance with the past study [4]. The thickness of structural panel, clay board and clay plaster was given at 90mm, 14mm and 7mm respectively. The indoor climate was given as a sinus curve with the average of 21°C and amplitude of ±1°C. The highest temperature and relative humidity is given on the 3rd of June and the 16th of August respectively. The minimum hithickness of the wood fiber board insulation was defined in the

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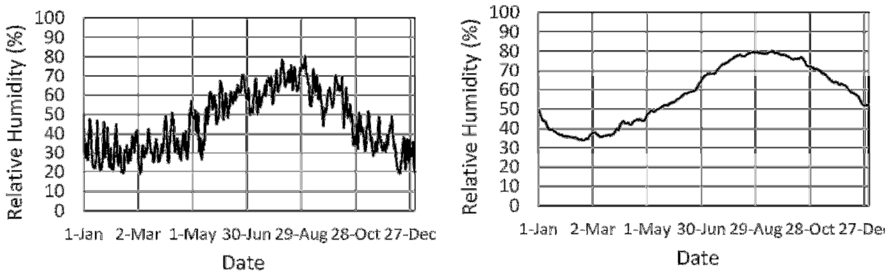
way that the retalive humidity at the most critical point in the wall (between the insulation and the structural panel) never exceeds 80%. Although this threshold was in fact rather low compared to the condition that mold growth is expected [9], this criterion allows a margin of safety.

The calculated minimum insulation thickness was as follows; 250mm for Atlanta, 40mm for New York City, 400mm for Shanghai and 30mm for Sydney. Figure 3 shows the calculated relative humidity at the point between the insulation and the structural panel of New York City and Shanghai as example cases. The difference of the smoothness of the curves in those figures is due to the insulation thickness difference. As the New York case has much thinner insulation, the influence of the fluctuating exterior air condition reaches to a certain extent as deep as the insulation layer itself.



(a) New York City *(b) Shanghai*

Figure 3 Calculated relative humidity between the insulation layer and the structural panel

5. Economically optimum insulation thickness

This study applied a simplified degree days method to define the economically optimum insulation thickness. In this method, the economically optimal point is given by the minimum value of equation (1).

$$C_{total} = C_{initial} + C_{running} \quad (1)$$

Where C_{total} (cost/m^2) is sum of the economic costs, $C_{initial}$ (cost/m^2) is cost of creating unit area of the insulation and C_{runnig} (cost/m^2) is cost due to transmission loss in the use phase per unit wall area. The initial investment $C_{initial}$ is given by equation (2).

$$C_{initial} = P \cdot d \quad (2)$$

Where P (cost/m^3) is cost of the insulation material per volume and d (m) is thickness of the insulation. In this simplified model the non-linear change of the cost is disregarded. Non-linear cost change is caused for example when the insulation layer becomes thicker than the conventional thickness that the insulation needs to be supported or connected by a different element than the conventional one. The running cost C_{runnig} is given by equation (3).

$$C_{running} = \frac{24}{1000} \cdot E_{money} \cdot D \cdot U \quad (3)$$

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Where E_{money} (cost/kWh) is energy price per 1 kWh, D (K) is sum of heating and cooling degree days over the life time of the insulation layer, U (W/m^{2}K) is heat transmission coefficient of the wall including the elements other than the insulation. It is important that the best practice is achieved by the optimal insulation thickness but it is not a very strict point to be aimed on. Both to the higher and lower from the optimal point there exists the reasonable good solutions. In the present study, 10% optimal ranges (the ranges which are defined by less than 110% of the optimum cost) were considered.

The input for each case was as follows. The material cost P was given as a constant price for all the places at 375 USD/m^3, which is the average price of 45 wood fiber insulation products from two manufacturers dealt by two retailers in Eurpope [10] [11]. The reasons for this price setting was that it is very difficult to define the retail price of a product in light of the dynamic pricing considering the local economy and that wood fiber board is not a common material in the selected markets yet. Therefore the price assumes that the material is imported from Europe where the market of wood fiber board is already established. The transportation cost was omitted. As for the running cost, the heating and cooling energy was assumed to be supplied only by electricity in each place [12] [13] [14]. The latest available electricity price was cited from database [12] [15] [16]. Individual prices (USD/kWh) were as follows: Atlanta; 0.11, New York City; 0.22, Shanghai; 0.05 and Sydney; 0.23. Heating and cooling was assumed to be performed by a heat pump with the coefficient of performance (COP) of 3.0. Therefore each of the input for E_{money} was devided by 3. The thermal conductivity of the insulation was set at 0.040W/m^{2}K, which is the average of the 45 products.The heating and cooling degree days was calculated based on the online database [17]. The base temperature for heating and cooling was set at 15°C and 21°C respectively. The caluculated heating and cooling degree days for each month for each city are shown in Table 1. The life time of the insulation layer was assumed to be 30 years.

Figure 4 shows the calculated initial and running cost and their sum for New York City and Shanghai as example. The optimal 10% insulation thickness range, the optimal thickness (in bracket) and U-value with the uptimal insulation thickness (in bracket) was given as follows; Atlanta; 7-59 mm (28mm, 0.58W/m^{2}K), New York City; 34-125mm (70mm, 0.36W/m^{2}K), Shanghai; 0-30mm (9mm, 0,79W/m^{2}K) and Sydney; 1-44mm (18mm, 0.67W/m^{2}K).

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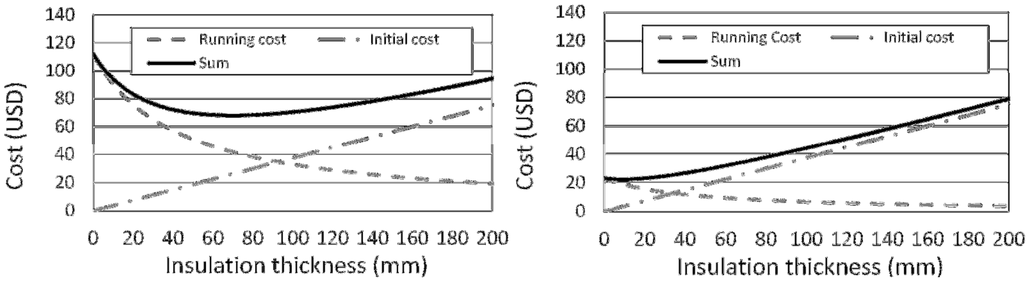
Table 1 Heating degree days (HDD) and Cooling degree days (CDD) of the selected cities

	Atlanta		New York City		Shanghai		Sydney	
	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD
January	275	0	432	0	291	0	0	80
February	203	1	373	0	256	0	0	56
March	137	12	301	0	146	3	0	54
April	50	29	142	2	29	12	4	18
May	16	70	32	12	1	59	37	2
June	0	119	1	56	0	113	55	0
July	0	152	0	154	0	304	75	0
August	0	127	0	98	0	269	51	3
September	3	69	6	33	0	118	19	17
October	59	19	56	5	3	25	9	29
November	164	2	212	0	64	4	0	37
December	208	0	309	0	265	0	1	45
SUM	1115	600	1864	360	1054	908	251	341
		1715		2225		1962		592



(a) New York City *(b) Shanghai*

Figure 4 Running and initial cost for New York City and Shanghai

6. Discussion

Figure 5 summarizes the hygrothermally minimum and economic optimal 10% insulation thickness for all the cities analyzed.

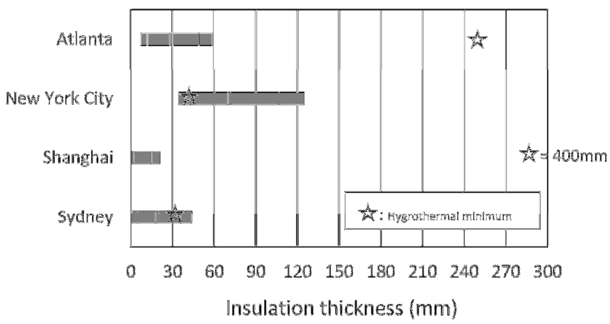


Figure 5 Running and initial cost for New York City and Shanghai

It was shown that both hygrothermal minimum and economic optimal thickness vary significantaly in different climatic and economic set-ups. Regarding the climate, the larger moisture load in the summer resulted in the overly thick insulation (250mm for Atlanta and 400mm for Shanghai). Regarding the economic condition, the difference of the electricity price resulted in a significant difference of the 10% optimal range. As the price of the wood fiber board is rather high, the regions with lower electricity prices showed low oprimal range (Atlanta and Shanghai). In the case of Sydney, although the electricity price is high, it showed a low optimal range. This is due to the low heating/cooling demand (see Table 1). Comparing the hygrothermal minimum and economic optimal thickness, it was shown that New York City, which has a higher electricity price and a lower exterior moisture load in the summer, has the high application potential of the envelope system. Furthermore Sydney, which has smaller heating/cooling demand, is also feasible for the application. It is recommended to apply cheaper materials with higher moisture sorption capacity in Atlanta and Shanghai.

7. Conclusion and outlook

In the present study, the applicability of a vapor-open wooden building envelope to subtropical regions was evaluated in terms of the longevity of the insulation layer and its life time cost. It was shown that regions with lower humidity load from exterior in the summer and higher electricity price have high potential to apply the system. In order to even further promote such an envelope system in the regions with lower electricity price and higher humidity load (which is often the developing regions), it is required to employ materials with lower price and higher moisture sorption capacity. In order to give a more holistic evaluation, sensitivity study should be carried out with such paraters as life time of isulation layer, electricity price, thermal conductivity, different heating/cooling systems and so on.

Reference

[1] CIB & UNEP-IETC (2002). Agenda 21 for sustainable construction in developing countries. Available at online http://www.cibworld.nl/site/home/index.html (accessed on 15/05/2014).

[2] Goto, Y., Ghazi Wakili, K., Ostermeyer, Y., Frank, T., Ando, N., Wallbaum, H. (2011). Preliminary investigation of a vapor-open envelope tailored for subtropical climate. *Building and Environment*, 46(3): 719-728, doi:10.1016/j.buildenv.2010.10.004.

[3] Goto, Y., Ghazi Wakili, K., Frank, T., Stahl, T., Ostermeyer, Y., Ando, N., Wallbaum, H. (2012). Heat and moisture balance simulations of a building with vapor-open envelope system for subtropical regions. *Building simulation*, 5(4): 301-314, doi:10.1007/s12273-012-0086-3.

[4] Goto, Y., Ostermeyer, Y., Ghazi Wakili, K., Wallbaum, H. (2012). Economic, ecological and thermo-hygric optimization of a vapor-open envelope for subtropical climate. *Energy and Buildings*, 55: 799-809, doi:10.1016/j.enbuild.2012.10.015.

[5] Peel, M.C., Finlayson, B.L., MacMahon, T.A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, 11: 1633-1644, doi:10.5194/hess-11-1633-2007.

[6] U.S. Department of Energy. http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm (accessed on 15/05/2014)

[7] Fraunhofer Institute for Building Physics. WUFI® PC-Program for calculating the coupled heat and moisture transfer in building domponents. Available at online http://www.wufi.de/index_e.html. (accessed on 15/05/2014)

[8] Künzel, H.M. (1995). *Simultaneous heat and moisture transport in building components. One- and two- dimensional calculation using simple parameters*. Stuttgart. IRB Verlag.

ISBN: 978-84-697-1815-5

[9] Viitanen, H., Vinha, J., Salminen, K., Ojanen, T., Peuhkuri, R., Paajanen, L., Lähdesmäki, K. (2010). Moisture and bio-deterioration risk of building materials and structures. *Journal of Building Physics*, 33: 201-224, doi: 10.1177/1744259109343511.

[10] Tŷ-Mawr. http://www.lime.org.uk/ (accessed on 15/05/2014)

[11] Natural Insulations. http://www.naturalinsulations.co.uk/ (accessed on 15/05/2014)

[12] U.S. Energy Information Administration. http://www.eia.gov/ (accessed on 15/05/2014)

[13] Chen, J., Wang, X., Steemers, K. (2013). A statistical analysis of a residential energy consumption survey study in Hangzhou, China. *Energy and Buildings*, 66: 193-202, doi:10.1016/j.enbuild.2013.07.045

[14] Australian Bureau of Statistics. http://www.abs.gov.au/ (accessed on 15/05/2014)

[15] Levine, M.D., Fridley, D., Lu, H., Fino-Chen, C. (2012). *Key China Eneregy Statistics 2012*. Lawrence Berkeley National Laboratory, China Energy Group. Available at online http://china.lbl.gov/ (accessed on 15/05/2014).

[16] Origin. http://www.originenergy.com.au/ (accessed on 15/05/2014)

[17] BizEE Software. http://www.degreedays.net/ (accessed on 15/05/2014)

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Technological Innovation Within Villas Miserias in Buenos Aires

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Abstract: *The main objective of the proposal is to modify and to improve the current social, economic and technological condition of the "villas miserias", the urban informal settlements in Buenos Aires, through the development of technological innovation processes. The principal strategies adopted are: the onsite production of raw material for building and construction, the development of building technologies using low and medium complexity processes to create new economic opportunities inside the formal construction market, the introduction of new building components to enhance the environmental sustainability and to improve the architectural quality of the existing "casillas".*

Technological innovation, slums, natural materials

Dwelling's constructionSection

In 1951 Martin Heidegger made a conference in Darmstadt where he raised the concept of "dwelling" as "the manner in which mortals are on the earth" and building "as the nature of dwelling". «[…]If dwelling is how the man defines himself in relation to the earth, the sky, the sacred and the mundane, house is the "shelter" of these relationships. To build the dwelling is to create space for shelter from the rain, to let in the sun, "to the altar corner behind the community table" and to provide all the places for life» (Heidegger, 1951).

Samuel Mockbee, the co-founder of the Rural Studio who dedicated his professional life to elevate the living standards of the rural poor, stated that: «Everyone, rich or poor, deserves a shelter for the soul» (Samuel Mockbee, 1996) and that architecture is a social art that has the responsibility to deliver both functional and spiritual comforts (Oppenheimer and Hursley, 2005).

The problem of the absolute degradation and neglect conditions, in which a large part of the world population pays, seems to be deeper and deeper. It is assumed that 30% of the world's population lives in slums, and that "poor of the twenty-first century are out of the modern production of wealth, but more importantly, marginalized from the resources of hope" (Fluvio Irace, 2008).

Considering the official rates from 2010, only in Buenos Aires city there are more than 200.000 persons who live in "villas miserias" (Argentinean slums), but unofficial sources give a number of 350,000 inhabitants. This problem is particularly acute in the rest of Argentina, where more than 25 percent of dwellings present housing deficit.

As in the case of other cities in the southern hemisphere, the growth of Buenos Aires is characterized by the densification of the urban center (inhabited by the middle and upper classes), and the expansion of the informal city, which is generally inhabited by immigrants

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who live on the margins of society. These last ones are marginalized from the processes of production and development, but provide the labor force for the creation of goods to which they have not access.

Considering that the great part of the able-bodied adults in urban ghettos work in the construction industry, the effort to increase work incentives in this sector and to create new economic opportunities through the study of unconventional building technologies, leads to encouraging conclusions about the endogenous growth of the slum. "Bidonvilles, from a certain point of view, are the laboratories of the future, in a world that slides into poverty "(Friedman, 2009). This study is based on some topics including economic and environmental sustainability, the attempt to obtain appropriate technologies through self-planning and self-construction, and possibly the independence in food production and water procurement.

The unconventional and sustainable production process within urban slums could modify the existing social, economic, and housing conditions. The availability of a large labor force in the "villas" would also allow experimentation and dissemination of the more successful techniques in other contexts and inside the formal construction market.

Appropriate technologies

Considering that the recent government policy tends to consolidate and urbanize the slums in their current location, the entire project is focused on developing appropriate new construction technologies within the "villas", along with a "technology's role review […] associated to resource's contention, waste's reduction, participation, control and process management by users, non-monetary factors evaluation, and attention to the man "(Bocco, Cavaglia 2008).

In order to reach this objective, attention must be paid to the green building materials available in the metropolitan or surrounding areas and to the more sustainable self-construction technologies, suitable to be developed in urban sites.

Exergy is a measure of the quality of energy and it can be consumed or destroyed through the operation of any physical or mechanical system. Exergy may be related to some environmental impacts and quantifies the sustainability of a process (Hau JL1, Bakshi BR. 2004). A great part of exergy could be destroyed during the life cycle of a building mainly during the production phase of materials and components and the construction phase (Koroneos, 2012).The whole project aims to reduce the use of most scarce exergetic resources encouraging improved process design and the introduction of new technologies.

In the present work local raw materials has been selected and new building component prototypes have been designed and self-built to improve the environmental sustainbility and the envelope quality of the existing "Casillas" (slum's houses). Densification and functional adaptation have been addressed through the planning of lightweight structures, separate from the existing ones. Higher insulation from the rainwater and the prevention from runoff and

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flooding have been solved adopting green roofs and creating new green productive areas. In addition to the technical requirements, this proposal took into account other issues related to the human needs, such as the social emancipation, the recognition of the individuality and the possibility to build up its own image.

Another objective of the work was to introduce new building components into the formal construction market, giving a new economic opportunity to the inhabitants of the slums.

Several surveys and site inspections have been carried out in two slums of Buenos Aires: Villa 15 y Villa 20. During which it was possible to identify materials and technologies used to build up traditional houses. Concrete and fired clay bricks resulted to be the principal construction materials. The most diffuse structural module shows dimensions ranging from 2.5x2.5x2.6 to 3x3x2.6 m, and an almost total absence of thermal insulation and waterproofing, as well as wall masonry coating materials. There is also an evident structural risk in the case of houses built up without any kind of prior structural analysis or soil verification, and subjected to increased loads due to vertical densification.

Plant Bases Materials: Bamboo and Hemp

Plant based materials, especially bamboo and hemp, are renewable resource which store carbon through photosynthesis during their growth and produce oxygen. Cultivation of these plants could take place in suburban and urban area, where there are large industrial infrastructures now disabled, and reduce the environmental impact of building industry. Pollution of the town could be limited and the control of rainwater runoff may be enhanced, improving the quality of the urban environment.

Different sites inside the metropolitan area of Buenos Aires are suitable to create productive parks in relation to the time of harvest, production and processing of raw materials. They can be designed also for a recreational function and provided with access control. These areas are in the neighborhood of the urban slums: there are more than 800 hectares within the city, and more than 8.600 in the metropolitan area. Furthermore the Delta of Paraná river is a particular case of production of forest area and processing material located at less than 25 km from the center of the city.

The exceptional geographic and weather conditions of Buenos Aires region, make it possible the cultivation of various species of bamboo. Nowadays in the Delta of Paraná river there is a large number of indigenous and imported species of bamboo. Clara Peña, a landscaper working at the Dirección General de Islas, verified that local bamboo could be an economic resource for local people. She developed technological transfer projects for cultivation, post-harvest treatment, and material processing (Peña, 2013).

Bamboo species which grow within the Delta could be cultivated also in the continent. Bamboo cultivation could be a sustainable alternative against deforestation because of its characteristics of cultivation: the possibility of a constant exploitation, the annual harvest of mature canes useful for forest subsistence, the rhizomes strengthening and the consequent

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growth of more robust canes. Figure 1 indicates possible species to be grown in Buenos Aires and the conditions and possibilities of exploitation (Rugolo 2013, Minke 2012).

The potential of bamboo as local natural material in housing has been tested during the workshop: "Construir con el Delta" (coordinated by Clara Peña -DPDI-, and Emiliano Cruz Michelena Valcárcel - Politecnico di Torino). A prototype of social housing was built using the structural module of the “casillas” and new technological solutions were experimented, such as standardized raw earth elements, green roofs and hydroponics.

The species of bamboo used in the project, which are also the most widespread in the area and the most suitable species to be cultivated in urban environment, are: Arundinaria Japonica, Phyllostachys Aurea (commonly known as tacuara) and Viridis Philostachys Bambusoide. They have been mechanically tested: Ph. Aurea reached 44 MPa in compression and 183 MPa in traction, while Ph. Viridis reached 38 MPa in compression and 166 MPa in traction.

Another bamboo type considered for cultivation is the Guadua Chacoensis, whose adaptation potential to the region is still under study but that counts some successful experimentation in Buenos Aires province. It is a native species from northern Argentina, having considerable dimensions and exceptional qualities for construction.

Figure 1 Bamboo and hemp cultivation characteristics

A green roof over bamboo prototype structure has been realized with a weight ranging from 45 kg/m^2 (dry) to 75kg/m^2 (wet), and a maximum bearing capacity of 1200 kg. The waterproofing has been realized using silos bag, waste of industrial production, and discarded plastic urban posters. This kind of roof could partially solve the problem of infiltration of rainwater in housing without a proper cover.

Basing on some technological solutions created by Yona Friedman , bamboo structures, obtained combining different species, are proposed for densification of the slum applying very low additional loads over the existing concrete structures.

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Hydroponic agriculture panels were also built, which control the solar radiation and improve the quality of façades. They provide also a partial solution to food procurement. During the workshop "Construir con el Delta" a prototype of brise soleil was built using bamboo canes (figure 2) as containers for different kind of cultivation. Vertical cultivation cladding panels were also experienced during Pro-Rom workshop (Politecnico di Torino, Italy), using pallets and other recycled materials and components. During this last project, bamboo was used to make panels for internal and external claddings coated with earth render. Hydroponic framing panels and bamboo cladding panels can be easily included into the formal building market due to the quality of design and the possibility of standardization.

Hemp cultivation and elaboration

Hemp cultivation is particularly complex because of the Argentinian drug control legislation (Law Number 23,737) forbids cultivation of Cannabis Sativa. Until the seventies of the past century, there was a big company in Buenos Aires, Linera Bonaerense, dedicated mainly to the production of flax and hemp, which developed one of the largest industrial complex in the country. The University of Buenos Aires has recently made a formal request to allow the entry of the hemp seeds inside the University campus for carrying out crop tests. The characteristics of growth, especially during winter period, will be studied in order to insert hemp as a rotation crop. Some characteristics of cultivation are reported in figure 1.

A hemp based lightweight bio-composite building material may be elaborated combining hemp shiv, a renewable plant aggregate, and a lime based binder. Hemp-lime is a non-structural material used for walls, roofs and under-floor insulation. In the present work a hemp-lime composite coupled with a bamboo structural frame has been developed to improve the thermal properties of the slum's houses, as suggested by Peter Walker: «Hemp-lime has modest structural proprieties, but it could enhance compressive timber/bamboo framework's load capacity, could reach higher levels of insulations and like many other natural materials it is hygroscopic, which enhances its heat storage capacity" (Walker, 2013).

Worldwide several companies have successfully begun to market hemp products and the chances of entering hemp building elements into the formal market have already been tested, for new constructions or existing buildings restoration.

Raw earth elements

Different elements made of raw earth could be combined with the hemp-lime to improve the thermal performances of the envelopes. Two kinds of prefabricated systems could be easily introduced into the formal market and even in the urban areas. During the project Pro-Rom (Giura, 2013) compressed earth blocks (5 cm thick) with different textures have been placed into metallic frames to create internal or external cladding panels. During the workshop "Construir con el Delta" a re-elaboration of the Peruvian quincha has been experimented using local canes and standardizing the internal panels characteristics.

Several samples of sediments coming from different sites located in the Delta of Paraná river and the Rio de la Plata were tested during the workshop and their characteristics were

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determined to verify the possibility to use these earths as construction materials. More than 160.000.000 tones/year of sediments are transported by the Parana and Uruguay rivers and arrive to the Rio de la Plata. The water flow causes the collapse of the banks and the transport over large distances of debris. The deposition of sediments which takes place in the Delta area produces a land growth of 50-90 meters/year towards the center of Buenos Aires.

Earth from Delta has been used to build houses, until the thirties of the last century after which its use was almost completely abandoned, being replaced by new technology and industrial materials. Sediments accumulated in the bed of the Rio de la Plata in Buenos Aires must be dredged and, contrary to what the law requires, they are thrown to the coasts enlarging the continental area. These sediments may be used for the elaboration of stabilized earth products which could be part of the commercial circuit of materials and building components.

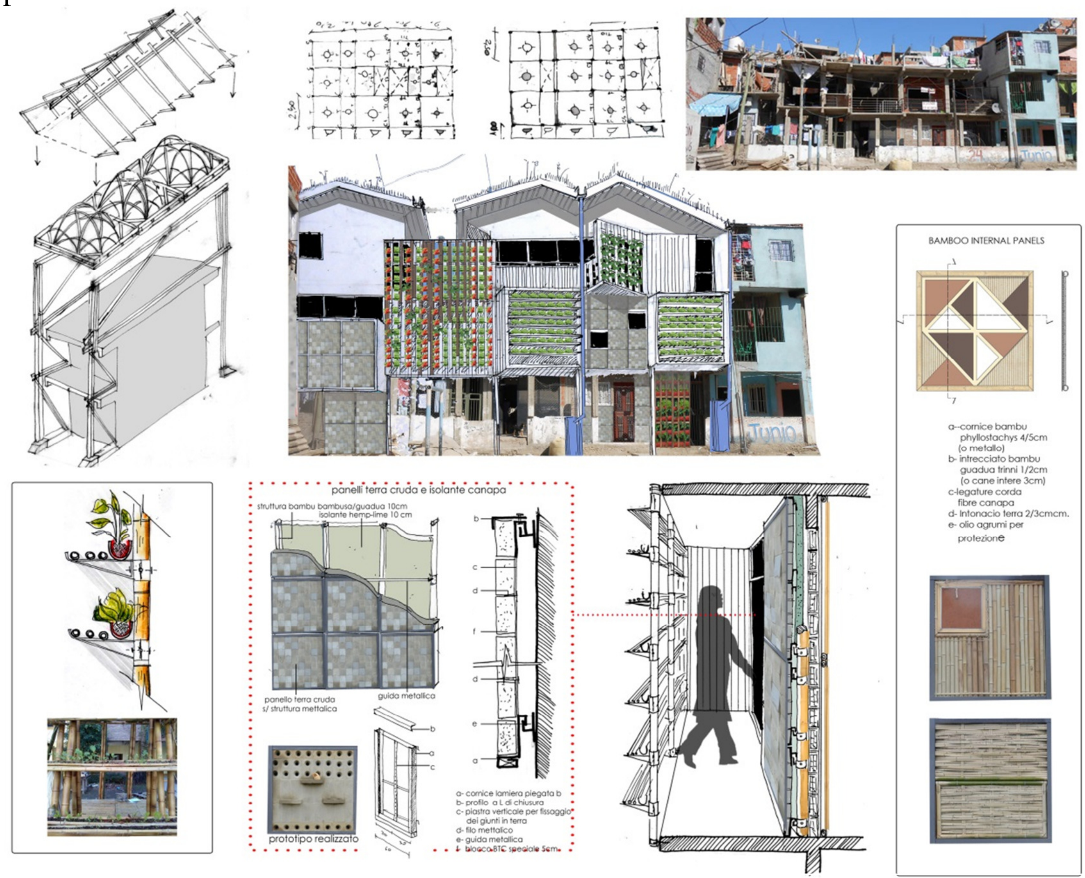

Figure 2: Current state of “Casillas” (slum’s houses) and low-cost enhancing project with natural materials

Technological transfer and diffusion

The diffusion among professionals and users of the economic, technological and environmental benefits of these materials and components is necessary to ensure the success of the project. During the workshop “Construir con el Delta” the communication system and the technological transfer have been experimented by the elaboration of self-construction manuals which simplified the comprehension for unskilled labor force (figure 3). At the same time a documentary movie was made on the construction process and different activities and workshops were carried out in professional institutions and universities.

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Figure 3 The project "Construir con el Delta": prototype and self-construction manual.

References

Martin Heidegger, Building Dwelling Thinking from Poetry, Language, Thought, translated by Albert Hofstadter, Harper Colophon Books, New York, 1971.

Samuel Mockbee and Coleman Coker, Thought and Process, Lori Ryker Editor. Princeton Architectural Press, 1rst edition, New York, 1996.

Andrea Oppenheimer and Timothy Hursley, Proceed and Be Bold: Rural Studio after Samuel Mockbee, Princeton Architectural Press, New York, 2005.

Fluvio Irace (2008). Casa per tutti. Abbitare la Citta Globale. Milano. Trienale Electra.

Jorge L. Hau, Bhavik R. Bakshi - Expanding Exergy Analysis to Account for Ecosystem Products andServices. Environmental Science and Technology . 2004 Jul 1;38(13):3768-77.

Christopher J. Koroneos , Evanthia A. Nanaki, George A. Xydis Sustainability Indicators for the Use of Resources—The Exergy Approach. Sustainability 2012, 4(8), 1867-1878; doi:10.3390/su4081867

Yona Friedman. 2009. L' Archiettura della Sopravvivenza, Una filosofia della povertá. Bollati editore. Andrea

Bocco, Gianfranco Cavaglià. (2008). Cultura Tecnologica della Architettura. Pensieri e parole, prima dei disegni. Torino, Caroci Editore

Clara Peña (2013) El bambú en el delta bonaerense y su gente. Dirección Provincial de Islas, edit. Gobierno de la Provincia de Buenos Aires.

Zulma Rugolo (2013). Generos y especies de bambú identificados en el Delta. El bambú en el delta bonaerense y su gente. Dirección Provincial de Islas, edit. Gobierno de la Provincia de Buenos Aires.

Gernot Minke (2012) Building with Bambu, Design and technology of a sustainable architecture Basel, Birlhouser.

Peter Walker 2013, El uso moderno de los materiales tradicionales de construcción. Revista de Arquitectura 250, a cura de Emiliano Cruz Michelena Valcárcel y Melina Berman, Buenos Aires. ISNN 0327-330X. p. 136 to 141.

Clara Giura, Emiliano Cruz Michelena Valcárcel, Simonetta Pagliolico, Construcción con tierra cruda, proyectos de difusión y transferencia tecnológica para contextos de emergencia. Arquitectura y Construcción en Tierra (SIACOT XIII) Material Universal, Realidades Locales, agosto de 2013 – Valparaiso, Chile – Libro Resumenes p 95 isbn : 978-956-353-181-7 , articulo entero formato CD-ROM isbn 978-956-353-225-8

---

[i] United Nations, Department of Economic and Social Affairs, Population Division. (2013). *World Population Prospects The 2012 Revision - Highlights and Advance Tables*. Working Paper.

[ii] Ernst and Young. (2012). Renewable Energy Country Attractiveness Indices, *RECAI*, .

[iii] Africa's Impressive Growth. (2011). *The Economist*. http://www.economist.com/blogs/dailychart/2011/01/daily_chart#sthash.i8KlYOf0.dpbs.

[iv] Ohrnberger, D. (1999). The Bamboos of the World: Annotated Nomenclature and Literature of the Species and the Higher and Lower Taxa. *Elsevier*.

[v] a) Chung, K. F. and Yu, W. K. (2002). Mechanical Properties of Structural Bamboo for Bamboo Scaffoldings. *Engineering Structures,* 24(4): 429–442. b) Kamruzzaman, M. et al. (2008). EFFECTS OF AGE AND HEIGHT ON PHYSICAL AND MECHANICAL PROPERTIES OF BAMBOO. *Journal of Tropical Forest Science,* 20(3). c) Gutu, T. (2013). A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization. *International Journal of Innovative Technology and Exploring Engineering*. 2(5). d) Narasimhamurthy, M. et al. (2013). A Study on Physico-Mechanical Properties of Thyrsostachy Ssiamensis (Kurz) Gamble and Dendrocalmus Membrances (Munro) in Tumkur District, Karanataka, India. *International Journal of Innovative Technology and Exploring Engineering*. 2(2): 262–266. e) Verma, C. S., Chariar, V. M. and Janpath AICTE. (2005). Study of Some Mechanical Properties of Bamboo Laminae.*Wood Science and Technology*. 39(6): 448–59, doi:10.1007/s00226-005-0016-y.f) Ahmad, M. and Kamke, F. A. (2003).Analysis of Calcutta Bamboo for Structural Composite Materials: Surface Characteristics. *Wood Science and Technology* .37(4): 233–40.

[vi] Mahdie, M.F. and Rinaldi, A. (2013).Pengaruh Pola Susunan Laminasi Balok Bambu Tali (Gigantochloa Apus Kurz) Terhadap Kerapatan, Delaminasi Dan Keteguhan Patah. *Jurnal Ilmu Kehutanan.* 1(2). http://journal.ugm.ac.id/jikfkt/article/view/1552.

[vii] Hidalgo-Lopez, O. (2003). *Bamboo: The Gift of the Gods*. Minnesota. O. Hidalgo-Lopez.

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Session 49:

Regulations, processes and systems to support Energy Efficiency in buildings: Are there contradictions between theory and practice?

Chairperson:

de Santiago, Eduardo

Consejero Técnico. Subdirección General de Urbanismo. Subdirección General de Urbanismo. Ministerio de Fomento. Gob. España

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Traffic Problems in the Core Area of Historic City of Casbah, Algiers: From Urban Conservation to Sustainable Development

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Abstract: *The traditional markets in the core areas have played a significant role in the development of historic cities in the Arab world; they were developed through time in response to socioeconomic and cultural needs of the society. The aim of this paper is to investigate the impact of transportation on the core area of historic cities, in order to suggest some guidelines for improvement and conservation. To achieve the aim the existing condition and problems being faced by core area of Casbah city, Algiers as an example were examined in order to determine its characteristics and the nature of the effects to which it have been subjected. A broad range of information was collected from various sources and through a field survey carried out in the selected case study of traditional market area in Casbah city, Algiers. The collected information was analyzed with particular regard to the special character of the city and its current conditions. This study is an attempt to address the important issue of traffic and its impact that have been raised in the historic cities of the Arab world and it is hoped that it is going to be a significant contribution to the subject of sustainable development as well as urban conservation. conclusion have been arrived at the end and specific suggestions are intended to assist in examining problem and helping in solving problems and developing sustainable guidelines for the improvement of the current situation in the core area of the historic cities of the Arab world.*

Keywords: traditional markets, transportation mode, socioeconomic needs, urban conservation, sustainable development

Introduction

It is appropriate to describe the special structure of such historic cities that can be seen all over the Arab world, such as Marrakesh in Morocco, Casabah in Algeria, Kairouan in Tunis, Cairo in Egypt, Aleppo in Syria, and Sana'a in Yemen. All these historic cities appear to share some common characteristics and a somewhat similar urban form. (Jamel. A, 1988). (Figure1). The Casbah is situated on the coast to the north of the city. The complex labyrinths and a fortress from the 1500s remain as th reminders of the past. The Casbah city of Algiers was founded in the 6 Century BC, and was constructed on a steep slope (118m.high), facing the harbour bay and the Mediterranean Sea. Its historical function was military and trade. (Bousaa, D, 2012).

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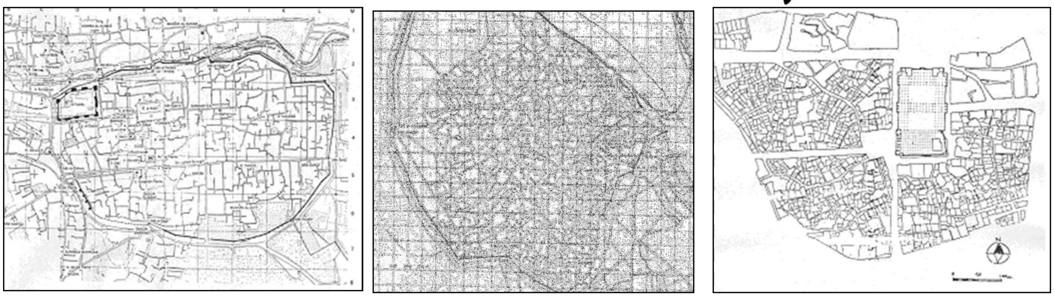

1. Aleppo, Syria 2. Mosul, Iraq 3. Madinah, Saudi Arabia

Figure 1: Plans showing the similarities of the various historic cities in the Arab world

Problem Satement

Historic city of Casbah, Algiers, is included in UNESCO's strong social identity. It contains the largest concentration of historic monuments in Algeria which together comprise an unrivalled urban heritage and the remaining historic buildings are a finite resource and an irreplaceable due to the pollution generated from transportation modes, congestion and traffic problems. Indeed, despite the fact that transportation has an essential and positive role to play in economic and social development, the traditional transport modes and the existing transportation network in historic city of Casbah, Algiers negatively affects the historical buildings and also the urban heritage of the historic areas.

Accordingly, this paper attempts to diagnose the transport and traffic problems in historic city of Casbah, Algiers in general and in traditional market area in particular, and investigate methods for conserving the urban heritage from the negative effects of traffic congestion and of the traditional modes of transportation. It also attempts to explore possible areas for intervention to mitigate transportation and traffic problems in the light of the principles of the sustainable transportation framework. It aims to draw conclusions and propose recommendations that would increase the efficiency and effectiveness of transportation plans in historic city of Casbah, Algiers and consequently achieve sustainable transportation.

Methodology

This paper has, so far, provided an overview of the main transportation features and problems of historic city of casbah, Algiers. It attempts to draw conclusions and propose a framework for sustainable transportation in the light of the sustainable urban conservation principles. This paper has highlighted the significance of the interrelationships between the issues related to the preservation of the urban heritage with the efficiency of transportation networks and transport modes and traffic solutions in order to maintain historic buildings and protect them from degradation caused by transportation and other activities.

Spatial Structure of Historic City of Casbah, Algiers

A typical historic city of Casbah, Algiers as other cities in the Arab world was often surrounded by a fortification wall, having a number of gates, the only access and egress points. (Figure 2). The street system in a typical historic city appears to consist of these types of streets. The primary streets entered the city from different gates and met each other near the main mosque and divide the whole city into a number of residential quarters. (Bianca, S, 2000). The secondary streets often join two or more primary streets and divide a residential quarter into smaller residential units. They tend to house shops needed for the day to day activities of the inhabitants in the residential quarters. The tertiary streets provide access

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within the residential areas. *Cul-de-sacs* could be attached to any type of streets. A cluster of ten (10) to fifteen (15) houses are often arranged around these cul-de-sacs.
They are quite private spaces and are only used by people living there. (Hakim B, 1986). In historic city of Casbah, Algiers public paths compose an irregular network enclosing large residential plots. The blocks represent the basic morphology unit in Historic Cairo. Each super block incorporates several uses (i.e. residential, non-residential, service uses and others). Local paths reach the interior of the super blocks in an organized (but organic) manner. Super blocks consist of two main components: (a) the inner core, which deals mainly with residential functions mixed with handicraft activities and is composed of several local path units; (b) the outer core, which is bound by the public paths and contains a combination of residential, commercial and social activities.

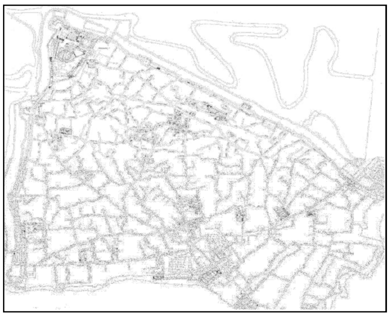

Figure 2: A typical historic city of Casbah, Algiers was often surrounded by a fortification wall and having a number of gates

Traffic Problems in the Traditional Market Area of Casbah City, Algiers
Population Growth and Economic Challenges

Many problems have been created by the expanding commercial activity in the traditional market area of Casbah city, Algiers which has been accommodated largely by the conversion of residential buildings and areas. In many cases commercial activity, because of its need for space, has led to speculative land trading and the demolition of residential buildings. In some cases the traditional street pattern has largely disappeared because of the construction of new shops. The new structures that have been erected sometimes do not relate well to their surroundings. Small-scale manufacturing has also spread into the residential areas of the historic cities. It is often the space in old residential buildings which has been converted for production use. In the absence of adequate space, such activities have sometimes been extended onto the adjacent street. Activities of this sort often generate obnoxious smells, fumes and waste of various sorts and have contributed significantly to the decline of the general environmental quality in the streets.
The increase in population and commercial and production activities is responsible for generating a large amount of traffic within the Casbah city, Algiers. The primary streets, which are often those along which traditional markets are also located and are the only access routes which constantly clogged with pedestrians and vehicles of various sorts. This situation has made many market streets hazardous for pedestrians and shopping somewhat less enjoyable. (Figure 3). Even the streets meant largely for pedestrian traffic are often clogged with cycles, motor cycles and hand carts.

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Figure 3: The streets of traditional market area are hazardous for pedestrians and shopping somewhat less enjoyable.

Although some congestion points is perhaps desirable in core area of the Casbah city, Algiers the present situation is often intolerable. The presence of encroachments of various sorts in the streets has further exacerbated the problem of accessibility within the historic cities. In addition, such encroachments have significantly affected the quality of the street space and the visual and functional relationship of buildings to one another and to the street pattern.

Under the impact of these many changes the historic cities have become predominantly the abode of low income groups with very high residential densities. This situation is further complicated by the fact that the commercial activity in the form of traditional markets is one of the most conspicuous special attributes of the historic city of Casbah, Algiers and its continued existence is highly desirable for the successful functioning of these markets. However, the traditional markets that are worthy of preservation have also been responsible for creating adverse affects on other special attributes of the historic city of Casbah, Algiers particularly because of intensification of commercial activity in more recent times.

Accessibility by Various Transportation Mode

The public service operates within very high traffic densities. The area is served by both public buses and private mini- buses with almost identical routes. Approximately 30,000 vehicular trips are produced or attracted by the traditional market area in Casbah city, Algiers. An additional 3,000 vehicular trips make-up the amount of traffic within the market area, which indicates the relatively low car-ownership of residents within the area. Most network links and intersections in the area suffer from severe traffic congestion during peak hours, due to high volumes in the organic layout system, where roads and sidewalks are used for commercial activities.

The highest traffic portion is the through-traffic (i.e. trips having both their origins and destinations outside the area) and consists of 120,000 vehicular trips daily.Moreover, the mentioned area suffers from severe parking shortage. Parking is unregulated, mostly on sidewalks and vacant lots, burdening the remaining historic paths deep inside the urban fabric. Most parking is currently provided along the streets. One-hour parking in the market area has 55 percent frequency, two-hour parking a 25 percent and subsequent longer parking duration's only 20 percent (Gamal, 2002). Accommodation of short-term parking is important. Enforced parking policies based on a pricing system need to be formulated. The area is neither serviced by parking lots nor underground nor multi-story garages.

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Delivery and pick-up trips are important traffic components in the area, and are the main cause of both congestion and over-extension of the network. Regulated access and entry/exit arrangements should be provided for their operation. They serve workshops and handicraft activities which are important to the area's economy. In addition to the presence of the heavy vehicular traffic in the narrow streets of Casbah city, the absence of adequate parking, loading and unloading facilities means these activities have generally to be carried out on the streets, creating severe problems with regard to the mobility and accessibility. (Figure 4).
Despite the fact that the area has a great potential as a walk for tourists, pedestrian movement is very difficult. Indeed, priority should be given to pedestrians. However, there are only few pedestrian zones and therefore the access to the monuments is difficult. At present, the highest pedestrian flows are observed on traditional market area.

Figure 4: The absence of adequate parking, loading and unloading facilities

Land Use Problems
Support activities in the traditional market area such as coffee shops, food outlets and small take-away restaurants are a small proportion of the total number of shops and they provide a poor level of service. However, Casbah city, Algiers lacks public toilets, telephone booths and tourist information facilities. Similarly, public facilities count less than 2 percent of all ground floor activities along the spine. There are also peddlers who park their stalls at strategic locations, generally facing historic monuments and public facilities and sometimes confront other shops, blocking their entrances and colonizing parts of the street.

Modern Changes and Its Impact
The modern changes have made the streets in Casbah city, Algiers hazardous for pedestrians and shopping somewhat less enjoyable. Even the streets meant largely for pedestrian traffic are often clogged with cycles, motor cycles and hand carfts. (Figure 5). Although some congestion is perhaps desirable in commercial areas, the present situation is often intolerable. The presence of encroachments of various sorts in the streets has further exacerbated the problem of accessibility within the historic cities. In addition, such encroachments have significantly affected the quality of the street space and the visual and functional relationship of buildings to one another and to the street pattern.

Under the impact of these changes many core areas of the historic cities have become predominantly the abode of low income groups with very high residential densities. This situation is further complicated by the fact that the commercial activity in the form of traditional markets is one of the most conspicuous special attributes of the historic city of Casbah,Algiers and its continued existence is highly desirable for the successful functioning

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of this city. Though many reports and proposals have been made by the planning authorities to improve the situation with regard to the revitalization and preservation of commercial activity in such markets, it appeared that generally they have failed in improving the situation. One major reason for this situation appears to be the fact that very little attention has been paid to the historic spatial structure, transport system, activity pattern and the traditional way of life in this historic city.

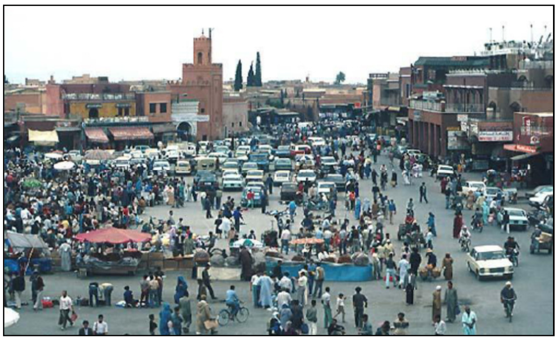

Figure 5: The streets meant largely for pedestrian traffic are often clogged with motor cycles and cars

Sustainable Development and Urban Conservation

An overall objective for Historic City of Casbah Algiers in general and its traditional market area in particular is to achieve sustainability. The sustainability depends on not only the environmental sustainability (natural, man made and socio-cultural environments), but also the continuity of the urban spaces to preserve their historically prominent identity in the city serving the residents with basic services together with the residential, commercial, recreational, and all other needs. A prerequisite to achieve sustainability is to have an efficient transportation network and smooth traffic flows. MOST (1999) points out that the goal of sustainable transportation is to ensure that environmental, social and economic considerations are factored into decisions affecting transportation activity.

Urban transportation systems play a critical role in city planning decisions due to their interaction with other urban systems such as environment, energy, land- use, safety and security, and in many cases may be viewed as the nucleus for sustainable cities. Sustainability in cities is extremely unlikely to be achieved without addressing the urban transportation problems (WIT, 2000). Indeed, transportation could have unfavourable & negative impacts on the city, for example: -Environmental impacts: air, noise and visual pollution are the most environmental pollution, which are produced or emitted by traditional modes of transportation (UNEP 2001, Cohn 1981, Buchanan 1963).

- Economic Impacts: transportation affects the efficiency of city activities and its function, wastes time and money that sometimes increases the costs of freight delivery due to the congestion of city streets and the resulting delay.
- Social Impacts: transport could have a negative effect on city street life, social isolation, and social insulation (Crawford 2000, Buchanan 1963).
- Historic Impacts: deterioration of historic buildings and monuments: chemicals reactions caused by traffic pollutants such as SO are damaging the structure of the rocks, which used in many historical buildings (Mediterranean Kit 1996). In addition, it can be safely argued that transportation facilities and activities could have significant negative impacts, including those listed below in table 1.

Table 1: Transportation Impacts on Sustainability

Economic	Social	Environmental
Traffic congestion	Inequity of impacts	Air and water pollution
Mobility barriers	Mobility disadvantaged	Habitat loss
Accident damages	Human health impacts	Hydrologic impacts
Facility costs	Community interaction	DNRR
Consumer costs	Community livability	
DNRR	Aesthetics	

DNRR= Depletion of Non- Renewable Resources (Source: Litman (1999))

Therefore, as Barten (1995) argues, transportation, as one of any city activities, can be planned through maintaining the global ecology, husbanding natural resources and improving the quality of the local human environment. Unsustainable transportation would negatively affect the urban heritage and indeed the livelihoods.

Conclusion and Recommendations

Though many reports and proposals have been made by the government bodies and planning authority in the historic city of Casbah, Algiers to improve the situation with regard to solve the traffic problems in such congested areas; it appeared that generally they have failed in improving the situation. One major reason for this situation appears to be the fact that very little attention has been paid to the historic spatial structure, streets pattern and the traditional market areas. It is argued that without such an understanding it is very difficult to engage in meaningful preservation and revitalization of such historic city. It is very important that the issue of traffic and its impact in the tarditonal market area that have been raised in this paper and it is hoped that it is going to be a significant contribution to the subject of transport management, sustainable development as well as urban conservation of historic city. It is worthy to end up with some recommendations, which could be as guidelines that will be useful for future development of the historic cities. Thus, these recommendations are as follows:

1. A comprehensive conservation plan of historic city of Casbah, Algiers should pay special attention to the significant role of traffic and its impact on the core area.
2. To provide amenity, convenience and comfort for visitors and people who live and work in the area. Pedestrianisation, accessibility and safety are to be reinforced while respecting the organic urban pattern. To enhance street life, vitality and activity, in order to attract people and increase economic prosperity.
3. In order to achieve sustainable transportation, there should be a traffic management system in order to preserve the pedestrian scale and vehicles should not be allowed to enter core area streets other than the main street except only for emergencies. To promote appropriate management system, including maintenance of the uniqueness of the street, parking areas, loading and unloading spaces should be reserved nearby the core area for the use of the workers and visitors.

4. To preserve the human scale of buildings and public open spaces by retaining the traditional nature of the street and by enhancing the unique character of the built form. An attempt should be made to revive an attractive image that, in general, accords with the appearance of the historic buildings, to promote the qualities of architecture in the area and to create the circumstances for contributing to the improvements of the street's aesthetics. Garbage disposal system and supply of goods should be scheduled at night.
5. Traditional market area of historic cities are places of great interest to tourists, tourism may serve to revive the economic life of the traditional city by encouraging artisan activities and using traditional modes of transport.
6. Educational programs should insist and invite new coming generations to understand and respect the local traditonal way of life, culture, history and built heriatge.

The mentioned recommendations could be adopted as guidelines that will be useful for sustainble development in the historic cities of the Arab world, which can always be modified by future research, and by implementing such framework it is hoped that the situation will be improved in the future.

References

Bianca, Stefano. (2000). Urban Form in the Arab World: Past and Present. London: Thames and Hudson.

Bousaa, D. (2012). The Casbah of Algiers: From an Urban Slum to a Sustainble Living Heritage. American Transactions on Engineering & Applied Sciences. Volume 1 No.3. ISSN 2229-1652 eISSN 2229-1660

Buchanan, C. (1963). Traffic in Towns: A Study of The Long Term Problems of Traffic in Urban Areas, Report of the Streeting Group and Working Group, Ministry of Transport, published by HMSO, London.

Crawford, J. H. (July 2000). Car Free Cities: Life City-Car Crisis", published by International Books, Internet materials found at http://www.carfree.com/intro_cfc.html, and was printed on 19/01/02.

Dilmi, D. (2014). The Formation of Traditional Markets in the Historic Cities. LAP, Lambert Academic Publishing.

Gamal, N. (2002). Designing Public Spaces: Towards a Sustainable Urban Form, Unpublished MSc thesis, Ain Shams University, Cairo

Hakim, Bessim. (1986). Arabic Islamic Cities: Building Planning Principles. , London Kepan Paul International.

Frey H. (1999). Designing the City: Towards a more Sustainable Urban Form, published by E & FN Spon, an imprint of Routledge, London.

Jamel, Akbar. (1988). Crisis in the Built Environment: The Case of the Muslim City. Concept Media Pte Ltd. Aga Khan Trust for Culture.

Kayvan, Karini. (1999). Urban Conservation and Spatial Transformation. London: University College.

Mustapha, Ben Hamouche. (2000). Souqs et Metier d'Alger a l'epoque Ottomane. Tunis: Publications of Tammimi Foundation of Scientific Research and Information.

MOST (1999). Transport Canada, Moving on Sustainable Transportation, Internet materials found at (http://www.tc.gc.ca/envaffairs/most), and was printed on22/07/00.

Walter, M.Weiss. (1998). The Bazaar, Markets and Merchants of the Islamic world. London: Theme and Hudson Ltd, London.

WIT, (2000). The Sustainable City Conference, First International Conference on Urban Regeneration and Sustainability, proceeding by Wessex Institute of Technology, UK and Universidade Rio de Janeiro, Brazil; with collaboration of the ISC Group of Companies of Italy, held in Rio de Janeiro, Brazil (25 –27 April,2000).

Zancheti, S. M. And Jokilehto, J. (1997). Values and Urban Conservation Planning paper published in Journal of Architectural, No. 1.

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Australian residential energy efficiency regulations – successes, shortcomings and learnings

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Abstract: *Australia has had energy efficiency regulations for new residential buildings for over ten years. Currently a minimum of six stars out of a possible ten stars is required. A study of over 400 houses in three different cities in Australia examined whether houses built to the current requirements were achieving better energy efficiency outcomes than houses built to the earlier lower requirements.*

Results reveal that the modelled savings have not always been achieved in reality. The energy savings that have been achieved and possible reasons why expected savings have not been achieved are explored including the impact of human behavior.

Finally, the paper discusses the controversial issue of construction cost impacts and reveals that a range of solutions are being employed to achieve the required standards and that construction costs have been minimised while still delivering lower energy costs and lower greenhouse gas emissions.

Keywords, Energy efficiency, regulations, building costs, compliance, energy use

Introduction

Energy consumption by Australian households represents 26% of Australia's total net energy use. Around 45% of household energy consumption is related to transport purposes, while the remaining 55% is related to energy used directly in houses, predominantly electricity and natural gas (1). Within the home, energy use is dominated by heating and cooling requirements (40%) and water heating (21%) (2) and consequently designing homes that have improved thermal performance and higher appliance efficiency is a critical part of reducing household energy consumption.

Australia has had energy efficiency regulations for new residential buildings for over ten years. During that period, the performance requirements of the regulations have been periodically increased to their present level of a minimum of six stars out of a possible ten stars based primarily on the thermal performance of the building's envelope. The effectiveness of these regulatory requirements had not been fully explored and consequently a study of over 400 houses in three different cities in Australia was established to examine whether houses built to the higher performance requirements were achieving better energy efficiency outcomes than houses built to the earlier lower performance requirements. Each

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house in the study was rerated under the regulatory star rating system and half the houses were equipped with an energy monitoring system to establish accurate energy consumption data. The majority of houses were detached dwellings and were required to have been subjected to the energy efficiency provisions of the Building Code of Australia that was first introduced in 2003. Consequently, no house was older than 10 years. Houses were evenly distributed between three major Australian cities with different climate profiles, Brisbane (sub tropical), Adelaide (temperate) and Melbourne (cool temperate).

The study examined three major areas. Firstly, compliance with the regulatory requirements - that is, were houses actually achieving their stated star rating level? Secondly, were the higher star rated houses using less energy than the lower rated houses? And finally, what was the additional cost of building houses to the higher energy efficiency standards?

The rating system utilised in Australia to determine the energy efficiency of a design is based on a 10 star rating, where 10 stars is considered to be a house that will require no additional heating or cooling over a typical year. Currently, the minimum standard required is 6 stars and for this study a house that rated 5 stars (or above) was regarded as a high-rated house, while a house less than 5 stars was regarded as a lower-rated house.

Compliance

A house design's compliance with the energy efficiency provisions can be determined by two methods: use of energy modelling software, or comparison against a compliance checklist. A surprising finding of the study was the level of difficulty encountered in trying to determine what compliance method had been used and the exact star rating result achieved for a particular design. A lack of a centralised database meant that original star ratings could only be established for 42% of homes in the study. From this reduced set it was found that when rerated almost half the houses rated below their original rating (Table 1). This was even after taking into account the more conservative approach of the rerating process by allowing a half star tolerance on the rerated results, that is, a house design that rerated at 4.5 stars was considered to achieve a 5 star rating.

Table 1 Comparison of original star rating to rerated star rating

	Brisbane	Adelaide	Melbourne
Below rating	54.3%	42.6%	48.6%
Above rating	6.5%	14.8%	2.7%
Same rating	39.1%	42.6%	48.6%

In addition, the study also found that as energy efficiency regulatory requirements have increased over time, the level of compliance has reduced. Figure 1 shows that houses built in 2003 to a lower energy efficiency standard were more likely to achieve the standard when rerated than homes built in 2010 to the higher energy efficiency standard. Indeed 71% of houses built in 2010 were rerated below their original rating, compared to 33% of houses built in 2003. The exact reasons for this are the subject of a current study, but possible

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explanations may include: changes in the design that occurred after the energy assessment was done, misinterpretation by energy assessors of information on plans, or overly generous assumptions being made where information is lacking or missing. Although no evidence of deliberate misrepresentation of the energy rating of a house design was found, a potential problem exists in that the energy assessor effectively works for the builder and not the house owner. It is in the assessor's interest to ensure that the design achieves the rating with as little impact as possible on the design itself as this could cause cost increases that the builder would need to pass on to the house owner. In addition, the building inspection regime that exists in Australia has a primary focus on the structural integrity of the house construction and consequently key inspection dates are linked to structural milestones. Energy efficiency compliance milestones may often fall between these structural milestones and consequently might be missed by the building inspector.

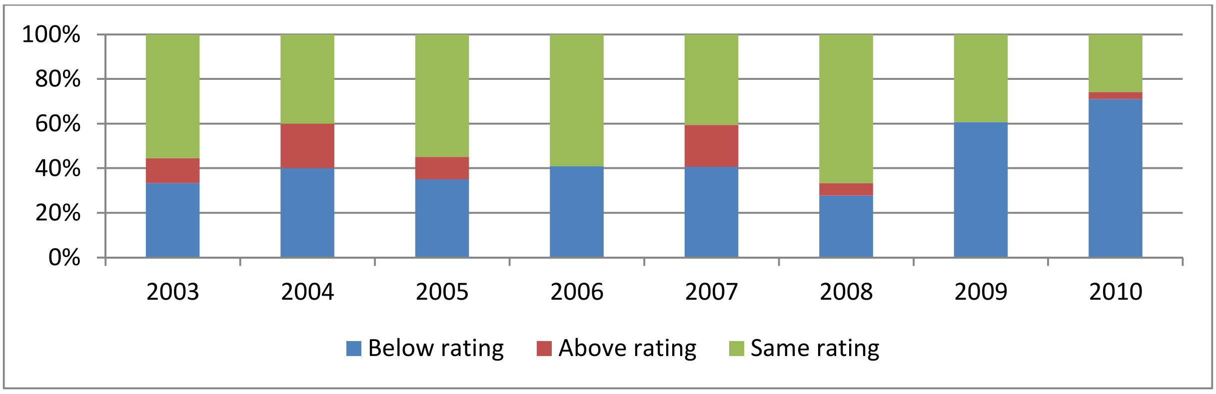

Figure 1 Comparison of rerated star rating to original rating by year of building approval

Energy consumption

Electricity and natural gas were the two main fuel sources used in the study households. For half the houses in the study, electricity consumption was monitored at a circuit level. For the remainder of the houses, billing data was used (where available). For natural gas consumption, only billing data was used. Monitored data was collected from June 2012 through to the end of February 2013. To allow for a full-year comparison, data was analysed for both the measured nine month period as well as a twelve month period where the autumn period (March to May) was considered to be the same as the spring period.

Electricity was used by all houses with air conditioners for summer cooling and in Brisbane and Adelaide for winter heating, while natural gas was predominantly used for winter heating in Melbourne. A small number of houses in Adelaide also used natural gas, but for the purpose of this analysis, natural gas consumption was restricted to Melbourne only, and consumption averages were derived from the billing data received from study houses in this city. Electricity consumption averages were derived from the monitored houses in each of the three cities.

Total energy consumption varied over the year, due to the effect of seasonal changes on space conditioning, hot water and lighting. This was especially true in heating-dominated climates such as Melbourne, which rely on heating for much of the winter period. It should be noted, however, that space conditioning (the component influenced by the energy efficiency star rating) was generally between 25% and 35% of the total house energy consumption which is less than the 40% that is considered the Australia wide average for all houses. In the case of electricity particularly, other loads could significantly affect total energy consumption. Gas consumption, which is only used for space heating, hot water, and to a lesser extent, cooking, could be more significantly influenced by thermal performance of the house.

Table 2 shows the average seasonal energy consumption for houses in each city. In Brisbane and Adelaide, the total energy consumption of the lower and higher star-rating cohorts was similar. However, in Melbourne, a significant 35% reduction in energy consumption was seen in the higher-rated houses. This was due entirely to a 54% reduction in gas consumption which was wholly attributable to the reduced gas required for house heating.

Only small differences in electricity consumption were seen between the star-rating cohorts in Brisbane and Adelaide. Annual electricity consumption in the higher-rated houses in Melbourne was significantly higher than in the lower-rated houses. Electricity consumption in the shoulder seasons (autumn and spring) was more than 8% higher in the high star-rating Melbourne cohort, even though space conditioning would not be expected to be in heavy use over these milder seasons.

Table 2 Seasonal energy consumption (kWh) by energy rating and city

	Brisbane		Adelaide		Melbourne	
	Lower Rated	**Higher Rated**	**Lower Rated**	**Higher Rated**	**Lower Rated**	**Higher Rated**
Autumn Electricity	1776	1723	1549	1506	1442	1562
Autumn Gas	0	0	0	0	3114	1406
Spring Electricity	1776	1723	1549	1506	1442	1562
Spring Gas	0	0	0	0	3114	1406
Summer Electricity	1899	2134	1674	1660	1362	1616
Summer Gas	0	0	0	0	756	540
Winter Electricity	1805	1531	1692	1545	1600	1585
Winter Gas	0	0	0	0	6362	2724
Total (kWh)	**7256**	**7112**	**6464**	**6218**	**19190**	**12401**

The results show that the higher rated houses performed as expected during the winter months, but in summer the results were not as obvious, especially in Brisbane and Melbourne, where the higher star-rating cohort showed around 16% higher electricity consumption than for the lower star-rating cohort. Closer examination of data reveals some possible explanations for the higher summer results, including the possible impact that human behaviour can have on the thermal performance of houses.

The energy efficiency provisions focus almost entirely on the thermal performance of the building's envelope. Consequently, building solutions tend to rely on increased insulation, improved sealing and the use of thermal mass. This will lead to buildings that perform well in winter by holding heat within their internal spaces and reducing heat loss to the external environment. This is reflected in the winter energy results and is also reflected in the internal temperatures that were recorded for each house in the study. In each of the three cities the average internal winter temperatures in the high rated houses were higher than the lower rated houses. In Brisbane temperatures increased by 0.6°C, while in Adelaide and Melbourne temperatures increased by 0.8°C and 0.7°C respectively. This indicates that the higher rated houses were not only delivering greater thermal comfort, but doing so with reduced energy consumption.

In summer, houses with higher levels of insulation and thermal mass can perform well by restricting heat gain from the external environment. However, there is a problem that as internal temperatures rise the heat will be trapped in the insulated internal environment. Thermal lag can also lead to the internal spaces continuing to warm even after external temperatures have dropped. Natural ventilation is often used to counter this effect and shed the internal heat to the outside by allowing breezes to pass through the house. The thermal modelling that underpins the energy efficiency regulations assumes a certain degree of natural ventilation will occur during the summer months, however, this relies on human interaction by opening appropriate windows and doors to allow ventilation to occur. Anecdotal evidence from the study suggests that this may not have been occurring and that households were relying more heavily on their air conditioners to maintain internal comfort than taking advantage of natural ventilation. Temperature data from all three cities indicated that during the summer months overnight internal temperatures were significantly higher than external temperatures (Figure 2). If overnight natural ventilation was occurring the expectation would be that by early morning internal temperatures would be close to the ambient temperature. However, data shows that at sunrise internal temperatures were often several degrees warmer than external temperatures. Consequently, this resulted in air conditioners being run for longer than would be the case if natural ventilation had occurred.

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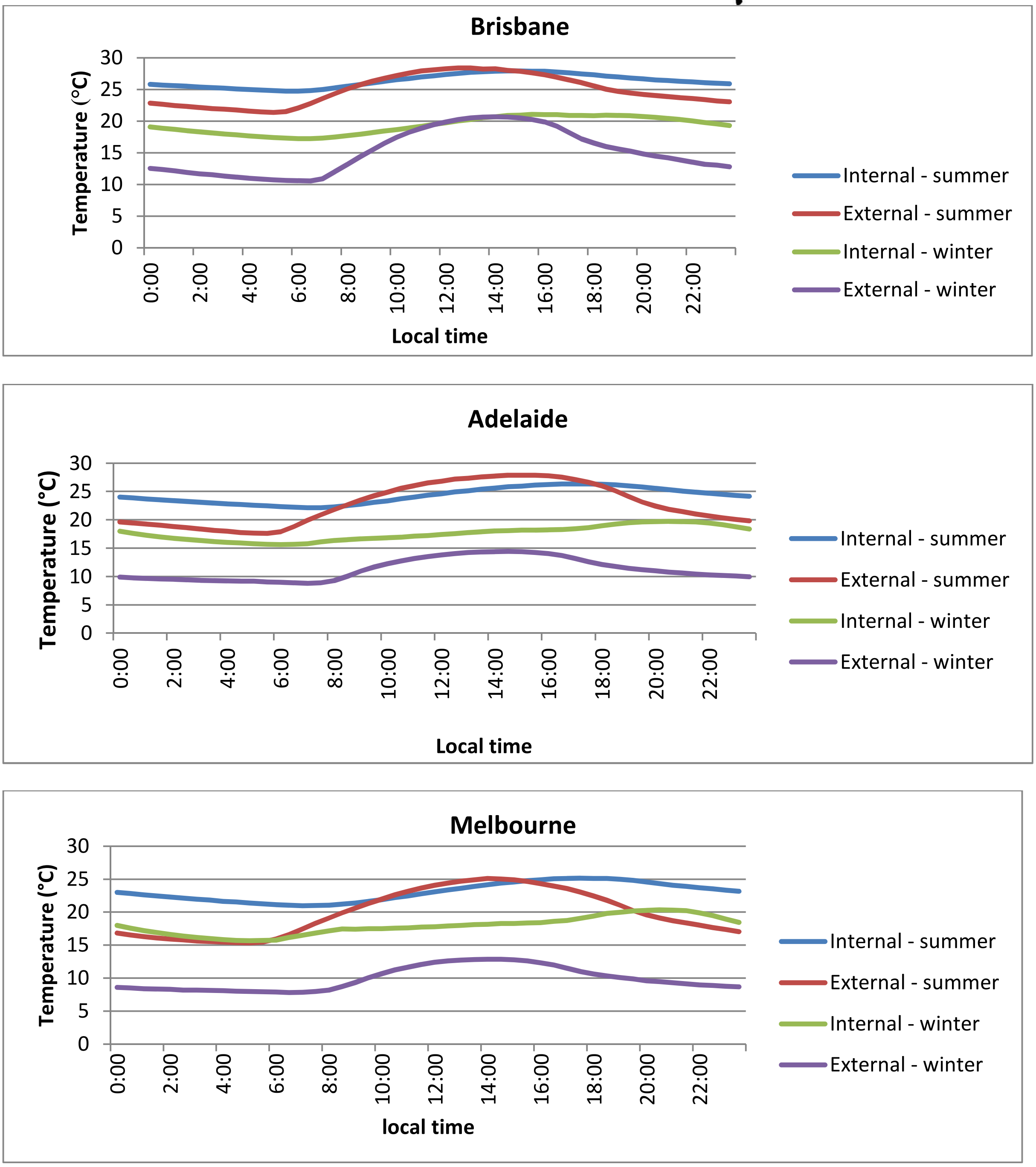

Figure 2Average internal and external seasonal temperatures for each city

Human behaviour may not be the only reason that summer energy consumption increased in some cities. The summer period that was measured was warmer than average and air conditioners are usually not sized to cool the entire house, but often just a few key living spaces. If air conditioners were predominantly running on maximum, then the measurements would primarily be reporting the capacity of the cooling appliances, rather than the thermal efficiency of the house.

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Cost of compliance

A controversial aspect of the energy efficiency regulatory requirements has been the cost of compliance. Before the introduction of the standard the Australian Government undertook a cost/benefit analysis or Regulatory Impact Statement (RIS). The RIS concluded that although there would be additional construction costs incurred, the environmental and energy saving benefits would be greater and consequently a cost/benefit ratio of 1.27 was achieved (3), that is, for each dollar spent $1.27 in benefits would be achieved. However, some housing industry groups have claimed that the original costings used in the RIS were under estimated and actual costs could be up to four times those used (4) while others claimed that moving to the current 6 star standard would result in a net cost to home owners of $40/m^2$ or $9200 for a standard 230m^2 house as these houses would require expensive technologies such as double glazing, floor insulation and external shading (5). However, analysis of the actual techniques employed by builders in the study houses found that the higher rated houses were actually cheaper to build than the lower rated houses.

House designers and builders have a range of options that they can employ to achieve the required energy efficiency star rating. The traditional approach has been to increase the amount of insulation or thermal mass or install expensive options such as double glazed windows. These technical solutions are what the RIS and those that have questioned the costs have assumed are the only solutions available and have ignored the option of design changes and creating houses that take greater advantage of passive design solutions. Analysis of the house plans found that builders and designers employed both technical and design solutions to achieve the standard.

The higher rated houses showed increased use of both ceiling and wall insulation with houses in the more heating dominated climates of Melbourne and Adelaide having around 80% of their external walls containing insulation, up from 60% for the lower rated houses. Expensive technical solutions like double glazing were rarely used and only showed an increase in use in the higher rated houses in Melbourne where winters can see low temperatures. Here 13.3% of windows in the higher rated houses were double glazed, compared to 7.7% in the lower rated houses. Windows typically account for the greatest amount of heat gain or loss in the building fabric. For example, heat gain through an unshaded window can be 100 times greater than through the same area of insulated wall (6). Consequently, reducing glazing area is an effective design solution to improve the star rating of houses. The window/wall ratio indicates the percentage of external facade that is glazed. Table 3 shows there was a small reduction in this ratio of around 1.1% in all cities. However, the average area of glazing was also significantly reduced, with around a 20% reduction in all cities. The reason why this has not translated to a bigger reduction in the window/wall ratio is that the houses themselves became smaller in area, and more rectangular. Consequently, the average external wall area was also reduced.

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Table 3 Glazing areas by city and star rating

	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
Window/wall ratio (%)	20.6	18.5	18.5	21.8	19.7	19.5
Average glazing area per house (m^2)	38.48	33.10	36.44	52.33	42.15	48.11

A surprising finding was that the average conditioned floor area reduced for the higher-rated houses. This occurred in all three cities, although only a small reduction was seen in Adelaide (2.3%) while reductions of 14% and 12% where observed in Brisbane and Melbourne respectively. With houses becoming smaller, the area of external walls would also be expected to reduce, and this was reflected in the houses in the study, but even after taking the reduced floor area into account, a further reduction of 14% in external wall area was still evident in all cities. The reason for the change may be due to simpler floor layouts and more rectangular buildings. Reducing the number of corners in a design will reduce the external wall perimeter and consequently reduce wall area. Smaller blocks may also be a factor in driving the change to smaller, more rectangular buildings.

The reduction in wall, floor and window areas in the higher rated houses translates to significant construction cost savings. These savings more than compensate for the increased cost of improved insulation. In most cases, the incremental cost of increasing insulation performance is small. For example, the cost difference between R2.5 and R4.0 ceiling insulation is only $AU3.40/m^2.

Overall, the measures required to achieve the higher ratings were costing at least $AU5,000 less than the equivalent lower-rated house. In Brisbane, the higher star rated houses were costing $AU7,400 less to achieve their requirement than the corresponding lower-rated houses. The reasons for the observed changes in design may be due to factors unrelated to the star rating requirements, such as smaller lot sizes and customer preferences. However, the inclusion of these design changes has an impact on both star rating and cost.

Conclusion

This study has revealed several important aspects of Australia's energy efficiency regulations for residential buildings. The aim of the regulations has been to reduce the energy consumption of new houses and consequently reduce greenhouse gas emissions. Overall, this has been achieved although savings were probably not as much as was anticipated. In Melbourne, although energy savings have been achieved through a significant reduction in gas consumption, it was countered somewhat by an increase in electricity consumption. The much higher emissions coefficient for electricity in Melbourne has consequently resulted in increased emissions from electricity consumption, countering the emission savings from the reduced gas consumption. This resulted in only an 8% decrease in greenhouse gas emissions in Melbourne for the higher-rated houses, compared with their 35% decrease in energy consumption.

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A concerning finding was the apparent increasing level of non-compliance that was observed, especially as energy efficiency requirements have increased over time. The exact reasons for this are the subject of a study that is currently underway, but potential issues with rating at the design stage verses what is actually built, the independence of the energy assessor and the lack of attention paid to energy efficiency measures by building inspectors were all raised as possible reasons.

Finally, the study found that house designers and builders are using a broad range of options to achieve the energy rating without impacting on construction costs. By using a combination of technical and design solutions, higher rated houses have not only been able to achieve the standard, they have done so for less construction cost. Overall, a higher rated house cost at least $5000 less to build than a lower rated house. This surprising finding is contrary to what many in the residential building industry have been saying, but demonstrates the effectiveness of performance based energy efficiency regulations that allow a range of solutions to be utilised by building designers to achieve a specified goal.

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References

1. Australian Bureau of Statistics (2012). *Household energy use and costs*. Canberra. Australian Bureau of Statistics,

2. McGee, Caitlin (2013). *Your Home: Australia's guide to environmentally sustainable homes - energy*. Canberra. Commonwealth of Australia (Department of Industry),

3. Australian Building Codes Board (2006). *Proposal to amend the Building Code of Australia to increase the energy efficiency requirements for houses*. Canberra. Commonwealth of Australia,

4. Centre for International Economics (2009). *Final regulation impact statement for residentila buildings (class 1, 2, 4 and 10 buildings)*. Canberra. Australian Building Codes Board,

5. Centre for International Economics (2010). *Energy-efficiency: building code star-ratings*. Canberra. Centre for International Economics,

6. Lyons, Peter (2013). : *Your Home: Australia's guide to environmentally sustainable homes - glazing*. Canberra. Commonwealth of Australia (Department of Industry).

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Development of a decision-making framework for the analysis of incentive schemes within the context of sustainable building

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Abstract: This research proposes a framework describing the decision-making process preceding pro-environmental action and applies the framework to building refurbishment incentive schemes. By documenting the influences on this process, the framework supports greater understanding of pro-environmental behaviour and the development of more effective incentive schemes. Focussing on non-habitual occupant behaviour within the owner-occupied housing sector, the framework brings together a wide range of secondary research concerning human decision-making behaviour. Testing is undertaken by using the framework to generate criteria describing a successful incentive scheme to encourage low carbon refurbishment of houses in the UK. These criteria are then assessed to determine their relevance and consequently the relevance of the framework used to generate them. The paper concludes that the framework and criteria could not only assist the development and evaluation of individual incentive schemes but could help facilitate a nationwide strategy of schemes in relation to sustainability issues.

Keywords: pro-environmental behaviour; incentive; decision-making; renovation; housing.

1.0 Introduction

Housing accounts for more than a quarter of energy use and carbon emissions in the UK[1], therefore energy reductions in this sector will play a key role in meeting the government's target to cut carbon emissions by 80% by 2050[2]. As only one per cent of the existing building stock is replaced each year[3] this will require 85% of the 26.5million existing homes in the UK that will still exist in 2050 to undergo refurbishment[4]. Incentive schemes including the current Green Deal, have sought to reduce the carbon emissions of owner-occupied properties, which account for almost 70% of UK housing stock[1]. However, despite the £23 billion spent each year on repair, maintenance and improvement (RMI) works in UK housing[5] uptake of energy efficiency measures and micro-generation technologies has not been as high as many hoped.

Studies by Roy *et al.*[6], Killip[4] and Watson *et al.*[7] identify barriers to the adoption of these measures including: financial costs[6, 7], a lack of necessary skills to undertake the work[4, 6] and poor provision of impartial, comparative information about the strategies available[6]. However, a more fundamental problem is identified by Barr[8] who criticises the assumption implicit in many schemes that increased awareness of the problem will automatically lead to action. Barr argues that individuals need time to 'engage' with the problem[8] whilst Stamm *et al.*[9], Wagner[10] and Schwartz[11] respectively argue the importance of understanding, education and evaluation. These studies suggest that pro-environmental decisions are likely to take place in several stages, each influenced by several

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factors. This study proposes a framework that describes these stages and identifies a set of criteria that address the factors influencing progression from each stage to the next.

2.0 Method

The research comprises three components: first the development of a framework describing the decision process preceding pro-environmental behaviour; second an analysis of factors or 'triggers' that influence this process, and finally the analysis of this framework to generate criteria for incentive schemes that support each stage of this process.

The study builds on existing theoretical models and concepts of human decision-making behaviour including Norm Activation Theory[11], the Theory of Planned Behaviour[12], and the Focus Theory of Normative Behaviour[13]. The research involves an iterative process of analysis, beginning using Norm Activation Theory[11] to structure a literature review of human decision-making behaviour, which in turn is used to define an extended framework. Concurrently, 'triggers' that influence this behaviour, both general and specific to the issue of housing retrofit, are identified through an analysis of: reviews of incentives directly related to low carbon refurbishment, literature on consumer psychology and literature on environmental psychology. The points at which these triggers act on the decision-making process are identified, stimulating further deductive analysis, including investigations of how these concepts are applied in other fields. This results in the formulation of the proposed criteria. A pilot study is then undertaken, to investigate methods of evaluating these criteria and also to gather some initial qualitative feedback from both policy makers and owner-occupiers.

3.0 A Proposed Framework

The proposed framework uses Schwartz's Norm Activation Model[11] as a basis, as it is long established and widely critiqued. In addition, whilst focussing on how self-expectations influence the transition to helpful intentions, the model also acknowledges the role of emotional arousal and social expectations. Finally, the model is comprised of four stages, with progression to each new stage contingent on the successful completion of the preceding stage. The first stage is concerned with the awareness of a need and the relevant actions required to meet that need. Stage 2 is the point at which the actor's personal norms are triggered and they feel a moral obligation to act. However, prior to the final response this moral obligation is mediated by stage 3; an assessment of the costs to the individual and the probable outcomes of various responses mediated by 'AC'; an awareness of the consequences of one's actions, and 'RD'; the willingness to assume responsibility for those consequences. Where costs to the individual are significant, this evaluation may prompt a reassessment of the situation, resulting in either postponement or a positive or negative response (stage 4).

However, Norm Activation Theory[11] is not comprehensive and by studying relevant critical reviews of this model as well as alternative theories, the proposed framework incorporates a more extensive range of influences.

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3.1 Awareness and Understanding

Like Schwartz's model[11], the proposed framework also begins with the actor becoming aware of a problem. However, drawing on Stamm's research[9], two intermediary steps are introduced, in which the actor develops their understanding of the causes and consequences of the problem allowing this to inform their identification of necessary actions (point 4, Table 1).

The most common type of trigger in stage 1 is the information gained from written, graphic, verbal and experiential sources. For this information to be effective as a trigger it needs to be clear, reliable, relevant and address people with a wide range of awareness and understanding [8, 9]. Experiential information is gained through perceived causes and effects within the local environment[14] and developing solutions at grass-roots level[8].

Table 1: Proposed Framework	
	AWARENESS AND UNDERSTANDING
1	Awareness of problem or need
2	Awareness of causes of problem
3	Awareness of consequences of problem
4	Awareness of solutions/actions.
	ENGAGEMENT AND FORMULATION OF INTENTION
5	Recognition of own ability to provide relief
6	Apprehension of some responsibility to become involved (may be influenced by previous behaviour).
7	Actor chooses to follow either their *personal norm* (what should be done) or a *descriptive norm* (what would normally be done). If the descriptive norm is chosen the actor proceeds immediately to point 10.
	EDUCATION AND EVALUATION
8	Assessment of costs and evaluation of probable outcomes. This assessment will be mediated by: • Perceived Behavioural Control (influenced by previous behaviour and contextual constraints). • Information • Personal tastes and preferences • Personality traits: RD=Responsibility Denial, AC=Awareness of consequences (influenced by acceptance of the New Environmental Paradigm and social expectations).
9	This evaluation will result in one of the following outcomes: a) The obligation remains intact (actor proceeds immediately to point 11) b) If costs to individual are high this may prompt a reassessment and redefinition of the situation.
10	This reassessment may result in: a) The actor's obligation remaining in tact (actor proceeds to point 11). b) The actor's intention to act being abandoned. c) The previous stages are reiterated in light of this reassessment (actor returns to point 1).
	ACTION
11	Action is initiated
12	Action completed

Table 1: Proposed decision-making framework, influences added to Schwartz's original model shown in grey.

3.2 Engagement and Formulation of Intention

This second stage begins with the process of recognising one's own ability to undertake the actions identified in stage 1, which may lead to a sense of responsibility to become involved. Acceptance of this sense of responsibility may be influenced by the actor's previous behaviour (point 6)[15] However, prior to formulating an intention to act, the actor must choose between their 'personal norm' relating to what *should* be done and a 'descriptive norm', influenced by sociological factors, relating to what *is normally* be done (point 7)[13].

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Stage 2 is predominantly influenced by triggers relating to problems of scale when encouraging individual actors to address a global problem. These may be overcome by providing suitably specific information to allow individuals to identify their contribution to both the problem and solutions to climate change[16] and increasing individual responsibility by addressing such issues in smaller social groups[16].

3.3 Evaluation and Education

The third stage of the framework marks the beginning of the conscious stage of decision-making. The actor gathers and evaluates information relating to the various costs and benefits of undertaking action (point 8). In addition to *awareness of consequences* and *responsibility denial*, the new framework also allows this evaluation to be mediated by information[17], perceived behavioural control[12] and personal preferences[17]. The framework also acknowledges the indirect influence that contextual constraints[17] and acceptance of the new environmental paradigm[18] may have on this process of evaluation. The actor then chooses to act upon their intention directly or the previous stages may be reassessed (points 9-10).

In this evaluative stage, financial[6], personal[19] or social[17] costs and benefits to the individual represent a significant proportion of triggers. The perception of these costs and benefits will be influenced by the availability of suitable information and the actor's ability to use tools such as labelling[20] 'rules of thumb'[10] and examples of good practise[21].

3.4 Action

This final stage is expanded to become a process, allowing for actions of greater complexity, where factors may prevent completion even after an action has been initiated (point 12). In this case the action can be logically divided into a 'design' phase and a 'construction' phase. Triggers influencing progress at this stage may be practical considerations such as planning legislation and difficulty obtaining materials[4] or trained contractors[4, 6].

4.0 Results and Discussion

The criteria listed in Table 2 (overleaf), are the result of an iterative process of analysis described in section 2.0. A pilot study is undertaken to investigate methods of evaluating these criteria and the associated framework. The pilot also sought to collect initial qualitative feedback on the criteria from the perspective of policymakers and potential applicants:

- The policy-maker's perspective was investigated using a semi-structured interview with an expert involved in the high-level design of incentive schemes. The interview was structured around the application of the criteria to an existing scheme but left the interviewee free to talk around some of the challenges and opportunities this presented. This was supplemented by the application of the criteria to an incentive with different characteristics to those discussed in the interview, giving an initial understanding of the transferability of the criteria across different types of schemes.
- The perspective of potential applicants was explored through semi-structured interviews in which owner-occupiers were asked to provide feedback on the influence of each criterion on their motivation to apply for an incentive scheme.

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4.1 Perspective of Policy Designers

The implementation study and in depth interview with a policy expert reveal a number of factors to be considered when applying these criteria to incentive schemes. Firstly, the expert interviewee was unable to comment on the compliance of the existing incentive with a number of criteria, as these aims are addressed by parallel schemes or delegated to other organisations. For example, awareness is addressed by the 'Act on CO2' campaign, whilst issues regarding financial costs are addressed by incentives such as Green Deal and ECO, where responsibility for encouraging uptake may be delegated to energy companies and Green Deal providers. Whilst this delegation of responsibilities creates difficulties due to the limited number of people with an overview of every aspect of the scheme, it may also provide further opportunities. Secondly, whilst the expert interviewee's feedback on the majority of the criteria was positive, two main types of constraints on the applicability of the criteria were identified: the scale of the incentives and the measure being promoted. For example, large, national schemes may struggle to provide information suitably specific to make individuals appreciate how the problem relates to them (criterion 3) whilst the nature of measures such as cavity wall insulation where the product is not visible to others, may make it difficult to promote these products as socially desirable (criterion 15).

Table 2: Proposed Criteria	
No.	**Criterion**
	Schemes should:
Pre-conscious - The first two stages can be classified as sub-conscious, therefore information must be presented where actors will encounter it unintentionally and it must be easily absorbed.	
1	Address different levels of awareness, understanding and interest in climate change.
2	Establish a greater sense of the relative importance of causes and solutions
3	Ensure information distributed is specific to the situation of the individual.
4	Use publicity to emphasize the perceived seriousness of the problem.
5	Use publicity that does not appear naïve/sensationalist and is disseminated by trusted organisations.
6	Make information available through a broad range of media.
7	Use more interactive forms of publicity that allow users to ask questions and give feedback.
8	Encourage the spread of information through Interpersonal Communication
9	Monitor and report on emissions in small groups to create a sense of accountability to the group.
Conscious - During the third and fourth stages, the individual will have formulated an intention to act, therefore, information can be more complex.	
10	Dis-courage free-riding in community schemes by linking individual and community benefits.
11	Reduce capital costs to widely acceptable levels.
12	Reduce payback periods to within widely acceptable limits.
13	Minimise the effort and inconvenience of practising pro-environmental behaviour.
14	Offer a range of different incentives targeted to different 'lifestyle groups'.
15	Encourage the promotion of 'green products' as desirable and identified with social status.
16	Provide information for people various levels of knowledge about sustainable products and strategies.
17	Provide householders with the necessary information to make informed comparisons between strategies.
18	Promote and maximise access to good-practice examples as valuable learning tools.
19	Work to promote the long-term security of investments in 'green products'
20	Take advantage of the affective relationship consumers develop with certain brands.
21	Channel information about unsuitable products back into R&D to improve products and technologies.
22	Act as intermediaries between regulatory organisations and householders to assist with applications.
23	Encourage investment in supply chains for 'green products' and any required expertise to maintain them.

Table 2: Proposed criterion for incentives that address each stage of decision-making framework.

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4.2 Perspective of Applicants

The importance of intrinsic knowledge emerges as a significant influence on homeowner's responses to the criteria. This is not only corroborated by the positive feedback to criteria relating to the heuristic application of knowledge, but also by the results of the homeowner interviews more generally, which indicate that knowledge can be a common influence on how homeowners respond to all criteria. Homeowners with prior knowledge of environmental behaviour more commonly had strong opinions on the relevance of the criteria; this stance could be positive or negative depending on their attitudes towards the environment, whilst those with less knowledge adopted more moderate positions. Homeowners also expressed that a range of incentives with different funding arrangements or benefits would be appreciated.

4.3 Limitations

The results indicate that not all criteria are equally applicable to different schemes. A full study, informed by these findings is needed to validate and improve the criteria and investigate how they could be applied to develop appropriate incentives for different contexts.

5.0 Conclusions

The research set out to develop a method for helping to formulate effective incentive schemes with particular focus on sustainable buildings. By identifying the process from the initial stage of gaining awareness of a problem to taking action to address the problem, a framework is developed that tracks this process and identifies the triggers for action. While the framework was developed in relation to sustainable building the decision-making process is universal and the framework can be applied to the adoption of environmental behaviour in other contexts (e.g travel) and other countries that make use of incentive schemes.

5.1 Nation-wide strategy of information and incentive schemes

As revealed through the interviews, different stages of the framework may be addressed by different campaigns or organisations. Therefore, the criteria could be used to map out at national level the triggers that engender behaviour change, facilitating the development of a national strategy of schemes stimulating pro-environmental action. However, this would require a coordinated approach with responsibility for addressing criteria allocated to organisations judiciously in order to maximise resource efficiency. The very initial stages of awareness and understanding of climate change generate criteria that could be addressed by stakeholders not directly associated with climate change policy or products. For example, the Department of Education could accept responsibility for ensuring the national curriculum focuses on important aspects of understanding identified by the framework, such as the relative importance of the causes, consequences and potential solutions to climate change.

5.2 Overcoming financial limitations

The importance of intrinsic knowledge indicates those with practical experience of pro-environmental action should be encouraged to share their experiences with others. This could complement homeowner requests for a wider range of incentives. Homeowners who do not have sufficient capital to benefit from FiTs or would struggle to achieve sufficient savings to

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repay loans may be able to benefit from increased financial support in exchange for pledging an agreed amount of time educating their neighbours.

5.3 The need for a multidisciplinary approach

Finally, this research exemplifies the challenges and opportunities presented by a more holistic approach to addressing pro-environmental decision-making and the need for a wide range of stakeholder expertise, from a range of local and national government departments to homeowners themselves. Only with a multidisciplinary understanding can the complexity of the decision-making process be comprehensively addressed and this framework attempts to contribute to that understanding.

References:

1. DECC. (2012). *United Kingdom housing energy fact file*. [Online]. Available at: https://http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201167/uk_housing_fact_file_2012.pdf. (Accessed: 24th May 2014).
2. UK. (2008). *Climate Change Act 2008*. Elizabeth II. Chapter 27 [Online]. Available at: http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf (Accessed: 8th February 2014).
3. CLG. (2007). *Homes for the future: More affordable, more sustainable - Housing Green Paper* London: Crown copyright.
4. Killip, G. (2008). *Building a Greener Britain*. London: F.o.M. Builders.
5. BERR. (2007). *Construction Statistics Annual 2007*. Norwich: The Stationary Office.
6. Roy, R., S. Caird, and J. Abelman. (2008). *YIMBY Generation – yes in my back yard! UK householders pioneering microgeneration heat*. London: Energy Saving Trust.
7. Watson, J., et al. (2008). Domestic micro-generation: Economic, regulatory and policy issues for UK. *Energy Policy*, 36(8): p. 3095–3106. doi: 10.1016/j.enpol.2008.04.028.
8. Barr, S. (2008). *Environment and Society: Sustainability, Policy and the Citizen*. Aldershot: Ashgate Publishing Limited.
9. Stamm, K., F. Clark, and P. Eblacas. (2000). Mass communication and public understanding of environmental problems: The case of global warming. *Public Understanding of Science*, 9(3): p. 219-237. doi: 10.1088/0963-6625/9/3/302.
10. Wagner, S. (1997). *Understanding Green Consumer Behaviour*. London: Routledge.
11. Schwartz, S.H. (1977). *Normative Influences on Altruism,* in *Advances in experimental Social Psychology*, L. Berkowitz. London: Academic Press. p. 221-279.
12. Ajzen, I. and T. Madden. (1986). Predictions of goal-directed behaviour: attitudes, intentions and perceived behavioral control. *Journal of Experimental Social Psychology*, **22**(5): p. 453-474.
13. Cialdini, R., C. Kallgren, and R. Reno. (1991). A Focus Theory of Normative Conduct: a theoretical refinement and re-evaluation of the role of norms in human behaviour *Advances in Experimental Social Psychology*, **24**(1991): p. 201-234.
14. Bonnes, M. and M. Bonaiuto. (2002). *Environmental Psychology: From spatial-physical environment to sustainable development,* in *Handbook of Environmental Psychology*, R. Bechtel and A. Churchman. New York: Wiley and Sons. p. 28-54.
15. Thogerson, J. and F. Olander. (2002). Human Values and the Emergence of a Sustainable Consumption Pattern. *Journal of Economic Psychology*, **23**(5): p. 605–30.
16. Gladwell, M. (2000). *The Tipping Point* London: Little, Brown Book Group.
17. Jackson, T. (2005). *Motivating Sustainable Consumption*. Guildford: U.o. Surrey.

18. Stern, P., et al. (1999). A Value-Belief Norm Theory of Support for Social Movements: the case of environmental concern. *Human Ecology Review*, **6**(2): p. 81.
19. DEFRA. (2008). *Framework for Pro-Environmental Behaviours*. London: Crown Copyright.
20. Belz, F.-M. and K. Peattie. (2009,). *Sustainability Marketing: A Global Perspective*. Chichester: Wiley and Sons.
21. Bandura, A. (1977). *Social Learning Theory*. Englewood Cliffs: Prentice Hall.

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Session 50:

What role must new technologies play in sustainable urban transformation strategies?

Chairperson:

Todd, Joel Ann
Environmental Consultant

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Photovoltaics in Italian historical city centers: do PV products and building codes have a meeting point?

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Abstract: *To design sustainable buildings represents one of the priority challenges that we have to deal with in order to reduce the use of global resources and preserve the natural environment. Within solutions for designing sustainable buildings, renewable energy systems (RES) have been introduced in order to provide buildings with non-fossil energy.*

However, when we consider historical buildings we can face issues in particular when it comes to the installation of photovoltaic systems. This is due to the aesthetical effect produced by photovoltaic modules on the typical view of the historic city centers. Within the Italian context, characterized by the wide presence of historical city centers, such issue is not yet solved. Therefore, facing this issue in such specific context can represent a significant objective.

The paper proposes a possible strategy for supporting the use of PV in Italian historical city centers, conceiving a meeting point between PV products and municipalities building codes.

Photovoltaics, historical city centers, building codes, strategy

Introduction

Nowadays, reducing the use of global resources and preserving natural environmental are priority topics. In order to reach these goals, designing sustainable buildings represents one of the main challenges that architects and designers have to deal with. On one hand, the use of building materials and technical solutions enable to reduce building energy demand can be a strategy for both achieving buildings sustainability and reducing natural resources exploitation. On the other hand, renewable energy systems (RES) for buildings can represent a solution to reduce the use of non-fossil energy during the building life cycle.

Indeed, photovoltaics (PV) are RES able to generate electricity to supply the energy demand of buildings by means of the direct conversion of solar radiation. Specifically, PV represents one of the most suitable RES for supplying electric energy for the buildings electricity consumptions. This is due to the design flexibility (PV modules can be designed with different shape characteristics depending on the purpose of the results) for which it's possible to generate enough electricity close to the buildings' energy demand (e.g. in the urban context or as a common building material) and the recent decrease in PV modules cost [1]. Moreover, PV can be defined in two different ways: BIPV (Building Integrated Photovoltaics) when PV modules are integrated into the envelope constructive system, otherwise BAPV (Building Added Photovoltaics) when PV modules are applied on top of the building skin [2].

If photovoltaics can be considered a common building material and integrated into the envelope constructive system, architects can consider PV use during the first building design phase. As a result, PV can be introduced during the building design process, influencing building shapes and orientation in order to optimize the architectural result and realize a "productive" envelope able to generate electric energy [3]. Such consideration can be real for new buildings but installing PV on existing buildings tested both the architects' and designers' abilities. As a matter of fact, designing photovoltaics for existing buildings involve difficulties related to existing restraints such as the envelope orientation and exposition, as well as the buildings relative shadows.

Moreover, the use of PV for existing buildings is regulated by building codes (BC) setting different regulations, especially for the installation in historical city centers, depending on the presence of the local regulations. PV installation into historical city centers is a delicate issue to deal with. This is mainly due to the visual alteration in typical urban views produced by PV modules when installed on the building envelopes. Such visual alteration of the typical urban view represents a common issue in the Italian context, considering that Italy accounts for about 22.000 historic city centers: 900 main historic centers, 6850 minor historic centers and 15.000 isolated clusters, villages, hamlets, religious or military settlements. The high quantity of historic city centers has been evaluated from the Italian Central Institute for Cataloguing and Information Materials, in the 37° Report on the social situation of the country [4], within the project for taking a census of historical city centers (1994).

In order to research a strategy to overcome this problem, within the paper some considerations on use of the PV in these contexts will be presented. Specifically, a brief investigation on the Italian building codes is taken into account in order to define common municipal perspectives. Moreover, within the current PV market some PV technologies are investigated in order to support the PV installation into historical city centers.

This study aims at investigating whether a strategy can be figured out as a meeting point between municipal perspectives and PV technological solutions, taking care of the cultural heritage and the historical city centers.

PV policies in the North Eastern Italian regions

As afore-mentioned, the use of PV into historical city centers is regulated by building codes (BC), set by local municipalities. This study takes into account the BC of the North Eastern Italian province capitals. They correspond to the 20% of the overall building codes of the Italian province capitals, but they can reflect the usual state-of-the-art of the Italian approach related to the use of PV in BC. The BC analysis [5] shows a heterogeneous scenario related to regulations about PV systems installations into historical city centers. As a matter of fact a few BC do not take into account the use of PV systems within historical city centers (e.g. the cities of Belluno, Rovigo, Gorizia) and a few municipalities avoid the use of PV in this specific context (e.g. the cities of Vicenza, Rimini, Ravenna and Reggio Emilia). In any case the remaining BC have been developed focusing attention on the use of PV in historical city centers. For instance, the municipality of Venezia allows the installation of a PV area equal to the 6% of the whole roof for the heritage listed buildings and no limits are set for the non-heritage listed buildings (Venice Municipality Deliberation n. 38 of 8/9/2009).

Other BC allow the use of PV into historical urban areas but they set specific regulations for the heritage listed buildings. They either set PV systems installation rules to preserve building historical and architectural characteristics or they refer to specific committees responsible for the environment and the historical buildings. Such kind of rules are included within BC of the cities of Trento, Bolzano, Verona, Padova, Treviso, Pordenone, Udine, Trieste, Bologna, Parma, Ferrara, Piacenza, Forlì, Cesena, Modena.

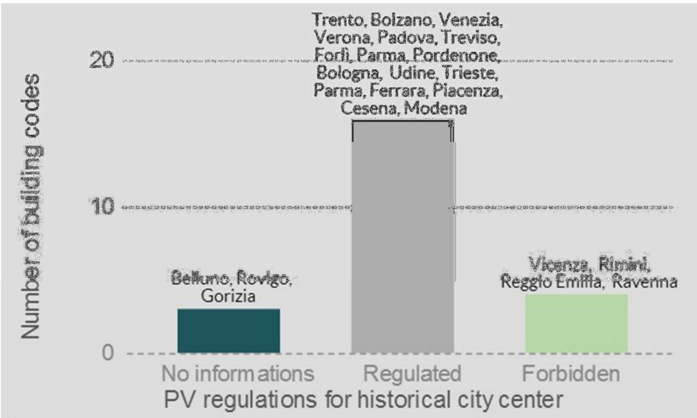

Figure 1. PV policies in building codes of North Eastern Italian administrative towns.

Therefore, some municipalities avoid the use of PV into their historical city centers in order to prevent its undiscriminating use. However, when PV installations are permitted, a common criterion is adopted: the visual effect of PV systems on buildings should be at least reduced. This issue is due to the need of preserving the typical formal and aesthetical characteristics of these buildings, however, no specific instructions to support these kind of PV installations are defined making the realization a difficult process. However, the importance of building PV installations to produce electric energy for citizens, building users and to reduce the land use for PV power plants is well acknowledged. As a matter of fact several municipalities set PV energy production by means of SEAP (Sustainable Energy Action Plan). These plans are voluntary and strictly related to the reduction of the municipality CO_2 emissions. As a result, these actions do not identify suitable areas for PV installations and they are usually taken into account only for new buildings and new residential urban areas, as well as the industrial ones.

In conclusion, the main aim of the BC related to building PV installations is to prevent the undiscriminating use of PV in historical city contexts.

Consequently, not many regulations have been developed in order to install PV systems on buildings within such specific urban context. Furthermore, after the setting up, regulations are generic and there is a lack of specific regulations supporting architects and designers.

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PV products for historical buildings

One of the main reasons that impede PV from being installed in the historical city centers can be related to the visual effect of PV systems on the typical view of buildings and historical urban areas. Traditional PV modules can be realized with monocrystalline or multi-crystalline cells. They can be considered traditional PV modules due to the fact that they account for 85-90% of today's global annual market while thin films account for the remaining 15-10% [6]. When traditional PV modules are installed, the resulting PV arrays are characterized by dark blue or blue surfaces, which are essentially different from the color of common traditional building material. Consequently, there is an incompatibility in colors, grains and textures between PV modules and building morphological characteristics [7], as shown in Figure 2.

Figure 2. PV installation in the historical city center of Treviso.

Moreover, within the Italian context, the visual effect produced by traditional PV modules, when installed on buildings, is also prudently taken into account because of the socio-cultural aspects. Indeed, citizens have a common "mental representation" of historical city centers. Such "mental representation" - which has developed over the years thanks to small changes and slow processes – is settled in communities that live in the historical city centers. Therefore, the use of traditional PV modules in such particular context can involve a rapid and radical visual change that communities cannot accept because PV modifies their mental representation of the historical city center.

In the current PV market, however, we can identify some products that are the result of researches aimed at supporting the integration of PV for building installation. For instance, traditional PV modules have been designed with different colors as well (Fig.3.a) in order to look better just like traditional roofs made of cotto tiles. However, colored PV cells have a lower efficiency (about 12-13% [8]) than traditional monocrystalline and polycrystalline cells (about 20-25% [9; 10]). Such colored PV modules are not representing a solution for supporting the PV use into historical city centers due to their grain and texture. Furthermore, within the PV products for building installation in the historical city centers, there is the PV roof shingle (Fig.3.b). Such shingles are characterized by dark surfaces that can be easily integrated into dark roofs, which are not typically Italian. Some PV roof tiles (Fig.3.c) have been developed in order to preserve shapes of traditional cotto tiles. But also, the resulting PV tile involves a high visual effect due to the dark surface produced. A model of "invisible" PV product for roof integration has been developed (Fig.3.d). Such product, called "Coppo

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Fotovoltaico", is a "fake"cotto tile where the PV surface is hidden and it is able to generate electric energy. Even though such product is not already available on the PV market, it can meet the need of preserving historical buildings and generate electric energy without compromising the typical view of Italian historical city centers, however, no information have been provided about their energy efficiency. The current PV market does not offer many products for supporting the use of PV into historical city centers. As a consequence, BC are developed in order to safeguard the typical historical view of city centers.

What if the development of innovative PV products could move a step towards more integrated PV products having the BC identify clear instructions for supporting the use of PV into historical city centers at the same time?

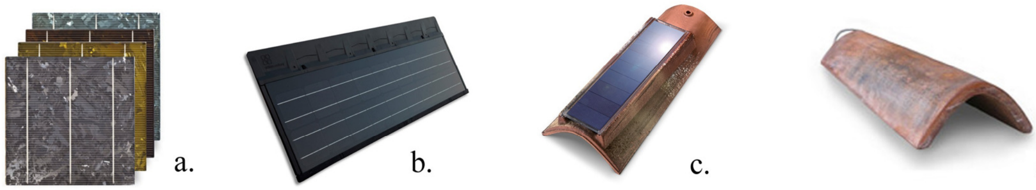
a. b. c. d.

Figure 3. PV products for historical city center:a) colored PV cells; b) PV shingle; c) PV tile; d) "invisible" PV tile.Sources: a. Sunways; b. Solarcentury; c. Cotto Possagno; d. Dyaqua Energy

Researching a meeting point between PV products and building codes

As previously introduced, the PV market does not offer many products to support the use of PV into historical city centers and the electricity generation by means of solar radiation for supplying specific urban areas. As a consequence, BC prevent an undiscriminating use of PV into these urban areas. Such difficulty should be overtaken considering that an appropriate use of PV into historical city centers as well, can provide a large amount of electric energy production reducing land use for PV power plants.

A possible solution can be figured out considering that on one hand the aesthetical improvement of PV products for building integration and, on the other one, the definition of specific regulations for PV installations into historical urban areas by local municipalities.

The aesthetical improvement of PV products for building integration should be the result of the needs coming from engineers, architects and the government department responsible for the environment and historical buildings. Specifically, the Ministry of Heritage and Cultural Activities in Italy is locally responsible with Superintendencies for Architectural Heritage and Landscape. Moreover, local municipalities should take care of this issue and deal with it, proposing an operational strategy.

It is worth to note that the government department responsible for the environment and historical buildings can play a fundamental role within the Italian context together with municipalities. Indeed, the government department responsible for the environment and historical buildings together with the local municipality should identify the historical urban areas. Such areas can be characterized by the high presence of heritage listed buildings.

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These heritage buildings should be kept out from the PV installations in order to preserve their architectural and historical values. Within such historical urban areas, several buildings have been built referring to the typical architectural features of the urban areas of where they are located. As a result, even though they are not historical themselves, they contribute to create the mental representation of the historical city centers [11]. Therefore buildings within the historical urban areas, but not historical themselves, should be firstly identified and, secondly, regulated in order to support PV installations.

With regard to the first issue, it is important to note that several tools for mapping urban areas and evaluating the related potential PV energy generation have been developed during the last years. In fact, some Italian municipalities have developed local solar maps: Bolzano (Bolzano Sun Solar City) and Bologna (Bologna Solar City). Municipalities can evaluate suitable building areas that can be used for PV installations at first glance.

Then, specific instructions for PV uses should be developed from municipalities together with the government departments responsible for the environment and historical buildings.
The instructions consist of:

- designing criteria of PV surfaces (orientation, inclination and shapes);
- evaluating the visual effect from public spaces, such as streets or urban areas;
- evaluating the reversibility of PV installations on buildings.

It is important to note that the reversibility [12] of a building PV installation is a requirement developed in the field of heritage restoration. Within historical urban areas, buildings represent the fundamental elements that have to be preserved. During the design of PV systems, architects and designers should consider PV installation as a system that could be optimal in the near future. This means that PV systems should not damage or modify the building envelope in a radical manner. In fact in the future, innovative PV products could be developed for a better integration into the historical urban areas.

A first example for supporting a correct use of PV within municipalities included into administrative territories of Trieste, Gorizia, Udine and Pordenone has been proposed by the local government responsible for the environment and historical buildings. In fact, it has defined some guidelines allowing – or not – PV installation for different urban areas within the historical city centers, by means of the “Circolare prot. 5450 del 24/6/2010”. Even though such guidelines are not binding, the Circolare represents a first step both for developing clear instructions for the use of PV into historical city centers and also for creating a synergic strategy between municipalities and local government responsible for the environment and historical buildings that play fundamental roles in such specific context.

Conclusions

This paper deals with the use of PV into Italian historical city centers that are regulated by municipal BC. From the investigation on BC of the main North Eastern Italian towns, a common need to preserve the typical formal and aesthetical characteristics of the historical city centers originates. Nevertheless, no specific instructions are defined to support the use of

PV. Considering that the "aesthetical issue" is the main obstacle, some PV products developed for the building use have been analyzed. Such PV market analysis shows that PV products developed for historical city centers cannot be integrated into such specific context due to their aesthetical effects or, when suitable products have been developed, they are only prototypes without any information on energy performances. As a result, current PV products availability and the current frame of BC cannot support an appropriate use of PV into historical city centers.

In order to both support electric energy production into historical urban areas by means of PV and to preserve the building heritage, a strategy based on the involvement of different stakeholders (municipalities, government department responsible for the environment and historical buildings, engineers, architects and researcher) has been proposed.

This strategy should be both aimed at preserving the existing building heritage and aimed at realizing an operational meeting point between PV products and the BC: researchers, architects and engineers should study innovative PV products aesthetically more feasible for historical urban context and buildings, while municipalities together with the government departments responsible for the environment and historical buildings should set specific instructions on PV use into such specific urban context.

References

[1] Scognamiglio A., Røstvik H. N. Photovoltaics and zero energy buildings: a new opportunity and challenge for design. *Progress in Photovoltaics: research and applications, published online in Wiley Online Library* (wileyonlinelibrary.com), 2012, DOI: 10.1002/pip.2286.

[2] IEA SHC Task 41 Solar energy and Architecture (2013). Report T.41.A.2: integration criteria and guidelines.http://task41.iea-shc.org/data/sites/1/publications/T41DA2-Solar-Energy-Systems-in-Architecture-28March2013.pdf

[3] Scognamiglio A., Privato C. (2008). Starting points for a new cultural vision of BIPV. *Proceedings of the 23rd European Photovoltaic Solar Energy Conference*, 1-5 September 2008, Valencia, Spain.

[4] 37° Rapporto sulla situazione sociale del paese - Censis 2003

[5] Paparella R., Saretta E., Scognamiglio A. (2013). Renewable Energy Systems Application into Italian Historic City Centres: Review of Building Codes. *Conference Proceedings of CIB W115 Green Design Conference,* ISBN 978-90-821698-0-5, pp. 46-51.

[6] IEA (2010). Technology Roadmap: Solar photovoltaic energy. https://www.iea.org/publications/freepublications/publication/pv_roadmap.pdf

[7] Scognamiglio A. (2009). Integrazione architettonica e componenti FV appropriati in Fotovoltaico negli edifici. Dimensionamento, progettazione e gestione degli impianti. *Edizioni Ambiente*: Milano (I), 2009. pp. 201-264.

[8] http://www.sunways.eu/static/sites/default/downloads/it/prodotti/solar-cells/colored/Sunways_SC_ColourMulti156_Datasheet_IT_09-04.pdf

[9] http://www.solartec.eu/en/research-development-and-production/products-and-services/products

[10] Green M. A. et al. (2014). Solar cell efficiency tables. *Progress in Photovoltaics: Research and Applications*.Volume 22, Issue 1, pages 1–9, January 2014.DOI: 10.1002/pip.2452

[11] Scognamiglio A., Et Al. (2009). Use of Photovoltaics in historical buildings: an architectural approach. *Proceedings of the 24th EUPVSEC*, 2009, pp. 3922-3930

[12] A.A."La Reversibilità nel restauro. Riflessioni, esperienze, percorsi di ricerca", Atti del Convegno a Bressanone, Ed. Arcadia Ricerche, 2003, ISBN 978-88-95409-07-8 pp. 705.

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The Empowered Policy on Kaohsiung City's Green Building Self-Governance Regulation for Skyline Transformation by Photovoltaic Roofs

Speakers:
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Abstract: *Kaohsiung city was a heavy industrial city since the Japan occupied ages, and the rapid development after 1960s comes from the industrial workers to build the typical row houses in the city center. The building type looks like the semi-modern building with flat rooftop as the rescue deck. However, the climate situation in Kaohsiung is hot and humid with strong sunshine and heavy rain, it cause the damage of the rooftop for the performance reduction effect both in thermal isolation and the waterproof. Therefore the inhibitant of Kaohsiung or in Taiwan they are always set the illegal metal huts above the flat rooftop.*

Kaohsiung City Government takes the advantage of geography to promote photovoltaic policy, which breaks the limitations of central statute to implement six innovative PV law instruments first in Taiwan. The new policies include Kaohsiung City Roof Photovoltaic Equipment Installation Regulations, Kaohsiung City Green Building Self-Governance Regulation, the Photovoltaic Intelligent Building Certificate Regulation, implementation of the Installation of Photovoltaic Power Generation System in Buildings, and PV Facility Promotion Team Establishment Guidelines. These encourage the public to establish photovoltaic and transform rooftops into a base for clean energy and also to improve the quality of urban landscape.

Green Building, Self-Governance Regulation, Skyline Transformation, PV

Introduction

Kaohsiung city is located in a subtropical area and having the climate characteristic of high-temperature and some disasters. As the former efficiently building style for the housing regulations, the city is filled by the flat roof buildings in 1980s. Therefore, the overheated and heavy raining by typical climate of Kaohsiung causes the building deteriorations. In order to solve the problems of leaking roofs and over heat of top units, the inhabitants often build illegal constructions of metal huts privately. The building type looks like the semi-modern building with flat rooftop as the rescue deck. However, the climate situation in Kaohsiung is hot and humid with strong sunshine and heavy rain, it cause the damage of the rooftop for the performance reduction effect both in thermal isolation and the waterproof. Therefore the inhibitant of Kaohsiung or in Taiwan they are always set the illegal iron roof above the flat rooftop. (Figure 1) The city statues cause the damage about the urban landscape and public safety, which demand to develop with a positive guidance.

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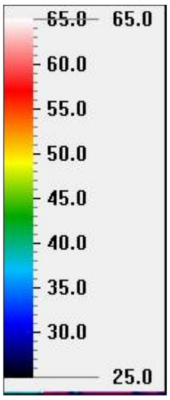
From the year 2012, the Public Bureau of Kaohsiung City Government started the program of "Kaohsiung City's Green Building Self-Governance Regulation" to enhance the environmental oriental green building development which can deeply reflect the local issues of urban and rural development. The strategy of promoting PV roof's buildings which is direct to transform the skyline patterns from illegal iron roofs to approved PV roofs. Moreover, it shows the content and construction of this empowered policy by this Regulation, the mechanisms of expanding public participation by integrating industry, government and academia.



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P5.	47.3℃
P6.	54.1℃

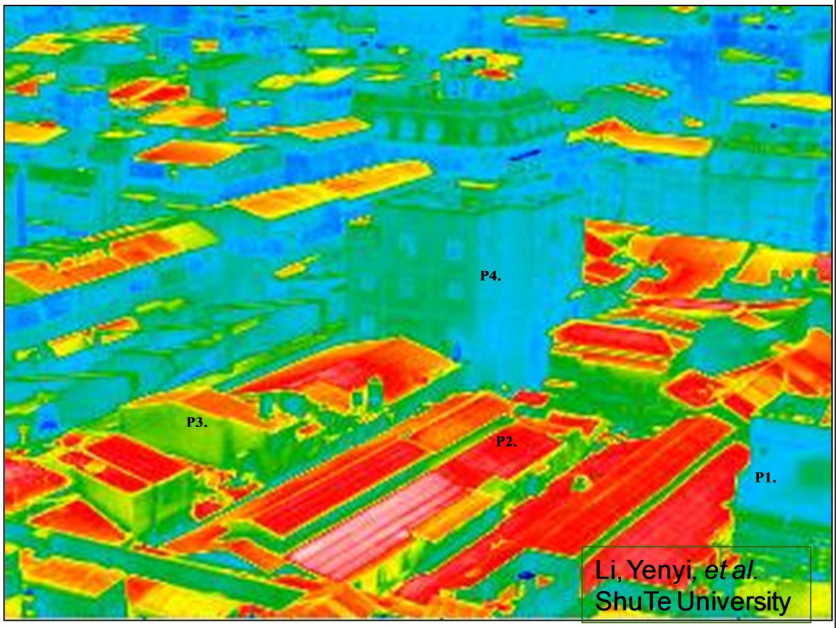

Figure 1 the landscape view of illegal metal huts skylines in Kaohsiung city

Photovoltaic promotion project

Aged buildings account for 97% of all domestic buildings. To avoid the illegal construction of metal huts and to transform rooftops into a base for clean energy, the public is encouraged to establish photovoltaics. The following environmental protection measures are emphasized for promoting rooftop photovoltaics: (Figure 2)

(a) Transforming illegal constructions and striving for urban beautification, thereby enhancing industries and creating business opportunities.
(b) Vitalizing landfills as photovoltaics bases.
(c) Combining agriculture facilities with the self-sufficient electricity concepts of farms.
(d) Integrating and collectively establishing photovoltaic communities.
(e) Adopting building-integrated photovoltaics as a diverse environmental protection measure, thereby effectively establishing thermal insulation and waterproof functions, decreasing CO_2 emissions, and achieving the goals of environmental protection and energy saving and carbon reduction.

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The promotion results from 2011 to 2012 show the great successful achievement within 508 cases applied for photovoltaic installation in the installation capacity of 21,968 kWp; annual power generation capacity of 27,815,550 kWh; and carbon reduction amount of 17,810 tons, which is equivalent to the amount of carbon absorption for a 885 hectare forest. (Table 1) In addition, the usable rooftop area increased by 264,464 m^2. Statistical predictions indicate that Kaohsiung City will establish a minimum of 10MW of photovoltaic power annually; thus, decreasing the consumption of air-conditioning electricity by 22.95 million kWh and saving NT$57.37 million each year. Furthermore, the temperature for the top floor will decrease by approximately 3°C, saving an additional 30% of air-conditioning electricity.

Figure 2. Transforming illegal constructions and vitalizing landfills and agricultural facilities.

Table 1 Comparison between the photovoltaic power carbon reduction in 2011 and that estimated for 2012

Year	Total generating capacity (kWp)	Generating capacity (kWh/year)	CO_2 emission reduction (ton-CO_2)	Reduction ratio (in comparison with former year)	Equal to Greenery of Kaohsiung Metropolitan Park
2011	6,633	8,616,300	5,400	—	5.0
2012	15,335	19,920,160	12,410	229 %	11.5
Total	**21,968**	**27,815,500**	**17,810**		

Green roof improvement project

As a response to urban disaster prevention challenges such as sudden torrential rain caused by climate change, and to achieve energy saving and carbon reduction, and enhance the feasibility of transforming urban landscapes, the green roof improvement project was conducted. Test results prove green roofs to be effective in thermal insulation, temperature reduction, and air-conditioner usage decrease. In addition, green roofs have the function of temporarily collecting water and delaying storm water runoffs, thereby mitigating the burden

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on urban drainage systems. The green roof improvement project was implemented according to the following points:

(a)The 3D greenification of urban gardens and community consultation and explanation mechanism.
(b)Establishing a micro-climate weather station for data collection, analysis and application.
(c)Establishing consultation enquiry, employing plant doctors, and providing technical service
(d)Establishing organic farming, promoting transformation, and supporting urban eco island hopping.
(e)Meta-analysis of benefits and R&D; thus, exerting maximum function of green roofs.

The green roof's practical benefits include disaster prevention and flood detention, carbon sequestration and air purification, urban heat island temperature reduction, and energy saving and carbon reduction through air-conditioning usage decrease.(Figure 3) Furthermore, the green roof has added values such as landscapes for leisurely activities, a natural attitude of lifestyle of health and sustainability, space reutilization, urban ecology diversity, and social interaction.
The goal for the green roof improvement project is to establish 10,000 ping of green roof coverage per year. Based on the calculation of a CO_2 fixation of 20 kg/m^2 for grass coverage, an annual carbon sequestration of 642 tons can be achieved. At the same time, Green roofs can be transformed into organic farms. (Figure 4) This self-sufficient life style and co-operation can improve the distancing between pa rent and child relationships and other interpersonal relationships that are a common phenomenon in cities.

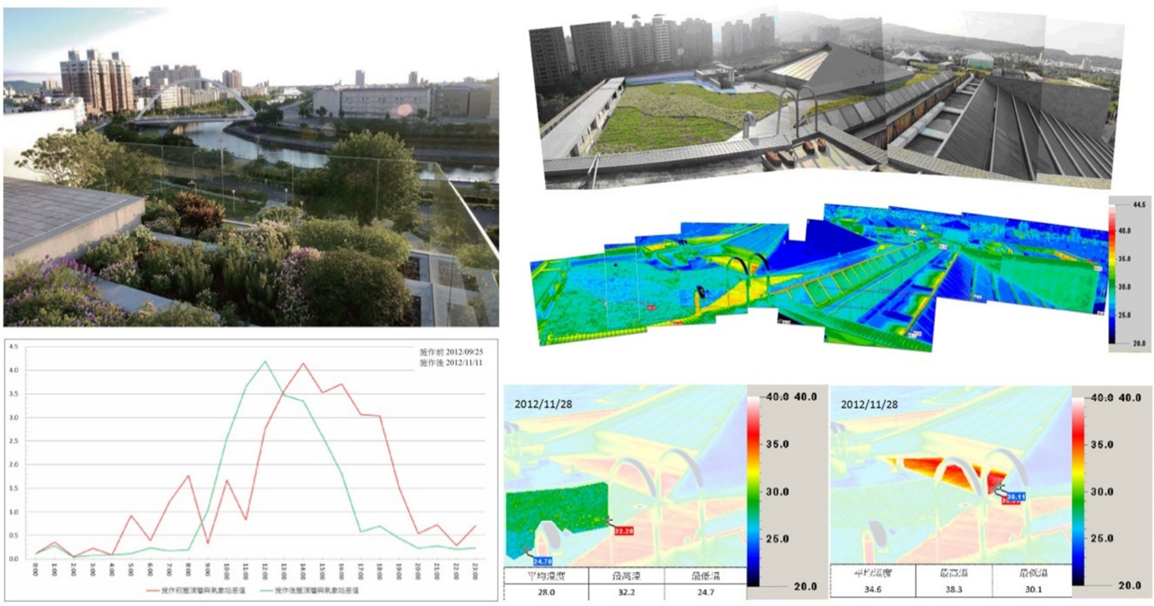

Figure 3. The efficiency evaluation for the green roof of the pilot project

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Figure 4. The benefits of psychological healing, space integration and utilization, and social interactions

Policy promotion and brand and overall mechanism establishment

The objectives of carbon and disaster reduction are achieved through stipulating Kaohsiung City Green Building Self-Governance Regulation that conforms to the City's needs, promoting an ecological city, constructing a green building environment, creating a healthy life quality, and supporting a green economy. In the proposed plan, photovoltaic construction, the practical construction of "Kaohsiung LOHAS" buildings, local academic research, the establishment of community workshops, and green roof improvement demonstrations are subsidized. Consequently, community construction is activated and a platform is available for collecting the consensus of social groups and community members. This down-to-up participation movement and the matchmaking mechanism have created a site for verifying and demonstrating the previously mentioned innovative laws and regulations.

The Photovoltaic Intelligent Building Certificate and Kaohsiung LOHAS Building Label were established through branding; thus promoting energy saving and carbon reduction, enhancing disaster prevention industries, and increasing opportunities for building designers. There are more and more private construction companies to join the programs and the roof garden of the high rise buildings in Kaohsiung now become an extra living space for the buyers to share the good quality. At the same time, the company also gets the high reputation than before, because they are now the green developers. Table 2 shows the relationship between strategic planning and innovative regulations in Kaohsiung, the reward and brand effects do realy help the policy to step further than before.

Table 2 The relationship between strategic planning and innovative regulations in Kaohsiung

Strategic dimension	*Innovative laws and regulations*	*Execution direction*
Policy	Kaohsiung City Green Building Self-Governance Regulation	Integrate and regulate various types of buildings in Kaohsiung City in conformity with the green building strategy
	Kaohsiung City Roof Photovoltaic Equipment Installation Regulations	Loosening the installation criteria
Reward	The 2012 Public Works Bureau of Kaohsiung City Government Subsidy Project for the Implementation of the Installation of Photovoltaic Power Generation System in Buildings	Encourage citizens to install roof top photovoltaic power generation systems in buildings
	The 2012 Kaohsiung City Government Subsidy Plan for "Kaohsiung LOHAS" Constructions and R & D	Subsidize constructions, academic research, and the establishment of community workshops
Brand	Kaohsiung City "Kaohsiung LOHAS" Building Accreditation Application Regulation	Branding of the "Kaohsiung LOHAS" label
	Kaohsiung City Photovoltaic Intelligent Building Certificate Regulation	Branding of the "Photovoltaic Intelligent Building" label
Integration	Kaohsiung City Government Photovoltaic Facility Promotion Team Establishment Guidelines	Promote the installation of photovoltaic facilities on buildings in Kaohsiung City and assist citizens in applying for installation
	Public Works Bureau of Kaohsiung City Government Sustainable Green Building Operation Fund Establishment Guidelines	Manage Kaohsiung City's Sustainable Green Building Operation Fund
	Kaohsiung City Government Green Building Technique Review Committee	Review questions regarding provisions for green building strategy regulations
Sustain-ability	Kaohsiung City Sustainable Green Building Operation Fund Revenues and Expenditures and Utilization Regulation	This fund is established as a response to disaster prevention, low carbon environment, and building development demands to create a sustainable and intelligent healthy green building environment.

Push and pull mechanisim by professional advise team

In the beginning the new policy was announced in 2011, there were few projects can catchup the Kaohsiung City Green Building Self-Governance Regulation to do the design. Therefore, the Kaohsiung city government first starts to make the demonstration from public building. The fine art museum was the first one to demonstrate the green roof in large scale, and the new building of Fisherman's Wharf market place was identified as the first pilot project to adopt the PV panels with the electricity business. However, the private sectors also stand wait and see the acceptance of market. After the surveys to the private sector, the professional committe find out some joint-key points to let the policy to be easy practice. 1. The education program from pilot project using the power of press. 2. To establish the service window helping the administrative process and the conjunctions. 3. To set the professional service team from academic sector to help the citizens get the free professional evaluation. 4. To establish the qualified design groups to help the citizens making the renovation plan. Figure 5 shows the first pilot project served by professional team and arised the interests of PV roof renovation. Figure 6 are the pilot projects of green roofs.

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Before renovation (illegal)   After renovation (legal)   The new community project by private sector

Figure 5. The pilot projects of PV roof demonstration

Figure 6. The pilot projects of green roof demonstration (left: Private high rise building, Right: the PV urban farming at the rooftop of Sanming district office)

Discussions and future perspectives

The policy started from 2011 and the promotion of the skyline changes attracted some of the inhabitants to strat the pilot projects. The strategy has put in the regulation for the new constructions in Kaohsiung, and forced the factory and residence above 5000 m^2 to install the PVs or green roofs. In the beginning, some of the industries have the complaints about the Kaohsiung city government for this policy. After some benefits from the pilot projects and the feedbacks from the electricity company and encourage processes, the policy now has been accepted in a growing progress. However, as the wholesale price of the electricity from the PVs getting lower and lower, the future step of the policy should focus on the holistic services by the government and the new encouragement by the social awareness with the slef-labelling system. The processes of Kaohsiung city government now become the demonstration for the other city in Taiwan, and the courage to challenge the regulation by the central government also provide the new window for the local self-governce thinking in Taiwan.

References

The promotion project of renovation toward the solar buildings in Kaohsiung (2012-2013), Kaohsiung city government, TAIWAN

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Barriers and drivers for energy upgrade of single-family housing in Norway

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Abstract: *This paper presents results from SEOPP (Systematic energy upgrade of single-family housing). The focus of this particular task was on house owner`s experience of barriers and drivers for conducting energy upgrade of their houses. Many single-family houses in Norway are from the 60`s, 70`s and 80`s, and a lot of building components have reached their expected lifetime. Renovation is due, and the possibility of improvements focusing on energy efficiency of the building stock should be seized. Based on 8 qualitative interviews of house owners who have conducted an energy upgrade of their house, an analysis of drivers and barriers is given. The findings show that the main drivers for introducing energy efficiency measures were increasing comfort and higher indoor temperature, improvement when there was a general need for maintenance, saving energy, and receiving low energy bills. The main barriers to energy upgrade were finding good enough information on energy efficiency measures, lack of knowledge among actors in the building sector of construction details and of technical installations to increase energy efficiency, as well as the house owner`s economic possibilities, and availability of materials and products for energy upgrade. Moreover, our findings show that due to little available information on energy upgrading, the owners have invested a lot of time in their projects. In some cases, the owners themselves have become experts on energy efficiency measures and have taught the builders how to solve construction details. Governmental founding for ambitious energy efficient upgrade and do-it-yourself was essential in several ambitious projects. In conclusion, energy upgrade of single-family housing in Norway still faces a great number of challenges. Founding and policies supporting house owners' initiative and pushing the level of ambitions upwards are important means that should be further developed. Also, further means to support and foster knowledge in the building sector of construction details for energy efficiency would be a major step to increasing the number of ambitious renovations.*

Keywords: Upgrade, renovation, rehabilitation, energy efficiency, single-family houses, drivers and barriers

Introduction

Norwegians spend a great deal of money on aesthetic renovation of their houses. However, energy upgrade of single-family housing is still rare. Most Norwegians (ca 70 %) own their homes (ssb.no). The number of single-family housing in Norway is about 80 % of the building stock. Many single-family houses in Norway are from the 60`s, 70`s and 80`s, and a lot of building components have reached their expected lifetime. Renovation is due, and the possibility of energy improvement of the building stock should be seized. Comprehensive upgrade of housing is an important step towards a more energy efficient building stock in Norway.

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The aim of our study was to investigate the barrierers and drivers for energy upgrade from the residential owners` perspective. Moreover, we were interested in how other benefits beyond energy savings, such as comfort improvements, increased space requirements, architectural expression and reduced maintenance needs, are drivers for descion-making regarding energy upgrade.

Other research has identified lack of knowledge about energy efficiency, personal economy and profitability, and personal attitudes as barriers to energy upgrade of privately owned houses.

Reddy (1991) stated that increased knowledge about energy saving and profitability for all groups, residents, retailers, manufacturing companies and energy companies are necessary to increase the number of ambitious energy upgrades.

A potential and barrier study (Enova, 2012) identified a lack of profitability as the main barrier to energy efficiency in Norway. The study concludes that energy efficiency measures are most appropriately carried out simultaneously with other upgrading of the residence. If no other upgrading is necessary, energy efficiency measures are rarely implemented. Another general challenge is little focus on energy conservation in society.

Jensen & Knudsen (2013) found that personal economy is one of the biggest barriers to private house owners. Personal economy limits the possibilities of measures to be implemented. However, economy can as well be a driver for ambitious upgrade. Noticeable savings on energy bills are among the biggest motivations for the decision to upgrade.

Method

The findings of the present study are based on eight case studies of upgraded houses. It was difficult to find single-house projects that have undergone a comprehensive energy upgrade, as this is still not common in Norway. Information on drivers and barriers as experiend by the residential owners is obtained through in-depth interviews.

4 interviews were conducted in 2010 for a PhD study (Risholt, 2013), 4 interviews were conducted in 2013. A semi-structured interview guide with questions on the following topics was used:

- Facts about the house and inhabitants
- Reasons to buy this house
- Upgrade - what was done?
- Motivation for upgrade
- Challenges experienced
- Evaluation of the process

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- Satisfaction with the result of the upgrade
- Point of view on energy efficiency and environmental issues

Project	Yr of construction / previous rehab.	Energy standard after upgrade	Size	Measures	Implementation	Bilde før/etter oppgradering
Isterdalen	1981	Passive house	223 m2 gross area	Passive house windows and door (u-value 0,8) Extra insulation: 25cm exterior walls (total 35cm after upgrade), 25+7cm basement, 30 cm roof (total 50cm), 12,5 cm ground floor over basement (total 17,5cm) Balanced ventilation, Air-water heat pump, hydronic heating, woodstove	Professional craftsmen, advisors, architect, own effort by house owners. Financial support from Norwegian State Housing Bank and Enova. Pictures before and during upgrade:M.Bergseth and J.Thomsen	 
Vikersund	1970	Not documented	127 m2 living	3-layer windows, Extra insulation: 10 cm exterior walls (total 25 cm after upgrade), 40 cm loft blown-in insulation New facade cladding, Air-air heat pump, floor heating, woodstove	Professional craftsmen, own effort by house owner (demolition) No governmental support Pictures before and during upgrade: house owner	 
Tønsberg	1950, 1980	Low-energy	280 m2 living	3-layer windows, Extra insulation: 10 cm exterior walls (total 25 cm after upgrade), New roof and roof insulation Geothermal heat pump to floor heating and warm water, balanced ventilation	Professional craftsmen, advisor Financial support by Enova Picture before upgrade: googlemaps.com	
Rissa	1936, 1960, roof 2008	Estimate: TEK 10 (current standard in Norway) or better (low-energy)	110 m2 living	3-layer windows, new entrance door, Extension 5m2, New insulation (cellulose): 10 -15cm + 5 cm exterior walls, 30 cm loft, 5 cm basement and drainage, Insulation of floor above basement, New vapour- and wind barrier, Biofuel to floor heating and warm water, solar collectors, woodstove,Mechanical ventilation, vents in walls	Professional craftsmen and own effort by house owner (50/50), architect, advisor, No governmental support Pictures before and during upgrade: house owner	 

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PhD interview 1	1987	Not documented	190 m2 living	2- and 3-layer windows, balanced ventilation, Air-air heat pump, woodstove, Extra insulation: some rooms in the basement	Professional craftsmen and own effort	
PhD interview 2	1980 +/-	Not documented	241 m2 gross area	Air-air heat pump, some new 2-layer windows, indoor upgrade	Professional craftsmen	
PhD interview 3	-	Not documented	200 m2	3-layer windows on main floor, indoor upgrade, other maintance work	Professional craftsmen	
PhD interview 4	1990, 2009	Not documented	180m2 1990, 286m2 gross area after upgrade	Extension 100m2, balanced ventilation. Extra insulation: 20cm roof, new windows	Professional craftsmen	

Figure 1: Overview of the projects

Findings

The greatest barrrieres to energy upgrade found in the interviews were:

- Challenges with information retrieval,
- The low knowledge level in the construction business about technical solutions and building/construction details for energy upgrading,
- Costs,
- Scarcely accessible materials and and products, e.g. passive house components.

The greatest motivation factors for the residents were:

- To get a warmer house (comfort),
- A general need for renovation,
- To save electricity and get lower electricity bills,
- Annex/ extension for more space and indoor renovation.

The initial goal of some house owners was to improve their house's energy standard. In other cases, the house owners decided to implement additional measures when the house already was in need of upgrading.

Internet was the main source of information in most of the projects. Also architects and advisors with experience or willingness to learn about energy efficiency measures were engaged. Involving architects and advisors with competence on energy upgrade was highly recommended by all house owners. Professional craftsmen were involved in all projects, but many house owners helped with the construction work in order to save money and to be in control over the work. In some cases, the house owners had thaught themselves about energy efficiency measures, and were the ones who controlled the solutions and details implemented.

Energy upgrade is a great economic strain for the households, often limiting the measures that can be implemented. Therefore, it seems important to provide (more extensive) support schemes for house owners willing to take a step beyond standard renovation. Expected economic effects after upgrading, such as electricity savings, were also a motivation factor, as

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well as the increase in property value. Most owners have a long-term perspective on living in the house, and would not have undertaken an equally ambititous upgrading if they did not.

The motivation factors also show that improving the energy standard often is a side-effect when a house is ready for renovation. In Norway, many single-family houses from 1960-1980 are in the target group for renovation in the years to come. Potentially, the energy standard of a major part of the existing housing mass can be improved. In order to start a comprehensive upgrading process there is still a need to tear down some barriers and to give better professional and economic support to housing owners.When the house owners already have decided to implement certain measures, in many cases there will be a great potential to propose several energy efficiency measures. When the house owners cannot afford comprehensive upgrading at once, they should still get help to make a future renovation plan, to avoid locking the possibilities for later measures. The approach presupposes that there is good enough knowledge about energy effciency in the construction sector. The interviews showed that energy efficiency is not a common subject in the construction sector yet, and that there is a great potential for improving advice and construction services in the building sector.

Conclusion

Based on the findings, we developed the following descion-making line that shows at which points during the process different barriers and drivers influence the project progress.

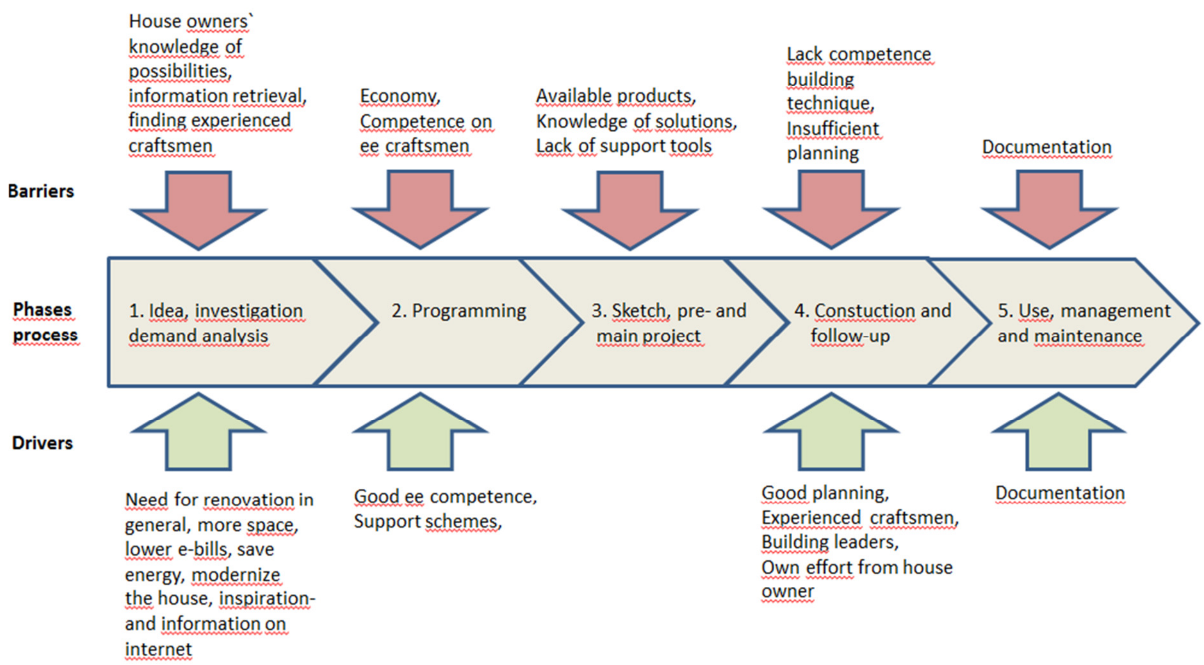

Figure 2: Barriers and drivers influencing the project process in the different phases of the planning and building process (Phases of the building process, adapted from SINTEF building research design guide 220.010).

Phase 1: Idea, investigation, and demand analysis:

- Barriers:

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- Lack of knowledge about possibilities in regard to technical standard of houses and possible energy efficiency measures among house owners.
- Lack of knowledge about consequences of different energy efficiency measures. (What energy efficiency measures do have an effect and what is it?)
- Lack of competence among craftsmen with regard to energy consultancy.
- House owners experience information retrieval on energy efficiency as difficult and confusing, and find it challenging to find experienced craftsmen. It is also difficult to find a professional willing to take responsibility for overall organization of the building process, where several diciplines are involved and have to be coordinated.

- Drivers:
  - A general need for renovation, a need for more space, a wish for lower electricity bills, a wish to save energy, a wish for less maintenence, the house owner has knowledge and interest for low energy/ passive houses, a wish for better comfort (air quality, thermal climate), a wish for a modern house (architectural expression and technical installations).
  - Inspiration and information retrieval on internet.

Phase 2: Programming:

- Barriers:
  - Economy limits possible measures. Many house owners have to prioritize between different measures without having enough knowledge about the different possibilities and consequences.
  - House owners often prioritize measures for improving housing quality (e.g. comfort and aesthetics, before energy efficiency.
  - Little experience among professionals to plan energy upgrading and little knowledge about the consequences of choosing different technical solutions.
- Drivers:
  - If involved, professionals with competence in energy efficiency (e.g. architects, craftsmen or energy advisors) act as important drivers for ambitious projects. The house owner gets help to prioritize measures and organize the process.
  - Support schemes give more ambitious projects and greater possibilitites than projects limited by private economy.
  - Personal knowledge or interest in energy efficiency is a driver for house owners.

Phase 3: Sketch, pre- and main project:

- Barriers:
  - Craftsmen and professionals' lack of competence in construction/building details
  - Lack of support tools to organize a time- and cost effectiv process.
- Drivers:
  - None identified

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Phase 4: Construction and follow-up:

- Barriers:
    - Insufficient planning, lack of avaliability of services, materials and products still not common on the market.
    - The craftsmen have little experience and competence in construction solutions for energy efficiency.

- Drivers:
    - Good planning and craftsmen with knowledge about energy efficiency building solutions.
    - The house owner is competent, and can contribute with his/her own effort to save money.
    - In total renovations, the process will be easier when the project leader organises and coordinates the different trades.

Phase 5: Use, management and maintenance:

- Barriers:
    - Documentation measures to get a certain energy standard approved. Documentation is important to apply for financial support as well.
- Drivers:
    - Documentation for the house owner: "Did I get the quality I paid for? Do I save energy?")
    - Documentation of work done by skilled craftsmen for sales documents if a sale is planned.

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References

Enova (2012) Potensial- og barrierestudie. Energieffektivisering av norske bygg.[Potential- and barrierstudy. Energy efficiency of Norwegian buildings]. Enova.

Jensen, O.M. & Knudsen, H.N. (2013). *Energirenovering. Incitamenter og barrierer blandt husejere i Furesø Kommune.* København: Danmarks Byggforskningsinstitutt.

Reddy, A. (1991), Barriers to improvements in energy efficiency. *Energy Policy,* 16**,** 953-

ISBN: 978-84-697-1815-5

961.

Risholt, B. (2013), Zero Energy Renovation of Single Family Houses, Dissertation, NTNU 2013:153, available at: www.diva-portal.org/smash/record.jsf?searchId=1&pid=diva2:632723

SINTEF Byggforsk (1999), Building research design guide 220.010 (Programmering av byggeprosjekter)

Ssb.no, (Statistics Norway)

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Retrofitting Russian cities; Addressing housing conditions in the regional masterplan for Berezniki, Solikamsk and Usolye

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Abstract: *The condition of the Soviet era Russian housing stock is gradually worsening. This poses a major challenge for municipalities in how to deal with cities in which the majority of residential areas are dilapidated. Residents have a poor quality of life and the image and attractiveness of the cities suffer. This paper presents the research and proposals involved in a masterplan for an agglomeration of three Russian cities, with a population of approximately 262,000. The research investigates and quantifies the condition of housing in the cities and proposes strategies on how to improve the stock over a 20-year period. The city scale involves demolition and replacement, renovation and repair and considers the relocation of residents during the processes. On a smaller scale this involves design proposals to be employed during the redevelopment to ensure the new housing is more sustainable.*

Housing condition, prefabrication, Russia, municipality.

1. Introduction

The poor condition of Soviet era housing, particularly the prefabricated buildings, is recognised as a question of increasing relevance for many Russian cities (1)(2). Residents live in dilapidated buildings, consuming large amounts of heat energy (3). Neighbourhoods are characterised by vast, low quality public space. According to expert estimates approximately 150,000 flats become uninhabitable every year due to lack of repairs (1). This not only means a poor quality of life for the residents of these buildings, but it poses a significant challenge for municipalities when it comes to dealing with a city composed of such buildings.

The most widely acknowledged cause of poor quality residential developments is the lack of maintenance, which stems from the weak policies on maintenance structures when the majority of the stock was privatised in the early 1990s (6)(1).The funding and trust in the maintenance companies suffers to this day. However, the monotonous buildings and loose urban structure themselves create a sense of anonymity and lack of ownership of anything outside the apartment, which is recognised as playing a role in the lack of collaboration on the maintenance issue, thus further contributing to the degradation of the buildings, and to the cities they comprise (7)(8)(9). The prefabrication construction industry that produced these developments still dominates the market, and while construction technolgy has improved somewhat, the planning model used remains relatively unchanged since the Soviet times(8). While policies regarding maintenance still need to be strengthened, the replacement or reconstruction of buildings and redevelopment of these housing areas is inevitable. Should the future want to see a more sustainable housing stock, and more attractive cities supporting a better quality of life, it is important that these rebuilding processes take into consideration the critiques on urban and architectural level.

The way in which residential areas can be redeveloped and reconstruction options for prefabricated buildings is a well investigated topic, with proposals being presented every year in architectural and urban forums, conferences, articles and university research projects, as was the theme for the Moscow Architectural Biennale 2012. However, the research into this housing issue on a city-scale has not received as much attention, particularly outside the major cities of Moscow and St. Petersburg. The government have set up emergency rehousing programs beginning in 1998, which aim to alleviate the most urgent cases first (3), and incentives for construction of new housing (10). However, according to expert studies the rate of both new build and renovation is too slow to meet demands of those needing rehousing (1). City-scale analysis would give municipalities an understanding of what the extent of their problem is, spatially and in numbers. It could also provide a basis for exploring and evaluating which types of block scale strategies are necessary and viable to be implemented to best achieve a more sustainable housing stock and better kept residential areas.

This paper presents an overview of the research and proposals involved in the masterplan for an agglomeration of three Russian cities, with a total of approximately 262,000 inhabitants. The plan was commissioned by mining company Uralkali together with local administrations, primarily because of geological insecurity, due to mining under the cities, causing increasing population decline. Though safety remained a priority, housing quality was focused on as another contributor to outmigration and a key issue for the city to address.

1.1 The masterplan-motivation

180 km North of Perm the agglomeration of Berezniki, Solikamsk and Usolye (BSU) sits on 30% of the world’s potash reserves. Despite its strategic economic importance, the region’s population has been steadily declining over the last decades, weakening its workforce supply and hindering industrial growth. The primary reason being the geological insecurity, though the national phenomenon of inter-regional migration for education and more diverse employment opportunities also plays a role(5). The flooding of the mine under Berezniki in 2007 gave rise to the formation of three sinkholes. This was a major cause for concern for the citizens for their own personal safety and the integrity of their properties. Aside from the sink holes, surface deformations and building cracks have also appeared due to insufficient backfilling in the mining areas stretching underneath the cities of Berezniki and Solikamsk.

1.2 Objectives

The aim of the masterplan was to deliver strategies to provide a better, safer quality of life in the area that would retain and attract citizens, so that the required workforce would be available for the area to reach its economic potential. In this paper we focus specifically on the housing strategy provided. In early field trips and meetings with local stakeholders it became apparent that buildings and the residential areas in general were in a poor state, and named as contributing factor to outmigration. Therefore, the housing strategy aimed to answer

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the following questions. Condition: What is the actual condition housing and extent of the problem in BSU? Causes: What are the factors contributing to the condition of the residential areas in the context of BSU? Proposals: Which urban and architectural design solutions could provide more sustainable housing for the future, offering a better quality of life?

2. Condition

In analysing the quality of residential buildings, the aim was to gauge the scale of the problem rather than give precise building level information. The outcome should give the local municipalities an understanding of what ball-park figures they were dealing with in terms of units needing to be: demolished and replaced; renovated; repaired or retained. It would also give them a time plan over 20 years of when works should be done and in what order, to manage people movement, to spread out costs, and to mitigate the worsening of the situation.

2.1 Data Sample

Data on the building condition was collated from the data available from the Central Technical Inventory (CTI). Each building in Russia has a 'technical passport' which notes the buildings percentage of wear: 0% is no wear at all, the building is in perfect condition and above 70% the building is deemed uninhabitable. The percentage of wear is noted whenever a technical inventory is carried out on the building, which happens when: the building is constructed; a change is made to the building; on request of the residents due to concerns about the building condition(11). This data was only available for multi-unit buildings, which thus comprised the study and which house 85% of the population. Individual houses were however identified for relocation when located in unsafe areas.

The urban fabric of these multi-unit residential areas in BSU can be differentiated according to construction period, and block type ranging from low- to medium-rise semi-open perimeter blocks in the Stalin era to medium- to high-rise free plan microrayons from the Khrushchyovka era to present times. (The microrayon is a planning model used for residential developments, conceived in Soviet times, ranging from 10-60 hectares in size.

2.2 Collation and mapping

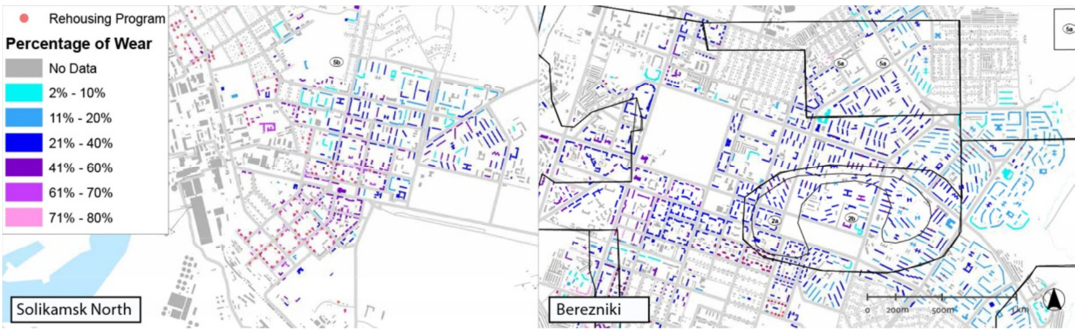

Figure 01. Samples of Percentage of Wear mapping 2013, Solikamsk North (left), Berezniki (right).

The first step was to project the building wear data forward to the current year, then 2013. The percentage of wear given was together with an inventory date and from this, together with the date of construction, it was possible to estimate a percentage wear per year for each building. These were compared to check for correlation. The majority of buildings showed an

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approximate average percentage of wear of 1% per year, which was taken as confirmation on the method. Having input the data into Geographic Information Systems (GIS), the buildings were mapped with their current percentage of wear, to spatially illustrate the condition of housing (fig. 01). The wear percentages were also cross referenced with their building year, geographical location – particularly in relation to the deformations caused by mining- and their construction type.

2.2.1 Correlation of building year, typology and construction type

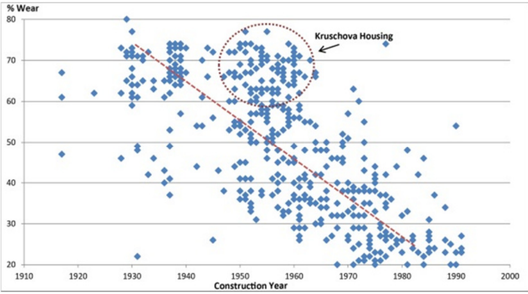

Figure 02. Percentage Wear by Construction Year

The building year showed the biggest correlation with the percentage of wear: the older the building the higher the percentage of wear. However, the Krushchyovka series from the 1960s-1980s show a slightly higher level of wear for their age (fig. 02). The information available on construction type was too detailed and too vaired to extract relevant correlations.

2.2.2 Geographical location

Deformations due to mining were not apparent within this data set; most of inventories were made before 2007. The buildings which were affected by the deformations due to mining were identified by a list of buildings formulated by a special committee for the emergency relocation rehousing program. The percentage of wear of buildings did not correlate with the presence of mines under the buildings. In fig. 01, in the inset 'Solikamsk North', high percentages of wear can be seen across the city, though this city has not been undermined. This illustrates that the analysis of this housing stock data is significant for other Russian cities and not solely for the unique situation of cities over mines.

2.3 Assigning strategies to percentages of wear over time

Determining whether a building should be demolished, renovated or repaired depends on the building condition and viability of the investment. The upper limit is set by Russian regulations, where by buildings with over 70% wear are deemed uninhabitable. With rate of wear appearing to be 1% per year on average, buildings estimated at 50% or more wear now are expected to require replacement within the next 20 years. These are assigned '(Future) Demolition', as due to the scale of the housing issue which has to be addressed in 20 years, it was seen as more financially efficient to invest funds in renovation of buildings in better condition so that they do not deteriorate further, rather than in those which are close to being uninhabitable. Repair is recommended for buildings in the early stages of disrepair, to avoid future degradation, requiring minimum investment by homeowners. Renovation is then recommended for buildings between 30 and 50% wear.

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2.4. 1 Results – housing program

The pie chart (fig. 03) shows the results of the analysis of over 1,600 multi-unit dwellings, containing over 97,000 individual apartments. Of this data 7,708 units are assigned for demolition by the emergency rehousing program, and a further 7,061 units are assigned for demolition due to their location in zones unsafe for inhabitation. The need for relocation is unique to this context, where the governmental commission of the Russian federation declared that it did not want any houses rebuilt on areas which had been undermined. If this was not the case these buildings would be demolished and replaced in the same area.

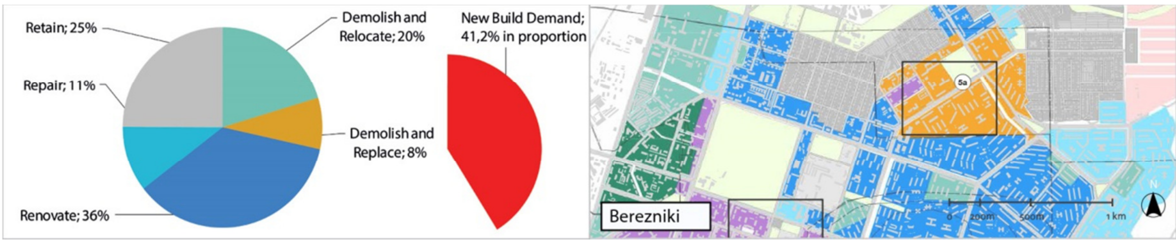

Figure 03. Pie-chart of strategies applied to Multiunit housing by % of total(left), strategy map section (right).

2.4.2 Phasing of housing program

This program was then phased into four five-year phases using the GIS model, The strategies were applied in order of priority over the 20-year period. The program also took into consideration the construction of new units for relocated residents and expected new comers.

3. Causes leading to poor condition of housing:

- Deformation of the structures due to subsidence: These units were identifiable by cross referencing the emergency rehousing program units with their geographical location.
- Poor quality construction: the buildings from the Khrushchev era (from 1950s) in particular were originally intended as temporary housing, with an maximum lifespan of 25 years (4).
- Poor levels of maintenance: The state handed over ownership of the individual apartment units to residents in most cases free of charge during the privatisatin period. The maintenance of buildings and associated open spaces, previously resting with the state, was to be taken on by private companies, funded by fees paid by homeowners. The policies both on the setting up of maintenances companies and home owners associations to communciate with these companies were weak. It proved difficult for homeowners to trust in this system, to rely on maintenance companies and to rely on their neighbours to also pay fees for repairs. This lead to a lack of funding and so very low levels of maintenance of both buildings and open spaces.
- Lack of sense of ownership and identity of place: There are no privately owned open spaces in the residential areas and the semi-private or communally owned spaces are unrecognisable. The legally defined plot of land associated with the building, is not demarcated by any lines in the landscape around the property - such as footpaths or roads. This reinforces the idea that all residents own is their own apartment, which reduces the will to pay fees for the upkeep of the rest. All the open space should be maintained by either maintenance companies or the municipality, which again suffers from lack of funding.

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4.0 Proposals - Urban design solutions

A set of urban design principles was applied to both new build and redeveloped areas. The overarching aim of these principles was to break down the areas into a hierarchy of public to semi-private to private spaces, each of which the residents could identify with. Only streets squares and parks are to be public, and to be maintained by the municipality. Where possible, courtyards should be created, so that spaces within them are more enclosed. The residents living around these spaces can recognise what is theirs. The semi-private spaces in courtyards are to be taken care of the maintenance companies. The ground floor apartments are to have private gardens, reducing the amount of semi-private space that needs to be taken care of by maintenance companies, and reducing the shared costs on residents.

The urban form of the Stalin block was taken as a motif for the new or redeveloped blocks. The buildings in these courtyard blocks are simple in form to accommodate prefabricated building designs, however a mix in typologies is introduced to vary the appearance of the blocks and to diversify living options. The blocks and spaces should be of a human scale. Lower buildings placed closer together were favoured over larger buildings set further apart - the trend in prefabricated construction. Studies were made to ensure that the necessary densities and levels of insolation could be reached with these lower-rise blocks.

Figure 04. Urban design, introducing hierarchy in redeveloped residential areas.

4.1 Proposals - Architectural design solutions

The architectural solutions aimed to create a new local aesthetic, yet still based on prefabricated panel construction – as this would be the only method which could viably supply the number of homes needed within the time frame. The abundance of forest in the area inspired the idea to include timber panels in the design, which would also be prefabricated and could be combined with the concrete panel designs (fig. 05). Orientation was to be considered in the building typologies, and facades designed with reduced openings to the north to reduce heat loss, and increased openings to the south – allowing for passive solar gain. Varying typologies by orientation would also reduce monotony.

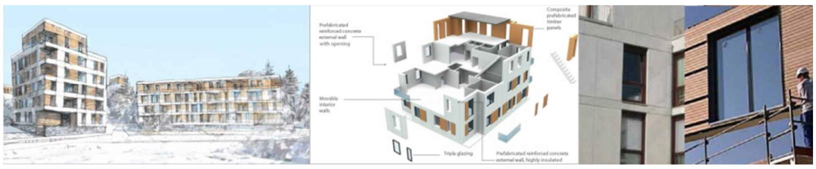

Figure 05. Architectural design, introducing variety and sustainability.

4.1.1 Panel and plan variety for typologies

Prefabrication plants can potentially produce a wide variety of panels for one building development. Panels can vary in opening sizes and types, and in finishes such as grooving, printing and engraving different textures in the concrete. The architectural proposal also wished to make use of this capability within the technology. The concept for each building typology was that on the same structural grid at least two different facades could be applied, which would employ a different composition of a set number of panels. And, within that same grid a variety of floor plans could be accommodated – allowing flexibility in unit size for the future. These design solutions can help increase individuality in building complexes while maintaining an efficient prefabrication process.

5. Conclusions

The work of the masterplan has illustrated how significant the housing issue is for local municipalities in terms of demolition, construction and renovation of housing and in terms of managing residents relocation. The design solutions also show the opportunities for change in urban and architectural form during the redevelopment process. The numbers of buildings needing to be address, coupled with the dominance of the prefabrication market in Russia indicate that developments in the prefabrication construction industry, taking on some of these design suggestions in both urban planning and architectural design, could have a major impact on the future sustainability of Russian housing and residential areas as a whole. Though these proposals would inevitably cost more on the outset, both in design and with less economy in construction, it would reduce the chances of cities like the BSU facing the same housing crisis again in years to come. While the impetus for the masterplan was somewhat unique, the data analysis, scenario modelling and empirical knowledge gathered in this process should be of value to municipalities of many Russian cities, as the housing is of similar stock and quality nationwide.

References

1. UNECE. (2004). *Country Profiles on the Housing Sector - Russia.* Geneva: UN.
2. UNDP. (2007). *Russia's Regions: Goals, Challenges, Achievements.* Moscow: UN.
3. Krasheninnokov, A. (2003). Urban Slums Report: Moscow. In *Understanding Slums: Case Studies for Global Report on Human Settlements 2003*: 195-228. London: Earthscan.
4. SVESMI. (2013). *Microrayon. Tomorrow* [Motion Picture].
5. Kashnitsky, I. (2014). A Cohort Study of Intraregional Migration of Russian Youth. *XV HSE Conference on Economic & Social Development.* Moscow: Higher School of Economics.
6. Hirt, S., & Stanilov, K. (2009). Revisiting Urban Planning in the Transitional Countries. In *Revisiting Urban Planning:Global Report on Human Settlements*:1-97. London: Earthscan.
7. Goldhorn, B. (2012, December). Privatize!. *Volume* (30): 12-16.
8. Bokov, A. (2009, May). Shaping the urban fabric: The future of residential unit. *Project Russia* (52): 68-79.
9. Grischin, S. (2002, July). Three generations of large panel housing and their future development. *Project Russia* (25): 60-63.
10. Carr, J. (2002). Residential Construction in Russia. *ASC Proceedings of the 38th Annual Conference*: 261 - 267. Blacksburg: Virginia Polytechnic Institute & State University.
11. Government of Russian Federation. (2010). Постановление Правительства РФ от 4 декабря 2000 г. № 921, с изменениями от 21 августа 2010 г. Moscow.

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Session 51:

New tools, more information…what are the key needs for the future?

Chairperson:

Salat, Serge

President Urban Morphology and Complex Systems Institute

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New tool to identify enviromental impacts on the construction works. BEDEC & TCQGMA

Abstract:

The Catalonia Institute of Construction Technology - ITeC is an independent, non-profit-making organisation that carries out its work in the area of operations intended to further the progress of construction.
Since 1985, it has owned both the generic Bedec DataBase (DB) and the Materials register DB that includes the reference prices, commercial products and legal specifications of constructive elements for buildings, civil engineering, urbanisation, rehabilitation, preventive and corrective maintenance, security and health, tests of quality control, etc. It allows designers to consult, and helps them assemble project budgets and technical specifications.
In parallel, ITeC has contributed to creating and maintaining other DBs on construction in two directions: DBs of Enterprises, containing their commercial information, and DBs of official and private Entities in Catalonia
Since 2004, Bedec DataBase has been expanded with environmental information in all its generic data, this information is 100% available online in metaBaseITeC at www.itec.cat.

information technology, construction databases, project definition knowledge, prices of constructive elements, commercial products information, environmental information.

INTRODUCTION

Currently included in metaBaseITeC has a total of around 85 Data Bases (DB) with prices of constructive elements (and related information), and around 317 Data Bases with commercial products and their technical information.

The information contained in the different DBs, in Catalan and Spanish, is periodically updated. This gives users the benefit of consulting (or downloading and dragging & dropping) the new and latest information contained in all DBs.

Users can also register for a free mailing list known as InfoITeC where they receive the latest news on metaBaseITeC updates and other products of interest.

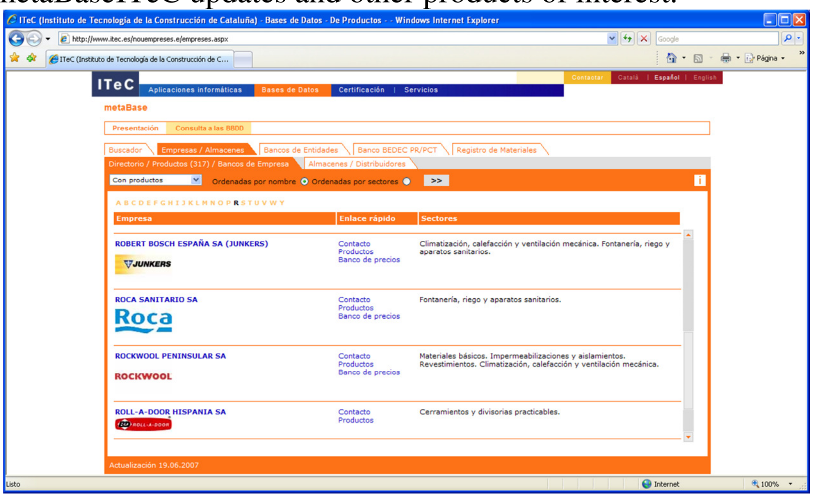

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Figure 1. View of DBs of enterprises (= Empresas / Almacenes). Also there are DBs of entities (= Bancos de Entidades), Bedec DB (= Banco BEDEC PR/PCT) and Materials register DB (= Registro de Materiales).

THE BEDEC DB

The Bedec DB is a parametric DB that allows designers to find a constructive element quickly by selecting the values of the properties shown in every constructive element class. During the values selection, incompatible values of other properties are disconnected automatically. This means they do not have to select from among the hundreds of different possibilities of the constructive elements in any particular class.

Information on the Enterprises and Materials register DBs is also integrated with the different constructive elements of the Bedec DB. Because of this related information, it enables designers to consult and parametrically select both generic and commercial products information.

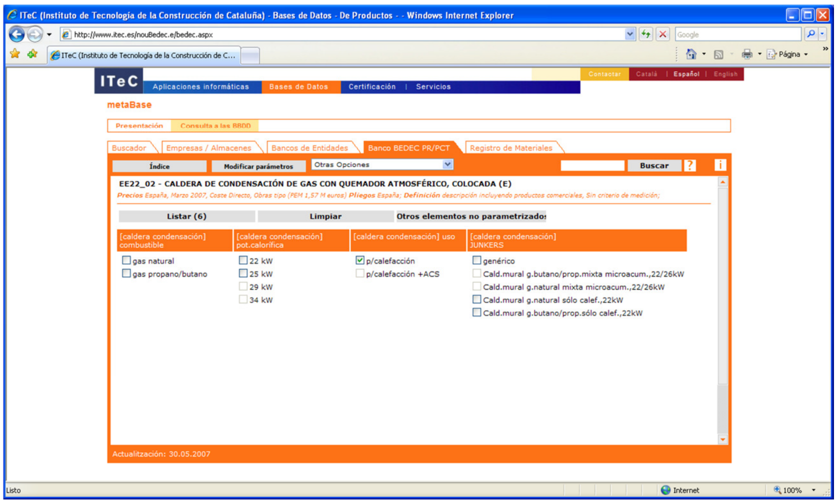

Figure 2. View of a parametric class. The values of the properties can be selected in any order, and this disconnects automatically the incompatible values of other properties.

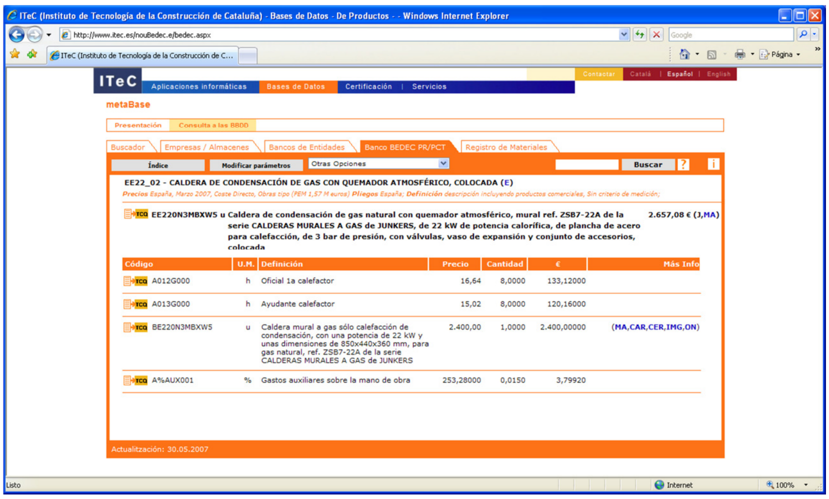

Figure 3.

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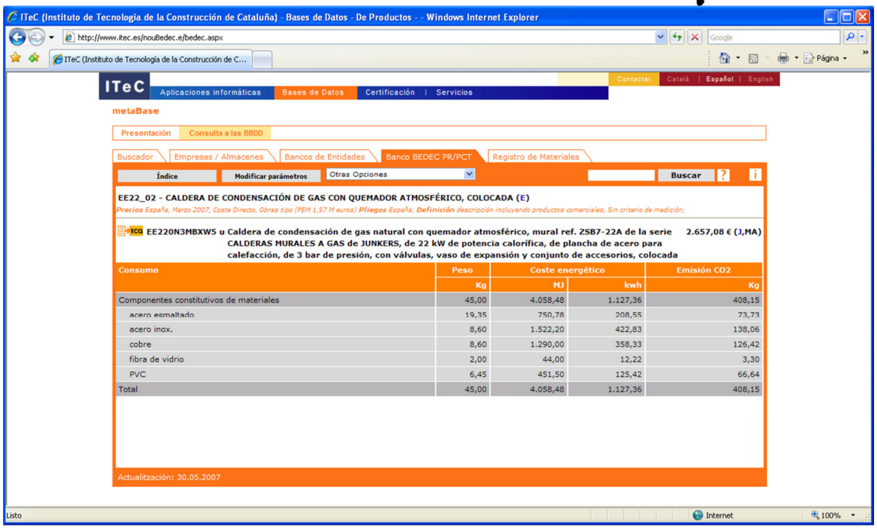

Figure 4.

Figures 3 and 4. Each constructive element has its cost justification in manpower, materials, machinery and auxiliary costs (as shown in figure 3), but also its related iformation of legal specifications, environmental information of construction and packaging waste, energy costs and CO_2 emissions (as shown in figure 4), commercial products (characteristics, certificates, images), etc.

The Bedec DB can also adjust the final results by selecting different filters. So, each constructive element can adjust for date and region of price, region of legal specifications, price depending on building volume; automatically insert the name and reference of commercial products into the definition, automatically insert measuring criteria into the definition, and finally, show price depending on contractual situation.

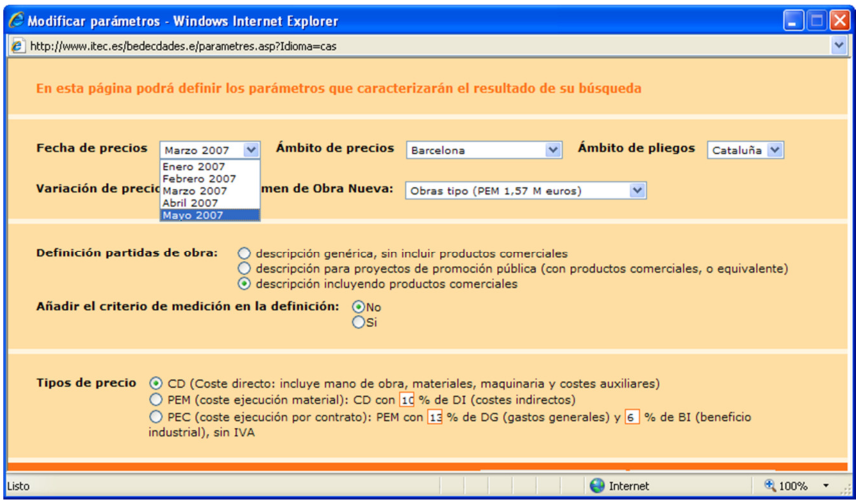

Figure 5. Filter selection.

SEARCH ENGINE

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In metaBaseITeC users can directly consult any of the DBs it contains (enterprises, entities, Bedec or Materials register DBs), or use a search engine that have access to all the DBs at once.

This dedicated search engine permits users to search for the name of an enterprise or entity, the name of a commercial product, the identifier of a constructive element, a code or any other word or group of words, giving as a result all locations where the different DBs provide a response. In addition, all the different DBs in metaBaseITeC have their own search engine that allow users to limit their search to a particular DB.

The search engine applies many search capabilities to ensure a positive result. These include synonyms (searches for the word and all its synonyms), equivalences (known words are substituted for others that give results), male/female, singular/plural possibilities, and measurement values.

If it doesn't obtain results, the words of the search are automatically included into a internal DB, to be treated if possible for synonyms, equivalences, etc. to obtain results in a subsequent search.

A search can obtain more than 500.000 results. Although the user can refine the search by giving more words, the results are always shown distributed in the blocs that correspond to the different DBs included in metaBaseITeC. Within each bloc, the results are also shown under the classification system of the constructive elements in each DB.

This lets users quickly obtain a concrete result by surfing in the different branches of the classification system instead of reading lists of results (i.e. if the user requires 'concrete' and the results in an enterprise DB show the classifications 'foundations' and 'structure' (amongst others), the user can quickly continue through the branch 'structure', for example selecting the next sub-branch 'pillar' etc., and so on).

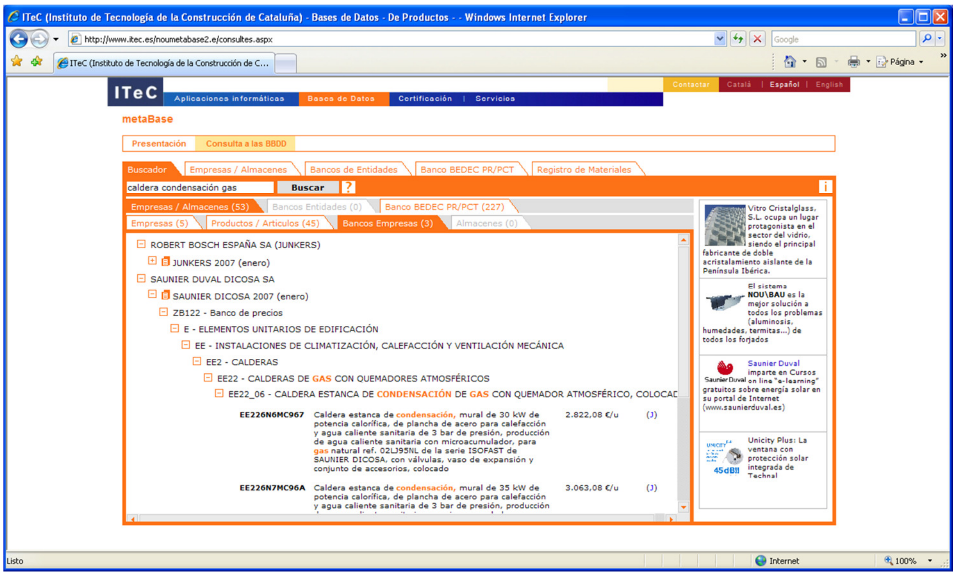

Figure 6. View of a result of a search in DBs of enterprises (=Bancos empresas). Also there are results in DBs of entities (=Bancos entidades) and in Bedec DB (Banco Bedec).

FORMATS OF INFORMATION

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The information can be exported in different formats (.bc3, .pdf, .jpg, .xls, etc). Some are free (information from the Enterprises DBs) while others need a licence (the Entities, Bedec and Materials register DBs) obtained when acquiring and installing ITeC's Bedec CD-Rom.

One format of particular interest to designer users is the FIEBDC format (extension .bc3). This is the Spanish Construction DB Standard Exchange Format between DB and programs, which is regulated by FIEBDC association. The information the format can contain includes anything relating to the prices of constructive elements, legal specifications, commercial products and their characteristics, images and certificates, information relating to the enterprises, etc. This permits a DB provided in this format to be used by any of the existing budget programs that accepts the format (more than 20 programs in Spain).

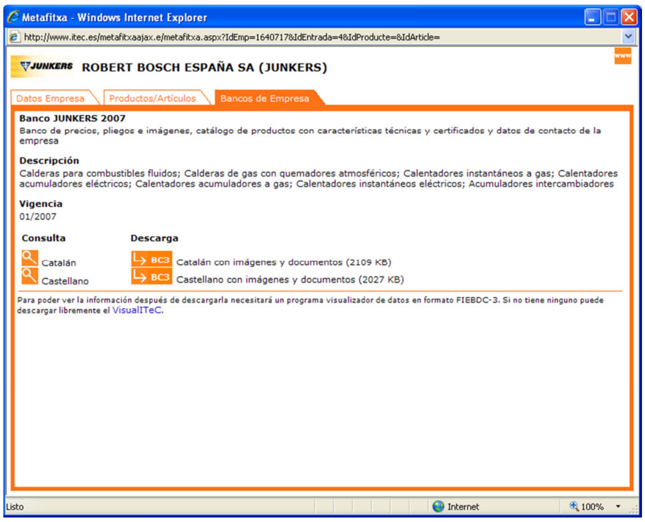

Figure 7. Consult (= consulta), download (= descarga).

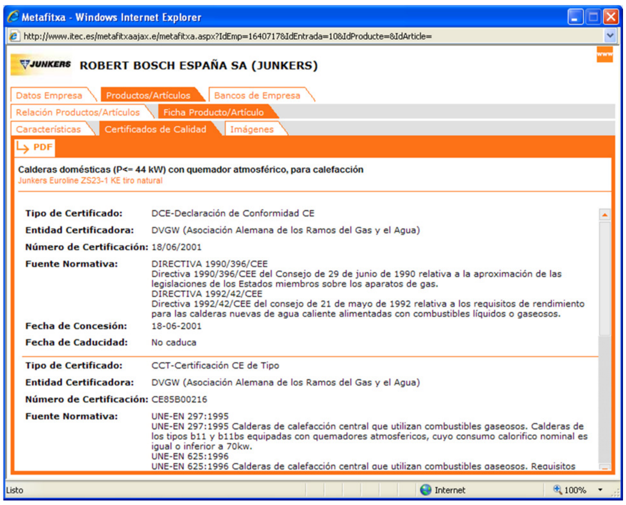

Figure 8. Technical characteristics (= características), quality certificates (= certificados de calidad), images (= imágenes).

DRAG & DROP WITHIN THE INTERNET NAVIGATOR

One of the benefits of metaBaseITeC is the possibility of using a new Drag & Drop technique from within the user's Internet navigator. This is especially interesting for designers, as they

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can transfer the prices of the constructive elements (with all their related information such as manpower, specifications, characteristics, images, certificates, environmental information, etc.) directly to a budget created using ITeC's TCQ2000 program. TCQ2000 is a program that permits preparation of budgets, specifications, planning and construction tracking, etc.

If the elements that the user wants to drop are from Bedec or an Entitie DB, the program verifies if the user has license to do that and enables him to continue or not. If the elements come from an Enterprise DB the program doesn't verify anything and the drop is free.

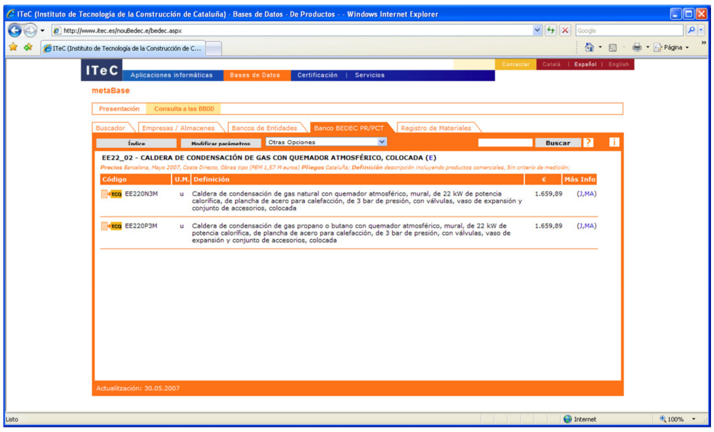

Figure 9. A constructive element and its related information can be drag & drop (by dragging the TCQ symbol) directly to a budget made using TCQ2000 program.

ENVIROMENTAL DATA

ITeC in recent years has developed a methodology to calculate the enviromental impact on construction works, mainly in CO2 emissions and Energy consumption.
Due to the growing interest in environmental data products in the construction sector, public entities, and in society in general, as well as different environmental labels for buildings, ITeC is carrying out a review of its generic environmental data bank.
This review is to adapt our current calculations in relation to the ISO 14040 methodology and to increase the impact vectors that are currently on offer.
We consider that our generic environmental database can help the construction sector to calculate the enviromental impact on buildings to be constructed.
Our enviromental data bank BEDEC is generic, but when a company has a product with specific environmental information, this information will automatically replace the generic data, and this information is also free on web.

The structure of the new environmental BEDEC data is as follows:
- Climate change (kg CO2 eq)
- Ozone depletion (kg CFC -11 eq)
- Ozone photochimique (kg ethylene eq)
- Human toxicity (kg 1,4 - DB eq)
- Formation of photochemical oxidants (kg NMVOC)

- Training of particles (PM10 kg eq)
- Terrestrial Acidification (kg SO2 eq)
- Eutrophication of freshwater (kg PO4 eq)
- Depletion of water (m3)
- Depletion of fossil fuels (kg oil eq)
-% Recycled content (% pre - consumer % post-consumer)
-% Recyclability
- Existence of an environmental seal of quality (Type1 , Type 2 , Type 3)

LIFE CYCLE ASSESMENT

ITeC uses a specific Methodology to calculate the Environmental data. It is a similar methodology used in eco-type labels III. The development of this metodology is based on a set of rules, requirements and specific guidelines laid down by product or product family, for Cycle Analysis Lifetime.

For ITeC, regulation takes for construction products indicated in the list on the previous page. When performing the EPD's (Environmental Statement Product) for the construction sector. There are two types of categorization rules in the main products is the standard international ISO 21930 and the European standard EN 15804. Moreover, some countries have their own for specific cases, the rules for example, France, the P010 NF. Environmental product declarations focuses on EN 15804. This European standard provides the main rules Product categorization for all products and construction services as well as a structure that ensures that all statements of environmental products, services and construction processes are derived, verified and presented in a harmonized way as expressed in EN 15804:

• Define the parameters to be reported and how they are reported.

• Describe what stage of Product Life Cycle is at considered in the DAP and what processes are included in these phases.

• Define the rules for scenario development

• Include the rules for calculating the inventory Life Cycle Analysis and Life Cycle marked EPD in specifying quality data to be applied.

• Includes, for necessary cases default rules for reporting environmental and health information has not been covered by ACV in the product, process or service construction.

• Define the necessary conditions to compare different construct products based on the info that EPD provides.

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HOW ITEC APPLIES THIS METHODOLOGY

IteC has an agreement with the Climate Change Office that validates the calculation methodology in differents vectors; Climate change (kg CO2 eq), Training of particles (PM10 kg eq). IteC also has an agreement with the Agència Catalana de l'Aigua to validate the calculation methodology of water consumption. At present we have conversations with the Agencia Catalana de Residus, to validate also the values of waste construction. The intention is that each vector of the enviromental data will be validated by each public entity that manages the vector at state level or autonomic level.

Climate change has become one of the most important environmental challenges of today. The intensive use of resources, especially energy, is the main ingredient. The European Union takes the fight against climate change as a cornerstone of its environmental policy. The agreement of Mayors is a European initiative that was born as a key instrument to involve local governments in the fight against climate change.
It is a voluntary commitment which municipalities undertake to reduce their emissions by 20% by 2020.

The main objective is to reduce greenhouse gas emissions in the municipality by more than 20%.
To do this they must:
1. Draw up a Plan of Action for the Sustainable Energy of the municipality within one year from the date of accession
2. Submit a biennal progress report from agreement of Majors to the Direction General of Energy of the European Commission one report biannual report from the agreement of majors.
3. Management activities dedicated to energy and the agreement

Barcelona Provincial Council supports the participating municipalities in each of the obligations arising from the agreement.

Today the most important vector we use is the Global Warming potencial but the interest in others enviromental vectors is increasing.

Each enviromental vector methodology calculation follows EN 15804, and takes into account the life cycle assessment from cradle to grave, a technician can calculate the building impact in many fases, the materials production, the building construction, the use of the building or its future deconstruction.
The potencial use of this database is huge. It is not only useful for technicians buit it can be used by the administration and also by the councils, to estimate the impact of management of

their buildings, energy consumption, impact on maintenance and water consumption. It can also contribute to present the action plan of action of the sgreement of majors.

IteC is also working on applying this methodology in administrative works and services, for example in the management of an enterprise, or in energetic auditory or in a bidding contest.

We know that enviromental vectors are not the most important issues to make decisions in the world today, but we think it is important to know the enviromental impact of our actions. We must know how to analise whether there are other options with less enviromental impact and at no extra cost.

CONCLUSIONS

In the field of DBs, ITeC is currently working on the selling and acquisition of licences for the DBs directly from the web site, enabling users to create their own (one or more) DBs online using the elements of all the DBs included in the metaBaseITeC, and letting them share their DBs with other users, and finally, on the inclusion online of the TCQ2000 program. This permits more flexibility in the exchange of information between designers and in the need of information (specifications, planning and construction tracking, etc.) during the execution of buildings and works.

It has developed, but wants to increase, the interconnection between the constructive elements of the DBs with some CAD programs, to improve the the process of design with the obtention of quick related information and also for the necessary control and coherence in the documentation of a project.

B2B is also a field of interest mainly to convert a generic (or semigeneric) budget into a real budget (charges, discounts, etc.), with the developing of the interconnection between the constructive elements of the DBs included in a budget with the contractation sites of the enterprises.

Our hope is that all companies working with construction products will develop their own enviromental data, but in the meantime all construction products have enviromental data (with a Enviromental Product Declaration or similar) ITeC is developing generic data to be applied to all construction products. This information is free for all users.
http://www.itec.cat/nouBedec.c/bedec.aspx .

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SOFIAS - Creation of a database of quantitative and reliable environmental information of construction products

Speakers:

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Abstract: *Applying a life cycle approach in the building sector faces several challenges being one of them the lack of quantitative reliable data about the environmental impact caused by construction products and processes. There exist commercial Life Cycle Inventory databases offering construction- related datasets which normally can only be used in connection with LCA software. A complementary strategy is the development of a Life Cycle Impact Assessment database with available Environmental Product Declarations (EPD) of construction products. This kind of database has been developed within the SOFIAS project, partially funded by the Spanish Ministry of Economy and Competitiveness. To this end, EPDs of construction products from different international schemes have been carefully selected and integrated in SOFIAS, taking into account the consistency of the calculation methods used in their development. SOFIAS integrates environmental impact information from cradle to gate of 300 products classified according to the Spanish construction elements catalog.*

Key words: LCA, EPD, database, construction, products, building

1. Life Cycle Assessment of buildings & SOFIAS

Applying a life cycle approach when designing a new building or refurbish an existing one faces several challenges being one of them the lack of quantitative reliable data about the environmental impact caused by construction products and processes throughout their complete life cycle. In that sense, to carry out a Life Cycle Assessment (LCA) study of a building requires the collection of a huge amount of quantitative data related to individual products and processes in the different life-cycle stages. There exist commercial Life Cycle Inventory (LCI) databases (such as Ecoinvent or GaBi) offering a limited amount of construction-related datasets which normally can only be used in connection with an LCA software. Therefore, the development of complete, up-to-date, flexible and free-cost LCI databases is needed to extend the use of LCA in the construction sector.

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As to count on a number of manufacturers to provide reliable first-hand inventory data is a long-term activity, a complementary strategy is the development of a Life Cycle Impact Assessment (LCIA) database with available Environmental Product Declarations (EPD) of construction products (Mabe & Gazulla, 2012). The objective of EPDs is to foster the demand and production of products with a lower environmental impact through the communication of verifiable and reliable information which stimulates the continuous environmental improvement among the different market players.

Continuing the effort undertook in the EnerBuiLCA and URBILCA projects (funded by the SUDOE Interreg program) a consortium of public and private Spanish organizations is creating a database of environmental information for construction products within the SOFIAS project, partially funded by the Spanish Ministry of Economy and Competitiveness. This database is compatible with the OpenDAP initiative lead by IETcc.

2. Environmental Product Declarations' database

2.1. Products classification: from buildings to singular products

In the analysis of the building life cycle (structured according the life cycle stages and modules defined by EN 15978, see Table 1), simplifications have been made taking into account existing studies and available information. In the manufacturing stages (A1-A3) and the end of life stages (C1-C4), considerations have been drawn up to product level. For the construction (A4-A5) and use stages (B1- B7), the data refer to the construction solutions' level.

Life cycle stage	Life Cycle Module	
Product	A1	Raw material supply
	A2	Transport
	A3	Manufacturing
Construction	A4	Transport
	A5	Construction, installation processes-installation
Use	B1	Use
	B2	Maintenance
	B3	Repair
	B4	Replacement
	B5	Refurbishment
	B6	Operational energy use
	B7	Operational water use
End-of-life	C1	Deconstruction, demolition
	C2	Transport
	C3	Waste processing
	C4	Disposal

Table 1. Modular information for the different stages of the building assessment according to EN 15978

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At the construction solutions level, the SOFIAS database follows the structure of the commonly used Spanish Catalog of Constructive Elements (CEC standing from *Catálogo de Elementos Constructivos*). Therefore, the “Reference Construction Solutions” are grouped into families of facades, roofs, horizontal interior partitions, vertical interior partitions, dividing walls and walls in contact with the ground. For each constructive solution the composition in layers, their thicknesses and densities are explained in detail. Energy and water consumption and waste generation during the installation of construction solutions are included, providing the information by layer (e.g. liter/m2 or MJ/m2). Regarding waste generation, the amount, classification (inert, non-hazardous, and hazardous) and management treatment (landfill, recycling, etc.) are explained, as well as an average distance to the waste facilities and an approximate cost. For example, in the case of the expanded polystyrene insulating EPS with density 10 kg/m3 and conductivity 0.047 W/mK, it is considered that the total product weight is treated as non-hazardous waste being landfilled (45%) or selected for its eventual recycling (55%); in addition, an average distance of 50 km to the management facility and an average cost of 0.12569 €/kg are considered.

At the product level, the information is organized by a taxonomy which generates a specific code for each product based on four major blocks: i) taxon for "Domain" which specifies the product version; ii) five “Rating” taxon classify and filter the products in a similar way to the Spanish Constructive Elements Catalog (CEC); iii) two taxon identification "Encode" the sub-products with a X99-X99 type code; and iv) a number of characterization taxon, expressing their properties and differentiate it from other products with identical taxon identification, by setting up a specific product. This same taxonomy is being applied in the OpenDAP initiative, an open database of EPDs of construction products that will be connected to SOFIAS.

Image 1 shows an example of the taxonomy for the product Expanded Polystyrene insulation (EPS) with conductivity 0.033 W/mK; 50 mm thick; density of 28Kg/m3, it is called B01_B01_b1. This product is filtered by its classification taxon as insulation, synthetic and non-hydrophilic.

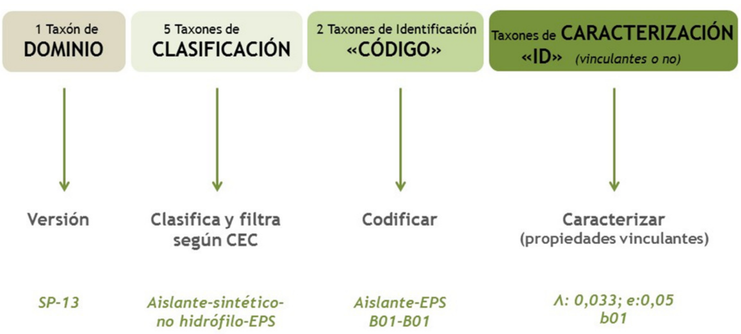

Image 1 Scheme of the product taxonomy

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2.2. Environmental Product Declarations as data sources

Environmental Product Declarations (EPD) – also called type III declarations - are defined by ISO 14025 as *"quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards, but not excluding additional environmental information"* (ISO 14025:2006). As other ISO ecolabels (Type I and Type II), EPDs main objective is to promote the use of products that cause low environmental impact, through the communication of verified and accurate environmental impact information that could stimulate the environmental awareness and improvement within the different stakeholders and market agents, including Business-to-Business and Business-to-consumer communication (ISO 14025:2006).

EPDs can be developed for any type of product, as it is the comparison between products fulfilling the same function the force that triggers the continuous environmental improvement within a specific market. In that sense, and in order to have a correct and transparent comparison, specific calculation rules must be established. Predetermined parameters included in an EPD (inventory results, impact category indicators and others) are based on the Life Cycle Assessment methodology (defined by ISO 14040-44 standards) carried out following specific Product Category Rules (PCR) applicable to the specific product.

General steps needed to obtain an EPD are (Gazulla, 2012):

- *Selection of an Eco-labelling program and administrator:* several international programs have been established in the past decades worldwide, especially in Europe and within the construction field.

- *Development of the PCR for each product category:* each eco-labelling program publishes its own PCR with the participation of stakeholders (companies, universities, administrations). Within the construction sector, CEN published the EN 15804 standard, which explains the main contents of a PCR document, including system boundaries, calculation rules and the impact assessment method used.

- *EPD development* by the manufacturer of the product implementing the applicable PCR according to ISO 14025.

EPD are promoted by several stakeholders and interested parts, from both public and private sectors. Some of the administrators of the ecolabelling programs are independent institutes (created out of an initiative of manufacturers and producers of certain field), universities institutes or government's expert bodies on environmental and sustainable procurement. These initiatives are normally supported and accompanied by the environmental authorities of the corresponding countries as well as national standardization bodies.

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2.3. EPD compilation process

Existing EPD programs tackling construction products have been evaluated as potential data sources for feeding SOFIAS database. However, it has to be noted that these programs differ in methodological aspects such as the validity period applied to their EPDs and the verification process, and even more important, the specific calculation rules (or Product Category Rules, PCR) applied to similar products. Finally, six programs were selected as potential data sources for SOFIAS:

- International EPD® System (Sweden)
- IBU (Institut Bauen und Umwelt) (Germany)
- Programme FDE&S (France)
- EPD-Norge (Norway)
- DAPc® system (Spain)
- BRE Environmental Profiles (United Kingdom)

Most of these programmes are centred in one country, but some of them have an international scope as the International EPD® System and the IBU (Institut Bauen und Umwelt).

In order to guarantee the coherence of the EPD data originated in different programs as much as possible, two main aspects were observed. First, the program had to provide EPD independently verified by third-party to be sure that the EPD followed the corresponding PCR. The verifier (expert) has access to a full LCA report to make the revision, despite only the EPD is finally published. The second aspect observed was the use of similar impact assessment methodology for calculating the following environmental impact results declared in the EPD:

- Global Warming Potential (GWP)
- Ozone Depletion Potential (ODP)
- Acidification potential (AP)
- Eutrophication potential (EP)
- Formation potential of tropospheric ozone (POCP)
- Abiotic depletion potential for non-fossil resources (ADP-elements)
- Abiotic depletion potential for fossil resources (ADP-fossil fuels)
- Total use of primary energy (renewable and non-renewable)

Data compilation process

Once the product classification and the information format were established in previous phases of the SOFIAS project, a search strategy was defined to recognize the quality and type of information existing for each product and family of products.

1. *EPD search for each product in the classification list*

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One of the main objectives of the SOFIAS project is to provide accurate information about construction products and materials, and since EPDs can differ in key aspects, an order of preference was established (see Table 2) to classify and prioritize those EPDs offering a higher data quality.

Order	Source	Comments
1	Verified EPDs with active validity period	Provides recent and accurate information and most of these EPDs follow EN15804. Since this norm is relatively recent, the number of EPDs at this level is
2	Verified EPDs without active validity period	Provides accurate and verified information, but the validity period expired few years ago (2009-2012).
3	Unverified EPDs with active validity period	There is a considerable number of EPDs within the construction sector that are not verified but in active period of validity, especially in the French System (Programme FDE&S).
4	Unverified EPDs without active validity	This level provides poor quality of data.

Table 2. Order of preference in the search of EPD's

As table 2 indicates, the verification from experts and the period of validity were the aspects that define the quality of the data contained in an EPD. However, at the current time, is not possible to have these aspects complied for every EPD. In that sense, the search descended in this order as the quality and uncertainty of the data until finding at least one EPD for each product.

The search strategy also established that in the case of finding several EPDs for the same single product, the maximum number per product should be four EPDs, giving preference according to the order explained.

2. Sectorial EPDs search

After looking for EPDs specific to singular products, the next step was to search for sectorial EPDs that give generic and average information about a product. Despite the valuable information given by sectorial EPDs, there are still few examples available.

2.4. Data compiled

The information fields included in the SOFIAS database for each selected EPD are listed in Table 3 presented below. Table 4 shows the product main categories included in the SOFIAS database for which EPDs with the required quality have been selected as well as the number of EPDs uploaded in each case. As it can be seen, a total of 369 EPDs have been uploaded into SOFIAS' database.

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Metadata	**Data for calculations**
Source	Thickness (mm)
Author	Density (kg/m3)
Reference year	Average transport distance (km)
Reference country	Means of transport used
Uncertainty	Materials used in the product installation
General data about the	Waste generated in the product installation
Manufacture's name	Water consumption in the product installation (m3)
Manufacture's country	Estimated product useful life (years)
EPD's original name	**Environmental impact results (modules A1-A3)**
Product's name	Global warming potential, GWP (Kg CO2 Eq)
Description of the product use	Ozone layer depletion (Kg CFC11 Eq)
Functional Unit	Acidification potential (Kg SO2 Eq)
EPD Issue date	Eutrophication potential (Kg PO43^{-} Eq)
EPD Validity date	Formation of tropospheric ozone photochemical oxidants (Kg ethane Eq)
EPD Program's name	Abiotic depletion of non-fossil resources (Kg Sb Eq)
Visual representation	Abiotic depletion of fossil resources (MJ)
EPD Scope	Primary energy consumption (MJ)
Reference flow	Renewable primary energy consumption (MJ)
	Non-renewable energy consumption (MJ)
	Use of net fresh water (m3)

Table 3. Fields included in the SOFIAS database

Environmental impacts results

The environmental impacts uploaded on the SOFIAS database are within the "cradle to gate" scope (A1-A3) and have been, in the majority of cases, extracted directly from the EPDs. In the particular case of the Programme FDE&S (France) the procedure was different. In this case, as inventory information (e.g. substances released to the environment) is provided, it was possible to ensure a better consistency with the other sources of information by calculating the environmental impact results through the characterization of the substances that contribute to each impact category. To do so, the characterization factors recommended in EN 15804 were applied.

Uncertainty analysis data

As with many decisions support tools, uncertainties are often not considered in LCA studies although they can be high. But, there is arguably a necessity for an analysis of the uncertainties involved in carrying out an LCA study to help focus research efforts and also to provide support in the interpretation of LCA study results (Finnveden et al., 2009). Uncertainty can be defined in many ways, but one definition that appears to be useful in the present context is: "the discrepancy between a measured or calculated quantity and the true value of that quantity", according to Finnveden et al. (2009).

Products category	EPDs uploaded
Insulating	57
Bituminous	20
Rubber	7
Ceramic pieces	30
Ceramics factories and concrete	23
Concrete	19
Alveolar slabs	1
Wood	29
Metals	22
Panels	10
Stone aggregate and grounds	11
Plastics	25
Sealants	7
Textiles	3
Glasses	6
Frames	7
Surface finishes, ceilings and floors	48
Gypsums	19
Plasters and mortars	20
TOTAL	**364**

Table 4. Product categories and EPDs uploaded on the SOFIAS database

Uncertainty calculation methodologies are currently being developed to incorporate in LCA studies. The uncertainty calculation methodology proposed by Ecoinvent Centre, aims to combine the basic uncertainty either measured or estimated with an additional uncertainty from data quality indicators. These additional uncertainties are based on a pedigree matrix approach, taking pattern from work published by Weidema & Wesnaes (1996) and Weidema (1998). To apply this uncertainty methodology in SOFIAS it was necessary to know specific data which only the manufacture's product knows as the measurements, technology used, geographical context, etc. Based on the lack of such important data, it was decided to allocate a quality uncertainty to each product based on the similarity of the referential products (database) and those object of the EPDs.

Based on aspects such as the density, conductivity or thickness of both products, three categories of uncertainty were defined for measuring the similarity of the product included in the database in relation to a referential product defined by the Spanish Catalog of Constructive Elements.

3. Conclusions

Environmental Product Declarations are becoming an important source of data for conducting

Life Cycle Assessment studies of buildings. Nowadays hundreds of EPDs for different building products are available and can be integrated in LCA studies. Environmental impact information from cradle to gate of 364 products has been included in SOFIAS' database, classified according to the Spanish construction elements catalog.

EPDs have been proved to be a good tool for the communication of environmental quantitative information needed to develop LCA studies. However, and despite the publication of the EN 15804 standard offering core Product Category Rules for construction products, different formats and calculations rules are applied when developing EPDs under existing EPDs schemes, making it more difficult (or even impossible) to combine them. It is expected that in the next years, these rules will be updated and harmonized. Meanwhile, the combined use of EPDs coming from different ecolabelling schemes requires a deep knowledge about their calculation methods as it has been done in the SOFIAS project.

To computerize environmental products information from EPDs and to integrate this information in LCA tools (such as SOFIAS) will contribute to increase the employment of these Ecolabels in building assessment as well as their development.

4. References

ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations – Principles and procedures.

EN 15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.

Finnveden. G., et al. (2009) Recent development in Life Cycle Assessment. Journal of Environmental Management 91 (1) 1-21.

Gazulla, C. 2012. Declaraciones Ambientales de Producto: instrumento para la mejora de productos. Doctoral Thesis - Universitat Autònoma de Barcelona.

Mabe, L. Gazulla, C. 2012. Use of Environmental Product Declarations (EPD) in LCA studies of buildings. Proceedings of the 1st International Conference on Building Sustainability Assessment (BSA). Porto.

Weidema B. P. (1998) Multi-User Test of the Data Quality Matrix for Product Life Cycle Inventory. International Journal of Life Cycle Assessment 3(5):259-265.

Weidema B. P. and Wesnaes M. S. (1996) Data quality management for life cycle inventories - an example of using data quality indicators. Journal of Cleaner Production 4(3-4):167-174.

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Rating and Environmental Certification of Buildings in the Life Cycle Assessment Tool "SOFIAS"

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Abstract: *This paper describes the rating system considered in the SOFIAS tool, that allows professionals to evaluate the life cycle impact of a building, considering the design, construction, building use and final disposal stages.*

Although the SOFIAS tool evaluates different environmental indicators, only the global warming potential is considered by the rating system. This system compares the building assessed value with a reference building. The reference building, which is created by the tool, has exactly the same geometry, but their constructive solutions meet the minimum standards set out in the Spanish Building Technical Code.

In order to determine the global rating of the building, a typical linear equation for each life cycle stage is considered. Two points define the fit line: the first one corresponds to a theoretical zero carbon building and receives the highest score, and the second one corresponds to the reference building which receives a lower score.

Keywords: LCA, environmental certification, sustainable buildings, assessment tools.

Introduction

The Strategic European plan is setting guidelines to reduce energy consumption in buildings. In fact, one of the European Directive 2010/31/UE objectives is to achieve Nearly Zero Energy Buildings in 2020. Both, Directive 2010/31/UE and Directive 2012/27/UE, focus on developing actions to increase energy efficiency in building. It is not only important the energy consumption in the building use phase, but it is also needed to calculate the total embodied energy in the building. European commitments related to the decrease of greenhouse gases involve the use of low-impact materials. It is also remarkable the unsustainable values that the carbon footprint construction/materials is reaching [1,2].

All these trends and strategies have created the need of appropriate and tested instruments to develop a measurement system that helps professionals and designers of buildings in thinking about the building composition from a different point of view. These instruments enable to have a comprehensive approach to the building, included in its life cycle assessment (LCA) stages: production, construction, use and end-of-life [3,4].

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Objectives

The objective of the SOFIAS project (Built-in Software for a Sustainable Architecture) is to design and develop a software prototype to assist construction professionals in the design and refurbishment of buildings in order to reduce their energy consumption, the greenhouse gas emissions and the environmental impact during the whole life cycle of the building. For this purpose, the tool combines the following functions: evaluation, ecological design assistance and environmental certification. In order to develop the calculation methodology of the tool, the existing regulations and methodologies related to the environmental impact of the building during its whole life cycle, have been considered in the SOFIAS project (ISO 14040 y 14044, ISO 14025, CEN TC 350 standards, ISO 1406). Also previous results achieved in other R&D projects, such as: Strategic Singular Project: CÍCLOPE (2009-10) and Interreg SUDOE EnerBuiLCA (2011-12) have been taken into account.

The aim is to get a complete vision of a building with a life cycle approach, which is essential to achieve the sustainability in the construction sector. Nowadays, the use phase of buildings is well known and it is possible to certificate it with some tools. However, these softwares don't have an overview of the complete LCA of a building, which will be very useful in the next years. When the energy consumption of building use phase is near zero, the energy consumption of a building will move to other LCA stages: products manufacture, transport, construction processes, etc. Thereby, the objective of this tool is taking one more step, meeting the needs of the evaluation of the buildings from the point of view of its environmental impact considering the LCA methodology.

In addition, the project also includes the elaboration of a regulation in line with these objectives, in order to certificate buildings and to inform and educate the users of the buildings.

Methodology for environmental qualification in the SOFIAS tool

The SOFIAS tool allows quantifying any environmental indicator in the different life cycle stages of a building. However, the classification system proposed is initially applied on a single indicator: the equivalent emissions of carbon dioxide. The rating methodology for the SOFIAS tool involves to obtain a qualitative assessment of the building's carbon footprint from a linear equation generated with two points:

Point with the highest qualification 10 (ordinate axis): a building whose equivalent CO2 emissions are zero at all the life cycle stages. (Value 0 on abscissa).

Point with qualification 4 (ordinate axis): "reference building" complying strictly with the existing regulation and considering the most unfavourable options for each stage of life of the building from the point of view of the equivalent CO2 emissions.

The linear equation is "y=mx+b " and it is generated by the SOFIAS tool for each of the life cycle stages of the building analysed. The graphical presentation of this equation is shown in Figure 1.

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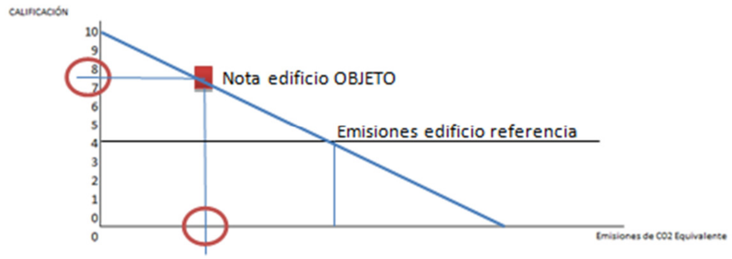

Figure 1. Graphic presentation of the rating system proposed.

Definition of the reference building

To obtain the rating of the building analysed, the tool generates a reference building, which provides the value of the equivalent emissions corresponding to a score of 4 points, in order to establish the calculation line. For this purpose, a number of features are determined in order to define a reference to each stage of the LCA (as defined in the regulation), so that, the user can know the rating of the building for each stage.

The aspects evaluated in each stage are defined as follows:

- **Production stage (A1-A3):** raw materials extraction, transportation and manufacturing processes of facades, dividing walls, walls in contact with the ground, cover, horizontal interior partitions, horizontal interior partitions in contact with climatized spaces, horizontal interior partitions in contact with the ground, horizontal interior partitions in contact with the outside, hollows, inside vertical partitions, vertical partitions in contact with indoor living space, inside vertical partitions in contact with no living space and vertical structure.
- **Construction processes stage (A4-A5):** transportation, construction processes, and construction waste management.
- **Use stage (B4-B6):** final energy consumption and replacement of materials.
- **End-of-life stage (C1):** deconstruction, transport and treatment of waste.

The final goal is to obtain an overall rating of the building from the calculation of partial scores of the previous stages.

Production stage (A1-A3)

In the production stage, the rating system classifies in different large groups the different parts of the building, providing a calculation system by type: walls, hollows and building structure.

Enclosures: to set the reference value, each type of enclosure, as defined in the Spanish Technical Building Code (CTE), is generated on a reference building using constructive solutions based on the official tool "Lider / Calener VYP" [5]. These constructive solutions set the insulation thickness according to the minimum transmittance indicative for different enclosures.

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In order to select the reference for the insulation material and its thickness, the SOFIAS tool calculates the impact of each existing insulation in the SOFIAS database (which is extendable), so that it selects the one that meets the requirements with higher equivalent CO_2 emissions.

The thermal transmittance (U) is calculated using the following equation:

Equation 1

$$U = \frac{1}{R_t} = \frac{1}{R_{si}+R_1+R_2+\cdots+R_{se}} = \frac{1}{R_{si}+\frac{e_1}{\lambda_1}+\frac{e_2}{\lambda_2}+\cdots+R_{se}} = \frac{1}{R_{si}+\sum\frac{e_i}{\lambda_i}+R_{se}}$$

- e_i Material thickness $_i$ (m)
- λ_i Material conductivity $_i$ (W/m.K)
- R_{se} Value of surface thermal resistance of walls in contact with the outside air, when the heat flow is vertical: 0.04 m^2.K/W.
- R_{si} Value of surface thermal resistance of walls in contact with the indoor air, where the heat flow is vertical: 0.13 m^2.K/W.

The reference building will have the same geometry as the building analysed, and will meet the thermal values that indicate the Appendix E of the Document "Energy Saving" of CTE [6]. However, it will use the worst thermal insulation from the equivalent CO_2 emissions point of view.

Hollows: the rating system consists of establishing in the reference building a solution using hollows with the same dimensions as the building analysed (keeping the same proportions of frame and glass), but with a basic solution that meets strictly the values suggested in the CTE DB-HE-2013 - Appendix E [6].

The tool calculates each possible combination of glass and frame in order to select the solution that best matches the regulations and generate a higher impact on equivalent CO_2 emissions, so that this solution will be the composition selected for the building reference hollows.

Structure: It is divided into two groups: pillars and foundations. Therefore, to set the rating of the building analysed, two references are generated:

- ***Vertical structure:*** the calculation of the reference is made from the equivalent CO_2 emissions of a reinforced concrete structure with a dimension according to a surface ratio equal to 0.1 m^2 of vertical structure (maintaining the same building headroom of the analysed building) per 25 m^2 of useful area in the building. These values have been estimated considering 5 m between columns and pillars.

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- ***Foundation:*** the reference equivalent emissions are calculated from a foundation with superficial brake blocks with an area of 9 m^2 and 0.5 m deep per pillar, which means 4.5 m^3 of reinforced concrete per pillar. The number of columns in a plant has been calculated based on a pillar every 25m^2 of useful area in a typical floor of a building.

Construction processes stage (A4-A5)
This stage includes mainly the transport of the material from the factory gate to the construction site, and the energy consumption for the placement of the materials.

In order to establish the reference values to generate the linear equation, the following criteria have been considered:

- ***Transport***: A road transport system by conventional truck is established for all the building products, considering an average distance of 300 km.
- ***Construction process***: 481 MJ/m^3 of materials of the building will be taken as energy consumption in the construction process, considering a distribution of 70% of diesel consumption for machinery and 30% of electricity consumption (data based on Kellenberger et al [7])
- ***Waste generation, transportation and waste management***: In order to set a reference value for the waste management system, a construction waste production, which strictly complies with current regulations, has been considered [8]. The impacts of the waste transportation to the landfill by truck and the further processes have been assessed as well.

Use stage (B4-B6):
Both the energy consumption of the building and the possible replacement of materials, which have less durability than the lifespan of the building, are considered at this stage.

- ***Operational energy consumption:*** In order to know both energy consumptions of the analysed building and the reference building, the use of the Spanish official tools for energy certification (such as CALENER) are proposed. These tools are based on the current regulations [9] to certify buildings. The energy rating provided by these tools turns into the numerical rating of the SOFIAS tool (see Table 1).

CALENER Energy Rating	SOFIAS Numerical Rating
A	10 points
B	8.5 points
C	7 points
D	5 points
E	4 points
F	2 points
G	0 points

Table 1. Equivalence between CALENER score and SOFIAS tool points

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- ***Replacement of materials:*** In order to define the durability of the materials in the reference building, the lifespan of each SOFIAS database material is reduced in two years. If the durability is lower than the lifespan of the building, the percentage of equivalent CO_2 emissions of the “new” material is assigned to the remaining years until the end of the lifespan of the building.

End-of-life stage (C1)

The end-of-life of the reference building includes the energy consumption from both demolition process and waste treatment:

- ***Energy consumption of the demolition process:*** 370 MJ/m^3 of building products is considered as a reference value. This energy consumption is distributed among 70% of diesel consumption and 30% of electricity consumption [7].
- ***Transportation and waste treatment:*** All the demolition waste is transported to the landfill in order to be treated. For this waste, transport by conventional truck is considered, covering an average distance of 50 km.

Global rating for the building

Once the references are calculated for the different life cycle stages, a global rating is calculated. This global score is achieved through a calculation of a new linear equation. For each stage, the addition of the equivalent CO_2 emissions from both analysed building and the reference building defines a new linear equation. With the aim of providing an easier visual rating, the SOFIAS numerical rating is converted into a “stars” system score. This will help to clarify the identification of the building rating by users.

SOFIAS Numerical Rating	SOFIAS Visual Rating
9 – 10	+++
7 – 8	++
5 – 6	+
Less than 5	NO RATING

Table 2. SOFIAS numerical rating and SOFIAS visual rating

Data quality

The rating calculation methodology involves compiling many data (building products, energy consumptions, etc.) from different sources. The rating will depend on the data quality. For this reason, the data source is of great relevance in order to obtain a realistic rating.

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PRODUCTION STAGE (A1-A3)		CONSTRUCTION PROCESSES STAGE(A4-A5)		USE STAGE (B4-B6)		END-OF-LIFE STAGE (C1)	
ORIGIN OF DATA: EPD	**QUALITY SCORE**	**ORIGIN OF DATA: WASTE, WATER AND ENERGY**	**QUALITY SCORE**	**ORIGIN OF DATA: USE**	**QUALITY SCORE**	**ORIGIN OF DATA: END-OF-LIFE**	**QUALITY SCORE**
EPD certificate – Real supplier	1	REAL WORK DATA: generation of waste / water consumption and energy	1	Simulation + correction with real invoices (electricity/gas /water) > 90% occupancy during 1 year	1	Have a report for the management of the building at its end of life: amounts by type of waste, management system and real distance	1
Very similar EPD	2	REAL WORK DATA: generation of waste and energy consumption	2	Simulation + correction with real invoice (electricity/gas /water) >75% occupancy during 1 year	2	Have a report for the management of the building at its end of life: amounts by type of waste and real distance	2
Similar EPD	3	REAL WORK DATA for energy consumption	3	Simulation + correction with real invoice (at least for the electricity consumption) >75% occupancy during 1 year	3	Real distance to each management system	3
Quite similar EPD	4	REAL WORK DATA: Excavated volume (m^3)	4	Simulation with Calener VYP or other energy simulation software that fulfil the Bestest	4	Average distance to the nearest management system	4
Generic EPD	5	DEFAULT VALUE SOFIAS	5	Energy consumption data estimated or calculated	5	Generic data SOFIAS	5

Table 3. Quality Valuation Breakdown of data according to the source.

The aim is to evaluate the data quality in each stage. Each parameter used by the SOFIAS tool, that determines the amount of equivalent CO_2 emissions of the building, has attributed a quality score that depends on the source. The sources may be more or less reliable. For this reason, the set of all data can be defined more or less credible.

The choice of the quality of the data is based on the source of each value used for the calculation. The quality score "1" indicates maximum quality, and the quality score "5" indicates minimum quality (see Table 3).

AENOR Certification

In order to strengthen this rating, the Spanish Association of Normalization and Certification (AENOR) has developed a General Rule of Certificates of Conformity. In this way, it is possible to obtain an AENOR certification of conformity of buildings in accordance with the SOFIAS Tool.

Using the SOFIAS tool, it will be possible to obtain an environmental certification of the building analysed. This certification developed by AENOR will include the score associated to the carbon footprint of the building, but also a score associated with the data quality used for the assessment, since input data can come from several data sources such as the Environmental Product Declarations (EPD), life cycle databases, life cycle studies in specific sectors, etc.

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References

[1] Cabeza, L.F. Rincón, L. Vilariño, V. Pérez, G. Castell, A. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews*, 29: 394-416. http://dx.doi.org/10.1016/j.rser.2013.08.037

[2] Solís-Guzmán, J. Marrero, M. Ramírez-de-Arellano, A. Methodology for determining the ecological footprint of the construction of residential buildings in Andalusia (Spain), *Ecological Indicators*. 25: 239-249. http://dx.doi.org/10.1016/j.ecolind.2012.10.008

[3] Teng, J. Wu, X. Eco-footprint-based life-cycle eco-efficiency assessment of building projects. *Ecological Indicators*, 39: 160-168. http://dx.doi.org/10.1016/j.ecolind.2013.12.018

[4] Zabalza Bribián, I. Valero Capilla, A. Aranda Usón, A. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and Environment*, 46(5):1133-1140. http://dx.doi.org/10.1016/j.buildenv.2010.12.002

[5] AICIA – Termotecnia Group of the School of Industrial Engineering at the University of Seville –. *Condiciones de aceptación de procedimientos alternativos a LIDER y CALENER. Appendix*. Instituto para la Diversificación y Ahorro de la Energía (IDAE) and Ministry of Housing a. May 2009.

[6] Ministry of Housing. *Order FOM/1635/2013, of 10 September*. CTE-DB-HE Technical Building Code - Energy saving Document updated. BOE nº 219 12th September 2013.

[7] Kellenberger, D. Althaus, H.J. Jungbluth, N. Lehmann, M. Thalmann, P. (2007) *Life Cycle Inventories of Building Products*: Final report ecoinvent Data v2.0 nº7. EMPA Dübendorf, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

[8] Comunidad de Madrid. *Order 2726/2009 16th July, production and management of construction and demolition waste.* B.O.C.M 7th August of 2009.

[9] Ministry of Housing. *Royal Decree 235/2013, of 5th April, establishing the basic procedure for certification of energy buildings efficiency*. BOE nº 89 de 13th April 2013.

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CESBA – Common European Sustainable Building Assessment

Speakers:

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Abstract: *Dozens of different building assessment systems have been implemented in Europe at international, national and regional level in the last years. These systems are different in methods, frameworks, physical and time boundaries, issues taken into consideration, number of criteria, priorities, etc. This lack of conformity makes the comparison of results impossible. An harmonization process is clearly needed at European level in the way to create a common approach to building assessment that would enforce the effectiveness of certification labels in moving the building standard practice toward a better sustainability. To achieve this objective the CESBA (Common European Sustainable Building Assessment) initiative has been launched with the involvement of more than 30 public and private European organizations from Austria, France, Italy, Spain, Czech Republic, Germany, Hungary, Poland, Slovenia, Slovakia, Switzerland, UK. CESBA is more than the assessment of sustainable buildings. CESBA is a process towards new building and neighbourhood standards in Europe.*

Assessment, Harmonization, Standard, Label, Life cycle, built environment

Need for building assessment harmonization in Europe

Recent studies carried out in the context of several EU funded research program (Enerbuild, CABEE, CEC5, Visible, IRH-MED, OpenHouse), showed that dozens of different building assessment systems have been implemented in Europe at international, national and regional level. These systems are different in methods, frameworks, physical and time boundaries, issues taken into consideration, number of criteria, priorities, etc. This lack of conformity makes the comparison of results impossible and creates confusion among the stakeholders of the building sector. An harmonization process is clearly needed at European level in the way to create a common approach to building assessment that could enforce the effectiveness of certification labels in moving the building standard practice toward a better sustainability. In the European Union, common directives and policies are issued in the filed of sustainable building, as the EU climate protection program. Common targets have been fixed concerning CO_2 emissions reductions and energy efficiency, as the Europe 2020 strategy towards a resource-efficient Europe. A common way of measuring the performance of buildings is necessary to really understand the level of fulfilment of the European targets in this field.

To achieve this objective the CESBA (Common European Sustainable Building Assessment) initiative has been launched with the involvement of more than 30 public and private European organizations from Austria, France, Italy, Spain, Czech Republic, Germany, Hungary, Poland, Slovenia, Slovakia, Switzerland, UK. CESBA is a collective European bottom-up initiative that provides knowledge on harmonised built environment assessment.

Harmonizations doesn't mean the establishment of a unique common building assessment system in Europe. The principle of contextualization and adaptation to local priorities is central in CESBA. Harmonization means to share a common vision about what are the main issues in sustainable building and to agree how to measure the performance of a building with their regard. The objective is to establish a common core of European indicators for the main important issues and relative assessment methods, to be included in all the assessment systems implemented in Europe. As Europe is a mélange of regional building cultures, European buildings standards must consider regional needs and conditions.

The CESBA harmonization is targeted in particular toward the "public" assessment systems. Public assessment systems are the ones promoted/managed by public organizations, such as ministries, regions, cities. The main application is in incentive based policies, building codes, urban plans, public tenders.

The harmonization of an assessment systems consist in the fulfilment of CESBA assessment aims and principles and in the adoption of the CESBA KPIs and Building Signature. The reached harmonization with CESBA is proven receiving the CESBA Stamp.

CESBA assessment aims and principles

One single European assessment tool will not be an efficient solution, due to cultural, historical and climatic reasons, various regional economic backgrounds and so forth. Therefore, a harmonization process is clearly needed at the European level in order to create a common approach to building assessment. Harmonizing assessment systems at the European level means, first of all, sharing common principles and aims. CESBA intends to give guidelines to harmonize the assessment approaches through principles, methods, performance issues and indicators. The CESBA principles and aims for building assessment are as follows:

- The user first: CESBA focuses on the people who use buildings. On average people spend 90% of their lives inside buildings. The aim is to design, build and operate the buildings in order to meet the users' requirements and needs, providing an improved comfort, and an ecological and economical construction and operation.
- Holistic approach: the assessment has to cover all aspects of sustainability: environmental, economic and social ones.
- Regional contextualization: Building assessment systems must be contextualized with the region where they are applied, in order to reflect the local specific priorities, cultures, habits and construction practices. This means using local units of measure, adopting national/regional standards and regulations, giving due consideration to the local climate, and accounting for availability of natural resources and cultural aspects of design. At local level it is fundamental to set the relative importance of environmental, social, economic, legal and political issues. Each criterion included in

the assessment tool should be assigned a relative weight and a reference benchmark (minimum acceptable performance level) adequate to the local conditions. The value of rating results diminishes when systems are used in contexts outside their origin.

- Comparability: the performance results shall be comparable thanks to points/targets.
- Mass oriented: Building rating systems can play a key role in moving the built environment towards a better sustainability. To reach this objective they have to be widely adopted by the different stakeholders of the building sector: architects, designers, public organizations, construction companies, investors, etc. Only a mass oriented approach allows reaching this objective. Mass oriented means that the objective of the certification is to reach 100% of constructions. A mass oriented assessment system has to fulfil some key requirements: simple to use, affordable (cost and time), contextualized, open source.
- Simple to use: a mass-oriented building assessment system has to find a right balance between the simplicity to use and the scientific/technical value. The assessment must be precise, not simplified, clear and visible. A system requiring complicated calculations or the availability of data that are not easy to find would request too much time and effort (costs) to be widely used. Simplicity helps the dissemination of assessment systems among the stakeholders. Effective training courses can be implemented to improve the skills of professionals in building assessment. Certification can be done in round tables with the stakeholders in place, Life Cycle-step by Life Cycle-step certifi cation.
- Open source: using an open source approach allows CESBA to be appropriate as to its context by paying special consideration to the environmental, ethical, cultural, social, political and economic aspects of the community it is intended for. Consequently, this approach allows for regional adaptations in the guidance system. The open source approach allows CESBA to be a low-cost alternative to more expensive and proprietary alternatives of sustainable building assessments. The open source way also provides for low entry barriers for users and supporters of CESBA.
- Co-creation: CESBA is developed by several people and organisations from various European regions, with experts providing input. The knowledge base and further areas of content development are discussed and agreed during common and open CESBA sprint workshops. All necessary support software, databases and tools are jointly developed.
- Transparency: the public should have access to the performance results especially for public buildings, while keeping in mind privacy rules. The visualisation of the results must be clear and offer guidance for further understanding. The assessment should follow a previously detailed guideline, with a step by step check of all indicators. An external certification body carries out the final control. The simplicity and transparency procedures (guideline, external independent control) guarantee the best possible quality of the assessment.

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CESBA Key Performance Indicators

CESBA proposes a common set of key performance indicators which shall act as the basis for all assessment tools in Europe. Key performance indicators (KPI) intend to be a European common base for building sustainability assessment. Their adoption by the regional/national assessment systems will facilitate the communication between stakeholders and the comparability of performance results. KPI will also support and facilitate the development of future assessment schemes.

Trough international workshops, based on the analysis of the main outputs of EU projects focused on building assessment, a first list of KPI for buildings has been defined: Non-renewable primary energy, Primary renewable energy use, CO2 emissions, Indoor air quality, Thermal comfort, Building Life Cycle Cost, Reused/recycled materials, Water consumption, Solid waste, User involvement, Monitoring / optimization of operation.

CESBA Building Signature

The CESBA Building Signature shows the values of the building's performance with regards to the CESBA Key Performance Indicators (KPI). The score produced by a rating system is valid only for the geographical area where the building is realized, as it reflects the local priorities and construction practice. Therefore, it is impossible to set common performance benchmarks between regions. To be able to compare the performance of buildings at a transnational level, it is necessary to use indicators expressed in absolute values, not scores. This is the key principle of the CESBA Building Signature. Beyond the usual score typical of each rating system reported on the certificate, the CESBA Building Signature informs about the performance of the construction by providing the absolute values of the CESBA KPIs (kWh/m^2, Kg CO2/m^2, m^3, etc.). In this way it becomes possible to compare the performance of buildings assessed by different certification systems in different geographical areas.

In all CESBA harmonized systems, the CESBA KPIs have to be adopted and included in the certification system. This means that they will be calculated as part of the performance assessment of the building, and then, on the one hand, they will be normalized with the other criteria to produce the building's rating score, and on the other hand, they will be used in the CESBA Building Signature. The certificates issued by the different CESBA harmonized systems will have to include a transnational section with a common format to illustrate the CESBA Building Signature: to do so, the values of the quantitative and qualitative KPIs will be listed in the common CESBA part of the building certificate issued by the specific rating system. The results of the quantitative indicators will also be graphically represented on a radar chart.

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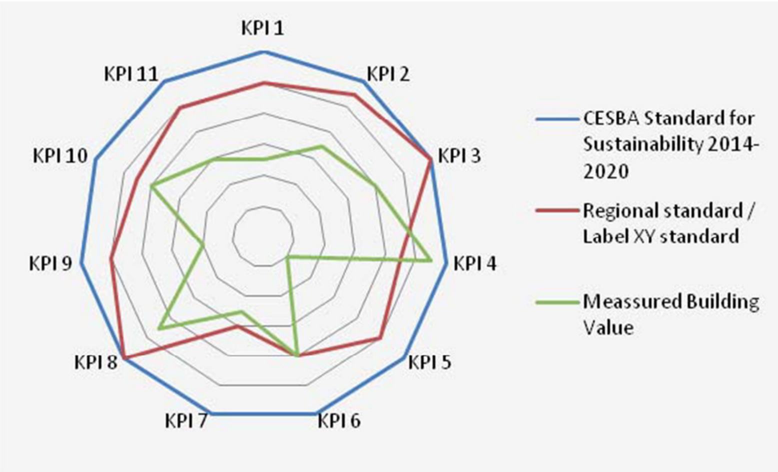

Radar Chart – Building Signature

The chart shows the green line of the KPI values of the building and the relationship between the KPI values and the regional standard / label standard (red line). The blue line shows the latest common Standard for Sustainability (valid from 2014-2020) agreed for the CESBA KPIs. The chart clearly shows that the closer the green line is located to the blue line, the more sustainable the building is. This aims to become a comprehensive graphical tool, used as an efficient element to assess the building sustainability and to communicate these factors to all the stakeholders in the design and construction process (owners, users, consultants, etc.). The Signature is meant to express the intrinsic building properties. Thus, no one can claim ownership of it - it is available for use by any organization. It can therefore be considered as a basis for further development

CESBA Stamp

It is the CESBA stamp that confirms the alignment with CESBA of a building assessment system. The real performance of a building shall be assessed and declared in a form of the Building Signature. The interpretation of the data will be available through the certification label. All organizations managing or owning a building assessment system can apply for the CESBA stamp to the CESBA Steering Committee. The CESBA Steering Committee checks the compliance to the CESBA requirements for harmonized building assessment systems.

The key requirements are:

- compliance of the assessment system to the CESBA aims and principles,

- implementation of the CESBA KPIs in the assessment tool,

- integration of the Building Signature into the certificate/label issued.

When the compliance is positive, the CESBA Steering Committee grants the use of the CESBA Stamp on the basis of the CESBA regulation.

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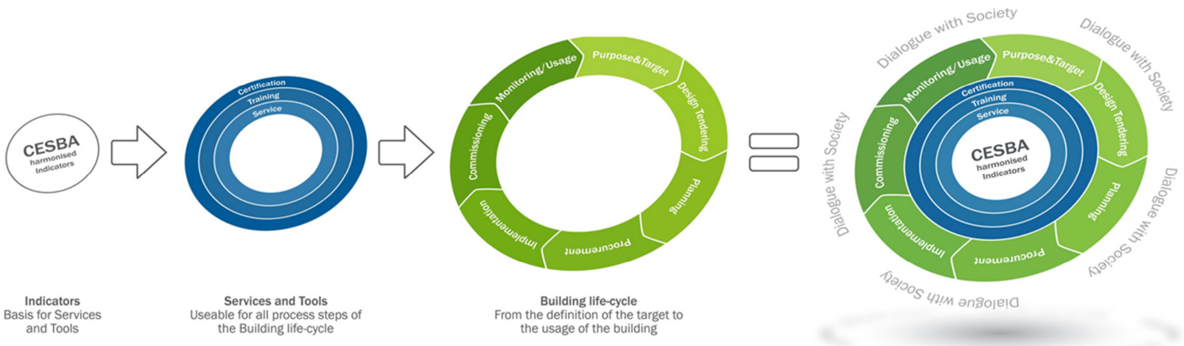
CESBA Stamp

The CESBA Cycle

CESBA is not only harmonization of building assessment. It is also the promotion of building assessment in the whole life cycle of a building.

The CESBA cycle conveys the concept of CESBA: harmonized indicators are the heart of the initiative; trainings, services and certification help with the application of those indicators during the whole building life cycle. CESBA is in dialogue with the European society.



CESBA Cycle

The indicators play a key role in fulfilling the various aspects of the CESBA Cycle. The operative and effective use of the indicators has to be supported by Services, Training and Certification. Establishing clear targets also facilitates the dialogue with the society.

CESBA defines reference service packages for helping public organizations in using building assessment. CESBA also defines minimum requirements to ensure the quality of certification processes. CESBA does not certify the built environment. Nevertheless CESBA supports low-cost, mass oriented public certification schemes.

CESBA indicates reference best practices in the use of building assessment in the whole life cycle of a building. A building is the source of local, regional and global impacts. These impacts start from the beginning of the Life Cycle of the buildings (from the design, the sourcing of the materials, etc.) and its end with the deconstruction or demolition phase. Building assessment systems have to take into account the whole Life Cycle of the building. The CESBA cycle is divided in 7 stages: Purpose/Target, Design Tendering, Planning, Procurement, Implementation, Commissioning, Usage and Monitoring.

Dialogue with the society

As a mass-oriented open-source initiative, CESBA directly interacts with the European civil society. The CESBA vision of a Europe where a high quality living in a sustainable built environment is the common standard practice can only be realized if sustainable constructed public buildings have a spill-over-effect on the society. Awareness-raising, the creation of acceptance and image promotion are essential for making the CESBA initiative visible to the society. But it is not only about communicating CESBA to the society. Rather, the interference between CESBA and the society is mutual, since on the one hand, citizens of Europe influence CESBA by expressing their needs, values and perceptions on a sustainable building culture, and these needs can then be transferred up to the national and European institutions by CESBA. On the other hand, CESBA influences the society by explaining and discussing national and European objectives and laws regarding sustainable high quality building to all relevant stakeholders including users. CESBA also influences the society by supporting the achievement and acceptance of EU policy targets. Thus, CESBA establishes a connection between institutions that deal with the built environment and the society. CESBA also offers step-by-step strategies to fulfil the objective of high sustainable building standards.

The CESBA Wiki is the main platform for facilitating the dialogue with the society. It allows the society for an active and direct contribution to the further development of CESBA. This corresponds to the bottom-up-approach of CESBA (www.cesba.eu).

Although CESBA is a public and open initiative and not a legal entity, it has a structure, defining its members and their tasks. The organizational structure has been determined on the basis of the scope of the CESBA members' commitment. There are 7 levels: Steering Committee, Thematic Working Groups, Ambassadors, Wiki Editors, Experts, Users, People and institutions.

Reference

V.V.A.A. (2014). CESBA Guide, a Collective Initiative for a New Culture of Built Environment in Europe – *www.cesba eu*

Andrea Moro (2012). Transnational comparison of instruments according to ecological evaluation of public buildings – *www.enerbuild.eu*

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Session 52:

Which are the limits of life-cycle assessment as a rating tool to evaluate sustainability in building? (I)

Chairperson:

Macías, Manuel

Profesor/Responsable del área de Investigación. Universidad Politécnica de Madrid/GBCe

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Survey of Allocation Methods in Life Cycle Assessments of Wood Based Products

Speakers:
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Abstract: *Allocation means that environmental aspects of the production process are appointed to different co-products. There are 3 different options for allocation methods: Main product allocation, mass or volume based, physical allocation and economic allocation. It is discussed which of these methods should be applied on wooden products, in order to picture reality in the most convincing way. Therefore, using the example of sawn timber and residues in sawmills, different approaches are analyzed and resulting allocation factors compared.*

Analysis of these case studies shows, that choice of allocation method has a significant impact on results of LCA of sawmill products. This implicates different assignment of environmental burdens to downstream processing industries like paper and particle board or building industry. Investigations in the impact of allocation method decisions in sawmills on particle board production, discovered negligible influences on environmental impacts. Comparative calculations with different price scenarios indicate the minor impact of price volatility.

Keywords: wood products, sawmill, allocation method, allocation factor

1. Multiple product output

Processes in wood working industry manufacturing often produce multiple products. Those products can be either main products or by-products, and the environmental burden of the process shall be distributed among these multiple products. As an example, sawmills can be mentioned, where sawn timber is the main product, but also co-products with an assigned value like saw dust and wood chips accrue. It is recommended to divide the unit process to be allocated into two or more sub-processes, or by expanding the product system to include additional functions related to the co-products. In some cases it is not possible to use a wider approach, then allocation has to be used in manufacturing processes. Since, beside other varying parameters, different allocation methods can be applied, results can differ significantly among different studies to the same product (1).

2. Definition

According to EN ISO 14040:2006, allocation is the tool for partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. Wherever possible, according EN ISO 14044:2006, allocation should be avoided by either dividing the unit process or expanding the product system. If a process must be divided but data is not available, inputs and outputs of the verified system

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should be divided by its products or functions in a way, that separation shows basic physical relations among them. If related co-production processes are not independent and can't be separated; allocation has to consider primary purpose of processes and assign it to all relevant products and functions adequately.

3. Allocation in standards and technical rules

During the last years, several methods for dealing with multi input or output processes have been proposed in different standards. The basis for all of them can be seen in EN ISO 14044:2006 which describes a three step procedure, how to deal with situations where an allocation is necessary. As a first step, wherever possible, allocation should be avoided. As a second step, the inputs and outputs should be partitioned in a way that reflects the underlying physical relationship between them. Where physical relationship alone cannot be used as the basis for allocation, different relationships (e.g. economic values) can be chosen. Suggestions for allocation procedures can be found in EN 15804:2012, EN 16485:2012, ISO/TS 14067:2003 and PAS 2050:2011.

4. Comparison of physical and economic allocation

Precondition to use physical values for allocation is that the physical values reflect the main characteristics of a product. In many cases – usually corresponding to multi-output co-products with different revenue – such physical values are not available. Mass or volume is in most cases not an appropriate figure to describe the technical value of a product. In lack of appropriate physical data, market prices are a possibility to value the products.

4.1 Economic allocation

Physical allocation means that physical properties of the different flows are used to allocate the environmental loads from the process. Mass and volume are usually used for physical allocation. Since varying moisture content in wood leads to enormous mass differences, but negligible volume changes, volume should be considered instead of mass for allocation decisions. Carrying out LCAs of wood and wooden products, one always has to deal with hygroscopicity of wood and resulting variable moisture content. Moisture content of green wood (softwood) in the forest is between 60 % and 100 % (2). Softwood timber, used for construction purposes, shows average moisture content of 15%, not exceeding 19 %. Softwood timber for different applications is dried to moisture contents between 7 % and 9 % (3). A possible solution could be to track moisture consequently during production process and to display amounts separately as carried out in (4).

4.2 Economic allocation

Percentages for economic allocation are identified by given prices or price-relations of products. Economic allocation might be seen as a kind of mass or volume allocation, but weighted by the economic value. Even sometimes economic values are not available or price can be an internal one within the company. In many cases, percentages of price relations are sufficient. Assessment experience shows, that these relations usually can be provided without any difficulty. If no prices are available at all, generic data has to be used.

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4.3 Effect of price volatility of sawn timber on LCAs with economic allocation

The main problem of economic allocation is that, compared to mass or volume, prices are not as stable and depend on and vary heavily with market conditions and fluctuations. Regarding price history for sawn timber, according (5) it can be seen, that since 1972, prices rise on an average of 1,9 % per year, which is 0,5 % higher than the rise of round wood prices. On a long term view prices are quite stable, but for the short term, prices vary heavily up to 20 % from one year to the other.

One argument against the use of economic allocation in case of sawn timber is the price volatility. Therefore, life cycle assessments for sawn timber, using economic allocation method, based on different price scenarios were carried out at HFA.

0. base scenario - economic allocation -
1. sawn timber + 10 %
2. residues + 10 %
3. sawn timber + 5 %, residues + 20 %
4. sawn timber + 5 %, residues + 50 %

Results of sawmill life cycle analysis with economic allocation based on these five different price scenarios are shown in figure 1. Basis of calculations is formed by Austrian prices for saw mill products as an average from June 2013 and for bark as an average from April 2013 according (6). In each one of these five scenarios, the highest differences of allocation factors can be found in sawn timber with -5,84 % and in wood chips with 3,69 %.

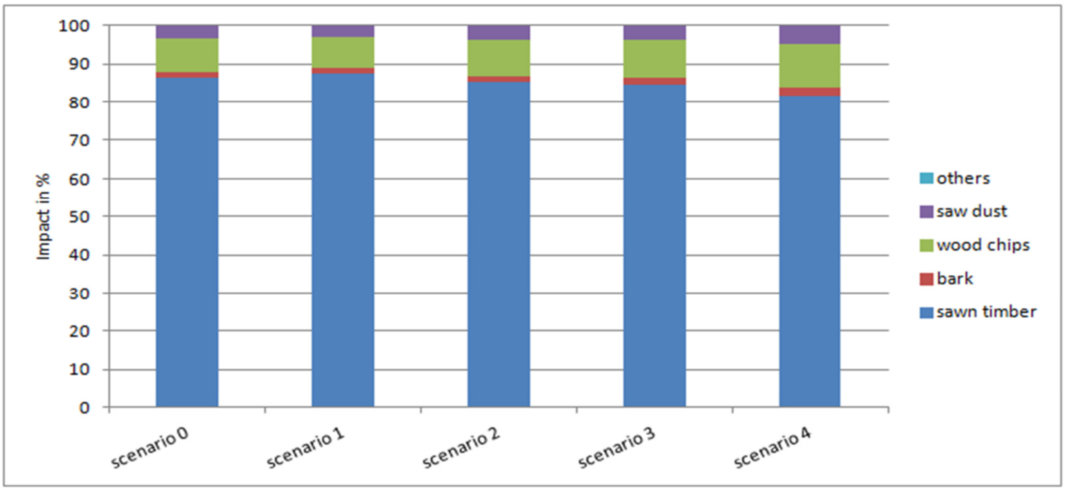

Figure 1: Impact of price volatility on allocation factor by using economic allocation

5. Different allocation methods applied on sawmill products and particle boards

5.1 Side products from sawmill industry

Since the sawmill industry is the most important wood processor in Austria and resulting products show enormous differences in their prices, LCAs of sawmill products are an excellent example for the impact of different allocation methods on results of environmental performance evaluations. Apart from sawn timber as the main product, bark and sawmill residues, containing wood chips, sawdust and hog fuel, are produced and serve as important

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raw materials for the paper and particle board industry, but in increasing quantities for the wood pellet production as well.

Saw dust is used in particle board industry and in wood pellet production, whilst wood chips without bark are an important source for the pulp industry. Bark and hog fuel (fuelwood) is mainly burned in own heating plants and resulting energy is used for the production process. According to (7) the ratio between pulpwood (timber direct from the forest) and sawmill residues in the paper industry is 1:1, in the particle board industry it is 1:2,5. These relations show the importance of this resource and also the severe impact of different allocation methods not only on sawmill products, but on downstream processing industries as well.

5.2 Case study – different allocation procedures in a sawmill

In the following case studies, mentioned allocation procedures (physical, economic and no allocation at all) have been applied in a sawmill in Austria. The different steps of the life cycle of sawmill products, that has been analyzed, and where system boundaries for the following calculations of allocation factors in sawmills and particle board production have been drawn is shown in figure 2.

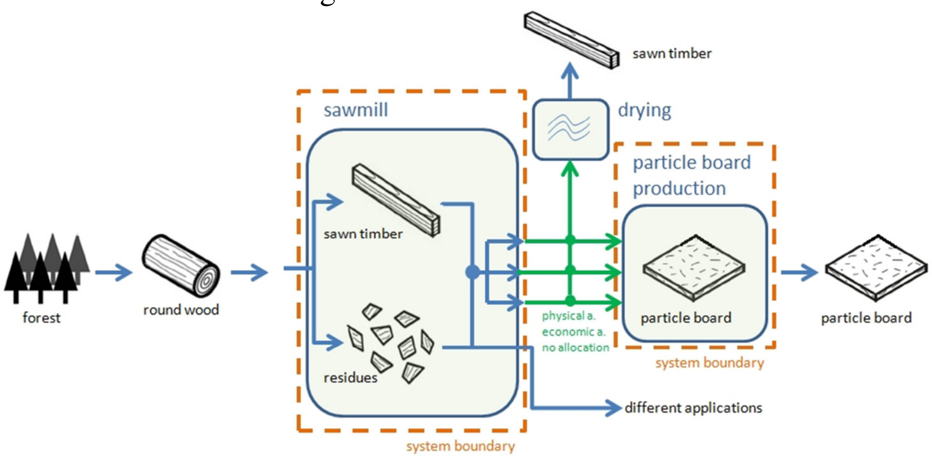

Figure 2: Table of investigations with system boundaries of carried out calculations

Three different allocation methods are applied on sawmill processes as follows:

- Physical allocation (mass based or volume based) – allocation based on physical properties.
- Value based or economic allocation – is a physical allocation as well, but different values of the products are taken into account
- No allocation or main product allocation - all burdens are assigned to the main product.

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In contrary to (8), results in figure 3 show huge discrepancies between the different methods. This means that, applying mass allocation, leads to lower environmental burdens for the main product (sawn timber) but higher ones for products made of residues (e.g. pulp, energy, wood pellets and particle boards). Results of environmental indicators like GWP, AP, EP etc. of sawn timber show differences up to 100%, as a function of the chosen allocation method.

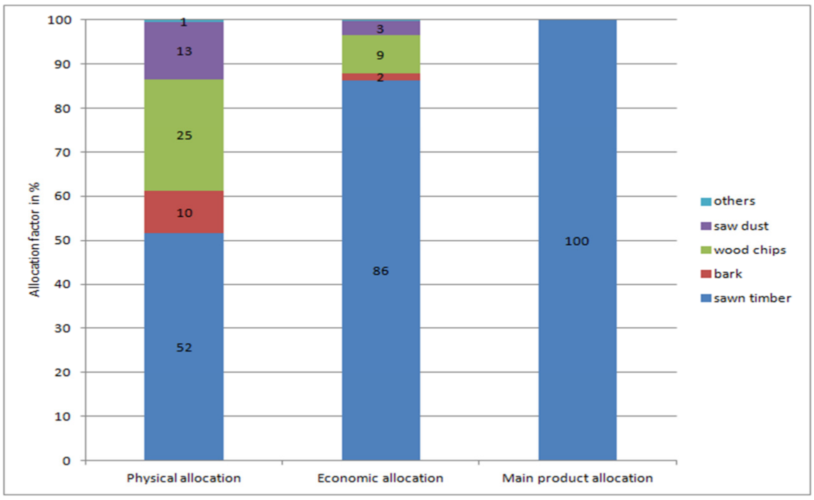

Figure 3: Allocation factor for 3 different allocation methods (own analysis)

Inclusion of drying process for sawn timber has nearly no impact on results of allocation factors as calculated above, suggesting more or less the same price for wet and dry sawn timber. Since sawn timber partly is sold in wet condition as well, blue bars from figure 3 simply are divided in the particular share, under consideration of different price and mass. Drying process is important when it comes to emissions and primary energy. Therefore it is recommended to choose a renewable source, like bark or different residues of the sawing process for the timber drying.

5.3 Impact of different allocation procedures in sawmills on particle board industry

As already mentioned above, sawmill residues, especially wood chips, are an important raw material for the particle board industry. Considering this, calculations were carried out to determine impact of 3 different allocation methods, applied on sawmill products, on the result of particle boards LCA.
Analysis is based on the ecoinvent dataset for 1 m³ “Particle board, outdoor use, at plant”. With physical allocation 25 % of impact category indicators for roundwood have been assigned to the wood chips, with economic allocation 10 % and with main product allocation 0 %.
The contribution of the softwood chips based on the three different allocation methods on several impact category indicators for the whole particle board is shown in figure 4. Overall the impact of softwood is relatively small, except for $CED_{ren,total}$. Economic allocation was used as a baseline, since this method is the one applied in the ecoinvent dataset.

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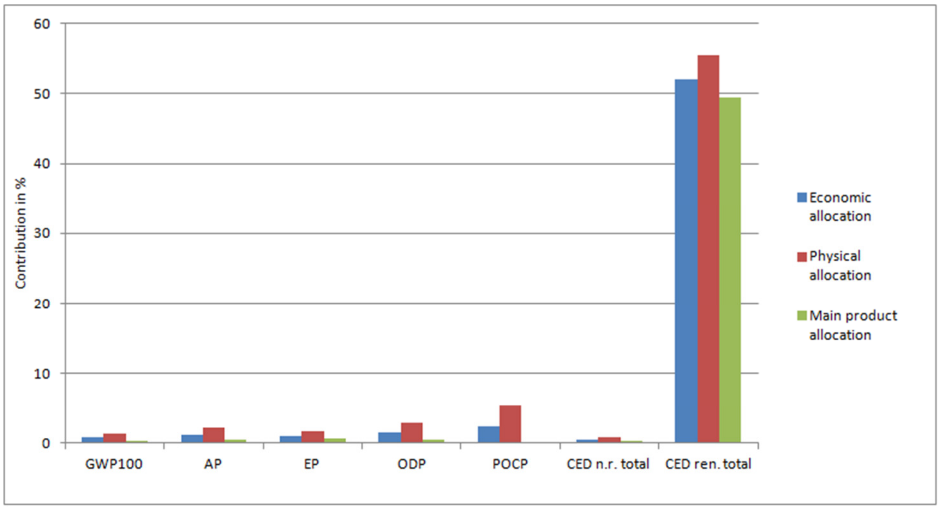

Figure 4: Contribution of softwood chips to different environmental impacts of particle board production considering different allocation methods in saw mills. Database: Ecoinvent, 1m³ Particle board, outdoor use, at plant including 0,823 m³ softwood chips.

When adopting physical allocation, higher impacts are assigned to softwood chips and therefore to particle board. However, overall impact category indicators increase between 0,3 and 3,3 %, except for CEDren,total which increases by almost 8 %. When adopting main product allocation instead, no impacts are assigned to the softwood chips. This decreases the overall impact category indicators for the particle board by 0,2 to 5,1 %.
Similar results also apply for particle boards for indoor use. Although the impact of resin is lower (e.g. about 56 % of GWP 100), the effect of softwood chips remains at about 1 % for all indicators except CED renewable, total.

6. Discussion

With physical allocation, large burdens are attributed to low value products, if they are produced in large amounts (9), e.g. rock as a side product of the gold productionThe examples of sawmills show the profound impact of the selected allocation method on LCA results of sawn timber. Depending on which method is chosen, environmental burdens are distributed differently. In case of economic allocation, sawn timber gets a larger share of the burdens and if physical allocation is chosen, bark and process residues take the major part. This leads to higher environmental impacts of products consisting of this sawmill residues and bark.
An important diagnosis of Jungmeier (8) is, that allocation from the upstream environmental loads (e.g. forestry, transport) to the different co-products can be more important than the allocation of the burdens in the sawmill. This leads to his recommendation of mass allocation in LCA of wood based products where timber production is the main function of the forestry system.
Since sawmill residues are used in particle boards, paper mills and for wood pellets, impact of allocation decisions on these industries have to be analyzed as well. This was carried out for the particle board production for a representative plant. Results of this investigation show that

effect of sawmill residues on the environmental impacts of particle boards, for the most important indicators, is relatively low.

7. Conclusion and Recommendations

Comparative calculations with different price scenarios indicate the negligible impact of volatility of prices of saw mill products on LCA when applying economic allocation.
Yield, amount of saw mill products and price relations seem to be similar for both case studies. Analysis of the case studies show, that choice of allocation method has a significant impact on results of LCA of sawmill products. Since sawmill process has only little impact on LCA results, allocation decisions are from minor importance. Nevertheless, this implicates different assignment of environmental burdens to downstream processing industries like paper and particle board or building industry as well. Analysis of downstream particle board production shows only minor differences if allocation factor for sawmill processes is changed. For the most of the important indicators, impact is below 1 %, less than the boundary for cut off criteria recommended by EN 15804. This means, influence of allocation decisions in sawmills on particle board production can be neglected.
In general, selection of allocation method depends on the specific case. In most cases mass or volume are not appropriate figures to describe the technical value of a product, as it does not reflect the main characteristics of the process. Since allocation is a subjective procedure, it is not possible to give a ubiquitous directive for allocation situations. When more decision makers are involved and a consistent methodology approach is required, negotiations e.g. in a standardisation process can lead to a commonly accepted and supported solution. This agreed allocation method shall be applied in order to produce consistent results, although it may necessarily be “not the right one” for a specific problem. In order to overcome this drawback, variants and sensitivity analysis should be conducted.

8. References

(1) Sinha, A., Gupta, R., Kutnar, A. (2013). *Sustainable development and green buildings = Održivi razvoj i zelena gradnja*. Drv. ind., 64(1): 45-53. doi: 10.5552/drind.2013.1205.

(2) Bauer, C. (2007). *Holzenergie*. In: Dones, R. (Ed.) et al., *Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz*. Final report ecoinvent No.6-IX, v2.0. Paul Scherrer Institut, Villigen, Swiss Centre for Life Cycle Inventories. Dübendorf.

(3) Werner, F., Althaus, H.-J., Künniger, T., Richter, K. (2007). *Life Cycle Inventories of Wood as Fuel and Construction Material*. Ecoinvent report No.9. Data v2.0. Swiss Centre for Life Cycle Inventories. Dübendorf.

(4) Nebel, B., Wegener, G., Zimmer, B. (2002). *Ökobilanzierung Holzfußböden*. Hg.: Holzforschung München –HFM TU München, 2. Überarbeitete Auflage. München. ISBN 3-89675-975-2.

(5) Puwein, W. (2008), *Die Preisbildung auf dem Rundholzmarkt in Österreich*. WIFO, Monatsbericht 6/2008. Wien.

(6) Ebner, G. (2013). *Markterhebung*. Holzkurier 16.13 und 26.13. Österreichischer Agrarverlag. Wien.
(7) Moser, G. (2008). *Business to Business Relations in der österreichischen Holzwirtschaft*. Report 0165. Umweltbundesamt, Wien. ISBN 3-85457-963-2.
(8) Jungmeier, G., Werner, F., Jarnehammar, A., Hohenthal, C., Richter, K. (2002). *Allocation in LCA of Wood-based Products*. Experiences of Cost Action E9. Part I. Methodology. Int. J. LCA 7 (5) 290 – 294. doi: 10.1007/BF02978890.
(9) Lundie, S., Ciroth, A., Huppes, G. (2007). *Inventory methods in LCA: towards consistency and improvement*. UNEP-SETAC Life Cycle Initiative. LCI program task force 3: methodological consistency. Final Report. ISBN 3836486210.

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Resource efficiency of buildings – a model for the assessment throughout the life cycle and implementation in a real case study

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Abstract: *The construction sector belongs to the most resource-intensive economic sectors due to its consumption of 30 % of raw materials, 40 % of final energy and 25 % of potable water. For this reason it is necessary to develop planning tools being able to analyse the resource efficiency of buildings.*

This paper presents a concept for the assessment of the resource efficiency of buildings throughout their entire life cycle based on existing standards for sustainable buildings from CEN/TC 350 and the German building assessment methodologies DGNB / BNB. Also a model focusing on the aspect of raw material efficiency will be discussed.

The model introduces an approach that takes into account the criticality of raw materials to measure their consumption along all life cycle phases from a building with the indicator "Abiotic Depletion Potential Elements (ADPe)".

In addition the model is applied on a DGNB and OPEN HOUSE certified office building. The results give hints how to establish a raw material based indicator. Furthermore, they demonstrate the potential of buildings as anthropogenic raw material deposit.

Resource Efficiency, Raw Material Efficiency, Abiotic Depletion Potential Elements (ADPe)

Introduction and Background

Our high demand for resources has a huge impact on the environment, economy and social life. For this reason, the topic resource efficiency is on the agenda of politicians in the EU and the German government. With concepts like "The Roadmap to a Resource Efficient Europe" [1] or the "German Resource Efficiency Programm (ProgRess)" [2] they try to give a framework for the responsible and sustainable use of resources to limit environmental damages, strengthen the economy and ensure our well-being. However these programs are currently lacking of a common understanding of the term "resource" and resource categories are not defined. Based on a glossary from the German Federal Environment Agency [3] the resources will be distinguished in substantial and insubstantial resources in the following way:

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Resources

substantial	insubstantial
Raw materials	Capital
Energy	Staff
Land	Time
Water	
Natural sinks	

Image 1: Forms of resources

Resource Efficiency in the Building Sector

With a consumption of 30 % of raw materials, 40 % of final energy and 25 % of potable water the construction sector belongs to the most resource-intensive economic sectors [4]. In standards from CEN/TC 350 like the EN15804:2012 a lot of resources are already adressed. Also in sustainable building assessment methodologies like the german DGNB / BNB systems which are based on the European standards the efficient usage of resources is already partly implemented. An analysis of the DGNB / BNB systems indicators over the whole life cycle of the building has shown that an indicator for the assessment of raw materials is still missing. Image 2 shows to which extent the DGNB / BNB system is actually assessing the different forms of resources.

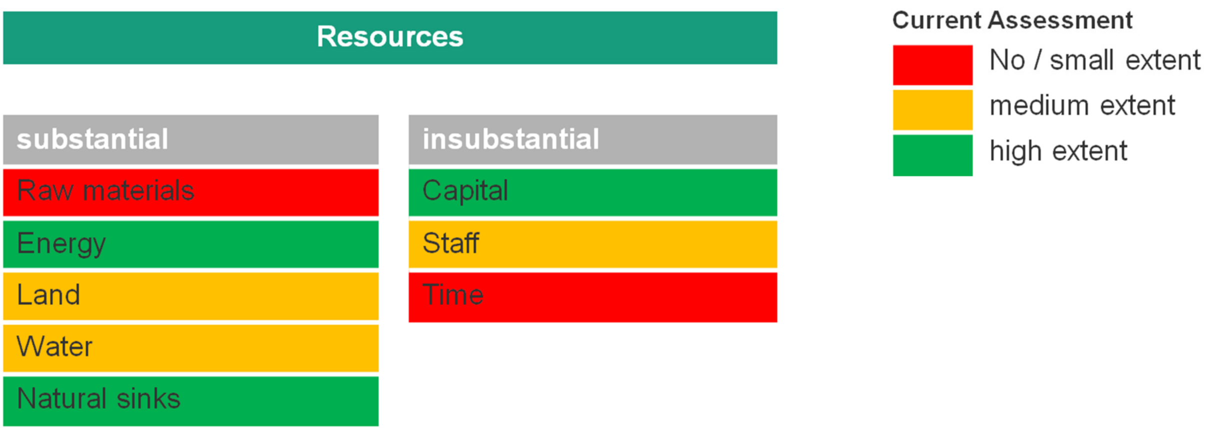

Image 2: Assessment of resources in the DGNB / BNB system

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Raw Material Efficiency in the Building Sector

Three levels could be useful to measure the raw material efficiency in the building sector. On the macro-level (e.g. country) and the meso-level (e.g. building sector) it is for example possible to figure out whether political aims have been achieved or certain regulations lead to their expected goals. These indicators can be also described as “monitoring-indicators”. To influence the raw material efficiency in the planning phase an indicator on the micro-level, in our case the building, seems the most promising. Here the planner can see directly which resources have the biggest impact on the raw material efficiency and improve the construction or choose alternative building products. This indicator can be mentioned as a “performance-indicator”.

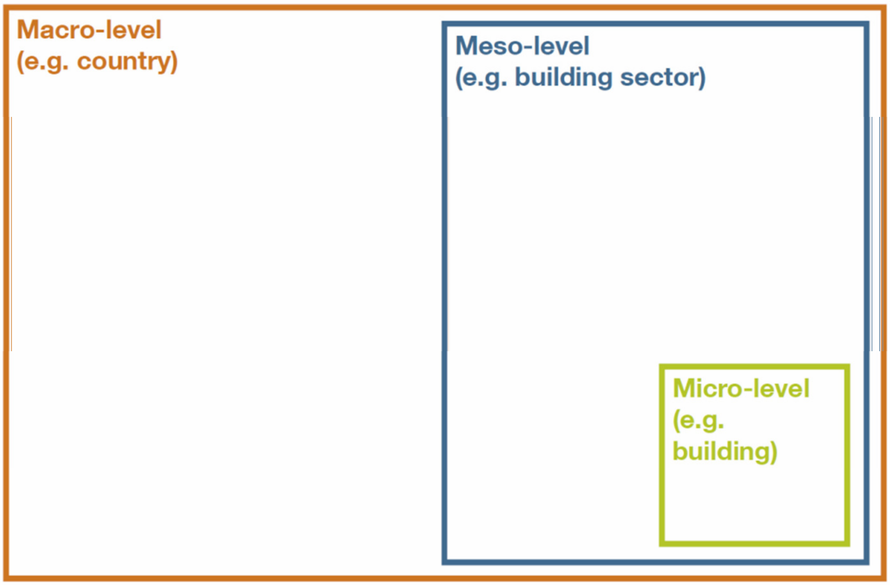

Image 3: Scales for indicators

To monitor the raw material efficiency in Germany on the macro-level, the indicator “raw material productivity” is currently used. This indicator is part of Germany`s national strategy for sustainable development from 2002 and describes the gross domestic product in relation to the used abiotic primary material [5]. The goal is to double the value of this indicator until 2020 on the basis of 1994. Weak points of this indicator are for example its relation to the gross domestic product which means that there can not be differentiated between an efficient use of raw materials or higher turnovers of the financial sector.

For measuring the targets on the meso-level specific indicators for the building sector would be more meaningful. These indicators should not only assess the input of materials but also the output and the further use of the materials. An approach for this could be a set of indicators being related to the 3r-strategy of Japan: reduce – reuse – recycle. The following table submits a proposal for indicators that deal with this issue.

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Indicator	Assessment Target	Calculation	Units
Construction-minerals-productivity	Use of raw materials	Construction investments [€] / Use of primary building materials [t]	€ / t
Coverage of the demand for construction minerals with recycling construction minerals	Use of recycling construction materials	Recycling construction materials [t] / Total production of construction minerals (primary + recycling) [t]	%
Amount of not recyclable mineral waste	Waste	Amount of not recyclable mineral waste	%

Image 4: Proposal of a set of raw-material-efficiency-indicators for the building sector

Raw Material Efficiency on the Building Level
As a performance-indicator to measure and improve the raw material efficiency on the building level the indicator "Abiotic Depletion Potential Elements (ADP_e)" represents to be the most practical indicator at the moment. It is already implemented in the EN15804:2012 but not commonly evaluated in current building life cycle analyses. Also the indicator – developed by Guinee and Heijungs from the university of Leiden in 1995 – is recommended by the Joint Research Centre (JRC) of the European Commission [6]. The indicator relates a resource on the basis of its yearly extraction rate and the ultimate reserves in the earth crust to the yearly extraction rate and ultimate reserves of the reference resource antimony. The unit of this indicator on the building level carried out by an LCA is kg Sb-equiv./m²*a.

The indicator has been studied by performing an LCA with the office building ICADE Premier Haus 1 „Funky", which is situated in Munich. The building was constructed between 2008 and 2010 and covers a gross floor area of about 29.000 m². The building was certified according to the German Sustainable Building Council (DGNB) methodology (Version 2009) and was awarded the best quality seal "Gold" with an overall rating of 87,2 %. Image 5 shows the allocation of the raw material input from the life cycle inventory analysis.

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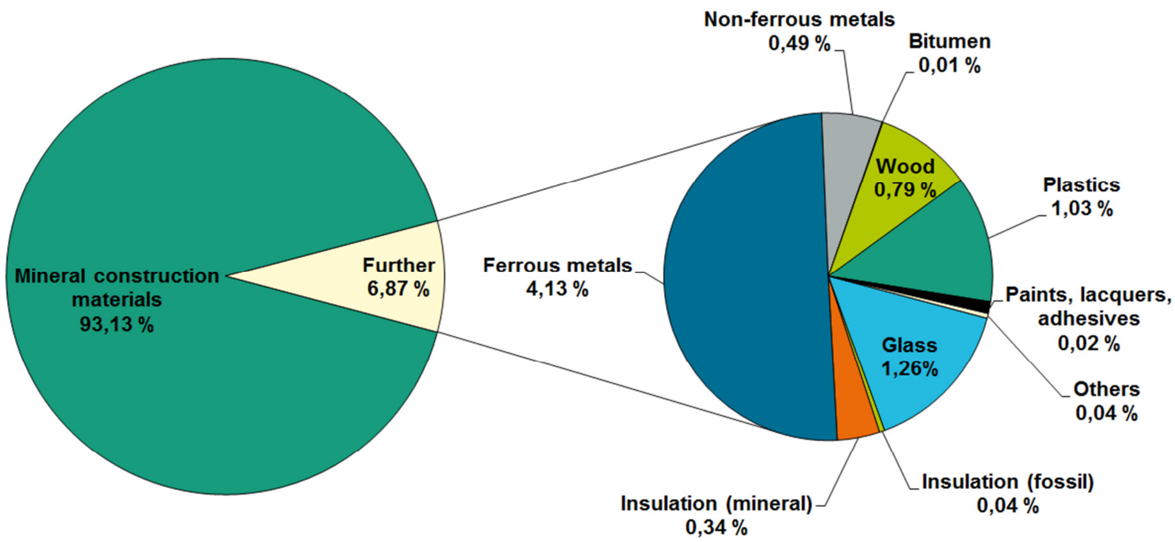

Image 5: Raw material mass input from the life cycle inventory in %

By far the most significant mass input with 93,13 % is represented by the mineral construction materials. Followed by ferrous materials with 4,13 %, glass 1,26 % and plastics 1,03 %. Further materials like non-ferrous metals, wood, insulation, bitumen or paints account for under 1 % each.

By calculating the indicator "Abiotic Depletion Potential Elements (ADP_e)" for the evaluated building, the allocation shown in image 5 completely changes. The values for the ADP_e have been extracted from the German life cycle database Ökobau.dat 2013 [7]. Module D – which describes the reuse, recovery and recycling potential – has not been taken into account, due to an incomplete database.

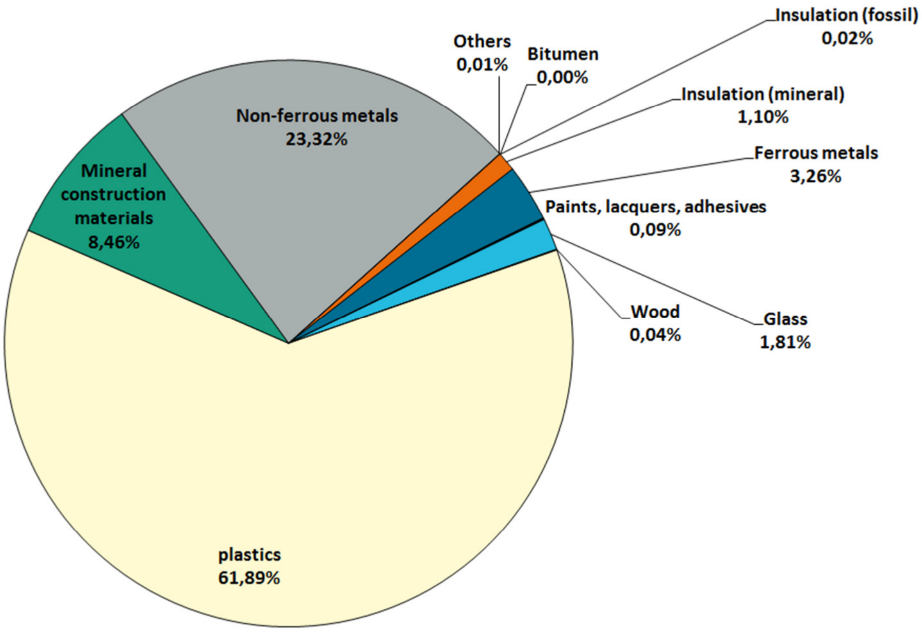

Image 6: Abiotic depletion potential elements (ADPe) without Module D in %

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Now the most significant material fraction are plastic components with a share of 61,89 %, followed by non-ferrous metals 23,32 % and mineral construction materials 8,46 %. A minor amount falls on ferrous metals with 3,26 %, glass with 1,81 % and mineral insulation materials with 11,10 %. Materials like wood, insulation (fossil), bitumen, paints and other construction materials have an impact with under 1,00 % for each material fraction.

An analysis of the ten building materials with the highest impact on the ADP_e has been carried out. The allocation of these materials is shown in image 7.

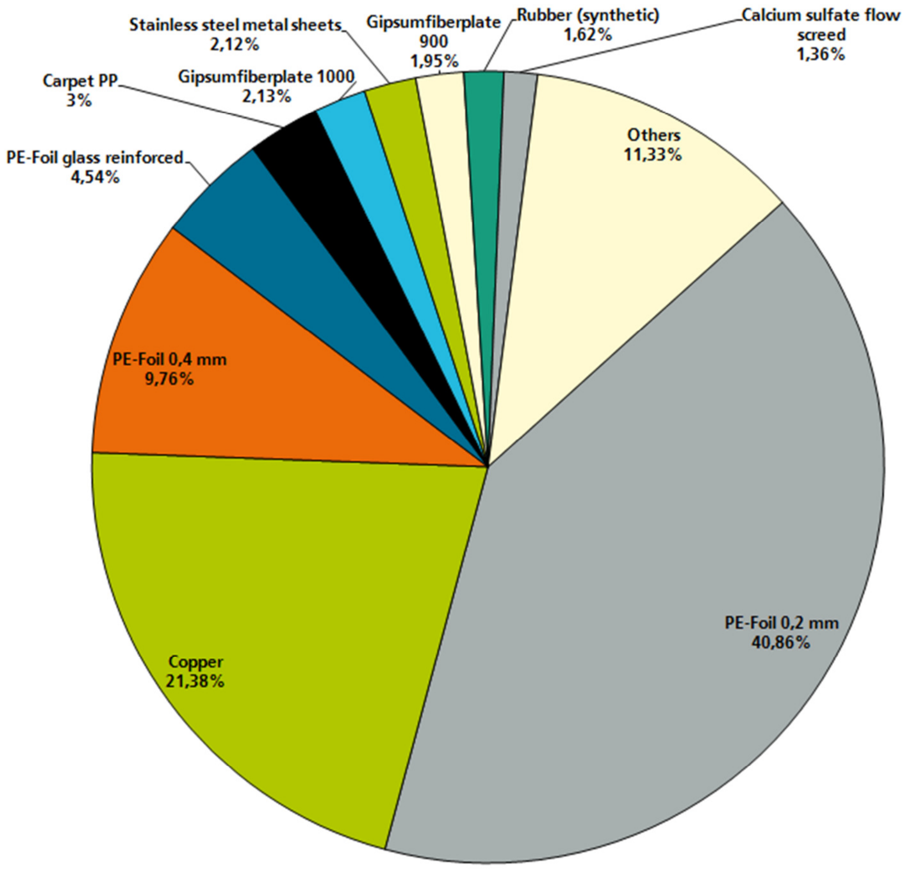

Image 7: The ten building materials with the highest impact on the ADP_e

By far the highest impact with altogether 55,16 % have the PE-Foils (0,2 mm, 0,4 mm, glass reinforced). This is caused by the flame protection agent antimony trioxide, which is around 3 % of the total mass of the PE-Foils. The second highest is copper 21,38 %, which is caused by the high characterisation factor (scarcity) of copper. Gipsumfiberplates (type 900 and 100) induce 4,08 % of the ADP_e, which can be related to the input of the rare element sulfur in the product. Also the calcium sulfate flow screed with 1,36 % can be related to the use of sulfur. Synthetic rubber and stainless steel metal sheets account for about 2% each. All other building materials make up another 11,33 %.

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Conclusion

The evaluation of the resource efficiency of buildings can be realised on the basis of already existing assessment methods and standards for sustainable buildings. Resource efficiency is classified as one aspect of sustainability.

To measure and improve the raw material efficiency of buildings the most promising indicator seems to be "Abiotic Depletion Potential Elements (ADP_e)" which can be calculated by performing an LCA. However further research should be done towards the system boundaries of the LCA and within the EPDs. The cables which incorporate the most copper are currently not included in the LCA within the DGNB certificate. Also the example with the antimony trioxide in the PE-Foils shows that small amounts of a certain element within the building products can cause a high impact on the overall ADP_e.

Further agreement is also needed for the reuse, recovery and recycling potential in module D, because at the moment there are some questions on how to interpret the standard EN15804:2012 with regard to this aspect. Furthermore, LCA databases are lacking of datasets for this life cycle phase which show if the raw material can be recovered or is depleted.

The next step would be getting more experience with this indicator by conducting meaningful LCAs and the setting of benchmarks to further advance and improve the raw material efficiency of buildings.

[1] European Commission (2011) *Roadmap to a Resource Efficient Europe. Brussels.*

[2] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2012) *German Resource Efficiency Programme (ProgRess).* Berlin.

[3] German Federal Environment Agency (2012) *Glossar zum Ressourcenschutz.* Dessau.

[3] United Nations Environment Programme (2013) *Common Carbon Metric.* http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf

[4] Federal Statistics Office Germany (2012) *Environmental-Economic Accounting (EEA).* https://www.destatis.de/EN/FactsFigures/Indicators/SustainableDevelopmentIndicators/ SustainableDevelopmentIndicators.html

[5] European Commission (2011) *ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European context.* Brussels.

[6] Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (2013) *Ökobau.dat 2013.* http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html

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Climate renovation can pay off
A life cycle cost analysis conducted as part of the LichtAktiv Haus experiment confirms the economic viability of modernizing a 1950s settler house

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Abstract:

Life Cycle Cost (LCC) calculations include both initial costs associated with an investment (purchase, modernization, new construction) and the consequential cost related to use and maintenance of the building. LCC enables a medium or long-term perspective to be applied in current decision making processes. A detailed evaluation of LCC calculations reveals significant influencing variables that should be considered in making current decisions, and can also indicate whichinfluence future energy price trends may have on the total costs. .

A Life Cycle Assessment (LCA) shows that from an environmental point of view, is is better to extensively modernise an existing building than to build a conventional new house. The LCC analysis now shows that climate renovation of an old settler also pays off in economic terms. The calculation, based on a realistic cost estimate for series production, shows that, even if energy prices only rise moderately, the modernisation costs are offset after approximately 15 years, when compared with continued use and forthcoming maintenance of the existing and unchanged building. This paper analyses and discusses the economic aspects of the current case study and in the context of other sustainability aspects. The paper is a scientific publication and will present and discuss the study accordingly.

Keywords: *modernisation, life cycle costing, model home 2020, net zero energy modernisation*

Introduction

Within the international building exhibition 2013 (IBA 2013), located in Wilhelmsburg, Hamburg, Germany, show case buildings demonstrating cutting edge energy efficiency and energy technologies have been realized. Different from other show cases demonstrating new buildings, Wilhlemsburg is an existing town district of Hamburg, with specific social concerns. VELUX participated in the IBA program and aquired a small single family building to be used as a model home (VELUX 2013). The Wilhelmsburg building was built in the 1950 and has not undergone significant changes ever since. It represents a rather typical settlers home, millions of these and similar buildings have been built in Germany in that period of time. As individually owned houses, many of them have undergone refurbishments, energetic upgrades or extensions. Originating from the 50ies, many of these buildings remain un-updated and are technically and functionally not up to date, and frequently face demolishion. Otherwise they would require extensive and costly modernisation, commonly assumed to be too costly.

Facing the alternatives demolition vs modernisation, VELUX developed a model home concept for modernisation, aiming to upgrade the building to a up-to-date living environment, creating open, light, healthy and energy efficient spaces that would be attractive in a market that does currently not appreciate that building type.

In the light of sustainable construction, the model home was supposed to be analysed from multiple purspectives – obviously quality of life and indoor environment issues, but also environmental aspects from a life cycle perspective. After TU Darmstadt had conducted a comparative LCA of the model home renovation vs continued operation and vs demolition and new construction, the obvious identified preference was the radical modernisation to a net zero energy standard. (Hegger et al 2011)

But what about the cost?

Life Cycle Costing

Life cycle costing (LCC) is a standardized approach to the quantification of costs related to a building. ISO 15686-5 lays out the principles and provides the necessary elements to carry out a life cycle cost calculation. The detailed approach is left open and adaptable to the scope and preferences or concerns of the cost analyst. In that way, an LCC calculation can be adapted to the analysed building, the options at hand, or to the parameters to be studied. In that manner it is as well possible to test the reponse of displayed results to parameter variations.

Applying LCC in the context of sustainable building directs the focus to the way in which established green buidling labels address the subject.

- LEED (LEED v4 2014) does currently not include life cycle cost assessments
- BREEAM (BREEAM) requires a repeated and refined cost calculation at distinct project stages, the calculation results are to be considered in decision making, and are to be established according to ISO 15686-5
- DGNB (DGNB NKW'12) details a simplified LCC calculation procedure, not aiming at cost optimisation in the planning process, but establishing a calculation on common grounds, resulting in a benchmark comparison. All details except for the building cost and performance data are prescribed for the sake of comparability.

For the analysis underlying this paper, it was rapidly clear, that it should not be oriented to one of the established building labelling schemes. Rather, it aims to analyse where the modernisation shows advandtages or disadvantages in comparison to a continued use (including operation and maintenance) of the existing building.

ISO15686-5 serves as the reference standard for the calculations.

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Questions to be answerd

In general, the question whether or not it is worth to renovate existing small single family buildings is in focus of this study. To complicate the question, the analysed renovation case study is doncucted in several case scenarios:

1. Continued operation of the existing building
2. Necessary renovation of the existing building without modernisation (scenario “REFERENCE”)
3. Modernisation and medium expansion of the building, energy performance 70% below current German energy performance standards (scenario “MEDIUM”)
4. Modernisation and expansion of the building, plus-energy-standard (active house) (scenario “PREMIUM”)

Cases 3 and 4 are modular, where elements of the expansion and the energy technology applied in building 4 are add-ons to case study 3. Both cases follow the design philosophy of the VELUX model home, where case 4 applies energy technology that today still has a prototype character and leads to a net-plus-energy building, on the basis of a modernisation of an existing building.

The questions were:

- Is it economically reasonable to move from option 2 to 3 or even 4
- Within which time horizon do the preferences shift (if at all)
- What influence does the assumed energy price increase have on the results
- Assuming that the demonstration building could be reproduced at reasonable market prices, what would the result be

The analysis of life cycle costs and the main cost drivers was to be integrated into the overall analysis and assessment of the model home at Hamburg Wilhelmsburg. Embedded in environmental life cycle assessment, technical and functional aspects, indoor climate and user friendliness, a multi-criteria overall assessment addressing relevant sustainability parameters was to be enabled. Social studies into the expericens of the real building users complemented the approach.

The cost model and the model home

The basic anticipation is that the additional initial investment required for the modernisation will need a medium to long time priod to show a break even – if at all. On the other hand, the 60+ year old building needs frequent repairs and partial refurbishments, meaning that parts of the modernisation’s disadvantage are neutralised within a short to medium time horizon. The remaining compensation for the efforts must originate from reduced operating costs. Many obvious advantages in terms of qualities provided are not measured and included in the cost calculation (development of value and income due to rent). Consequently, the LCC does not provide an answer of the ECONOMY, but only on the direct COST.

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From the setup of the study, it was assumed that the modernisation would pay off in case of high increase rates for energy prices, but equally interesting it was to see whether or when it would do so for low energy price increase rates. If not paying off, how big a distance would remain? Could that price difference be reasonable at hand of the provided qualities, or would it be out of discussion?

Concpetionally, a corridor for results was to be drawn up. As LCC calculations rely on many assumptions and scenarios, it was preferred to describe a “lower” scenario (with low energy price increase rates) and a “higher” one. Optimistic assumptions for the energy price development presumably lead to pessimistic associated results for the modernisation case.

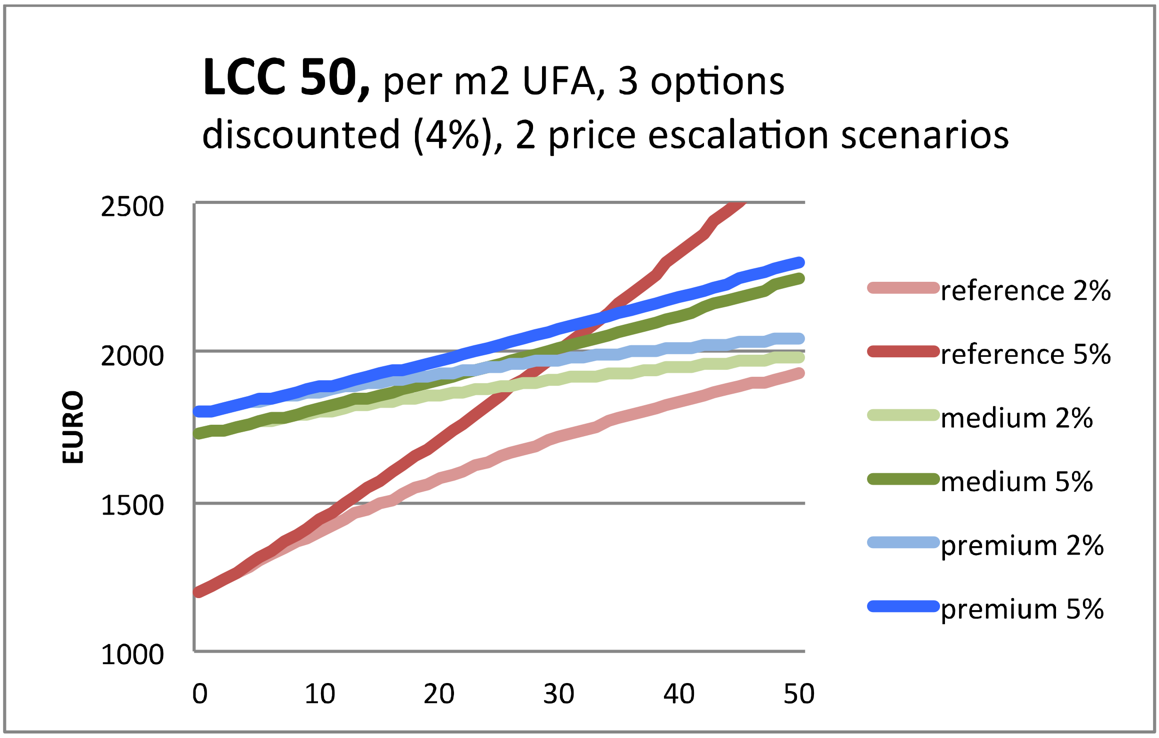

Figure 1. cost corridors resulting from investment and operation cost, applying different energy price development scenarios – conceptual illustration

Feeding that model with real project data produces the results illustrated in figure 2. At first glance it demonstrates, that the energy prices have a smaller influence on the magnitude of results than in the conceptual illustration above. Further, the inclusion of replacement scenarios and maintenance produces a stepwise but significant cost accumulation for the continued operation scenario.

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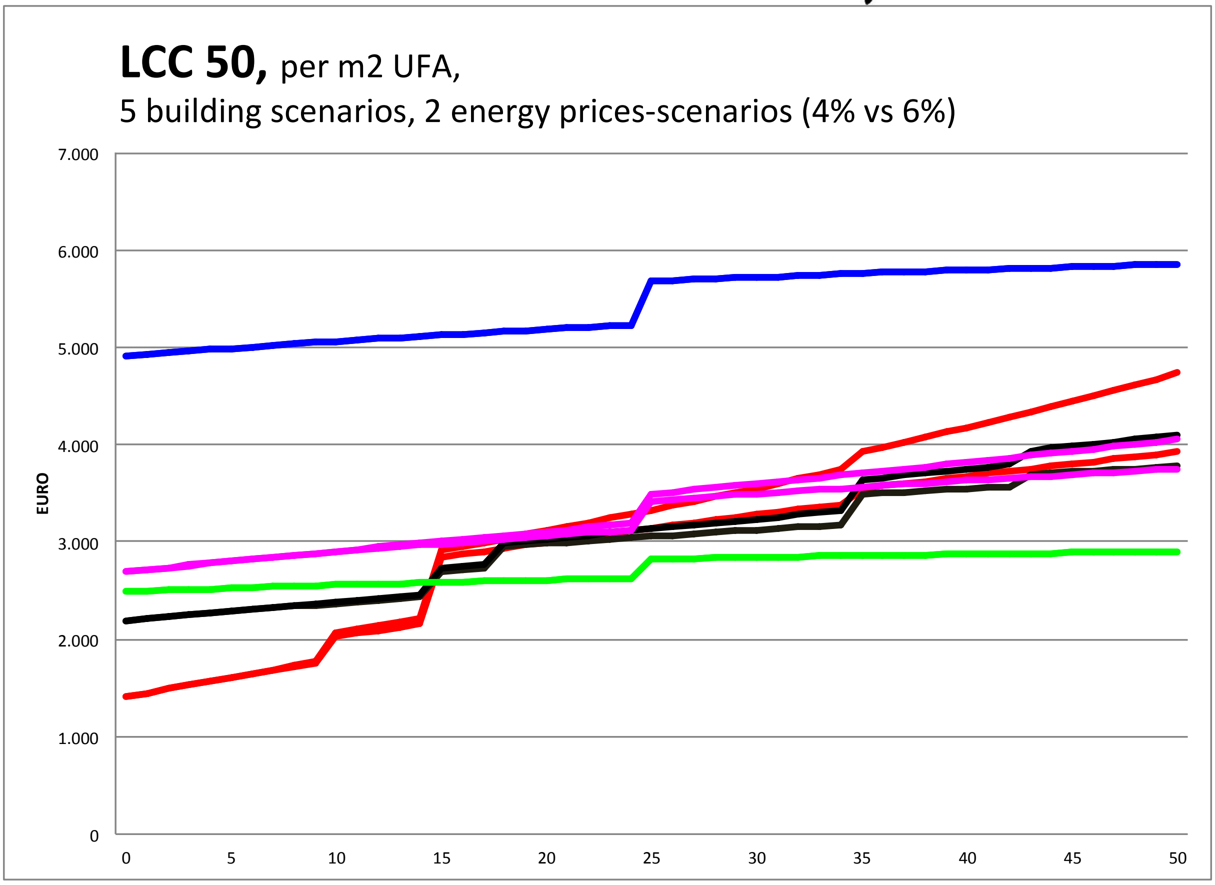

Figure 2. cost corridors resulting from investment and operation cost, applying different energy price development scenarios – building specific cost information
with RED line: existing building; BLACK line: basic renovation; PURPLE line medium expansion and high energy efficiency standard; BLUE line: demonstration case model home 2020; GREEN line: model home 2020 as series production

The life cycle cost calculations can be applied in a highly flexible way allowing many parameters to be varied. Buidling scenarios, service life scenarios, price escalation scenarios can be specified and combined to define the compared "case studies". For the inserted graphic, the above-presented building options have been included, and the increase rates for energy prices have been set to 4 and 6% respectively. These are to represent moderately low and moderately high expected escalation rates. The cost figures are discounted at 4,5%

- The energy demand of the MEDIUM and the PREMIUM option are close to zero, or equal zero. Consequently, their cost-over-time is not or nearly not affected by the energy price scenario. Consequently the lines (blue and green) do not open a gap, or a small gap only (purple)
- The MEDIUM modernisation (expansion and high energy efficiency) proves to be cost-competitive in the range of year 15 (higher energy price increase) to 30 (lower price increase)
- The PREMIUM modernisation (expansion and net-zero energy demand) can not compensate for its substantial initial cost. Given the fact, that the PREMIUM

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modernisation is a show case buiding with prototype and demonstration character, many of the components were specifically designed and adapted to the Wilhelmsburg buidling

- Should such components be available to reasonable prices in a mass market, the initial cost would decrease to a magnitude half way between a current standard refurbishment (black line) and the MEDIUM modernisation. This today still fictitious scenario is illustrated by the green line. Under such conditions, the return on investment would be reached after 15 years. Over a period of analysis of 50 years, this scenario produces LCC that are between 25 and 40% below the continued operation of the existing building.

Conclusions and discussion

The cost calculations show that the realized model home in Hamburg Wilhelmsburg is not cost-competitive when produced as a single demonstration building. If however taking the concept from prototype to repeated realisation, it would be competitive within a time horizon of roughly 15 years (compared to continued operation of the non-refurbished building).

Life cycle cost calculations are established taking into account a wide range of parameters. Each of these parameters can be defined according to the context and assumptions or expectations of the audience towards which the results are intended to be communicated. A generalisation is consequently difficult. If however displaying result spreads caused by variations of selected parameters, corridors for expected results, rather than pseudo-accurate figures can be provided and can be interpreted reflecting the drivers behind those parameters.

The key cost drivers for the reference building in this study are the assumed remaining service life and the energy cost. The corresponding key cost driver for the modernisation case is the cost of the modernisation itself. Due to the net-zero energy demand of the model home 2020, these buildings become independent of future energy price development.

The study underlying this paper does not intend to tune the data and present unrealistic potentials. It shows that under certain conditions, the model home may be competitive. The main result is consequently, that the increased quality of life and the decrease environmental impact come – with realistic expectations – with no extra cost, and when applying a long term perspective, with an assumed cost advantage.

The overall relevance of strategies directed towards settler houses is large. Different, but not scientifically validated sources estimate the total number of these houses to be of 7 digits. Considering their age and their potential to be adapted to modern living standards and high environmental performance, sustainable strategies for these buildings are needed. The model home 2020 demonstrates a radical, but senseful option.

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References

IBA 2013	www.iba-hamburg.de: Internet presentation of the international building exhibition Hamburg Wilhelmsburg, IBA Hamburg GmbH, Hamburg 2013
VELUX 2013	hwww.velux.com/sustainable_living/demonstration_buildings: Internet presentation of demonstration buildings, VELUX AS, Hørsholm 2014
Hegger et al 2011	Hegger, Bialucha, Hartwig, Elschen,: Ökobilanzierung des Velux Model Home in Hamburg Wilhelmsburg, TU Darmstadt, Darmstadt 2011
ISO 15686-5	ISO 15686-5:2008 Buildings and constructed assets – Service life planning: Part 5, Life cycle costing, International Standardization Organization (ISO), Geneva 2008
LEED v4 2014	LEED Reference Guide for Building Design and Construction, v4, US Green Building Council, Washingten DC, 2013
BREEAM	BREEAM International New Construction 2009, BRE Global Ltd, Garston/Watford/Herfordshire, 2009
DGNB NKW'12	Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), DGNB Zertifizierungssystem Nutzungsprofil Neubau kleine Wohngebäude (NKW) Version 2012, Stuttgart 2013

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The Application of LCA calculation methods in building certification systems in Austria

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Abstract: *In the past few years a various number of building certification systems were placed on the market to endorse green and sustainable buildings. Recently there has been an increasing demand for such labels. The goal of this paper is to compare different building certification system in Austria focusing on the implementation of the Life Cycle Assessment (LCA) for quantifying the environmental performance of buildings and to stress the gap between "simplified" and "complete" LCA. The validation of the assessment methods for assessing the environmental performance regarding the use of LCA shows that the majority of the certification systems are currently not in line with the upcoming European framework. In contrast, the assessment methodology used by DGNB/ÖGNI does correspond with it. Although the most commonly used "simplified" LCA calculations method used in building certification involves a rather small workload, the results are not satisfactory regarding accuracy. "Complete" LCA calculations are highly complex and involve high workload and for this reason are not applied in practice.*

Keywords: LCA, sustainability certification of buildings, ÖGNI, DGNB

Intoduction

The political discussion about societal and environmental problems increasingly focuses on the overall concept of sustainable development. The construction sector plays a key role regarding energy and resource consumption as well as solid waste accumulation. In the past few years a various number of building certification systems like LEED, BREEAM, HQE, DGNB, ÖGNI and TQB were placed on the market to promote green and sustainable buildings. Recently an increasing demand for such labels has been noticeable. In these building certification schemes aspects of sustainability (economic, social and environmental as well as functional and technical) are considered very differently – especially regarding the assessment of the environmental performance. Since 2004 CEN/TC 350 has been working on a set of standards to harmonize the methodology for the sustainability assessment of buildings using a life cycle approach. According to EN15978 the assessment of the environmental performance of buildings is based on Life Cycle Assessments (LCA) expressed through quantitative assessment categories.

The aim of this paper is to stress out priorities in the assessment of environmental buildings performance with the use of LCA methodology. Thereby the differences of LCA calculation methods applied in Austria´s building certification systems are compared and discussed by a comprehensive analysis, based on several residential buildings.

The major result, which will be presented in detail, is a comparison between "simplified" and "complete" LCA to quantify the environmental performance of buildings.

Building Certification Systems

In the past few years, an increasing number of building certification systems have been placed on the market. Due to multi-characteristic influences in the context of sustainability assessments of buildings a complete evaluation criteria-structure is essential. A very large number of international building certification systems have existed since the 1990s. In Austria, three national certification systems currently exist, DGNB/ÖGNI, klima:aktiv and ÖGNB (TQ-B). As regards assessment of buildings, these certification systems implement different approaches to environmental performance, e.g. completely or partly using LCA methodology [1–3], [5], [6]. The differences between the three certification systems used in Austria are described below taking into account certifications on "new construction dwellings"[4].

DGNB:

The German Sustainable Building Council (DGNB) together with the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) developed a voluntary certification system for sustainable buildings in 2007. The building certification system of DGNB is based on the CEN/TC350 approach. The assessment is based on a holistic life cycle approach considering the before-use phase, use phase and end-of-life phase with a reference study period of 50 years. DGNB implemented an explicit LCA method. The goal of the assessment is to quantify and document the environmental performance of the building under consideration (office building, retail, hospital, school, etc.) by means of applying LCA methodology and to compare the results with a defined benchmark.

Klima:aktiv:

The klima:aktiv building and refurbishment certification system for new construction office is divided into four assessment categories according to a system of 1000 points. Klima:aktiv assessment allows LCA to be carried out in two different ways. On the one hand, category C 2.1a (ecological benchmark of the whole building) and alternative category C 2.1b (ecological benchmark of building envelope). The assessment considers three environmental impact categories GWP, AP and PEI.n.e. (or CEDnr). For the final assessment these three environmental impact categories are aggregated into one ecological benchmark (OI 3).

In the first case, the assessment goes only partly in line with the CEN/TC 350 approach. The Use phase only focuses on environmental impacts. Due to the fact that the construction and maintenance processes are considered by the assessment, environmental impacts caused by energy demand during use phase are not included in the aggregated results. Environmental impacts are partly embedded in category B 2.2 (CO2 emissions) and B 2.3 (cumulative energy demand).

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In the second case, due to time-related focus of the before use phase and the spatial-related focus of the building envelope as well as the declaration of environmental impacts in CO2-emissions, the environmental assessment concept does not correspond to the CEN/TC 350 concept, which is based on a holistic approach. The influence of neglecting spatial and/or time related aspects is shown in detail in. At most, 100 points (or 10%) can be achieved by using case one, and 75 points can be reached by accomplishing LCA in case two. Taking into account the previously mentioned categories B 2.2 (125 points) and B 2.3 (125 points), a total of 350 points using case one, and 325 points using case two, can be achieved.

ÖGNB (TQB):

The ÖGNB (Austrian Association of Sustainable Building) certification system (also named TQB) is separated into five main categories behind a 1000 point system as in the klima:aktiv certification system. LCA is embedded in category E.3.1 ecology of materials and construction. The time-related system boundary chosen for ÖGNB-assessments for dwelling-types considers before-use, use and end-of-life-phase. Compared to case two assessments in klima:aktiv, the spatially related system boundaries have been enlarged. Next to the building envelope, finishes are also included, but the technical equipment is not included due to missing data-sets. Environmental impacts are assessed in a similar way to the klima:aktiv assessment system, thus it is also not in line with CEN/TC350. The reference study period is stated to be 100 years. At most, 60 points (or 6%) can be achieved with LCA within the sustainability assessment by ÖGNB certification system.

ÖGNI:

The Austrian Green Building Council (ÖGNI) was founded in 2009. Due to a cooperation agreement with the DGNB, signed in June 2009, a substantial basis for the operation of the council was established, and thus the German certification system for sustainable buildings (DGNB) has been successfully adapted to Austria. The DGNB/ÖGNI certification scheme criteria-set includes the same criteria as DGNB. Each of the main topics is divided into several assessment criteria. For instance, the Global Warming Potential, Total Primary Energy Demands and Proportion of Renewable Primary Energy, Thermal Comfort in Winter and Summer or Energetic and Moisture Proofing Quality of the Building's Shell are considered for the evaluation of a building. For each criterion, measurable target values are defined, and a maximum of 10 points can be assigned. The measuring methods for each criterion are clearly defined. The certificate follows the concept of integral planning that defines the aims of sustainable construction with the related building performances at an early design stage. This means sustainable buildings can be designed which are based on the latest state of technology, and their performance can be communicated with the relevant criteria in the pre-certificate at the planning stage and in the certificate after completion. The consulting auditor accompanies the owners during the certification process and prepares an accompanying planning and construction documentation in accordance with the specifications of the documentation

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guidelines. Having completed the building, the auditor compares and checks the building specifications with the realized project.

Finally, DGNB/ÖGNI reviews the entire certification process and performs a conformity inspection based on the documentation guidelines, makes plausibility checks and takes control samples, and checks whether everything was executed properly according to the documentation. If all requirements are fulfilled, the owner receives a certificate.

Case Study

In this study, life cycle assessment (LCA) is used to calculate the environmental performance of buildings using different system boundaries. This section briefly explains the LCA methodology. To compare different system boundary scenarios, the study assesses the different calculation rules in different building certification systems used in Austria. The two reference buildings and the energy consumption concepts are taken for two residential buildings, described in. It comprises two buildings, one in the passive house and one in low energy standard. Finally, the assumptions and limitations of the different methods and the data used will be described.

The key parameters for the assessment are shown in Table 1:

Tab.1: Key parameters for the assessment

Goal	Complete LCA
Scope	two residential buildings over the building life cycle with the entire building products
Reference study period (Tref)	50 years
Operational energy	According to ÖNORM H 5055
Functional unit	Square meter net floor area (m² NFA)
Environmental data	ecoinvent 2.1
Methods	CML 2001, cumulative energy demand
Indicators	AP, EP, GWP, ODP, POCP, PEe, PEne

The evaluation is undertaken for different assessment approaches, one according to the CEN/TC350, one according to klima:aktiv/ÖGNB, and one according to DGNB/ÖGNI for which the results are explained more in detail.

Functional equivalent: the object of the assessment is the entire building

Reference study period: the reference study period is defined at 50 years. The scenario for the operational energy use is calculated for this period, as is the scenario for replacements.

The assessment is carried out based on four system boundaries:

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1) LCA of the building according to the CEN/TC 350 approach for the whole building and its components as well as technical equipment (called CEN - system boundary 1 and defined as 100% for the comparison).

2) "Complete" LCA of the building according to the DGNB approach with defined cut-off criteria (1% and 5%); - system boundary 2

3) "Simplified" LCA of the building elements (product and construction stage) according to the DGNB approach (- system boundary 3)

4) OI3-Approach, based on building elements (building envelope - TGH- - system boundary)

The system boundary includes:

- the product stage (raw material supply, transport and manufacture of products),
- a use stage scenario (operational energy use, replacement and end-of-life),
- an end-of-life stage scenario (waste processing and disposal).

The calculation is carried out by means of a whole-building analysis using local climate data. For the life cycle inventory (LCI) based on the bill of quantities for each building, ecoinvent[1] v2.1 was chosen. It consists of approximately 2,800 contract items (with their construction products), which were investigated and analyzed for their LCA relevance.

The environmental indicators, shown in Table 2 a) and b), were calculated for each object per square meter net floor area per year for the building life cycle.

Tab.2 a) and b): Environmental indicators selected

Indicators describing environmental impacts	Code	Unit
Acidification potential of land and water	AP	kg SO2 equiv
Eutrophication potential	EP	kg PO4 equiv
Global warming potential	GWP	kg CO2 equiv
Depletion potential of the stratospheric ozone layer	ODP	kg CFC 11 equiv
Formation potential of tropospheric ozone photochemical oxidants	POCP	kg ethylene equiv

Indicators describing resource use	Code	Unit
Use of non-renewable primary energy (energy resources)	CEDnr	MJ-equiv
Use of renewable primary energy (energy resources)	CEDr	MJ-equiv

1 www.ecoinvent.org

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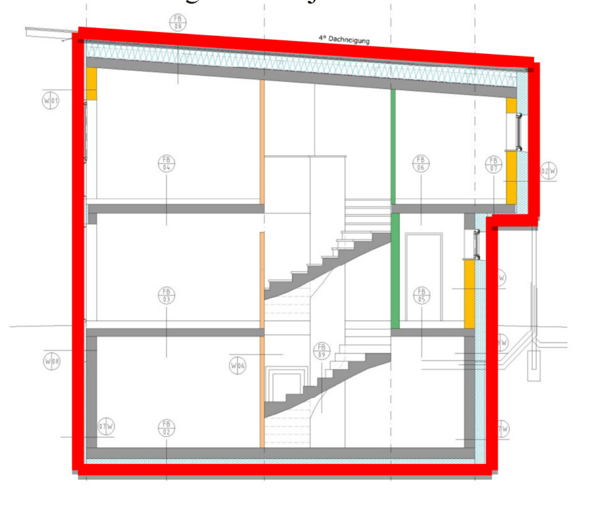
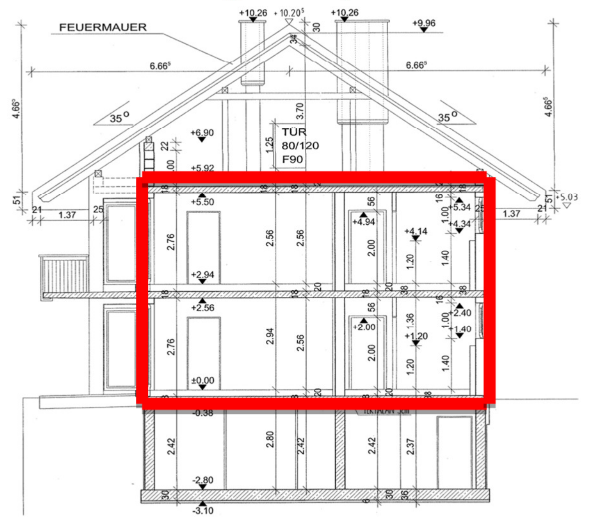
Figure 1 and 2 show the differnt systemboundaries for the simplified assessment. While the termal system insulation in object one includes the whole buildings, for objects two cellar and roo fis not included. Theses principals of the choice of system boundaries are applied for energy calculations and certifications in Austria.

Figure 1: Object 1	Figure 2:Object 2
	

Results

The LCA results are presented for the different spatial system boundaries i.e. system boundaries in the different building certification systems according to LCA in Austria and for the different time related system boundaries i.e construction phase and whole building life cycle. In the first step, the results for the assessed indicators are compared for the construction phase for system boundary 1 and 4.

In Table 3 it can be seen that the assessment of the building envelope – between 56% and 66% for object 1 and between 29% and 36% for object 2 are assessed with the chosen system boudary. As in the building certification system of klima:aktiv and TQB, the OI3 consists only of the indicators AP, GWP and CEDnr: only these indicators are compared to the CEN-system boundaries.

Tab.3: Comparison of the results for the construction phase for system boundaries 1 and 4

	Object 1		Object 2	
Indicator/System boundary	CEN	OI3	CEN	OI3
AP	100%	56%	100%	29%
GWP	100%	66%	100%	36%
CEDnr	100%	65%	100%	30%

Table 4 shows the results for object 1 and object 2 over the life cycle. The low ratio results from the definition of system boundary 4 which does not include the energy demand in use phase.

Tab.4: Comparison of the results for the life cycle for system boundaries 1 and 4

	Object 1		Object 2	
Indicator/System boundary	CEN	OI3	CEN	OI3
AP	100%	12%	100%	6%
GWP	100%	9%	100%	4%
CEDnr	100%	19%	100%	3%

Secondly, the system boundaries defined in the building certification system of DGNB/ÖGNI (simplified and complete) are compared with the CEN/TC 350 approach.

The "complete" system boundary 2 for the LCA of the building according to the DGNB (NWO10-01) defines the cut-off criteria as follows:

All building products/components for the cost group 300 and 400 according to DIN 276 need to be included with a mass or an environmental impact more than 1%. The total sum of excluded materials should be less than 5% of the mass and less than 5% of the environmental impacts over the life cycle. Within the "simplified" system boundary 3 LCA according to the DGNB (NWO10-01), the following building elements need to be calculated:

Outer walls including windows and coverings, roof, floors including ceiling, foundations, inner walls including coverings, doors and shoring, technical equipment for heating. The LCA results for "complete" system boundary 2 and "simplified" system boundary 3 are shown in Table 5 for the construction phase, where CEN is 100%.

Tab.5: Comparison of the results for the construction phase for system boundaries 2 and 3

	Indicators						
Indicators	AP	EP	GWP	ODP	POCP	CEDr	CEDnr
Object 1 - complete	97%	98%	98%	97%	98%	95%	97%
Object 1 - simplified	80%	67%	90%	84%	88%	91%	85%
Object 2 - complete	97%	98%	97%	95%	87%	98%	96%
Object 2 - simplified	74%	47%	89%	87%	82%	95%	86%

The LCA results for the whole life cycle for "complete" system boundary 2 and "simplified" system boundary 3 are shown in Table 6, where CEN is 100%.

Tab.6: Comparison of the results for the whole life cycle for system boundaries 2 and 3

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	Indicators						
	AP	EP	GWP	ODP	POCP	CEDr	CEDnr
Object 1 - complete	96%	98%	97%	96%	98%	93%	96%
Object 1 - simplified	82%	69%	88%	83%	89%	91%	85%
Object 2 - complete	97%	99%	97%	94%	96%	98%	96%
Object 2 - simplified	72%	48%	86%	85%	79%	92%	83%

It can be seen that with the system boundary „simplified“ in some indicatore a not neglectable failure is undertaken which varies from max. 53% (indicator EP construction phase in Object 2) to 5% (CEDr in Object 2 construction phase).

Discussion

Life cycle assessments constitute an important role in determining the environmental performance of buildings which has been reported in previous. The comparison of LCA used in building certification systems or in general sustainability investigations is difficult because LCA results are implemented in two different ways. The first group uses LCA results implicitly (e.g. LEED), and the second group uses the LCA results explicitly for the assessment procedure. This means that only the second group uses the LCA indicator values for benchmarking and rating (e.g. DGNB/ÖGNI kg CO^2/m^2). Additionally, the different building certification system use different system boundaries, i.e. as shown in this work for building certification system used in Austria.

The results over the whole life cycle for system boundaries 1 (CEN) and 4 (building envelope) point out that a spatial system boundary which only consists of the building products of the building envelope neglects a large number of the environmental indicators and is therefore no longer appropriate for LCA.

Table 5 demonstrates that the cut off criteria for the "complete" system boundary 2 (as used in DGNB/ÖGNI) is meaningfully defined. The total amount of neglected building products included for the environmental indicator values in this case is less than 5%. Whereas when calculating the LCA according to the "simplified" system boundary 3, there is a gap of up to 20% in the environmental indicator values. The results clearly indicate that the safety margin in the DGNB/ÖGNI system for the "simplified" system boundary 3 needs to be adapted (i.e. from the current 1.1 to a future 1.3), whereas the "complete" system boundary 2 is meaningfully defined.

This also seems important with regard to high workload involved in "complete" LCA as currently no commonly accepted methodology to implement LCA in different planning stages exists. However, the depth of LCA should correspond to the project stage. This means that assessing the environmental performance needs to be split up into a pre-certificate during the planning phase and more detailed LCA investigation at the end of the planning phase.

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Conclusion

In the past few years a variety of building certification systems were placed on the market to endorse green and sustainable buildings. Recently, an increasing demand for such labels has been recognized. As has been shown, in the case of Austria, five building certification system are currently used in practice. This paper compares different building certification systems focusing on the implementation of LCA for quantifying the environmental performance of buildings. Moreover, the gap between "simplified" and "complete" LCA is investigated in detail.

The evaluation of building certification systems used in Austria shows that the majority do not include the assessment of the environmental performance with the use of LCA method explicitly and are not currently fully in line with the upcoming European framework of CEN/TC 350. In contrast, the assessment methodology used by DGNB/ÖGNI corresponds to it. While the more commonly used "simplified" LCA calculations method within building certification involves a rather small workload, the results are not satisfactory regarding accuracy. "Complete" LCA calculations are highly complex and involve high workload, and are therefore not applied in practice.

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References

[1]COLE, RAYMOND J ; HOWARD, NIGEL ; IKAGA, TOSHIHARU ; NIBEL, SYLVIANE: Building Environmental Assessment Tools: Current and Future Roles. In: *World Sustainable Building Conference 2005*, 2005

[2]HAAPIO, APPU ; VIITANIEMI, PERTTI: A critical review of building environmental assessment tools. In: *Environmental Impact Assessment Review* vol. 28 (2008), Nr. 7, pp. 469–482

[3]PASSER, ALEXANDER ; KREINER, HELMUTH ; MAYDL, PETER: Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings. In: *The International Journal of Life Cycle Assessment* vol. 17 (2012), Nr. 9, pp. 1116–1130

[4]PASSER, ALEXANDER ; MACH, THOMAS ; KREINER, HELMUTH ; MAYDL, PETER: Predictable Sustainability ? The role of building certification in the design of innovative façades. In: *Advanced Buiding Skins*, 2012, p. 14

[5]WALLHAGEN, MARITA ; GLAUMANN, MAURITZ ; ERIKSSON, OLA ; WESTERBERG, ULLA: Framework for Detailed Comparison of Building Environmental Assessment Tools (2013), pp. 39–60 — ISBN 4670600966

[6]ZABALZA BRIBIÁN, IGNACIO ; ARANDA USÓN, ALFONSO ; SCARPELLINI, SABINA: Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. In: *Building and Environment* vol. 44 (2009), Nr. 12, pp. 2510–2520

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Session 53:

What impact does good ventilation have in energy efficiency?

Chairperson:

Baillon, François

Commercial Director, International Federation of Consulting Engineer (FIDIC), Geneva, Switzerland

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Computerized Numerical Analysis on Stipulations of Taiwan's Localization Design Principles of a Sustainably Built Environment

Speakers:

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Abstract: *Kaohsiung City Government initiated Project Kaohsiung Houses in 2012 and stipulated Ten Key Design Principles and Certification Mechanism, such as Deep Sunshade, Green Roof, Local Building Materials and Technology, Courtyard Design, Universal Design, Environmentally Friendly and Healthy Building Materials and Sufficient Ventilation, as well as the Kaohsiung Residents with Sustainable Development, Localization Identity and Healthy Living. This research compared practical case studies and computerized simulations for the two detached house projects in Kaohsiung City, where both of the houses were designed in compliance with the Ten Key Design Principles of Kaohsiung Houses. To cope with Kaohsiung's high temperatures and high humidity, CFD Simulation Analysis was applied to the aspects of Ventilation and Airflow of the two houses with Quantitative Numerical Analysis and the demonstration of Summertime Ventilation and Environmental Impact to verify the operability of the design principles of the Project Kaohsiung Houses.*

Kaohsiung Houses, Kaohsiung LOHAS Building, CFD Simulation Analysis, Ventilation, Computerized Numerical Analysis

1.Introduction

Taiwan is located in subtropical climate zone, and thus the high temperature, high humidity climatic conditions should be considered (Chiang and Chou, 2000), so that the building in the whole life cycle, from planning and design, construction , use and maintenance to the demolition and reconstruction process, can be corresponding to local natural climate and environment to achieve the targets of saving energy, reducing material consumption, and reducing pollution and waste.

Therefore, Kaohsiung City Government proposed Kaohsiung House Project in 2012, By considering the local climate and geographical environment, the project develops the three core concepts of "sustainable environment", "local self-evident reflection" and "healthy living" with 10 extended design guidelines. It is expected to establish a sustainable Kaohsiung house to solve the problem of the home environment caused by the high temperature and humidity in the Kaohsiung area, to meet the needs and trends of sustainable development, to arouse the community to rethink the positioning of the land environment and how to respond to global environmental change, industrial restructuring, and disaster prevention to create a culturally self-evident environment.

In this study, two single-family detached houses planned and designed according to the 10 design guidelines of Kaohsiung House Project were selected as samples for the case study. We conducted the numerical digital analysis of the ventilation and airflow of the two buildings and compared the verification results. The findings can be a reference for the design guidelines of Kaohsiung House Project. It is expected to find out the really suitable sustainable development model for Kaohsiung according to the climate characteristics of Kaohsiung to improve indoor air quality of the environment and reduce environmental impact to stimulate the development of the construction industry of more high quality and sustainability as a basis for future development of sustainable buildings in Kaohsiung.

2.Literature Review

Natural ventilation can be defined the indoor and outdoor air exchange via a ventilation surface such as doors, windows, etc. generated due to indoor and outdoor pressure gradient(Sandia National Laboratory, 1982). Thus, natural ventilation's main function is to remove or dilute indoor air pollutants to provide an acceptable quality, and provide heat exchange mechanism (CIBSE, 1997), in addition, as the natural ventilation can reduce energy consumption (Sherman and Levin, 1996), therefore, in the initial stages of the development of architectural design, natural ventilation must be considered.

2.1 Computational Fluid Dynamics (CFD)

With the improvement of the computing performance in these 10 years, CFD numerical analysis has been used to predict the building flow field and heat conduction phenomena, and has also been used as an alternative way of determining flow fields inside the building and the surroundings. CFD calculations usually can be divided into three major types: Direct Numerical Simulation (DNS), Large Eddy Simulation (LES) and Reynolds Averaged Navier-Stokes (RANS). RANS is most widely used; it usually has a good predictability of the average velocity of natural convection, and requires a relatively short computation time (Chou, 2012).

2.2 Experimental Facilities

Environmental numerical simulation and test device of this study are described below:

1. The indoor air environment numerical simulation system CFD numerical simulation can be used in the assessment of the architectural design alternatives. It can display the computation of the three-dimensional flow field of unsteady, irregular, dissipative and

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diffusive turbulent in building space and time on the terminal.

2. The smoke flow apparatus: by using the smoke generated by the smoke flow apparatus, to observe the state of the air flow, and thereby to simulate airflow field real environment.
3. The project lamp, by using the heat generated by the bulb of the project lamp, the front and stairwells of the scale model can be heated. The increase in temperature, produce the effect of buoyancy ventilation to simulate the real environment of a building to absorb the sun's heat.

2.3 Test Case

According to the three core concepts of "sustainable environment", "local self-evident reflection" and "healthy living", ten design guidelines are developed for the sustainable building (Table 1). The buildings built based on these principles include "Kaohsiung House I" and "Kaohsiung House II". In this study, we mainly discussed one of the major guidelines "to create effective ventilation openings" in this study.

1. Kaohsiung House I

The base is located in Daliao District of Kaohsiung City of flat ground, facing the road in three directions of 8 meters each side. The front of the house is faced with the land reserved for the market next to a park. It is terraced single-family houses of four stories. The total length of the building is 21.8 meters, the width is 51 meters and the height is 15.6 meters. The length of a standard building floor of one house is 21.8 meters, the width is 5.1 meters and the height is 3 meters. According to Kaohsiung House Project design criteria, patio is set in an appropriate distance from the stairwell and the side window opening is set in the rooftop to take advantage of the principle of hot air buoyancy ventilation, forming a good convection effect to achieve great comfort and comply with the high temperature and humidity climate in

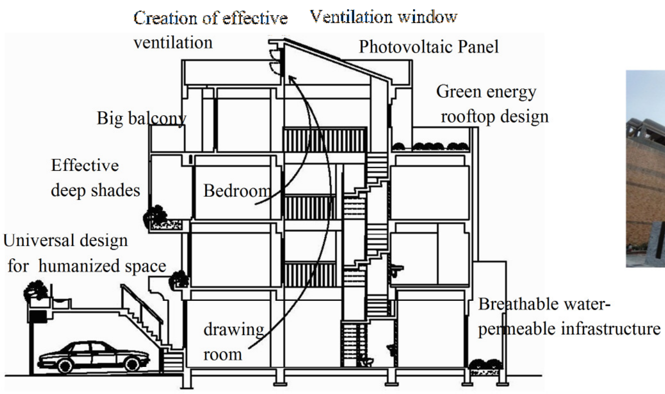

Figure 1 Section of Kaohsiung House I

the Kaohsiung area (Kaohsiung City Government, 2012).

2. Kaohsiung House II

The base is located in a newly developed residential area in Renwu District of Kaohsiung City. It is surrounded by single-family detached houses. The house front is at a distance of 8 meters from the road facing a river. Behind the building, it is the land reserved for the park

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and parking lot. The building is a single-family residential build of four houses of five stories. The total length of the building is 27 meters, the width is 31.2 meters and the height is 3.4 meters, the length of the standard floor of a house of the building is 27 meters, the width is 7.8 meters, and the height is 17 meters. According to Kaohsiung House Project design criteria, a large balcony is designed to increase the natural convection of air and reduce the CO2 content of the indoor air. Good indoor ventilation can effectively adjust the indoor temperature and humidity. In addition to bringing more comfortable residential living space, it can reduce the damage to furniture or appliances caused by moisture (Kaohsiung City Government, 2013).

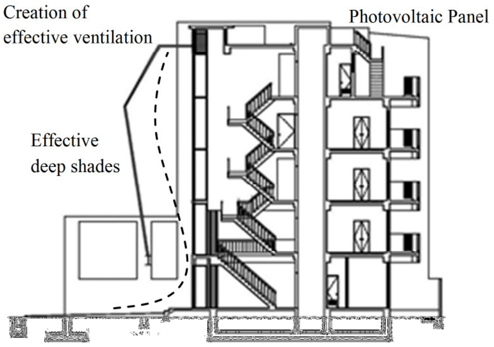

Figure 2 Section of Kaohsiung House II

Table 1 Comparison of design criteria corresponding to two cases

10 Design Guidelines for Kaohsiung House Project	Kaohsiung House I	Kaohsiung House II
1.Effective deep shade	Deep balcony with grill system	Deep balcony, shade, cornice
2.Green rooftop design	Solar panel	Three-dimensional greening, solar panel
3.Breathable and permeable base plate	permeable pavement	permeable pavement
4.The creation of courtyard space	The new type of courtyard space displayed by overlapped large balcony and deep terrace	Community courtyard space flexibly connected by the road-facing terraces on the second floor of each house
5.Imagery design blended with field	Changes in the level of metal grilles and balcony walls and the opposite Tso Chun form the imagery of gurgling river and flowing springs	dark brown grille with rock and brick are the metaphor of rice and the historical memory of Daliao community land
6.Local material and technology introduction	local manufacturers and construction teams	Copper sculpture master, Mr. Xiao Qilang created the local imagery and blended the strengthening of the local memory into the building
7.The creation of effective ventilation opening	A large number of balcony and bedroom large-area windows	The setting of suitable stair well beside the staircase
8. Appropriate spatial function	Increased diversity in staircases and entrance	Comfort and appropriate size for spatial design
9.Application of environmentally healthy building materials	Green Mark Green building materials	Green Mark Green building materials
10. Humane universal spatial design	The door opening minimum clear is 90 cm	The use of each spatial environment will not be different due to age, body and mind

3. Research Design

In this study, computer simulation is the main research method by setting the cases of Kaohsiung House I, Kaohsiung House II as experimental conditions for CFD numerical simulation. In addition, we established scale models of the two cases for smoke flow experiments. By using CFD numerical simulation results and smoke flow experiments, we confirm whether the indoor heat may arise can be smoothly and directly discharged through the appropriate building design meets the design criteria of Kaohsiung House Project to achieve the ventilation and effect .

3.1 Numerical Methods

3.1.1 Basic Assumptions

When Computational Fluid Dynamics (CFD) is applied to analyze the fields of interior space, temperature and concentration of pollutants, the main numerical method is to analyze mass balance, moment balance and energy balance equations of the equation group of Navior-Stokes. Prior to this, we also collected meteorological data of Taiwan Central Weather Bureau to understand the current situation of the air environment of local buildings (Table 4-1), 4 commonly used statistical meteorological factors were: average temperature, average relative humidity , average wind speed, average wind direction for related basic assumptions to simplify the problems.

3.1.2 Physical Model

In this study, we mainly applied RANS, the existing software packages as a predictive tool for the flow field of the built environment to discuss the numerical basis of the model, the basic assumptions and operating settings and geometric boundary conditions of design criteria, and establish the a reasonable value analytical and conditional settings for the application in building ventilation design.

3.2 Flow Field CFD Simulation

To understand the interior space natural ventilation of Kaohsiung House I and Kaohsiung House II, in the numerical simulation, the continuous distribution of physical values can lead to the computational results of the indoor and outdoor air velocity field, temperature field and concentration field. In terms of impact factors, we mainly discussed indoor wind speed, window position and launching design.

3.3 Smoke Flow Experiments

This study used 1:30 scale model of the five-story building of Kaohsiung House II to conduct the smoke flow experiments, and the lead and experimental procedures are as described as follows. The doors and windows of the laboratory exchanging with the exterior environment were shut to prevent the experiments from external interference. By using the project lamp to continuously heat the front and staircase of the scale model to create temperature difference of the air and the effect of buoyancy ventilation. The smoke and position of the smoke flow apparatus is to simulate the wind direction of Kaohsiung House II in summer. Using smoke is beneficial for visual observation of the airflow to understand the path of natural ventilation throughout the building.

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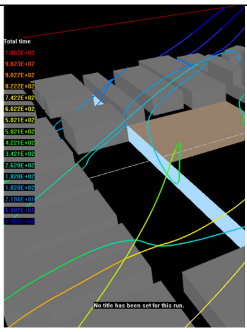
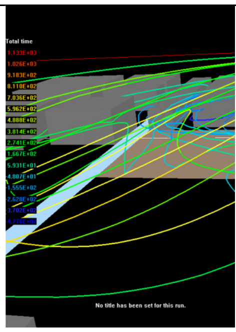
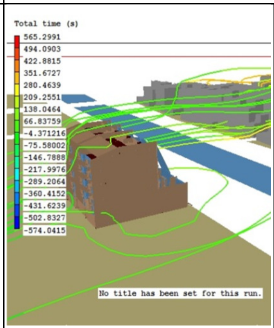
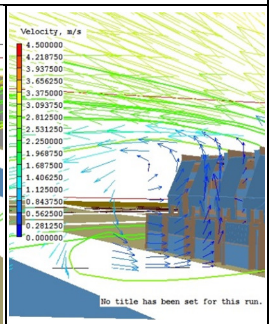
4. Numerical Simulation Results

4.1 CFD Numerical Simulation

Case / Category	Kaohsiung House I		Kaohsiung House II	
Flow Track diagram				

1. Kaohsiung House I

(1) As the surrounding buildings are of 2~4 stories, except for the building on the right above 6 stories to form a wind blocking wall, the area close to the building is mostly in deep blue (approximately windless), in particular, at the height near the ground.

(2) The stagnation flow of the surrounding wind flow filed has no completely windless conditions, in the future, through the opening set, the exterior airflow can be introduced into the indoor space.

(3) It can be learnt from the sectional wind speed distribution diagram: a regional wind shade area can be easily formed at both sides of the building and bottom of neighboring buildings; therefore, the appropriate spacing with neighboring buildings in design can help the air flow surrounding the building.

(4) As shown in flow track diagram, the air vortex phenomenon commonly occurred in the summer in the public reserved land and such phenomenon does not occur in winter.

2. Kaohsiung House II

(1) Since there are no surrounding buildings, the main neighboring buildings are located across the front stream, most of which are 2~4 storied buildings. Only a few buildings are of more than 6 stories. Therefore, it is good for ventilation in summer, and is a barrier in winter.

(2) The wind flow field is open around the building, thus, by setting the openings at the front and back of each story to create cross-ventilation to introduce the exterior airflow into the indoor space.

(3) It can be learnt from the sectional wind speed distribution diagram: in summer, the negative pressure on the front will result in getting ground dirt into the room, thus ground separation device may be considered and the plant filtering effect should be strengthened.

(4) As shown in flow track diagram, in winter, the front façade will stop the cold wind and

force it to move upward and thus the impact of penetrating cold wind is reduced.

4.2 Smoke Flow Experiment

1. This experiment was to simulate the wind direction in summer, namely, the wind blows into the building through the back opening. It can be learnt from the diagram that the airflow direction displayed by the smoke is from the opening in the kitchen to the stairwell (from the back to the front of the building), and moves upward to flow out of the roof opening.
2. As the air absorbs thermal energy in the stair well in the front of the building to generate the buoyance ventilation effect. The pressure gap drives the flow of the air, coupled with the summer wind; the building can have a good ventilation with the help of natural ventilation.
3. It is suggested that openings should be set at the front and back of the building on each floor to produce cross-ventilation, and the launching windows can be set in the stair well to help produce buoyance ventilation. Under such a cycle, the exterior airflow can be naturally introduced into the indoor space to create a good ventilated environment.

5. Conclusion and Suggestions

In this study, we used CFD computer numerical analysis supplemented with smoke flow experiments, focusing on "Kaohsiung House I" and "Kaohsiung House II" designed according to the local sustainable building design criteria in Taiwan, to discuss the establishment of objective and quantitative assessment tools and methods to predict building natural ventilation, providing designers and users in the planning stages of building design with a reference. The research findings can be summarized as the following conclusions:

1. "To create effective ventilation openings" can be realized by large opening and launching window design, through CFD numerical simulation and verification of smoke flow experiment, the interior space can be achieved for good natural ventilation.
2. The flow field characteristics generated by different opening positions and methods may have great changes due to the position of the plants. In addition, we may discuss the air flowability in the case of different types of plants or consider the planting factor in building planning.
3. The Kaohsiung House Project sustainable building design criteria were developed based on the large-scale geographic and humanity environmental factors of Kaohsiung area. In this study, we used CFD to analyze "Kaohsiung House I" and "Kaohsiung House II", and incorporate the environmental climatic conditions around the buildings. The results of simulation verified the feasibility of the design criteria of "to create effective ventilation openings" and proposed the quantitative data and strategy in response to the "micro-environment" climatic factors to improve the efficiency of ventilation openings.

Overall, for the case buildings of this study, we can achieve good natural ventilation for the interior space, suggesting the concern of the local sustainable building design criteria about

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the ventilation function. It provides us with the direction of improvement in local building design planning to achieve the energy saving and low power consumption effect.

Acknowledgement
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References

1. Che-Min Chiang ,Po-Cheng Chou (2000). A Methodology to Assess the Indoor Environment in Care Centers for Senior Citizens, Building and Environment Vol. 36, No. 4.
2. Kaohsiung LOHAS website〈http://pwbgis.kcg.gov.tw/kaohsiunghouse/〉
3. Po-Cheng Chou , Che-Min Chiang, Jian-Jhih Liou, Lo Mao, Ming Chen Ho. (2008). Comparisons on the Indoor Environment Measurement of the Historic Building during the Renovation Steps: Jin-Tang Temple in Jia-Li Town as Illustration. Journal of Architecture No.64 Special Issue on Technology,p1-14. [in Chinese]
4. Po-Cheng Chou, Sin-Hong Lin. (2013). The CFD Simulations on the Improvement of Opening Design via the Natural Ventilation for the House Boat in Sun-Moon Lake , Chinese Institute of Interior and Aechitectural Design, F127-F132. [in Chinese]
5. Public Works Bureau of Kaohsiung City Government. (2012). 2012 Kaohsiung LOHAS Building results. Taiwan: Kaohsiung [in Chinese].
6. Public Works Bureau of Kaohsiung City Government. (2012). The final report of the promotion of the "Kaohsiung LOHAS Building" project. Taiwan: Kaohsiung [in Chinese].
7. Public Works Bureau of Kaohsiung City Government. (2013). 2013 Kaohsiung LOHAS Building results. Taiwan: Kaohsiung [in Chinese].
8. Public Works Bureau of Kaohsiung City Government. (2013). The final report of the promotion of the "Kaohsiung LOHAS Building" project. Taiwan: Kaohsiung [in Chinese].

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Cross Ventilation CFD Modeling: Characterization and Study of Different Façade Openings Configurations at the Refurbishment of a Residential Building in Málaga (Spain)

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Abstract: *The opening of new windows on the façade is proposed as a refurbishment strategy in an existing building in Málaga to facilitate cross ventilation of dwellings. The building is a residential block of 140 public housing units for rent for people with low income in Málaga (Spain), property of the City Council. By modeling with Computational Fluid Dynamics (CFD), eleven configurations of openings are studied in two different areas of the main housing type of the building.*

The quantity of introduced/extracted air into/from the room and the generated airflow patterns are obtained. The modeling allows comparing the different openings configurations to determine the most appropriate ventilation option for every room.

Cross Ventilation, Sustainable Refurbishment, Computational Fluid Dynamics (CFD)

1. Introduction

The European Directive 2010/31/UE announces that Member States should draw up national plans for increasing the number of nearly-zero energy buildings. Namely, the Directive highlights the problems created at peak load times because of the rise in the number of air-conditioning systems in European countries. Natural cross ventilation has great potential as an alternative to conventional air conditioning systems in climates such as Málaga. Therefore, it is proposed as a strategy for the refurbishment of the building under study, a residential block of 140 apartments.

The capacity to predict the behaviour of a fluid such as air was a major advance in the control of this phenomenon and, consequently, also in the product or technology that use it. Since the 90s, the use of numerical simulation programs or Computational Fluid Dynamics (CFD) has increased. These tools are highly developed in some fields of engineering, but its use is very recent in enclosed spaces such as apartments, where there is still some degree of uncertainty about its characterization and modeling. The need to improve energy efficiency in buildings with passive systems such as cross ventilation requires the application of CFD models, finite element models, which allow the evaluation and analysis of these systems at low cost and time, compared to other alternative models. The protocol used in this research defines how to generate the CFD model for enclosed rooms. The application of this protocol in the building under study has enabled to calculate the air exchange that is achieved with each of the openings configurations that were proposed.

2. Background

There are different methods to determine the location and the necessary surface of openings in cross ventilation. They can be classified into two categories [Allard 1998]. Empirical simplified methods use simple mathematical formulas to calculate the inlet and outlet that are required for cross ventilation. Other methods are the iterative computerized methods which are based on computer model simulations.

2.1. Natural ventilation in national regulations and in tools or guidelines of sustainability assessment of buildings

In general, these methods consider only the effects of wind and not those of temperature. They are useful in pre-design stage. Almost all of them are intended for new buildings rather than for existing ones. Most determines minimum surfaces required to illuminate and ventilate the indoor spaces at homes as a measure to ensure their salubrity. They established a ratio of floor space-glazing surface-openings surface.

This is the case of the *Design Standards for Social Housing in Andalucía*, the *Provisional Ordinances for Social Housing (1981)*, various municipal ordinances derived from the *General Urban Plan* of each locality, the *Technology Building Standards* or the Spanish *Technical Building Code* (CTE) in its *Core Document HS3 Salubrity. Indoor Air Quality.* All derived from the *Minimum Hygienic Conditions Act of 29 February 1944*.

The cross ventilation has greater cooling potential than the simple ventilation, up to 3 times higher with the same openable surface [Velasco 2011]. To find specific requirements for cross ventilation is necessary to go to tools or guidelines for evaluating sustainable buildings such as the *Guide to Sustainable Building of the Basque Country*, GREEN, LEED, RESET, PASSIVHAUS or BREEAM.

2.2 Computational Fluid Dynamics (CFD)

These methods combine the effects of wind and temperature, so they do not have the limitations of the previous ones. They are methods for predicting the behavior of air in rooms using a computer. Currently, CFD tools are the most used methods for calculating ventilation flow rates compared to other analytical, empirical or scale models methods [Chen 2009].

The computational fluid dynamics model solves the Navier-Stokes equations using numerical methods. The CFD methods are based on a geometrical model introduced by the user through a graphical interface. From the graph model, the software obtains the boundary conditions which are restrictions to the equations of the fluid in motion. The envelope is the most important element when introducing the model, because it is in contact with the fluid. Once the geometry data is introduced, other data about the fluid such as density, viscosity, pressure, velocity, temperature, etc. are provided. With all these data, the program calculates the fluid variables at all points, and represents them in the graphical model. Thus, it is able to give values of parameters such as pressure and gas velocity, temperature, etc. Due to the nature of natural ventilation physical phenomenon, there is always going to be a high degree of uncertainty. However, these methodologies can be used as tools for dimensioning air inlets and outlets approximately.

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The results can be displayed in countless ways, for example, isolines, maps, directions of flows, etc. It all depends on the power of the program that is used. In this paper, FLUENT software is used which belongs to ANSYS group.

3. Methodology

3.1. Analysis of possible solutions to improve natural ventilation via windows

First, the natural cross ventilation options that is possible to apply in the existing building are evaluated, considering the following aspects:

1. Building typology and morphology: isolated multifamily residential block with semi-open courtyard. The most numerous housing type has opposing façades, but it just has windows on the exterior façade not on the interior one, except the front door to the apartment (Figure 1).

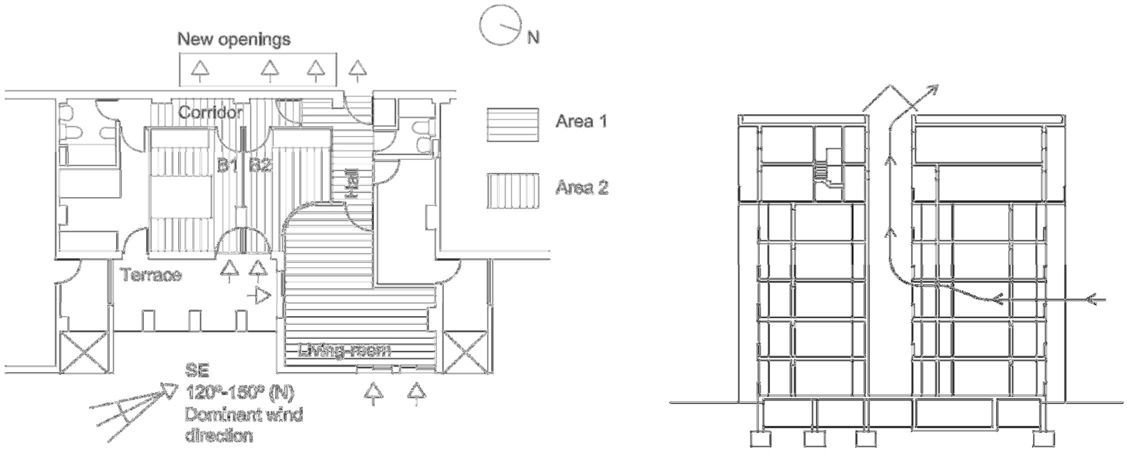

Figure 1. Floor plan of housing type A with Areas 1 and 2 (left). Cross section of the building (right).

2. Climatic zone: warm humid climate (A3, according CTE classification). It is favourable for night cooling and, also, for natural ventilation during the day in warm periods, depending on outdoor temperature. It can be useful also for hygienic reasons throughout the year.

3. Dominant wind direction: velocity, frequency and wind direction obtained from the compass rose of Málaga (Figure 2). Pressure zones (windward) and suction (leeward) in building are determined, considering also the obstacles to the arrival of the wind. The East and West façades receive wind from SE (120°-150° to the North) with different speeds and frequencies. The interior walls (courtyard) are sheltered from the wind.

4. Distribution, size of openable windows, opening systems and complementary elements (sun protection, etc.): façade openings are analyzed and it is verified that housing type A fulfills geometrical requirements of the VERDE tool criterion *D11 Ventilation efficiency in areas with natural ventilation* [GBCe 2011].

3.2. Geometrical definition of the different façade openings configurations

To enhance natural ventilation, it is proposed to open new openings in the interior façade, facing those of exterior façade (Figure 1). The size of the new openings fulfills the minimum openable surface required in CTE DB HS3, 1/20 of floor area, adapted to the structure and

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geometry of the space. The different cases presented in location and sizes aim to analyze different possible circulation of air flow inside the apartment to select those that meet best the needs of the user (Table 1).

		Inlets							Outlets	
Area 1	Living-room A=18.91m² A/20=0.95m²	1	2	3	4				Hall A=4.14m² A/20=0.21m²	1-4
Area 2	Bedrooms B1: A=11.14 m²; A/20=0.56 m² B2: A=8.34 m²; A/20=0.42 m²	5	6	7	8	9	10	11	Corridor A=1.17m² A/20=0.21m²	5-11

Table 1. Possible openings configurations on façades of Area 1 (living room-hall) and Area 2 (bedrooms-corridor).

3.3. Definition of operational conditions for CFD modeling

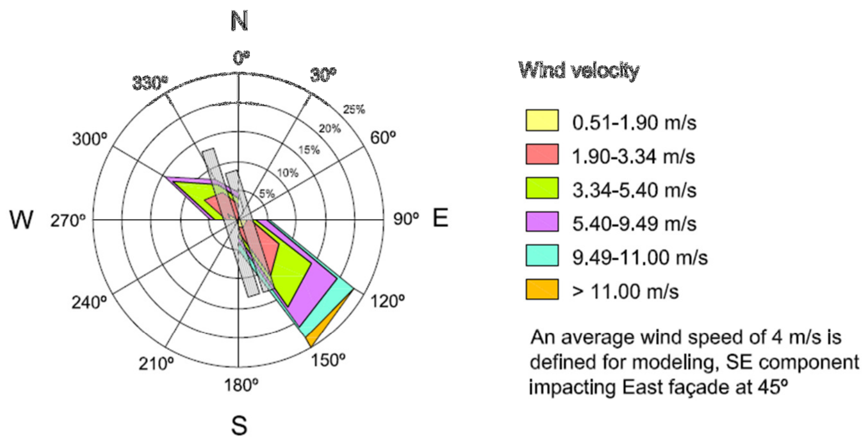

Figure 2. Boundary conditions. Building orientation with respect to the annual compass rose of Málaga [Source: Mapa estratégico de ruido Ciudad de Málaga, Ayuntamiento de Málaga]

First, the orientation of the building with respect to the dominant wind direction is checked. Then, the direction and characteristic intensity of the wind is determined from the compass rose (Figure 2). Finally, the pressure coefficient applied to the opening is calculated in vector form with the following formula (Table 2):

$$\Delta P_{wind} = \frac{1}{2} C_p \rho v^2$$

The suction effects are not considered at leeward, on the outlets, because they are sheltered from the wind. So, ambient pressure is considered, without wind effects.

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	Pressure coefficient (Cp)	Wind velocity (v)	Pressure (ρ)
Windward	0.3	2.828 m/s	0.9487
Tangent	0.1	2.828 m/s	0.3162
$|\rho|$			1.549 Pa

3.4. CFD modeling

ANSYS Fluent software is used for the implementation and development of the CFD models. Geometry of Zones 1 and 2 is generated by modeling all possible inlet and outlet openings (Figure 3). In Zone 2, the furniture (a double bed and two wardrobes) is modeled so that the predicted flow is more realistic. The details about the selection of the turbulent model, the near-wall treatment, the type of mesh used and the resolution can be found in the Final Project "Calculation CFD protocol for coefficients of heat transfer by convection in enclosed rooms" (Solleiro 2013).

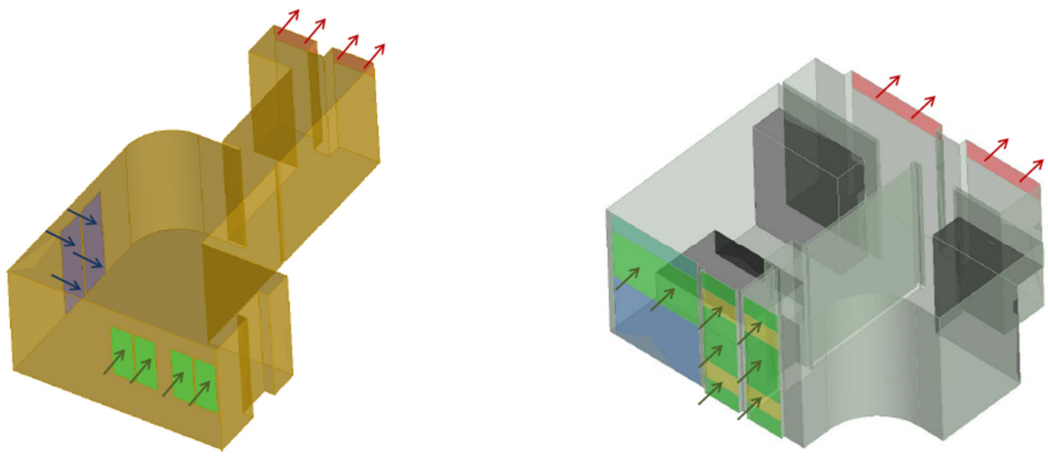

Figure 3. Geometry generated with ANSYS Fluent for Area (left) and Area 2 (right) with inlets (green, blue and yellow) and outlets (red).

4. Results

The air flows obtained by CFD modeling are summarized in Table 3.

		Area 1					Area 2						
		1	**2**	**3**	**4**		**5**	**6**	**7**	**8**	**9**	**10**	**11**
Q	kg/s	0.934	0.945	0.937	0.933		1.578	0.747	1.167	0.759	1.179	1.177	1.647
	1/h	46.11	46.65	46.26	46.06		87.20	41.28	64.56	41.94	65.15	65.04	91.03
So (m2)	Inlet	2.82				D1	2.02	0.29	0.58	0.29	0.58	0.58	3.73
						D2							2.02
	Outlet	0.66					1.17						
So/A (%)	Inlet	15				D1	18	3	5	3	5	5	34
						D2	24	4	7	4	7	7	24
	Outlet	16					28						
V (m³)		59.528					53.180						

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Table 3. Airflow introduced/extracted into/from the room (Q), openable surface (So), ratio openable-area-to-floor-area (So/A) and volume (V)

In the living room area, the same air change is observed in all cases. This is due to the assumption that the vector components of the wind affect the same way in the South and East orientations. So, the higher the inlet surface, the higher the level of ventilation. In Cases 1 and 4, it is noteworthy that a better air sweep occurs without producing recirculation (Figure 4). Case 4 is the most favorable for nocturnal ventilation because the air flow is projected on two walls of the apartment with thermal inertia. Additionally, the sliding windows could be replaced by folding ones to increase the ventilation of the room in order to get more cooling capacity.

In the bedroom area, it happens something similar. The air changes increase as the inlets surface increases. However, when adding one more opening in bedroom 1, Case 11 shows that it is not achieved a significant increasement in air changes with respect to Case 5. This is because the level of ventilation by the action of wind has already saturated the room. So, this solution is rejected. Case 5 is the one that gets more air changes. The openings in Cases 6 and 8 are sufficient to achieve a similar level of ventilation to the one of the living room area, with better air flow pattern in Case 6 than in 8 (Figure 5). Cases 7, 9 and 10 reach an intermediate level of ventilation. Case 10 shows more appropriate flow distribution for night ventilation.

Figure 4. Flow lines for Area 1 generated with ANSYS Fluent. Cases 1 (left) and 4 (right).

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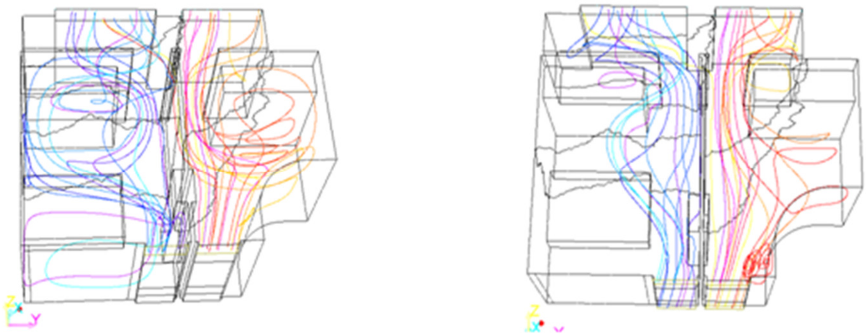

Figure 5. Flow lines for Area 2 generated with ANSYS Fluent. Cases 6 (left) and 10 (right).

The velocity of air is limited to an average value of 1m/s except in walls in front of inlets where the velocity is around 1.5 m/s and near the outlets where the maximum value is 2.5 m/s because the inlet size is much bigger than the outlet one, up to 4 times bigger in the living room-hall area and up to 3 times larger in some of the cases of the bedrooms-corridor area (Case 11).

5. Conclusion

The opening of new windows in the housing type A, on the inner façade of the semi-open courtyard, provides adequate levels of ventilation in living room and bedrooms. Even with inlets size smaller than A/20 (CTE DB HS3 Salubrity), a good ventilation level is generated under the wind conditions of this case study. The air changes achieved with cross ventilation exceed by far the minimum air changes required by the CTE DB HS3 Salubrity (around 1/h).

In Area 1 (living room-hall), with 100% of the inlets opened, air changes around 46/h are achieved (Cases 1-4). This is a similar value to Cases 6 and 8 which have much smaller inlets in bedrooms. The smaller oultlet size of Area 1 than in Area 2 may be the reason of this similar value. The ratio openable-surface-to-floor-area is 16% in Area1 and 28 % in Area 2.

In Area 2 (bedroom-corridor), with 100% of the inlets opened, air changes around 90/h are achieved (Cases 5 and 11). If the inlets are reduced to 30%, the air renewal decreases to 65/h, 75% lower (Cases 7, 9 and 10). When the inlets are reduced to 15%, the air renewal decreases to 40/h, around 50% less (Cases 6 and 8). Openable-surface-to-floor-area ratios are between 15-25% for higher air changes (Cases 5 and 11), 5-7% for intermediate (Cases 7, 9 and 10) and 2-4% for the lowest. As you reach the 25-35% range of openable-surface-to-floor-area ratio the increasement of air changes due to the bigger size of openable surface is less significant (Case 11).

References

Allard, Francis (Ed.) (1998). *Natural ventilation in buildings: a design handbook*. London. James & James Science Publishers.

Chen, Qingyan (2009). Ventilation performance prediction for buildings: A method overview and recent applications. *Building and Environment*, 44: 848-858, doi: 10.1016/j.buildenv.2008.05.025.

GREEN BUILDING COUNCIL ESPAÑA (GBCe) (2011): *VERDE RO. Guía para los evaluadores acreditados (Nueva edificación. Multirresidencial y oficinas).*

Solleiro Bellón, Andrés (2013). Proyecto Fin de Carrera "Protocolo de cálculo CFD de coeficientes de tranferencia de calor por convección en recintos". Escuela Superior de Ingenieros, Universidad de Sevilla.

Velasco Roldán, Luis (2011). *El movimiento del aire condicionante de diseño arquitectónico.* Madrid. Catálogo de publicaciones de la Administración General del Estado, Ministerio de Fomento.

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Evaluation of ventilative cooling in a single family house - Characterization and modelling of natural ventilation

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***Abstract**: Passive cooling through window airing presents a promising potential for low energy houses in order to avoid overheating risks and to reduce energy consumption of air conditionners. One barrier against this solution is the complexity of evaluating air flows, which limits the use of natural ventilation during the design phase of a building. This study aims at analyzing a characterization and modelling process allowing natural ventilation to be accounted for in the evaluation of energy performance and thermal comfort of a single-family house. The evaluation of summer comfort and passive cooling performance will be compared to measurements performed on a zero energy house Maison Air et Lumière, located near Paris. Window characterization, on-site air flow measurements, as well as ventilation evaluation method will be described in this paper; the accuracy of the evaluation method (ventilation flow rates and thermal comfort) will be assessed thanks to a specific measurement campaign.*

Ventilative cooling, natural ventilation, airflow, windows, summer comfort, night cooling.

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Introduction

Low energy buildings, especially nearly Zero Energy Buildings (nZEB), are subject to significant overheating risks during summer and mid-season [1] [2]. Thermal simulations as well as experimental studies has shown the large potential of ventilative cooling; nevertheless, these studies were mainly focused on potential energy savings in office or commercial buildings [3] [4] and only few papers were published on the cooling potential of natural ventilation in dwellings.

One major barrier against the use of natural ventilation in the design process of a house is the difficulty of evaluating air flows through windows opening. The use of appropriate hypothesis and relevant coefficients regarding windows is crucial to perform building thermal simulations and accurately evaluate indoor thermal comfort of occupants.

The present work aims at studying a characterization and modelling process allowing natural ventilation to be accounted for in the evaluation of energy performance and thermal comfort of buildings. The approach is tested using the monitoring system of the zero energy Active House Maison Air et Lumière, located near Paris.

The project went through the following steps:

- A test bench has been used to characterize the air flow features of a roof window (such features of roof windows are not well described in literature)
- These air flow features have then been used for numerical simulations of the air flows and air temperatures in the building
- On site measurements of air flows and air temperatures have been performed in order to get realistic data about natural ventilation and its contribution to summer comfort
- Comparisons between simulations and on site measurements have been performed in order to validate the models used to evaluate air flow rates through windows. These comparisons are also used for checking the relevancy of numerical simulations in terms of summer comfort

Laboratory measurements

A test bench has been built in a laboratory in order to evaluate aerodynamic features of a roof window. A ventilator is used to create a regulated pressure difference between inside and outside environments of the roof window.

Air flow rates and pressure differences have been varying in order to get a curve and to derive C and n characteristics from the below empirical equation (powerlaw) [5] [6]:

$$Q = C.(P_2 - P_1)^n = C.(\Delta P)^n \qquad (1)$$

Figure 1: Test bench: aerodynamic chamber and regulated ventilator

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The flow coefficient C is depending on the free opening area (geometrical area), which is linked to the window size and opening angle. The flow coefficient can then be evaluated using the free opening area S, a discharge coefficient $C_d$and the air density ρ, using the following equation $C = C_d.S.\left(\frac{2}{\rho}\right)^n$. Measurements were performed for ΔP varying from 0.05 to 10 Pa. The log-linearization of equation (1) gives $Log(Q) = Log(C) + n.Log(\Delta P)$

An example of a fully opened window is shown in Figure 2.

It shows a log-linearization of measurements for a full opening of the window (maximum length of the actuator), measured for a large range of ΔP.

In this figure, $n = 0.45$ and $C = 0.32$.

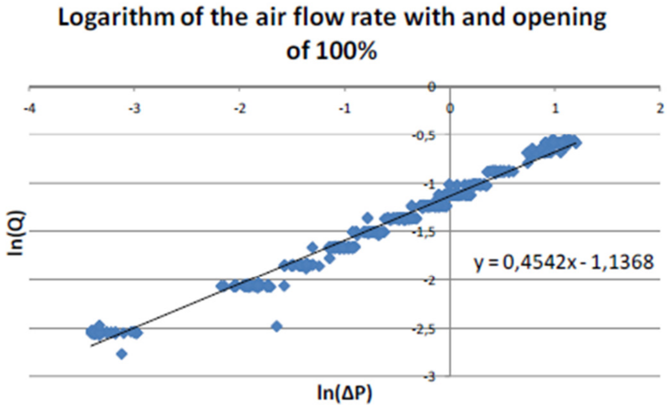

Figure 2: Logarithm of the air flow rate with an opening of 100%

Similar measurements are performed for different openings. All C and n coefficients are shown in Table 3.

With the assumption that the opening area S is around 0.07 m² (, we find a Cd value $C_d = \frac{C}{S}.\left(\frac{\rho}{2}\right)^{0.5}$ of around 0.75, which is near the standard values [7] [Etheridge, 1996].

Window opening percent [%]	n coefficient	C coefficient
50	0.49	0.074
60	0.46	0.12
70	0.45	0.17
80	0.48	0.22
90	0.45	0.27
100	0.45	0.32

Table 3: Air flow characteristics of the roof window

On site measurements

The house extends over 2 storeys, 135 m² and is designed as a net zero energy house. Concrete slab on the ground floor and first floor are providing its thermal mass. The window-to-living-area is 1/3. All windows are equipped with dynamic solar protection and the operation of all systems in the building is fully automated.

The house is equipped with a detailed monitoring system providing event-logged data for both indoor and outdoor environments: indoor

Figure 4: The nZEB Active House Maison Air et Lumière, located near Paris. © Adam Mørk

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temperature, humidity, light level, as well as outdoor wind speed and direction, sun radiation and temperature, are continiously monitored and recorded. Windows and awning blinds positions are continiously recorded in order to bring a complete description of the house: these input data will then be used with the dynamic simulation software Pléiades+Comfie for evaluating the complete approach of ventilative cooling.

The evaluation of on site air flow rates passing through this house were performed with tracer gas measurements using CO_2. In addition, wind velocity and pressure sensors were placed within the free opening areas of windows in order to validate the precision of the simplified models used for simulations (i.e. the “powerlaw” described in equation (1)).

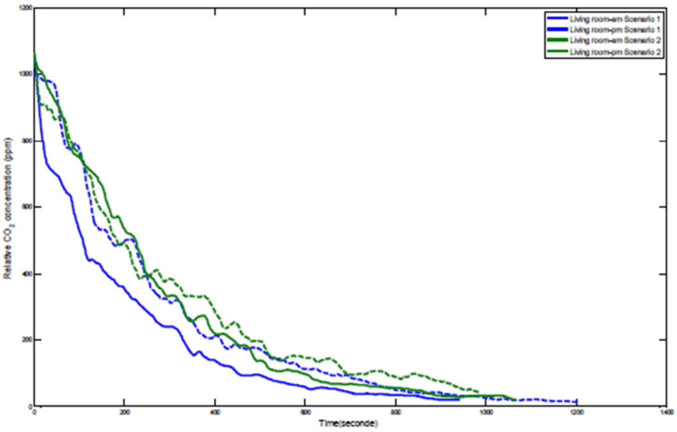

Figure 5: Relative CO_2 concentration in the living room during CO_2 decay test

Figure 5 shows as an example the relative CO_2 concentrations (CO_2 concentration above outdoor level), measured in the living room for the two scenarios: internal doors being opened (blue curve) or closed (green curve). The continuous lines and the dashed lines respectively correspond to the measurements during the morning and the afternoon.

The calculation of the air change rate is deduced from the general tracer gas mass balance equation [8]:

$$V.\frac{dC_{int}(t)}{dt} = S(t) - Q(t).\left(C_{int}(t) - C_{out}(t)\right) \qquad (2)$$

Where:

- $C_{int}(t)$ is the CO_2 concentration of indoor air (ppm)
- $C_{out}(t)$ is the CO_2 concentration of outdoor air (ppm)
- $S(t)$ is the injection rate of tracer gas into the room (m^3/h)
- V is the indoor air volume (m^3)
- $Q(t)$ is the air flow rate (m^3/h)

Integration of equation (2) leads to an exponential function where the concentration is a function of time $\left(C_{int}(t) - C_{out}(t)\right) = C.e^{\frac{-Q.t}{V}}$ where C is a constant.

After log-linearization, the relative tracer gas concentration can be plotted against time and a linear regression gives the corresponding air change rate (being the slope of the line).

Air flow simulations

Thermal numerical simulations have been carried out in order to understand the behaviour of the building. The study of natural ventilation is then improved by using both thermal and air-flow models.

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Air flow simulations requires data about wind pressure on external sides of windows. These pressures can be evaluated according to wind velocity and direction using pressure coefficients C_p. The software "Cp generator"[1] was used in this study to evaluate C_p values of the windows.

Air flow simulations have been performed using CONTAM 7, allowing infiltrations, windows and room-to-room airflows to be evaluated, taking into account mechanical systems, wind pressures on windows and buoyancy effects.

CONTAM simulations were performed using laboratory measured C_d and n for roof windows – 0.75 and 0.5, respectively – and default CONTAM values for vertical windows $-\ C_d = 0.6$ and $n = 0.65$ [9].

Each tracer gas measurement period has been simulated using CONTAM. Table 6 shows the comparisons between on-site measured values and simulations output.

		South bedroom temp [°C]	North bedroom temp [°C]	Bathroom temp [°C]	Wind speed [m/s]	Tracer Gas [ACH]	CONTAM simulation [ACH]
Morning	Closed door	23.7	21.3	22.5	3.6	13.4	13.9
	Open door	23.7	21.3	22.5	2.8	22.5	20.6
Afternoon	Closed door	27.1	26.5	26.2	2.3	13.2	16.6
	Open door	27.1	26.5	26.2	2.3	19.8	19.5
Morning	Closed door	24.2	22.5	23.3	3.6	13.4	14
	Open door	24.2	22.5	23.3	3.6	14.6	17.4
Afternoon	Closed door	26.5	25.2	25	2.9	10.6	13.2
	Open door	27	26.1	25.6	2.8	13.1	17

Table 6: Measured and simulated Air Change per Hour (ACH)

Thermal simulations

A dynamic thermal simulation tool was used to evaluate temperature profiles in the house [10] based on measured outdoor conditions. It turns out that air change rates have a large influence on temperature profiles.

Different measurement and simulation conditions were used to compare typical cases and present the direct influence of natural ventilation on indoor thermal environment:

- From 23rd to 26th of July 2012 without any natural ventilation
- From 27th of July to 3rd of August with natural ventilation (all windows open) and internal doors open
- From 4th to 7th August with natural ventilation (all windows open) and internal doors closed.

[1] cpgen.bouw.tno.nl/cp/

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Figure 7 shows simulation and measurement results during the second period (internal doors open). There is a good correlation between simulated (blue) and measured temperature profiles (green), whereas the impact of night ventilation can easily be seen from the external temperature curve (red line).

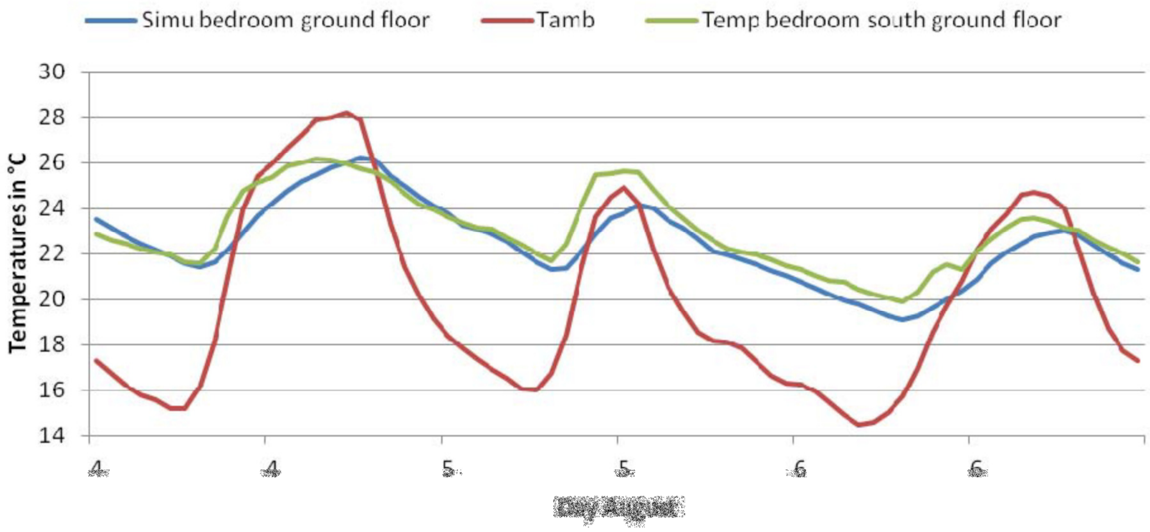

Figure 7: Comparision of simulated and measured indoor temperature in the ground floor bedroom. All windows open and all internal doors closed

As a reference, simulations with closed windows have been carried out in order to evaluate the potential of ventilative cooling in a single family house. Figure 8 shows a comparison between "free-running" temperature (windows closed, in green), natural ventilation (windows open, in blue) and exterior temperature (in red).

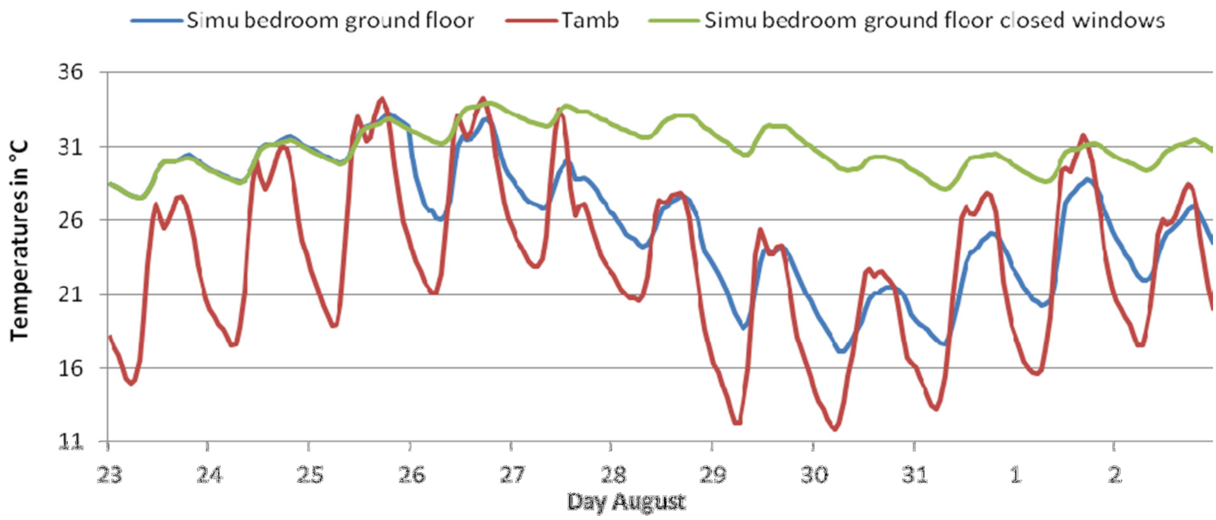

Figure 8: Comparison on simulation cases. In green: all windows closed. In blue: all windows open. In red: outdoor air temperature

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Feedback on occupation period

In order to confirm the house indoor climate, especially its summer thermal comfort, a family of 4 moved into the house from September 2012 to August 2013. This family lived inside the house for one year without any restrictions on their behaviour and use of the automated

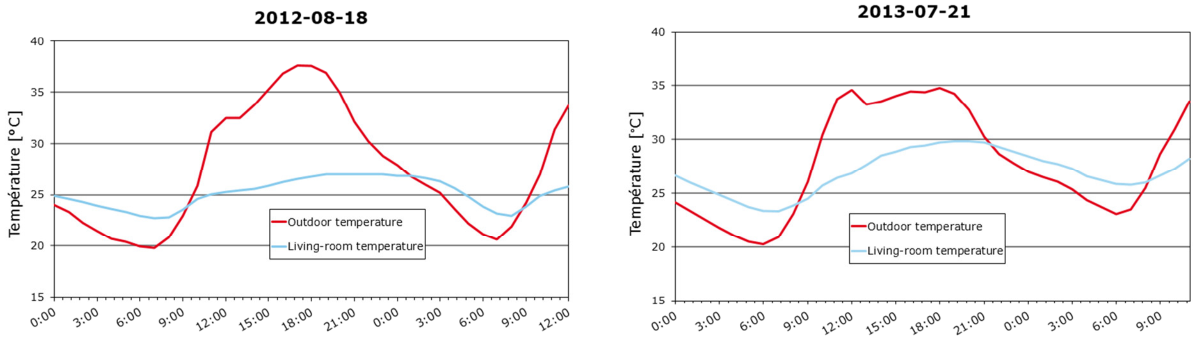

Figure 9: Comparison of ventilative cooling benefits during a heat wave in unoccupied (left) and occupied periods (right). Blue: indoor temperature. Red: outdoor temperature

system: wall-mounted push buttons were installed in order to allow a by-pass of windows openings or blinds moves. Figure 9 shows a comparison between a free running system (summer 2012, no occupants) and a "real case" scenario (summer 2013, 4 people inside the house) during a heat wave of the summer period.

It can be seen from Figure 9 that indoor temperature was 11°C lower than exterior temperature during unoccupied period, while the difference during the occupied period was 8°C. This deviation could be explained by the "real use" of the house, which leads to frequent opening of doors and sliding-doors, letting the outside warm air enter into the house. The presence of four people inside the house led to higher internal gains which added a significant heat source inside the house. In addition, the family got used to limit window openings during night time so that they were not disturbed by the wind effects while sleeping.

The indoor thermal comfort, as described before, has been described by the family after summer 2013:"When we were arriving inside the house, the heatwave still was present and the exterior air was above 30°C, and the temperature was 24 to 25°C inside the house without any other cooling system than natural cooling"[2].

Conclusion

Measurements performed in Maison Air et Lumière have shown that, without ventilation, indoor temperature can reach 35°C. Ventilative cooling allowed a fast decrease of indoor temperature, keeping rooms below 27°C most of the time: this has shown that ventilative cooling was very efficient during this period.

During typical indoor and outdoor conditions – wind speeds between 2 to 3 m/s and temperature a difference lower than 3 °C – Air Change Rates between 10 to 22 h^{-1} have been

[2] Quote from inhabitant of Maison Air et Lumière. Final conference Decembre 2013 « *L'habitat de demain : au-delà des expériences. Retour sur l'expérience Maison Air et Lumière VELUX MODEL HOME 2020* »

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achieved. Air flow rates, measured on site and simulated with CONTAM, have shown a very good predictability with an average difference of 10% and local differences up to 30%.

In addition, dynamic thermal simulations have reproduced the indoor air temperature quite precisely, with an average difference between calculated and measured values around 1K. The accuracy of these simulations has allowed to evaluate the potential of ventilative cooling, by comparing 2 similar cases with and without natural ventilation during night. Indoor temperatures have then been reduced by 5°C on average thanks to ventilative cooling.

This work shows the feasability of modeling ventilative cooling and its impact on indoor thermal comfort for a project: it has been illustrated in this work, and could be extended to the design process of a project, assuming that relevant weather data are available. Natural ventilation provides a relevant way to achieve carbon neutral passive cooling in nZEB houses; thermal simulations have shown good correlation on temperature and the relevant air flow models used in this study could now be implemented into national regulatory softwares assuming the use of an efficient thermal model.

References

[1] Lomas, KJ. (2012). Summertime temperatures in 282 UK homes: thermal comfort and overheating risk. *The changing context of comfort in an unpredictable world* (7th Windsor Conference, London).
[2] NHBC Foundation (2012). Overheating in new homes. A review of the evidence.
[3] Artmann, N. (2006). Climatic potential for passive cooling of buildings by night-time ventilation in Europe. *Integrating Environmentally Responsive Elements in Buildings* (4th Annex, 44 Forum, Torino).
[4] Yao, R. (2009). Assessing the natural ventilation cooling potential of office buildings in different climate zones in China. Renewable Energy (Volume 34, Issue 12, pages 2697-2705).
[5] Axley, J. (2002). Modeling the Performance of a Naturally Ventilated Commercial Building with a Multizone Coupled Thermal/Airflow Simulation Tool. *ASHRAE Transactions 2002* (V. 108, Annual Meeting, Honolulu, pages 1-16).
[6] [9] Walton, G. (2010). CONTAM User Guide and Program Documentation (Report NISTIR 7251, Gaithersburg).
[7] Etheridge, D. (1996). Building Ventilation: Theory and Measurement. Wiley.
[8] Cheong, K.W. (2001), Airflow measurements for balancing of air distribution system-tracer-gas technique as an alternative?. *Building and Environment* (Volume 36, Pages 955–964).
[10] Peuportier, B. (1990). Simulation tool with its expert interface for the thermal design of multizone buildings. *International Journal of Solar Energy* (Volume 8, Pages 109-120).

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Conversion from CAV to DCV with reuse of existing ductwork

Abstract:

Most existing non-residential buildings have Constant Air Volume (CAV) ventilation leading to over-ventilation in periods with low or no occupancy. Demand controlled ventilation (DCV) can considerably reduce the ventilation airflow rate and energy use for fans, heating and cooling compared to CAV ventilation.

Conversion from CAV to DCV with reuse of exiting ductwork has been done in an office building Norway. The building was originally built in the early eighties and is considered to be representative for a large number of buildings in need for an upgrade.

Reuse of existing ductworks was very profitable. The ductwork cost in Solbraaveien 23 was roughly cut in half compared to the alternative which was demolition and new ductwork installation.

Conversion from CAV to DCV was one of several energy measures carried out in Solbraaveien 23. Total delivered energy use was reduced from 250 kWh/m^2 to 80 kWh/m^2, and the indoor environment was improved.

Conversion, CAV, DCV, Reuse, Ductwork

Introduction

CO_2 emissions from buildings must be reduced from 50 MtCO_2 in 2010 to 5 MtCO_2 in 2050 in the Nordic countries to avoid severe problems of global warming [1]. A consequence for the building sector is that a widespread conversion of buildings to very low energy consumption and even zero energy buildings is necessary.

Demand controlled ventilation (DCV) can considerably reduce the ventilation airflow rate and energy use for fans, heating and cooling compared to constant air volume (CAV) ventilation [2] due to relatively low simultaneous occupancy in office buildings [3].

The central ductwork-components will have more capacity in a DCV-system than in a CAV-system because of limited simultaneous use. Hence, conversion from CAV to DCV with reuse of existing ductwork could increase the system capacity and actually solve a former capacity problem. There is a potentially huge upcoming marked for converting from CAV to efficient DCV in existing commercial buildings [4].

Conversion from CAV to DCV with reuse of existing ductwork has been done in Solbraaveien 23 in the municipality of Asker, which is a Norwegian office building in the Oslo area. The building was originally built in the early eighties and is considered to be representative for a large number of buildings in need for an upgrade. This paper presents this conversion in Solbraaveien [5].

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Description of Solbraaveien 23

Solbraaveien (Figure 1) is an office building built early in the eighties.

Figure 1. Solbraaveien 23 before and after refurbishment.

It was originally built with CAV-ventilation with reports of annoying noise from the ventilation system. The air inlet was below the windows, blowing upwards with room air induction. Such air inlet is space consuming (Figure 2).

Figure 2. Left, the old air-inlets were space consuming. Right, after retrofitting.

The following main retrofit measures were carried out:

- New air-handling-units
- Conversion from CAV to DCV
- The windows were changed, new U-value of 0,8 W/m^{2}K
- Additional insulation on walls and roof
- Reduced leakage
- Air-water heat pump

Total delivered energy use was reduced from 250 kWh/m^2 before retrofitting to 80 kWh/m^2 after retrofitting and the indoor environment was improved [5].

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Premises and procedure for re-use of existing ductwork

The procedure for re-use is developed by the entrepreneur (GK AS) and SINTEF in the R&D-project UPGRADE Solutions [5]. It is existing ductwork at the "user-side" of the air-handling-unit that is of interest to re-use in upgraded DCV.

A stepwise procedure is shown in figure 3.

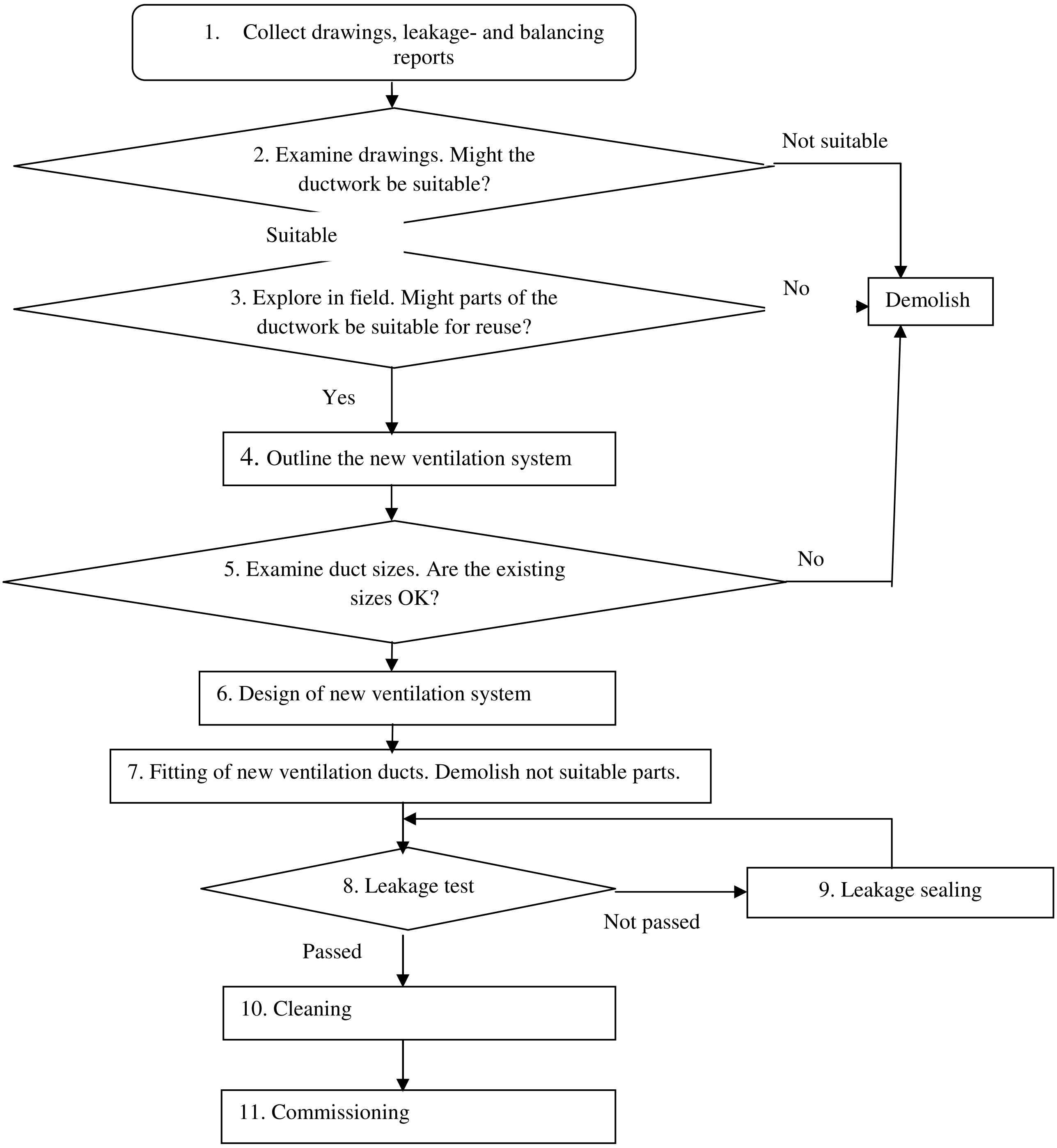

Figure 3. Stepwise procedure for re-use of duct-work.

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The ventilation system is upgraded with the use of variable supply air diffusers (VSAD). The DCV-units (same as VAV-damper) are integrated in the air diffusers, making it espcially suitable for upgrading to DCV. Figure 4 shows a schematic diagram where variable supply air diffusers are regulated by a controller, and communication is performed via bus.

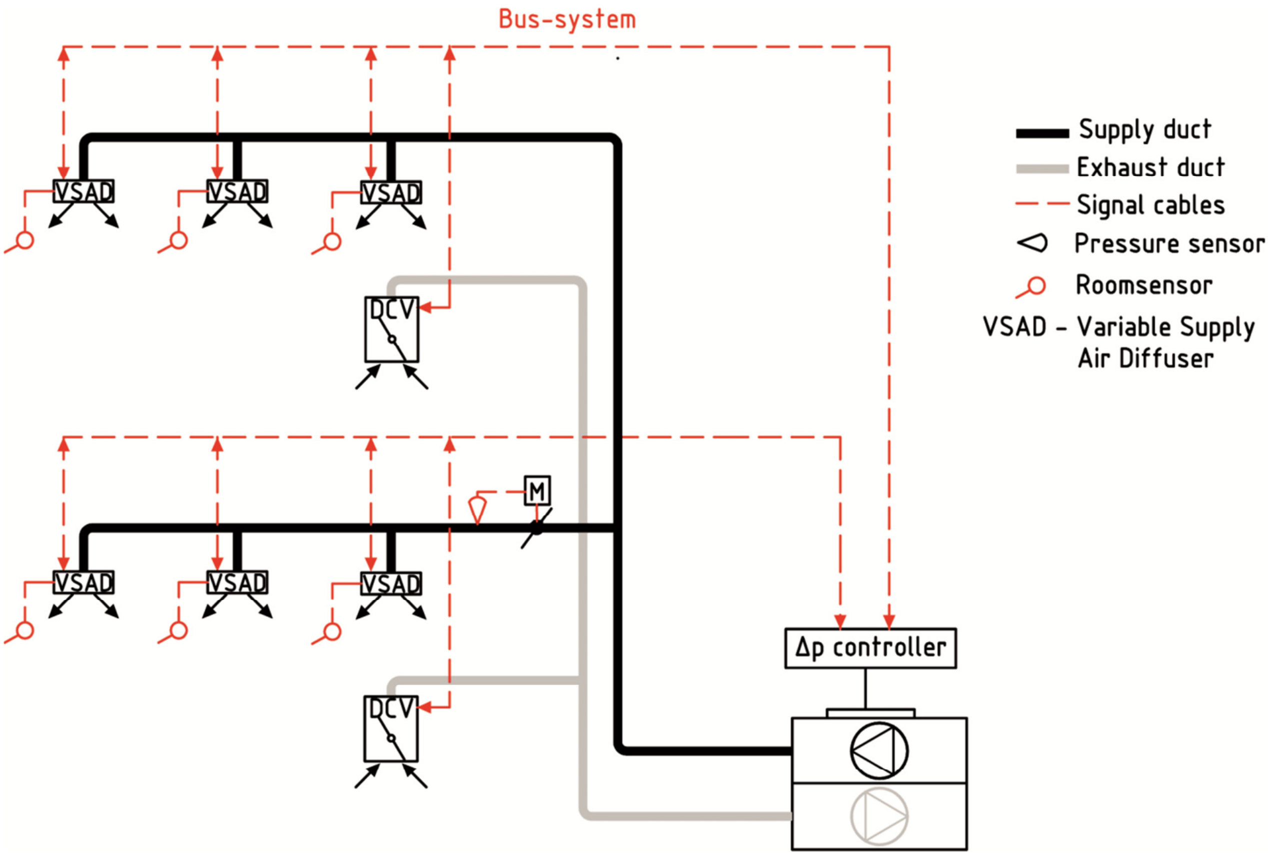

Figure 4.Schematic diagram with VASD regulated by a main controller.

The controller records the required airflow rate, the supplied airflow rate and the damper angle for all the DVC-dampers, and regulates the fan speed such that one of the VSAD is in a maximum open position opened on the supply side, and such that one of the DVC-damper is in a maximum open position on the exhaust side. The integrated motor-driven damper makes sure that the pressure remains in the working range of the VSADs. This damper should normally remain in a maximum open position and only throttle if the pressure in the duct becomes too high relatively to the working range of the VSADs. Such a situation can happen in the branches closest to the fan in large ventilation systems.

VSAD is combined with overflowing arrangement from the offices to corridors and outlets controlled by traditional VAV-dampers.

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Table 1. New and re-used parts of the ventilation system after retrofitting.

Ductwork	90-95% is re-used
Air inlets	New VSAD
Air outlets	New, controled by new VAV-dampers
Air-handling-units (AHU)	New
All ventilation-parts between outside air and AHU (main building air-intake and air exhaust)	New

Investment costs for re-use versus new ductwork

Table 2 shows the estimated costs in Solbraaveien 23 compared with a new ductwork-solution. Additional costs related to demolishing or fitting of new duct-work is roughly estimated based on Norwegian prices and experiences from Solbraaveien which has a total net area of 10.000 m^2.

Table 2. Costs with reuse of ductwork compared with new ductwork.

Activity	*Total cost in Solbraaveien (with reuse) [Euro/10.000 m^2]*	*Total costs with new ducts (traditional solution) [Euro/10.000 m^2]*
1. Collect drawings, leakage- and balancing reports	1 250,-	
2. Examine drawing. Might the ductwork be suitable?	1 250,-	
3. Explore in field. Might parts of the ductwork be suitable for reuse?	1 250-13 000,-	
4. Outline the new ventilation system	No difference	
5. Examine duct sizes. Are the existing sizes OK?	2.500 – 6.000	
6. Design of new ventilation system	0	
7a. Demolish not suitable parts.	19 000,-	150 000 – 200 000,-
7b. Fitting of new ventilation ducts	50.000-62.500,-	400 000 - 500 000,-
8. Leakage test	No difference	
9. Leakage sealing	6.250	
10. Cleaning	112.500 -225.000	
11. Commissioning	0	
12. Unforeseen costs		
SUM	194 000 – 328 000	550 000 – 700 000

This rough estimate shows that reuse was a very profitable alternative to new ventilation ductwork in Solbraaveien 23. Maximum additional cost for reuse was estimated to 40 Euro/m^2, while the minimum alternative cost for demolishing and installation of new ductwork was estimated to 70 Euro/m^2. Reduction of the demolishing costs is an important cause of the profitability.

Discussion and conclusions

Conversion from CAV to DCV was one of several energy measures carried out in Solbraaveien 23. Total delivered energy use was reduced from 250 kWh/m^2 to 80 kWh/m^2, and the indoor environment was improved.

Reuse of existing ductwork might require some compromises when it comes to normal requirements for specific fan power, maximum air velocity, noise generation and leakage. Before considering ductwork reuse, one has to clarify that the builder owner has a pragmatic attitude towards such normal requirements.

Furthermore, one must clarify if the ductwork is suitable for reuse as early as possible in the process. Based on the experiences from Solbraaveien 23, it is specified a step by step procedure for reuse of existing ductwork that can be used in all projects where such reuse is considered (Figure 3).

The following success criteria are identified for the successful conversion from CAV to DCV with reuse of existing ductwork:

- Can the original system partition be reused?
- Do shafts have sufficient capacity and availability?
- Does the ductwork have sufficient access and quality?
- Are there any visible corrosion?
- Are there risks for any duct parts with asbestos?
- Is the ductwork sufficiently airtight?
- Are the drawings up to date and easily accessible?

Reuse of existing ductworks was very profitable in Solbraaveien 23. The ductwork cost was roughly cut in half compared to the alternative which was demolition and new ductwork installation. Reuse of the existing ductwork can potentially reduce the refurbishment period and therefore reduce loss of rental income. This is not included in the economical consideration.

References

1. IEA & Nordic energy research (2013). *Nordic Energy Technology Perspective*. Paris/France, OECD/IEA. www.IEA.org.
2. Maripuu, M.-L. (2009). *Demand controlled Ventilation (DCV) systems in commercial buildings: functional requirements on systems and components*. Goteborg/Sweden. School of Electrical and Computer Engineering. Chalmers tekniska högskola.
3. Halvarsson, J. (2012). *Occupancy Pattern in Office Buildings - Consequences for HVAC system design and operation.* Trondheim/Norway. Doctoral Thesis, NTNU.
4. Mysen, M. Schild, P. Drangsholt, F. Larsen, B.T. (2011) Convertion from CAV to VAV - a key to upgrade ventilation and reach energy targets in the existing building Stock. *Proceedings Roomvent 2011*, Paper 142, ISBN:978-82-519-2812-0, June 2011, Trondheim/NORWAY.
5. Mysen, M. Aronsen, E. Johansen, B.S. (2014) *Conversion to DCV with reuse of ductwork (In Norwegian).* Oslo/Norway. SINTEF Fag 15. SINTEF akademiske forlag. ISBN: 978-82-536-1377-2.

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Session 63:

Which are the keys to have energy efficient office buildings?

Chairperson:

Sauer, Bruno

Director Técnico GBCe, socio Bipolaire Arquitectos. Profesor Universidad Europea de Valencia

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Carbon Reduction of Office Building Retrofit Packages

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Abstract

Building industry is one of the high energy-consuming industries in the world. 23% of national GHG emissions are responsible for buildings in Australia. Many energy efficient measures and technologies have been developed and/or developing to improve building energy performance for the lighting, window, HVAC, insulation system etc. Many existing buildings have being applied these measures to improve their energy performance and reduce carbon emissions. There is no doubt that building retrofit would save lot of energy and it eventually leads operational cost benefit of buildings. Many of these options are mostly focused on 'net zero' or 'building operation. Building owners or investors tend to consider potential energy saving for their retrofit options and simply calculate IRR or payback time required to recover the initial investment of capital from the savings from the retrofit options installed. Energy or carbon saving for building operation do not provide whole picture of building. They might miss or ignore the energy consumption and corresponding carbon emissions of capitals of retrofit options considered. Many retrofit packages can reduce energy and carbon emissions during their service period in the building, but it would not be very worthwhile if it consumes lot of energy and thus causes carbon emissions when it manufactured. This study focuses here and selects various retrofit packages which are being considered in commercial building retrofit in Australia ranged from inexpensive services through to mid-priced packages involving energy efficient T5 lighting through to expensive packages in replacing with double glazing. Then this study evaluates carbon payback time of various retrofit packages considering initial and recurring embodied carbon footprint during maintenance for a typical existing commercial office building. The main goal of this study is to provide the answer to the questions; are retrofit options above really save energy for existing building considering their life span, if so, what is the carbon payback time of potential retrofit options for existing office building. And thus, the results will enable decision makers, who consider retrofit, can distinguish energy usage and payback time for their potential retrofit options of building.

Keywords: building retrofit, payback time, embodied carbon, LCA

1. Introduction

Building industry is one of the high energy-consuming industries in the world. In Australia, 23% of national GHG emissions are responsible for buildings [1]. Of these amounts, 10% comes from commercial buildings [2]. According to COAG [3], commercial building consumed 135 PJ in 2009 in

Australia. This amount has been expected to increase 170 PJ by 2020, which is 24% more than 2009 [3]. In Australia, commercial buildings are quite dependent for electricity (82.4% of total fuel mix), which has 90% of fossil fuel energy mix for their generation and gas (17% of total) [3]).

Commercial buildings contributed to about 4.7% of gross energy consumption (or 277 PJ) in Australia in 2009 [4] with stand alone offices representing a 25% share of this gross consumption [5]. Office buildings have the highest energy savings opportunity compared to other commercial stock, with an estimated total energy reduction opportunity of 5142 GWh by 2020 [6], with the largest opportunities in rationalisation, insulation, HVAC, lighting and electronics

Many energy efficient measures and technologies have been developed and/or developing to improve building energy performance for the lighting, window, HVAC, insulation system etc. These include replacing/converting LED, CFL and T8 tubes for lighting systems, VFD chiller system, VAV boxes, conversion of hotwater boiler etc for HVAC system, and mechanical systems such as variable flow primary/secondary systems. Eren and Erturan [7] show parameters and alternatives for energy efficient building skins. Xue et al [8] suggest integrated control system of EPS thermal insulation and exterior window insulation systems to reduce building energy. Gil-Lopez and Gimenez-Molina [9] demonstrate double glazing with circulating water chamber enables thermal energy savings in buildings. Boyano et al [10] present lighting has significant energy improvement potentials and investigated using different lighting control systems in building energy performance. Zheng et al [11] suggests smart lighting technology, which is combined smart LED lights and wisdom lamp holders, hardware and software, can bring more than 30% of energy saving in library building. Fan et al [12] shows an energy recovery ventilator (ERV) in HVAC systems could reduce 20-30% of air conditioning energy or 60-70% of outdoor load for the ventilation systems.

New technologies have being applied new building construction. In Australia, roughly 2% of building stock is considered as new construction [13]. Given that, 98% of existing building stocks will remain in place beyond in near future. In UK, 87% of building stocks already built and will remain there in 2050 [14] and 80% for Germany [15]. Australia is not much different with these countries and would be doing that. Many technologies have been considered new and existing building stocks to improve their building energy performance. State and federal governments have been implementing various programs to improve building energy performance. These including Green Building Fund (GBP), which granted by federal government between A$50,000 and A$500,000 for half of the cost of retrofit and/or retro-commissioning of commercial buildings, and Environmental Upgrade Agreements (EUA) run by NSW government to make easier to access finance for environmental improvement of existing buildings [16]. These governments supporting programs may give sweet offers many building owners or tenants in terms of important capital investment opportunity. Due to the rising energy bills, and national energy efficiency mandatory program, Commercial Building Disclosure (CBD, www.cbd.gov.au), which requires energy efficiency information of commercial office building having more than 2000 square metres for their sale or lease, energy efficient building would be merit for existing and potential tenants.

Many existing building stocks are considered to improve their energy performance and reduce GHG emissions due to new technologies and governments' support programs. Many successful cases are reported including US Empire State Building's whole building retrofit, which can cost effectively reduce energy use by 38% and save 105,000 metric tons of CO_2eq over the next 15 years [17]. With building energy efficiency retrofits, United States could save 600 million metric tons of CO_2 every year, which is amount of 10% national emissions in 2010 [18]. City of Melbourne is expecting to reduce 38% (383,000 tonnes of CO_2eq) of their carbon emissions through existing commercial building energy efficiency improvement by 2020 [19].

There is no doubt that building retrofit would save lot of energy and it eventually leads operational cost benefit of buildings. But most of retrofit cases or studies are focused on building operation. Building owners or investors tend to consider potential energy saving for their retrofit options and calculate payback time required to recover the initial investment of capital from the savings from the retrofit options installed. Energy or GHG saving for building operation do not provide whole picture of building. They might miss or ignore the energy consumption and corresponding carbon emissions of capitals of retrofit options considered. For example, lighting upgrade is one of the very popular options in building retrofit [19]. Energy saving/efficient bulb for traditional one (eg. incandescent bulb) may consume less energy during their service period in the building. However, lot of energy consumption may happen in the manufacturing or disposal phase of the energy efficient product. If a potential retrofit option would be successful to improve energy and reduce carbon of building operation, but it would not be very worthwhile if it consume lot of energy and release carbon when it manufactured. This study focuses this, and presents retrofit options which can be considered in commercial office building and examines financial and carbon payback time of potential retrofit options considering its capital energy and carbon emissions over the life cycle.

2. Methodology

This study was conducted in accordance with the ISO 14040 standard [20] to assess and compare the environmental impact (energy, carbon) of various retrofit options for commercial office building. According to ISO 14040, there are four steps in LCA: Scope & goal definition, Inventory analysis, Impact assessment and Interpretation.

The goal of this study is to quantify the environmental impact (energy/carbon) and compare each of retrofit options for commercial building. To compare of various options, a square metre (m^2) of floor area was chosen as the functional unit for retrofit option for commercial building. Figure 1 shows the system boundary of this study.

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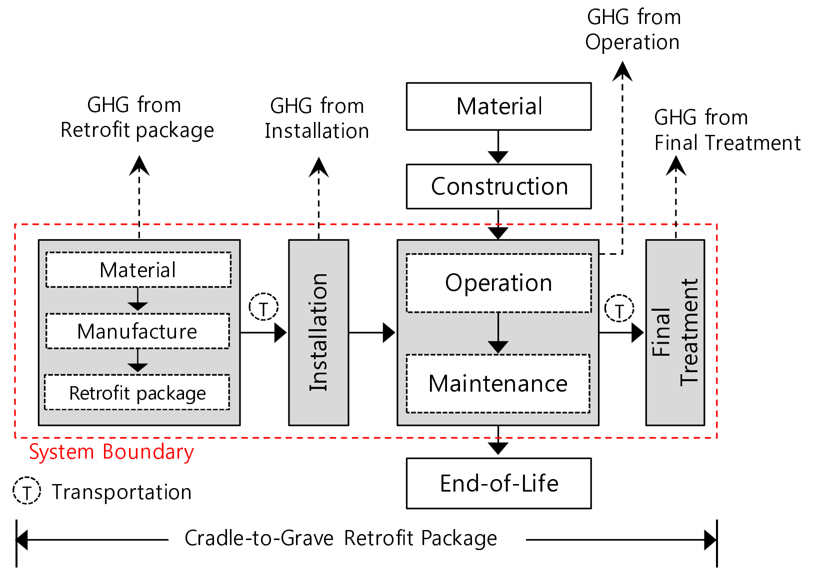

FIGURE 1. System boundary of retrofit options for commercial building

As indicated in Fig 1, the total life cycle carbon of retrofit a building (E_{Total}) which applied different retrofit options can be obtained by summing the whole carbon emission from initial embodied ($E_{Initial}$), installation ($E_{Install}$), operation (E_{Oper}), maintenance (E_{Maint}) and final disposal ($E_{Disposal}$) of each of retrofit package, which is then normalised to a unit of floor area of building as follows:

$$E_{Total} = E_{Initial} + E_{Install} + E_{Oper} + E_{Maint} + E_{Disposal} \qquad (1)$$

Initial embodied carbons ($E_{Initial}$) for various retrofit packages are calculated

$$E_{Initial} = \sum_{i} \left(M_{Req,i} \times C_{Mat,i} \right) \qquad (2)$$

Where, $M_{Req,i}$ is requirement of raw material i for retrofit package (kg). $C_{Mat,i}$ is the carbon intensity for raw material i. Carbon emissions due to installation ($E_{Install}$) of retrofit packages are;

$$E_{Install} = \sum_{j} \left(E_j \times C_j \right) \qquad (3)$$

Where, E_j is requirement of energy type j to install retrofit package and C_j is carbon intensity of energy type j. Operational carbon (E_{Oper}) comes from energy consumption of HVAC, lighting, electric equipments, hotwater, etc which require to run a building.

$$E_{Oper} = \sum_{q} \left(E_q \times C_q \right) \qquad (4)$$

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E_q is energy consumption of type q (electricity, gas etc) from building (HVAC, lighting, hot water, electric equipment etc) and C_q is carbon emission factor for energy type q. To quantify the E_q, commercial software can be used. In this study, eQUEST 3.64 (http://doe2.com/equest/) is used for energy modelling for building operation. eQUEST tool runs DOE-2.2 as its simulation engine and performs an hourly simulation of a building for a year [21].

Carbon emission of maintenance of retrofit package includes recurring embodied carbon and carbon emissions due to installation and waste disposal of material required to replace during the life cycle. It can be represented as;

$$E_{Maint} = E_{Recur} + E_{Install} + E_{Disposal}$$
$$= \left(\sum_k \left(M_{Req,k} \times C_{Mat,k} \right) + \sum_l \left(E_l \times C_l \right) + \sum_m \left(M_{Req,m} \times D \times C_m \right) \right) \times N_{Rp} \quad (5)$$

Where, E_{Recur} is recurring embodied carbon to maintain the retrofit package over the life cycle of building. Similar to initial embodied carbon, it can be quantified by multiplying material requirement k ($M_{Req,k}$, kg) with carbon intensity of material k ($C_{Mat,k}$, kg of CO_2eq/kg). Similarly carbon emission from installation of retrofit package, it needs to take into account of carbon emission due to energy consumption l (E_l) to replace of material/product to maintain a retrofit package. C_l (kg CO_2eq/MJ of energy type l) denotes carbon emission factor of energy l (MJ). Replaced material/product needs to final treatment (disposal). Carbon emission from final disposal of retrofit package is only considered transportation to the final treatment (landfill or recycle) of material/product m. Here D is the transportation distance (km) of material/product for final disposal to landfill/recycling centre. C_m (kg CO_2eq/t-km) is carbon emission factor of transportation. Each of retrofit packages would be replaced repeatedly over the life span of building. N_{Rp} is number of replacement of material requirements, installation and final disposal of material/products for each of retrofit package. Total carbon emission from maintenance is quantified by multiplying the amount of final disposal material/product ($M_{Req,m}$) with carbon emission factor of transportation and transportation distance of material/product considering its replacement times during the life cycle of building (equation (5)).

Finally carbon emission due to final disposal of retrofit package is quantified carbon emission from disassembly of the retrofit package and its transportation to final landfill/recycling centre. It can be represented as equation (6).

$$E_{Disposal} = \sum_d \left(E_d \times C_d \right) + \sum_g \left(M_{Req,g} \times D \times C_g \right) \quad (6)$$

Where E_d is energy consumption (MJ) of type d for disassemble and C_d is carbon emission factor of energy type d. $M_{Req,g}$ is material/product amount (kg) from retrofit package for final disposal. D and C_g are transportation distance (km) to final disposal and carbon emission factor of transportation (kg CO_2eq/t-km). Using the equation (1) to (6), total life cycle carbon emissions can be quantified for the various retrofit packages.

3. Case Study: Retrofit of commercial office building in Australia

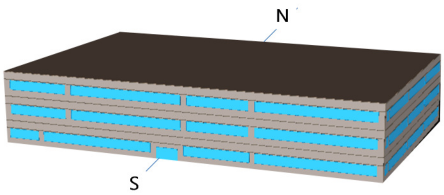
ISBN: 978-84-697-1815-5

3.1 Building description

Commercial building in Australia is estimated 734 million square metres across the country [36]. Of these, roughly 41% is considered office building [22].

In this study, the structural frame – whether concrete or steel – is assumed not to affect energy performance for streamlined modelling. In Australia, medium-rise commercial building occupies dominant building stock having more than 40% of total commercial building stock in different cities. This study selects medium rise office building model as a prototype building. The baseline specifications of the prototype building are shown in Table 1.

Table 1. Specification of prototype building for energy performance modelling

Building geometry	**Building type**	
	Total floor area (m^2)	7240 (70% office area, 30% for others)
	Floors (storey)	3
	Wall	150 mm LW concrete
	Floor	150 mm concrete
	Glazing	single-colour tinted single glazing
	Building operation	9:00 am~6:00 pm
	HVAC system	VAV with reheat
	Temp. cooling (°C)	24
	Temp. heating (°C)	21
	Lift	N/A
	Occupancy* (m^2/person)	15
	Equipment load* (W/m^2)	16
	Lighting load* (W/m^2)	13

Climate zone: 6 major cities in Australia

Melbourne: Temperate climate with plenty of sunshine

Sydney: Temperate, humid climate with abundant sunshine

Adelaide: Mediterranean climate with warm and sunny weather

Brisbane: Subtropical climate with warm and hot weather

Perth: Extremely sunny with around 3,200 hours annually

Darwin: Tropical climate with wet and dry season

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3.2 Baseline energy consumption and carbon emissions

In Australia, average commercial building has 2.5 to 3.5 energy star ratings [23]. Figure 2 shows the comparison of real energy consumption for modelling of commercial office building using equation (5) in different cities in Australia. The real energy consumptions are taken from governmental national mandatory energy reporting program (NABERS, www.cbd.gov.au) for different capital cities. These NABERS data (averaged 2.5 to 3.5 energy star for cities) are compared with prototype building energy in different Australian capital cities. As shown in Fig 2, the energy gap between modelling versus real energy consumption for typical medium-rise building shows 1 to 10% difference.

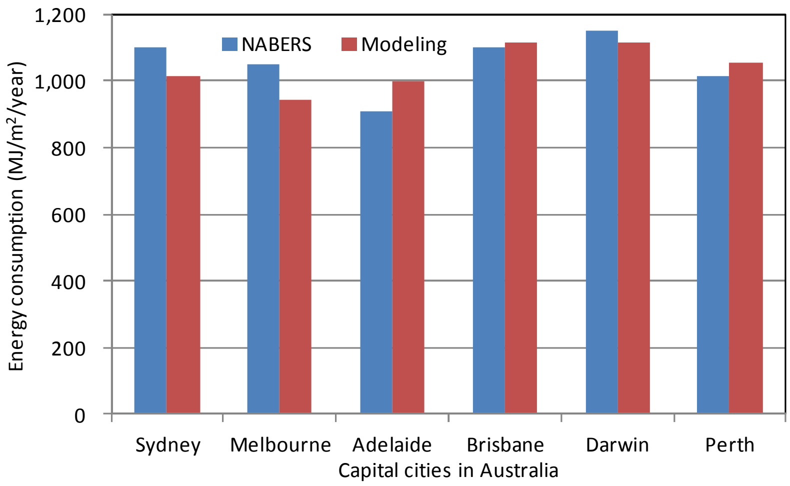

FIGURE 2. Baseline energy consumption of commercial office building in different cities

For different capital cities, annual GHG emissions of commercial buildings are shown in Fig 3. As seen in this figure, HVAC system shows dominant contributor of carbon emission, particularly Brisbane and Perth, which have tropical or subtropical climates, represent more than 45% of total carbon emissions. Perth and Sydney are also highly influenced by HVAC system with 40% and 38% respectively. Lighting, ventilation and electric equipments also highly contributed to the total carbon emissions of buildings in most of cities. These are contributing more than 98% of total GHG emission.

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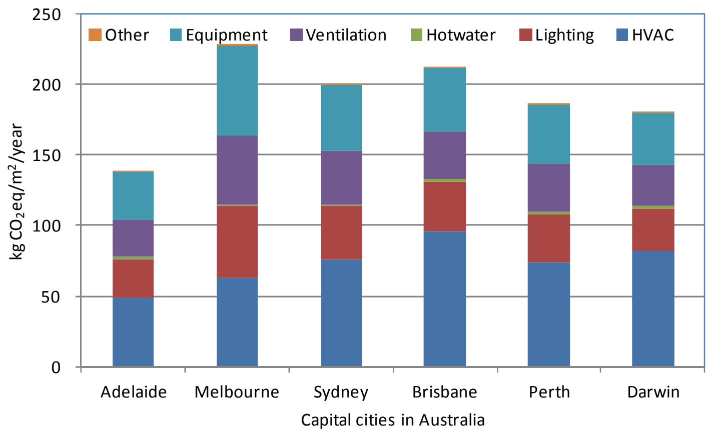

FIGURE 3. GHG emissions of commercial office building in different cities

3.3 Retrofit example

There are number of retrofit options available for commercial office building in the demand and supply sides of management. Demand side retrofit options can be divided into two ways; increasing insulation for wall, roof, floor etc, window retrofit and air tightness etc for heating & cooling demand reduction. The other way is to increase energy efficiency of electronic equipment such as lighting upgrade, thermal storage, control upgrade, natural ventilation etc. For commercial office building, Higgins et al [24] evaluates uptake of six different retrofit packages in NSW (Australia) which ranged from inexpensive services through to mid-priced packages involving energy efficient T5 lighting through to expensive packages such as double glazing and Solar PV. Since most GHG emissions come from HVAC, lighting, and ventilation, as shown in Fig 2, this study examines three typical retrofit packages for its carbon impacts during their life cycle in the different capital cities in Australia. Selected retrofit packages are shown in Table 2.

TABLE 2. Overview of retrofit packages

Package	Description
1	Replacing T5 lighting in office area (28W T5 fluorescent tube)
2	Chiller replacement (COP 4.2)
3	Replacing single glazing with high performance double glazing (6mm low-E)

The packages are not an exhaustive list of all possible retrofits but are commonly considered commercial retrofit options for both landlords and tenants.

3.4 Life Cycle Carbon of retrofit packages

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Comparing to the base case, each of retrofit packages reduces carbon emission during the running of building. However, each of retrofit options causes carbon emission during their manufacture, maintenance and end of life for its final disposal. This chapter considers carbon emissions due to manufacture, maintenance and final treatment of retrofit packages.

3.4.1 Replacing T5

Initial embodied carbon

For the example building, lamp requirements are calculated using the following equation;

$$N\,(Number\,of\ lamp\ fitting) = \frac{E \times A}{F \times \mu F \times LLF}$$

Where, E: Lux level required on working plan (desk, normally 320 lx from AS [37])

A: Area of room (L X W) Office area assumes 70% of total building floor area.

F: total flux (lumens) from all the lamps in one fitting

µF: Utilization factor from the table for the fitting to be used (0.5 for ceiling reflectance)

LLF: Lighting Loss Factor, depreciation over time of lamp output and dirt accumulation on the fitting (typical LLF for air conditioned office = 0.8 [38])

Total required T5 lamp for the building is

$$\frac{320\,lx \times 1690.9\,m^2\ /\ floor}{3320\,lm \times 0.5 \times 0.8} = 407\ of\ lamps\ per\ floor, thus, total\ lamps\ are\ 1{,}222\ (= 407 \times 3\ floor)\ of\ lamps.$$

Garrett et al [25] (2009) evaluated various electronic lamps for New Zealand including T5. According to this study, T5 linear fluorescent lamp (35W) released 874 kg of CO_2eq during the 100,000 hours operation. Considering NZ's GHG intensity for power generation (0.161 kg CO_2eq/kWh) and T5 lamp's life span (8000 hours), each T5 lamp initial embodied carbon can be obtained 24.7 kg of CO_2eq. Thus total initial embodied carbon by replacing T5 lamp in the building is 30.3 ton CO_2eq with 3.3 years life span of lamp (8000 hours/(10hrs/day x 20 day/month x 12 month/year)).

Installation carbon

GHG emission from installation can be calculated using the equation (3). Carbon emission in this stage includes emissions from use of machinery, power on the site to install the retrofit package. However, it is not easy to get data for this. Also, it can vary depending on the site situation. Because of this, Cole and Rousseau [26] assume GHG emission from installation as 1.2% to 10% of total embodied carbon for building industry. Buchanan and Honey [27] also estimated similar range of GHG emission for installation as 6.5% to 10% for total embodied carbon. Considering these studies, this study assumes 8.25% of total embodied carbon, which averaged 6.5% to 10% of total.

Maintenance carbon emission

Building assumes 50 years life span. Since each lamp has 3.3 years life span, it is requires 14 times replacement of the lamp. Thus, carbon emission in this stage is quantified using the equation (5).

Carbon emission for final disposal

When the lamp finishes its service, it needs to replace and final disposal. Carbon emissions from this stage also require taking into account for total life cycle carbon. Here, the carbon emissions come from de-installation of the lamp and to deliver the lamp for final disposal at the landfill site or recycling centre. There is no data for this. This study assumes most of works for this are done by man-power and it goes to landfill site or recycling centre. Then, carbon emission for final treatment of the T5 lamp is calculated using the carbon emission of transportation of the lamp to the final disposal site (landfill and/or recycling centre). And then the distance is assumed to be 30km away from the building site.

3.4.2 Life Cycle Carbon of chiller

Initial embodied carbon

Screw type of packaged air-cooled chiller (80-500 tons with 0.67 kW/ton of efficiency) was considered, which is typical type of medium size of commercial office building. Initial embodied carbon for this is calculated by multiplying raw material requirements for new chiller with carbon intensity of raw materials as shown in eq. (2).

Chen [28] (2011) compared various HVAC system for commercial office building and evaluated life cycle carbon for different HVAC systems in Australia. Raw material requirements for chiller replacement are taken from Chen's data for screw chiller. And corresponding embodied carbon data for building materials are taken from publicly available Australian data sources for building materials [29-32].

Installation carbon emissions

To replace chiller, requires mechanical and/or electrical tools. However, there is not easy to get data for this. Similar to Buchanan and Honey [27], Chen [28] also assumed carbon emission for HVAC system installation as 8% of total embodied carbon in her thesis. Carbon emission for chiller replacement is assumed 8.25% of total embodied carbon emissions for T5 installation.

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Maintenance carbon emission

HVAC system has a typical service life of 20 to 30 years [33]. In this study, chiller needs to replace at least one time over the building's life span (50 years), after initial installation. Then, carbon emissions from maintenance stage of chiller are quantified by summation of initial embodied carbon, installation and de-installation & final disposal of chiller.

Carbon emission for final disposal

It is not easy to get the data for finial disposal of chiller. As described for T5, it assumes chiller only considers carbon emission due to transportation to final disposal site and the distance also assumed 30km away from the building site as similar to T5. Then carbon emissions due to final disposal of chiller are quantified by multiplying the raw material of chiller with carbon emission due to transportation of raw material to the disposal site.

3.4.3 Life cycle carbon of double glazing aluminium window

Initial embodied carbon

Australian windows market is dominated by aluminium framed window having 99% for commercial building [34]. But majority of window are dominated with single glazing [34]. Initial embodied carbon of double glazing window is calculated by multiplying the raw material requirements for window with carbon intensities of raw materials. Window area was designed 883 m2 over the three stories for the prototype building. Initial embodied carbon is quantified considering 10% residual rate of material requirements for aluminium window and 6mm double glazing. Carbon intensities for aluminium frame and double glazing are taken from FWPA [30, 34] and other publicly available Australian LCI data source [29, 31, 32].

Carbon emissions from installation & maintenance

Similarly with two other cases, carbon emission owing to installation of windows is assumed to 8.25% of total embodied carbon. Typical life expectancy of aluminium windows is considered more than 44 years [35]. Thus, once installed aluminium window, this study assumes not necessary any replacement of window components over the building's life span.

Carbon emission due to final disposal

Similar to other cases, final disposal assumes aluminium window go to landfill/recycling centre for its final treatment. It only considers transportation impact (carbon emissions) to deliver the double glazing to the final disposal site. The distance is assumed 30km away from the building site.

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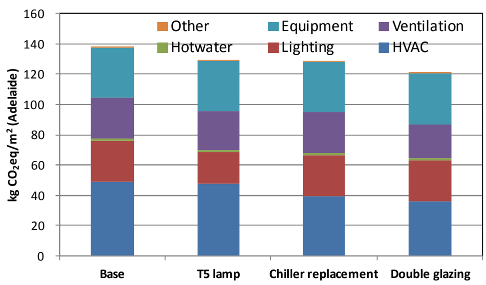
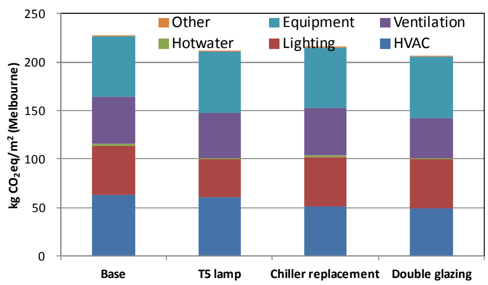
4. Results

4.1 Carbon reduction effect

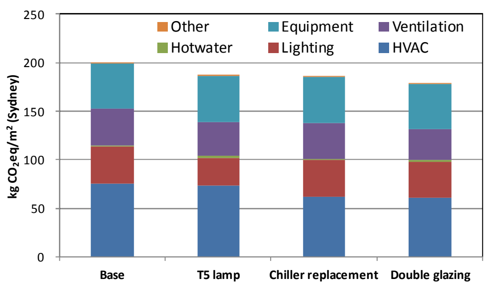
Carbon reductions of each of retrofit packages are shown in Fig 4. Carbon emissions decrease depending on the different options in each of the cities. For example, replacing existing lamp into more energy efficient one in office area shows similar proportion of carbon reduction effect in the most of cities. For Adelaide, capital city of South Australia, typical commercial office building, having 2.5 to 3.5 energy star rating (Base case as reference case), emits 138 kg of CO_2eq/m^2 every year. By replacing existing T8 lamp with T5 in office area for prototype building, carbon emission reduces into 129 kg CO_2eq/m^2 every year, which has 24% carbon reduction (27 kg CO_2eq/m^2 to 20 kg CO_2eq/m^2) for lighting or 6% less for total carbon emission for whole building's emission. This reduction effect appears similarly to other cities. Chiller replacement shows slightly higher carbon reduction effect in most of cities. In Melbourne, for example, replacement of chiller shows 5% of total carbon reduction. While Brisbane or Darwin, which having tropical or subtropical climate, present 10% of total carbon reduction, which are more higher than Melbourne due to tropical climate condition. Upgrading with double glazing of window shows highest carbon reduction effect in most of cities. By upgrade window into double glazing, heating, cooling and ventilation energy demand decrease and thus corresponding carbon emission shows large amount reduction effect in most of cities having more than 12% total carbon emissions except for Melbourne and Sydney. Melbourne and Sydney show slightly less carbon reduction (1~3%) than other cities, this might due to temperate climate zones.



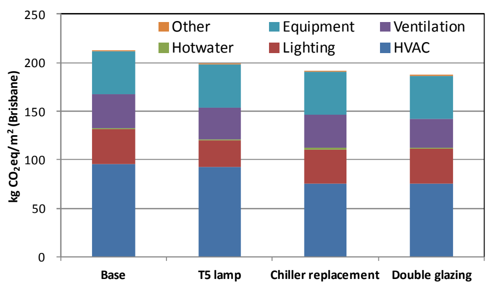
(a) GHG reduction in Adelaide



(b) GHG reduction in Melbourne



(c) GHG reduction in Sydney



(d) GHG reduction in Brisbane

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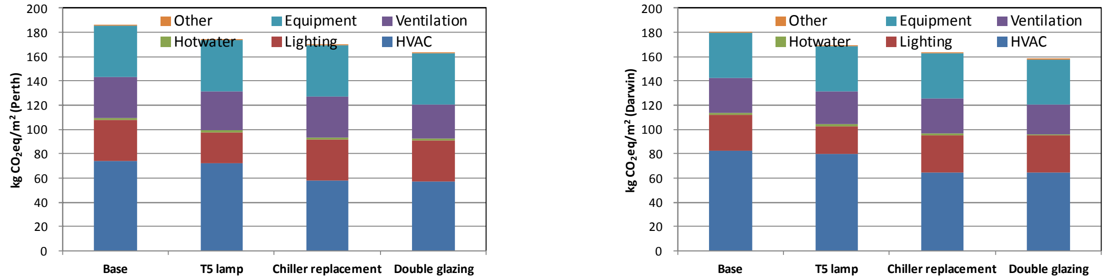

(e) GHG reduction in Perth *(f) GHG reduction in Darwin*

FIGURE 4. GHG reduction by each retrofit options in different captial cities

4.2 Life cycle carbon emission of retrofit packages

Carbon emissions of different retrofit packages are compared considering its life cycle. The results are shown in Fig 5. Total carbon emission of replacing T5 lighting shows 69.6 kg of CO_2 eq/m^2 for the prototype building. Initial embodied carbon is only 4.2 kg of CO_2eq/m^2. But most of carbon comes from maintenance stage of the building, accounting for 93% of total carbon emission. This is because of due to short life span of T5 lighting (3.3 years) and requires 14 times replacement during the life cycle of building (50 years).

Replacing with double glazing for the prototype building shows 107 kg of CO_2eq/m^2 over the building's life span. Of these emissions, initial embodied carbon is 99 kg of CO_2eq/m^2 which contributes 92% of total carbon. The rest (8%) of carbon emission are caused from installation of double glazing window. While carbon emission from other stages (maintenance and final disposal) shows negligible.

Chiller replacement has the least carbon emission accounting for 3.2 kg of CO_2eq/m^2 as total. This is only 5% for T5 or 3% emissions for double glazing window. Chiller's life span is between 25~30 years thus it needs to replace at least one time over building's life span. Considering this, most of carbon emissions come from initial embodied (46% of total) and maintenance (50%) stages.

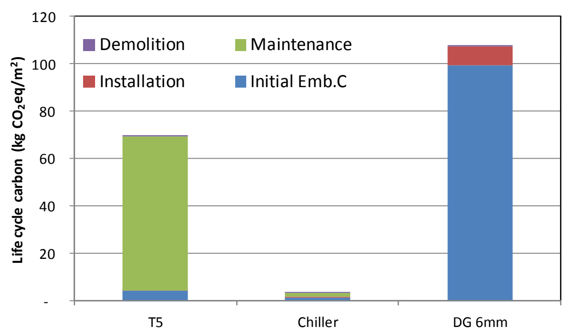

FIGURE 5. Life cycle carbon of retrofit packages for commercial office building in Australian capital cities

4.3 Carbon reduction effect of retrofit packages

Australian cities have different climate conditions. And thus their energy consumption and corresponding carbon emission may have different characteristics as shown in Fig 3 and Fig 4. That means the same retrofit package may have different effects depending on the different climate conditions. Table 3 shows the summary of carbon reduction effect of each retrofit package for different cities having different climate zones.

Carbon reduction by replacing with T5 lighting in office area shows 8.8 to 16 kg CO_2eq/m^2 for the base case (reference case) depending on the different cities. Its reduction for the base case doesn't show much difference between cities (only less than 1% difference). Chiller replacement shows more carbon reduction effect in the cities having a tropical/subtropical climate conditions (Brisbane and Darwin). In the tropical/subtropical climate zone, carbon reduction shows 7% decrease comparing to the base case. In Melbourne and Sydney, which are temperate climate zone shows 4~5% carbon reduction. While Mediterranean climate condition zone (Adelaide), carbon reduction shows slightly higher as 6% of total carbon emission.

Comparing to chiller replacement, double glazing has more effective carbon reduction. Its carbon reduction pattern shows similar to chiller replacement cases. But the reduction has more than chiller replacement.

TABLE 3. Life cycle carbon and carbon reduction in different cities

Option		Unit	Melbourne	Sydney	Adelaide	Brisbane	Perth	Darwin
T5	LCCO2eq	kg CO_2eq/m^2	70	70	70	70	70	70
	C- reduction	kg CO_2eq/m^2/year	16	13	8.8	13	12	11
Chiller	LCCO2eq	kg CO_2eq/m^2	3.2	3.2	3.2	3.2	3.2	3.2
	C- reduction	kg CO_2eq/m^2/year	9	10	8	15	13	13
Double glazing	LCCO2eq	kg CO_2eq/m^2	107.4	107.4	107.4	107.4	107.4	107.4
	C- reduction	kg CO_2eq/m^2/year	22	21	17	25	23	22

LCCO2eq: Life cycle carbon emission
C-reduction: Carbon reduction
T5: T5 lighting replacement, Chiller: chiller replacement, Double glazing; replacement of double glazing

4.4 Carbon & financial payback times for each of options

Carbon payback time is the time it takes for each of the retrofit packages to reduce the same amount of carbon required for life cycle carbon (manufacture, installation, maintenance and final disposal). The lower the figure, the better the retrofit package can save carbon emissions. Carbon payback time may vary depending on the different cities which have various climate conditions.

Figure 6 presents carbon payback time (year) of each of retrofit packages for the prototype building in different cities.

T5 replacement emits carbon 69.6 kg CO_2eq/m^2 for its manufacturing, installation, maintenance and end-of-life. While this retrofit option saves carbon as 8.8 kg CO_2eq/m^2/year for the prototype building in Adelaide. In this city, the carbon payback time represents 7.9 years.

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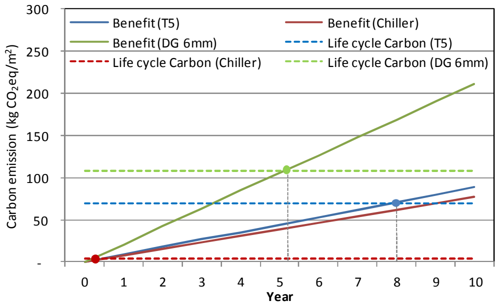
Double glazing shows similar to T5 as 6.3 years. The shortest one is chiller replacement. Total carbon emission (3.2 kg CO_2eq/m^2) by replacing chiller shows to be compensated within a year by carbon reduction effect (17 kg CO_2eq/m^2/year) in Adelaide ((a) in Figure 6).

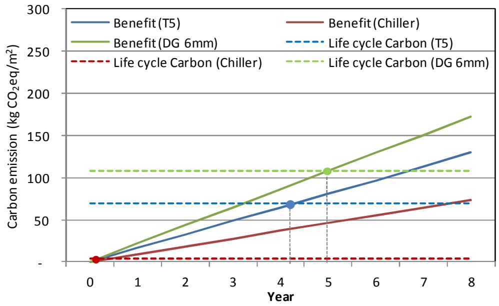
Melbourne shows a bit short carbon payback time than Adelaide. But T5 replacement in Melbourne is 4.3 years. Similarly to Adelaide, double glazing shows 5 years carbon payback time and chiller replacement appears total carbon to manufacture, install, maintenance and final disposal of chiller can compensate within a year.

For T5 replacement, Adelaide has longer period carbon payback time (7.9 years), while Melbourne has shortest (4.3 years). Other cities show between 5.3 to 6.4 years. In case of chiller replacement, most of cities have short carbon payback time (less than 1 year).

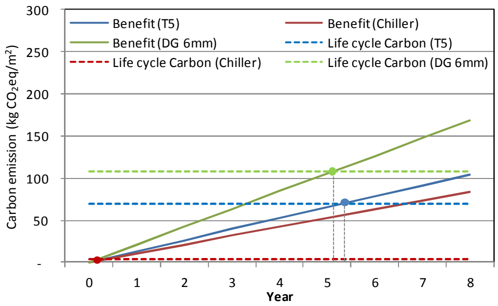
To replace existing single glazing with double glazing 107 kg CO_2eq/m^2 release over life span (50 years) of prototype building. Throughout this, prototype building shows 25 kg CO_2eq/m^2 reduction every year. It takes 4.3 years in Brisbane to payback of life cycle carbon for T5 replacement. Perth and Adelaide take 4.3 and 4.9 years, respectively. Carbon payback time for double glazing shows between 4 to 6 years in the most of cities (Fig 6).



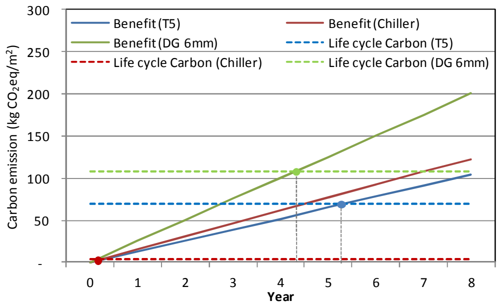
(a) Carbon payback in Adelaide



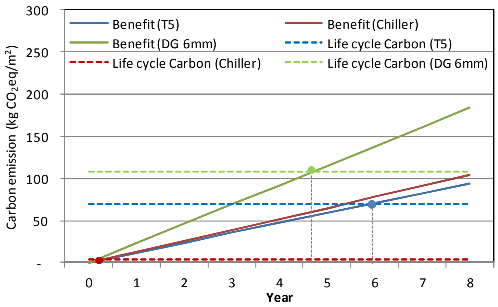
(b) Carbon payback in Melbourne

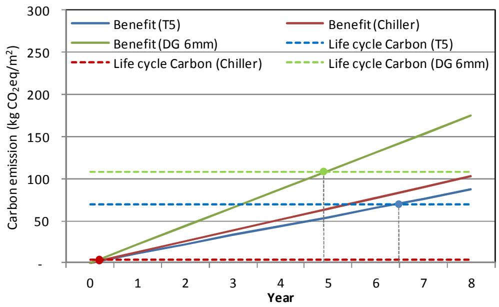


(c) Carbon payback in Sydney



(d) Carbon payback in Brisbane





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(e) Carbon payback in Perth *(f) Carbon payback in Darwin*

FIGURE 6. Carbon emission vs life cycle carbon for retrofit packages in different cities

The payback time of a given retrofit options is an important determinant of whether to uptake the retrofit option. Financial payback time, in general, is defined the length of time required to recover the cost of investment. Financial payback time for each retrofit option is analysed dividing the total investment costs (initial and maintenance cost) for each option by energy saving benefit. Investment costs for each option are obtained from Australian construction cost book [31] and energy saving benefits are calculated dividing total annual energy saving (kWh) by average energy price for power and gas (0.27$/kWh for power and 0.032$/MJ for gas [39]).

Table 4 shows carbon and financial payback times of each option in different cities. As seen in this table, the less the figure, the better the option for retrofit. Considering life cycle carbon of retrofit option, chiller replacement has short payback time as less than a year in most of cities. Comparing other options, chiller replacement has small amount of life cycle carbon during the life cycle of building, while the carbon reduction effect has similar effect with other two options. On the other hand, T5 replacement has longer payback time for its life cycle carbon. T5 and double glazing have similar carbon reduction effect as shown in Table 4, but total life cycle carbons for both options have much more than chiller replacement as shown Figure 5. .

TABLE 4. Financial & Carbon Payback time for each of retrofit option considering its life cycle

	Carbon payback time (year)			Financial payback time (year)		
	T5*	Chiller*	D-Glazing*	T5	Chiller	D-Glazing
Adelaide	7.9	0.4	6.3	9.9	11.0	8.0
Melbourne	4.3	0.3	5.0	10.3	17.4	7.9
Sydney	5.3	0.3	5.1	9.2	11.3	8.0
Brisbane	5.4	0.2	4.3	8.6	7.3	7.1
Perth	5.9	0.2	4.7	9.1	8.2	7.4
Darwin	6.4	0.2	4.9	8.6	7.3	7.8

*T5: T5 replacement, Chiller: Chiller replacement, D-Glazing: Replacement of double glazing window

5. Conclusion

Building retrofit has been concerning to save energy and carbon from existing building. Many retrofit options have been selected based on the its input/output of operational building energy or carbon performance. Though some retrofit options can save energy and carbon emission during the building operation, but it may also consume lot of energy and carbon emissions for manufacturing, maintenance and final treatment of the retrofit.

This study presented a systematic life cycle evaluation for retrofit options and demonstrated life cycle impact of several retrofits based on Australian cities having different climate zones.

This study demonstrated chiller replacement has the least carbon emission while replacement double glazing window was identified having largest carbon emission during the life cycle of building (50 years). Efficient lighting (T5) replacement has small amount of initial embodied carbon (6% of total) but it requires lot of carbon emissions in the maintenance stage having more than 93% of total carbon.

Payback time can provide decision makers to distinguish short payback time for their retrofit selection. While carbon has relatively short payback, financial payback generally requires longer period (Table 4).

This study identified HVAC replated retrofits are more effective for the carbon reduction in the tropical/subtropical area due to shorter payback than other regions. But there exists trade off relationship between carbon emissions versus economic (investment). As shown in Table 4, chiller has shortest payback time in terms of carbon emission, but it has longer payback for financial point of view.

This study only several retrofit options considered but there are more various options available. Also, to reduce national carbon emissions, government has been developing many financial support programs. These remain as further study to consider.

6. Reference

[1] YourBuilding (2009) The buildings sector and greenhouse: fey factors, Property Council of Australia.

[2] Clark, D., Treloar, G., Blair, R. (2003) Estimating the increasing cost of commercial buildings in Australia due to greenhouse emissions trading, The CIB 2003 *International Conference on Smart and Sustainable Built Environment* (SASBE2003), 19-21 Nov, 2003, Brisbane, Australia.

[3] COAG (2012) *Baseline energy consumption and GHG emissions in commercial buildings in Australia*, November, Council of Australian Governments.

[4] ABARES (2011) *Energy in Australia 2011*. Australian Bureau of Agricultural and Resource.

[5] DCCEE (2012) *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia—Part 1*, Department of Climate Change and Energy Efficiency, Commonwealth of Australia.

[6] ClimateWorks (2010), *Australian Carbon Trust Report: Commercial Buildings Emissions Reduction Opportunitie*s, ClimateWorks Australia

[7] Eren, Özlem; Erturan, Banu (2013) Sustainable Buildings with Their Sustainable Facades, *International Journal of Engineering and Technology*, Vol. 5, p.725

[8] Xue, Yun; Wu, Rong; Wen, Hui Xia. (2013) The Main Control Measures of Envelope Insulation Building, *Applied Mechanics and Materials*, 593, 409-410

[9] Gil-Lopez, Tomas and Gimenez-Molina, Carmen (2013) Influence of double glazing with a circulating water chamber on the thermal energy savings in buildings, *Energy and Buildings*, Vol 56, 56-65.

[10] Boyano, A., Hernandez, P. and Wolf, O. (2013) Energy demands and potential savings in European office buildings: Case studies based on EnergyPlus simulations, *Energy and Buildings*, vol. 65, 19-28.

[11] Zheng, R.M., Liu, G.X. and Xu, Y.H. (2013) Smart lights technology used in library energy-saving, *Advanced Materials Research*, 773, 227-232.

[12] Fan, Y., Kameishi, K., Onishi, S. and Ito, K. (2014) Field-based study on the energy-saving

ISBN: 978-84-697-1815-5

effects of CO_2 demand controlled ventilation in an office with application of energy recovery ventilators, *Energy and Buildings,* 68, 412-422.
[13] GBCA (2010) *Federal Election 2010: Green Building Priorities: The green building agenda for 2010-2013*, Green Building Council of Australia.
[14] Kelly, M. J. (2008) *Britain's building stock – a carbon challenge*, 12 November, Seminar of Engineering for a Low Carbon Future, University of Cambridge
[15] Neuhoff, K., Amecke, H., Novikova, A. and Stelmakh, K. (2011) *Thermal efficiency retrofit of residential buildings: The German experience*, CPI report, September, Climate Policy Initiative Berlin.
[16] DE&H (2013) NSW Environmental Upgrade Agreements, Department of Environment & Heritage retrieved on 5th December 2013 from website (http://www.environment.nsw.gov.au/sustainbus/eua.htm)

[17] ESB (Empire State Building) (2011) *The Empire State Building: Repositioning an Icon as a Model for Energy Efficient Investment*, Green Property Summit, March.
[18] US EPA (2013) *National Greenhouse gas emissions data*, retrieved on 5th Dec 2013 from http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.
[19] CoM (2013) *1200 Buildings*, City of Melbourne, retrieved on 5th December, 2013 from website (www.melbourne.vic.gov.au/1200buildings)

[20] ISO 14040 (2006) *Environmental management: Life cycle assessment- Principles and framework*, ISO.

[21] Zhu, Y. (2005), "Applying computer based simulation to energy auditing", *Energy and Buildings*, Vol. 38, pp. 421–428.

[22] Davis Langdon (2011) *Carbon Price on Construction Costs*, AECOM.
[23] ABCB (2003) *Class 5 (office) Benchmarking*, Australian Building Codes Board.
[24] Higgins, A., Syme, M., McGregor, J. Marquez, L. and Seo, S. (2014) Forecasting uptake of retrofit packages in office building stock under government incentives, *Energy Policy*, 65, 501-511.
[25] Garrett, P., Collins, M. and ERM (2009) *LCA of product stewardship options for mercury-containing lamps in New Zealand*, Ministry for the Environment, New Zealand.
[26] Cole, R. and Rousseau, D. (1992) Environmental auditing for building construction: Energy and air pollution indices for building materials, *Building and Environment*, 31, 307-317.

[27] Buchanan, A. and Honey, B. (1994) Energy and carbon dioxide implications of building construction, *Energy and Buildings*, 20, 205-217.
[28] Chen, S. (2011) *System dynamics based models for selecting HVAC systems for office buildings: A life cycle assessment from carbon emissions perspective*, Master thesis, RMIT University.
[29] BPIC (2011) *Building Product LCI database*, Building Productd Innovation Councils (BPIC) (www.bpic.asn.au/LCI)
[30] FWPA (2010) *Development of an embodied CO_2 emissions module for AccuRate,* Forest& Wood Products Australia.
[31] Rawlinsons (2013) *Australian construction handbook*, Ed. 31, Rawlinsons.
[32] LCS (2013) *Australianasian LCI database*, Life Cycle Strategies (www.lifecycles.com.au)
[33] AIRAH (2012) *AIRAH response to the draft National Building Energy Standard-Setting Assessment and Rating Framework, Australian Institute of Refrigeration*, Airconditioning and Heating (AIRAH).

[34] FWPA (2007) *Comparative service life assessment of window systems*, Forest &Wood Products Australia.
[35] CML (2014) Typical life expectancy of building components, Costmodelling Limited, taken from

website (http://www.costmodelling.com/downloads/BuildingComponentLifeExpectancy.pdf) on 28 April, 2014.

[36] GA (2013) *NEXIS database*, GeoScience Australia, Canberra, available website (www.ga.gov.au)

[37] SA (2009) *Australian/New Zealand Standard: Interior lighting – Safe movement*, Standards Australia.

[38] Grondzik, W. T., Kwok, A. G., Stein, B. and Reynolds, J. S. (2010) *Mechanical and electrical equipment for buildings*, 11th Ed, John Wiley & Sons, Inc., Hoboken, New Jersey.

[39] AE (2014) Electricity & gas rates and charges, Aurora Energy, (http://www.auroraenergy.com.au).

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Sustainability paradigm of high-rise office buildings in Barcelona: AUDITORI Tower of IBERDROLA.

Speakers:
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Abstract: *Auditori Tower, a 25 floors building located in Barcelona, with a constructed surface area above ground of 23.575 m*^{2}*, has become a benchmark of sustainable buildings in high-rise offices sector. The building obtained the 'A' in energy efficiency rate, with a consumption in primary energy of 66,40 kWh/(m*^{2}*·year) and 75% reduction in* CO_2 *emissions comparing to a reference building. The design strategies for energy optimization of the building include the three main vectors of energy saving in building: To decrease energy demand through modular facade design by optimizing its light-thermal proprieties which takes into account facade's orientation. To improve energy efficiency of artificial lighting equipment. And to incorporate renewable energies by connecting to the District Heating&Cooling ECOENERGIES. The energy engineering ISOLANA Ahorro Energético SL is managing the process of obtaining the BREEAM® sustainability seal with a pre-assessment of very-good rate, showing the IBERDROLA environmental commitment.*

Energy efficiency, Distric Heating&Cooling, Lighting, Solar Factor, Energy Efficiency Rating, Sustainability, BREEAM®.

Design strategies to urban scale

Auditori Tower is an office building for public use belonging to the tertiary sector in Barcelona *Porta Firal,* the largest private development of business park for leasing in Barcelona, composed by 4 buildings with a floor area of 91.111 m^2, owned by *IBERDROLA INMOBILIARIA CATALUNYA, SAU*.

The total floor area of the whole is divided into four towers. Three similar towers (*Auditori Tower*, *Pedralbes Tower* and *Montjuïc Tower)* are 80 meters high and 1.200 m^2 per floor, and a somewhat smaller building, *Marina Tower* that is about 50 meters high and it is composed of a three-story base and an upper body also 1.200 m^2 per floor. The project occupies the Northwest parcel, intersection between the *Paseo de la Zona Franca Street* and the future *Firal axis*, which constitutes the main entrance door of *Barcelona Fira*. The buildable area is concentrated on four high-rise buildings in close proximity and strategically placed from each other, which helps fluffing the platform floor. This idea allows free movement between buildings and their access, level "street" perspective and at the same time shorten distances.

Sustainability and visual comfort will play a key role in facades design of these volumes. Access of solar radiation to the facades of the four buildings is optimized. This allows natural lighting become a reality in the highest percentage of floor space for 4 buildings with energy saving in lighting consumption.

Three of the buildings are designed for office use, and the fourth building is a commercial hotel with commercial attachments. Currently, an office building on all sides of the central core is considered "efficient" when the built plant it is close to the 1.200 m^2 with square geometry.

Auditori Tower has a floor area of 25.317 m^2 developed over 25 floors above ground and 3 below ground. It comprises a structural core of 16 x 16 m. incorporating inside vertical communication of people and facilities, surrounded by 900 m^2 surface area of offices per floor. Facade perimeter is 34,5 x 34,5 m. and also acts as a second structural ring.

Figure 1. Auditori Tower - Porta Firal

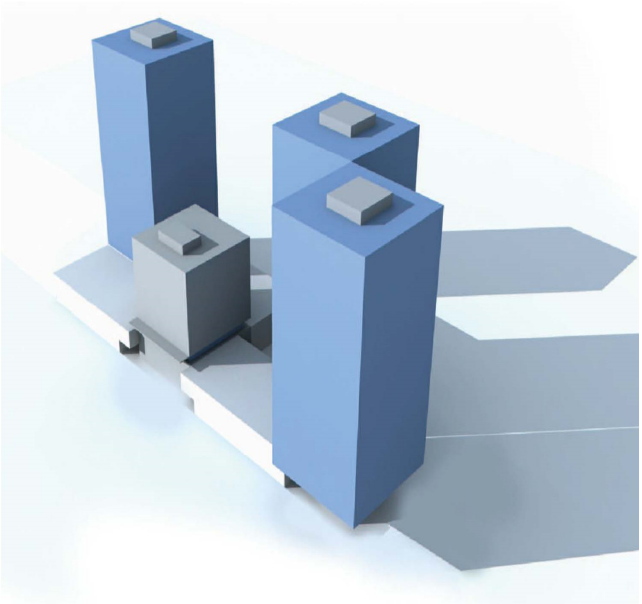

Figure 2. Porta Firal tertiary development

The special feature of this building is just missing this perimeter ring in the first three levels, being only the core intersecting with the floor. This section reduction provoques a transparency and cause a release of the visual space from the entire environment at the "street" level. The same decreased section occurs symmetrically on the upper floors, incorporating major facilities inside.

Figure 3. Elimination of ring bottom edge

Figure 4. Office type within the building

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Design strategies to scale building

One of the main requirements of the building's design was to get a nearly zero energy building. To achieve this end, the building was modelled with two thermodynamic simulators: *Energy Plus*, developed by the *DOE of United States* and capable of simulating life cycles cost of building considering all relevant variables for their energy performance; and the calculation motor *DOE2.2*, via its interface *CALENER GT*, the official program for building energy efficiency certification in Spain. Analysis of building energy optimization was developed to design the thermal envelope. Life cycle cost analysis was developed to design the light & thermal properties of exterior glasses and the building air conditioning and lighting systems. The design approach is based on the improvement of the 3 main concepts of energy savings in building sector: to reduce energy demand, to improve energy efficiency and to incorporate renewable energy.

The energy consumption of a standard office building located in Barcelona is broken down into 74% (lighting), 14% (cooling) and 12% (ventilation). To reduce energy consumption of the building lighting systems was established as a premise. Barcelona receives high solar radiation, which allows to establish natural lighting as a proper and sustainable lighting system and to improve indoor comfort of buildings. The Mediterranean weather of Barcelona has an annual oscillation of temperatures not too far from thermal comfort strips. This together with contribution of internal heat gains allows control or even eliminates energy consumption in heating, prevailing high in most European countries.

The *CTE-HE 5*[1] requirements to be fulfilled are to install 35,1 kW photovoltaic collectors. The area available on deck in a building of these features is very limited. Moreover, short-term profitability of a photovoltaic system in Spain is uncertain. This led us to undertake a series of negotiations and analysis in conjunction with the Energy Agency of Barcelona to find a solution. We focus the problem from two sides: the specific treatment of the facade to reduce energy demand and to improve lighting systems energy efficiency.

Firstly, we opted for a glass with high light transmission and solar factor (57% and 36% respectively) in the Northern facades, with lower contribution of natural light and without risk of causing glare to users (greater visual comfort). Reducing both parameters in the South facades (48% and 31% respectively) that receive many hours of light and with risk of glare, especially to the West. After life cycle costs analysis, the best solution found was double glass composite by an heat strengthened outer layer of 8 mm, dehydrated air cavity of 16mm with black spacer and inner glass sheet laminated and 4 + 4 mm thick bonded with structural silicone. Light transmissivity (Tv) = 48%, Solar Factor (g) = 31%, Heat transmission coefficient (U) = 1,3 W/m^{2}K, Acoustic attenuation (dB) = 41(-1; -5).

[1] *Código Técnico de la Edificación - Documento Básico HE5*. Spain Building normative – Instruction Energy saving about Photovoltaic systems.

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Regarding to the lighting equipment efficiency, we opted for the most advanced model on the market, with performance of 94% and lighting systems energy efficiency value *(VEEI*[2]*)* of 1,63 W/m²100 lx, far superior to that required by the *CTE* (3,5 $W/m^2$100 lx). Daylight and others electronic controls were installed.

Figure 5. Glazed façade elements.

The results were conclusive, with the same investment cost; the installation of photovoltaic panels would have generated 79.830 kWh/year of electric power. While actions carried on: To increase *VEEI* values and to improve glass optical parameters get a reduction of 517.284 kWh/year, representing a final energy saving of 437.454 kWh/year compared to the photovoltaic system.

The third premise of nearly zero energy building design: the integration of renewable energy in buildings is achieved thanks to the existence of District Heat&Cooling (*DHC)* in the zone, belonging to the concessionaire *"Ecoenergies (DALKIA)"*. The power installed is 16,6 MW of cold and 9 MW of heat with a centralized production. This uses a networks system that carry fluids heating to 90°C and 7°C. This system was chosen to satisfy the demand of air conditioning and Domestic Hot Water in the building. The main advantage of the *DH*C is to increase energy efficiency in heat generation and emission´s reduction by integrating renewable energy (residual biomass from logging of parks and gardens of Barcelona) and heat recovery. Heat recovery is possible thanks to instantaneous production of cold and heat, and the scale factor of the thermal plant (cold recovery from vaporization of liquefied natural gas from Barcelona port factories). This allows using local resources that otherwise would be lost

[2] *Valor de Eficiencia Energética Iluminación - CTE*. Lighting Systems Energy Efficency - Spain Normative.

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(free and natural cooling, hot or cold leftover from the nearby industry, etc.) and arrange the production of high-efficiency systems. Independent systems would not be economically feasible due to its high initial cost and multi-year maintenance.

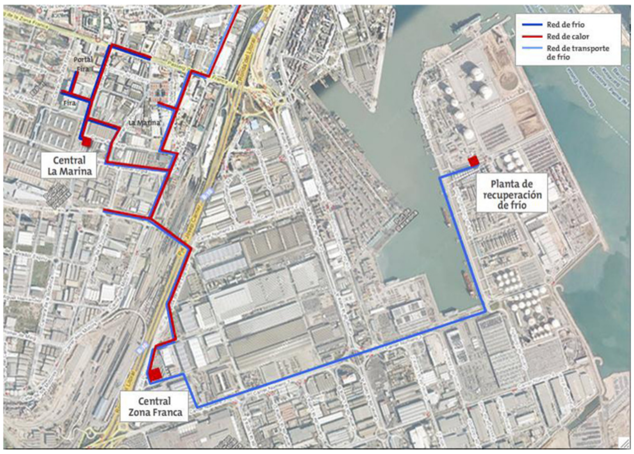

Figure 6. DHC - ECOENERGIES Development.

Figure 7. Room facilities Auditori Tower

The air conditioning system corresponds to an all water system: 4 ways fan-coils without refrigerants and any atmospheric pollution risks. The distribution is done with four pipes (hot and cold) that allow simultaneous and independent air-conditioning with thermostat in each office, powered through the District Heat&Cooling (DHC). Individual installation by floor permits hiring independent power by tenant. The consumption is individually attributed to tenant through a Building Management Software and heat and cold counters installed in each floor module.

Results

The building energy simulation data taken into account for both buildings: the baseline building, which strictly fulfils the *CTE*, and the proposed building, is summarized in the following table:

	VEEI Perimeter zones	VEEI Core zones	Transmittance glazing (NE/NW/SE/SW)	Solar factor (NE/NW/SE/SW)	Visible transmittance (NE/NO/SE/SO)
Projected Building	1.9	1.5	1.3/1.3/1.3/1.3	0.36/0.35/0.31/0.31	0.57/0.57/0.48/0.48
Baseline Building	3.5	4.5	2.2/2.2/3.5/3.5	0.7/0.7/0.7/0.7	0.7/0.7/0.7/0.7

Table 1. Thermal - light properties of facade glasses and lighting equipment

Total consumption quantified by the software *DOE2.2* for the Proposed building is 685.567 kWh/year, while for the Baseline building *(CTE)* is 1.202.852 kWh/year, broken down into 65% lighting and 22% and 13% for cooling and ventilation respectively.

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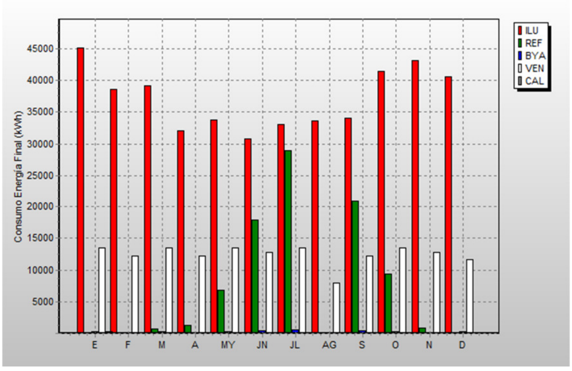


Figure 8. Proposed building Consumption.

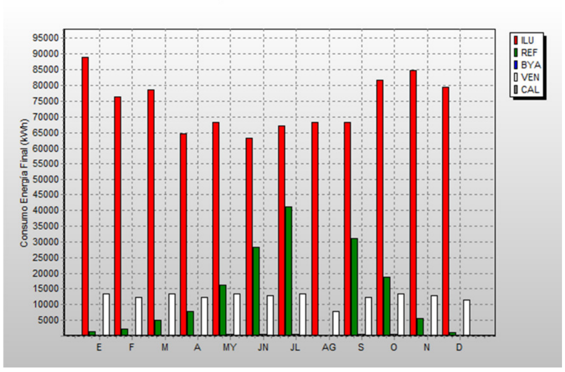


Figure 9. Baseline building Consumption.

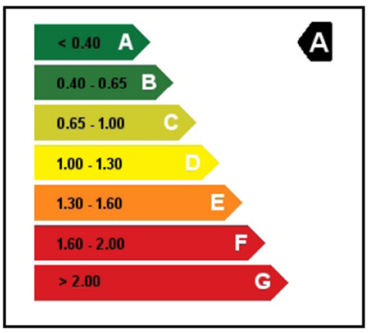
The achieved energy savings results obtained through the implementation of different Design Energy Saving Measures were:

Consumer group	Projected building saving (KWh/year)
Lighting	444.463
Cooling	72.066
Pumps and Auxiliary	1.088
Heating	-298
Total	**517.319**

Table 2. Achieved energy savings results

Thanks to efficient lighting system and light filtering from the windows, the largest savings occur in the lighting section, followed by cooling. To achieve similar values to that achieved by efficiency savings measures implemented, it would have been necessary to install more than 1.000 solar collectors, equivalent to 1.630m^2 that does not own the cover building and whose feasibility in terms of profitability would not be justified.

Auditori Tower has a Final energy consumption of 31,2 kWh/m^2 year, 75% less consumption than a reference building (100,5 kWh/m^2 year) and the emission level is down to 16,1 kgCO$_2$/m^{2}year, almost 75% less than a standard building (64 kg CO$_2$/m^{2}year), which has led us to obtain the "A" efficient energy certificate according to Spanish normative.



Concepto	Edif. Objeto	Edif. Referencia
Energía Final (kWh/año)	854410.9	2750460.0
Energía Final (kWh/(m²año))	31.2	100.5
En. Primaria (kWh/año)	1817449.0	7022755.0
En. Primaria (kWh/(m²año))	66.4	256.5
Emisiones (kg CO2/año)	**440863.7**	**1752537.0**
Emisiones (kg CO2/(m²año))	**16.1**	**64.0**

El consumo real de energía del edificio y sus emisiones de dióxido de carbono dependerán de la climatología y de las condiciones de operación y funcionamiento reales del edificio, entre otros factores.

Figure 10. Energy efficiency certificate of the building.

Isolana Ahorro Energético, SL (Energy Engineering) is developing a Measurement and Verification Plan of current energy consumption of the building. We are following the *Option*

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D: Energy simulation calibrated (viable option for new buildings) from *IPMVP* Protocol of *EVO*. *Auditori Tower´s* users have secured the energy consumption of their units according to the ratios specified in the building design. Nowadays, we are calibrating energy simulation results to weather real data and building real occupation. We are gathering the consumption real data to compare it to the calibrated energy simulation.

Given the technological and sustainable nature of *IBERDROLA*, committed with the environment through a sustainable construction and energy efficiency, the *Auditori Tower´s* project is now a reality. As a guarantee of the building sustainability, *Isolana Ahorro Energético, SL* is managing the sustainability seal *BREEAM*® to achieve the "very good" rate. Sustainability vectors implemented in the building, as well as energy factors, correspond to the *management of water*, with a reduction of more than 40% water consumption. This is possible by installing innovative technologies for electronic faucets with presence detector and reduced flow of 6 liters per minute. In toilets, it has been installed double discharge for liquids/solids (Dual Flush system) valves. These only consume 3 liters in each drive for the evacuation of liquid; allow saving up to 55.000 liters of water for year by toilet. All urinals in male toilets have an electronic discharge system with presence detector.

Other vectors such as the *health and welfare* improve internal comfort by using natural lighting, the *choice of healthy and regional materials*, the *domestic waste management* using a clean point and an auto-compactor of paper and cardboard, the *mobility and urban interconnection* with urban development for access in bicycle, etc. All of them together make the *Auditori Tower* building a sustainability paradigm of high-rise offices buildings in Spain.

Fase de la evaluación	Puntuación BREEAM ES	Clasificación BREEAM ES
Certificado - Fase de Post-Construcción	59.92%	★★★ MUY BUENO

Requisitos Mínimos BREEAM ES					
Nivel de Clasificación	Aprobado	Bueno	Muy bueno	Excelente	Excepcional
Requisitos Mínimos alcanzados	SI	SI	SI	NO	NO

Nivel de Sostenibilidad por Categoría	Ponderación	Puntos disponibles	Puntos Alcanzados	% alcanzado	Puntuación Ponderada
Gestión	11.50%	11.00	7.00	63.64%	7.32%
Salud y Bienstar	14.00%	14.00	11.00	78.57%	11.00%
Energía	18.00%	23.00	19.00	82.61%	14.87%
Transporte	8.00%	9.00	7.00	77.78%	6.22%
Agua	10.50%	11.00	5.00	45.45%	4.77%
Materiales	12.00%	10.00	1.00	10.00%	1.20%
Residuos	7.00%	6.00	5.00	83.33%	5.83%
Uso del Suelo y Ecología	9.50%	10.00	1.00	10.00%	0.95%
Contaminación	9.50%	12.00	6.00	50.00%	4.75%
Innovación	10.00%	10.00	3.00	30.00%	3.00%
				Total	56.92%
				Puntos de nivel ejemplar obtenidos	3.00%
				Puntos de innovación obtenidos	3.00%
				Puntuación Total BREEAM ES	59.92%

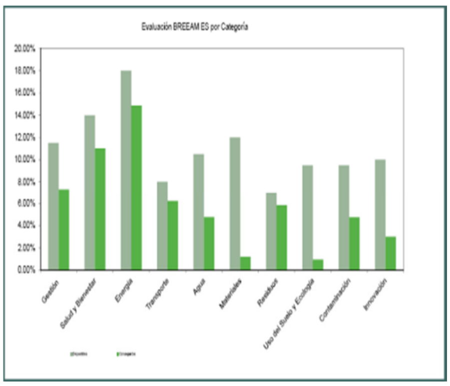

Figure 11. BREEAM pre-evaluate results.

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Life cycle analysis as tool for environmental assessment of office and administration buildings – a critical review and evaluation of the LCAs practical feasibility for a future roadmap

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Abstract: *In recent years the dynamic in green building assessment and certification was rather positive as many different methods and labels compete in the market. In Austria the DGNB system is implemented pretty well and several office and administration buildings have been assessed. According with the increasing use of this system several profound life cycle assessments (LCA) are now available since LCAs constitute the basis for the environmental criteria.*

23 sample buildings serve as reference for the critical review. All LCAs were carried out in line with the CEN/TC 350 framework and EN 15978 standard especially. A first comparison on the results for the given indicators within the rating system was done independently. A more detailed analysis was separated into the main elements of an LCA, as the constructional and operational related parts are calculated different in matter of methods and temporal characteristics. Special focus was laid on the embodied primary energy and embodied carbon at different levels of an LCA related to the construction as well as the share of the utilization phase. The results indicate a first tendency if the set ecological indicators are adequate and independent to each other. Furthermore the final results are used to draw a roadmap for possible future simplifications and improvement on environmental assessment.

LCA review, empiric LCA analysis, DGNB system, LCA benchmarks

1 Introduction

In line with the rising attention in green building assessment, the methods and tools for the environmental assessment of buildings getting applied and evaluated. LCA as international recognised method is standardized, but rather complex. In several studies measures for simplified LCA calculation [1,2] or analysis of specific building parts [3,4] as well as different weighting strategies for indicators and criteria [5] have been investigated. Most commonly, these studies focus on residential buildings / single houses or LCA in general.This paper focuses on office buildings and highlights the results for construction and operational related impact of a selected data sample. A similar study on office buildings for energy and CO_2 emission is done in Wu et al [6].

2 Methodology and data sample

All buildings of the data sample are office buildings and certified projects of the ÖGNI (using the DGNB system) utilising the LCA method. The underlying standards are the general framework of CEN TC 350 for sustainability assessment of buildings and the ISO 14040 group for life cycle assessment, [7,8]. All LCAs in this study have been calculated regarding the simplified calculation method as specified in the ÖGNI criteria set for environmental

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quality, [9]. For all buildings the LCIA was calculated with the dataset of ökobau.dat 2009. The analysed LCA indicators are carbon dioxide equivalents (GWP), acidification (AP), eutrophication (EP), ozone depletion (ODP) and photochemical ozone creation (POCP). The primary energy input (PE_{nr+r}), renewable (PE_r) and non-renewable (PE_{nr}), has been assessed in addition.

Within the DGNB system the reference service period for all buildings is 50 years. This is a quite relevant parameter, as all construction related impact is divided by the reference service period. Considered life cycle stages are A) the production of the building components, B) the operational phase including maintenance and replacement as well as C) the end of life scenario. For all specific LCA results the net floor area is defined as the functional unit. The operational related energy demand is calculated according to OIB-Directive 6 as the Austrian implementation of the Energy Performance of Buildings Directive (2010/31/EU).

The data sample consists of 23 buildings in the scheme “Office and Administrative buildings” assessed within the DGNB system. The building size started by about 1.000 m² gross floor area expanding to 87.000 m². Table 1 shows some key figures of the selected buildings. The construction types are different, ranging from reinforced concrete skeleton structures to timber constructions. Also the building service technologies are different, whereas most of the buildings use mechanical cooling and ventilation systems. Depending on the location the energy sources differ from district heating, natural gas, geothermal to electricity.

Table 1: Selected certified office buildings

Certified office building	Energy certificate class	Gross floor area category [m²]	Overall GWP [CO2 kg/(m².a)]	Overall PE_{r+nr} [kWh/m².a]
1	B	1.000-5.000	25	135
2	B	25.000-30.000	35	156
3	A	5.000-10.000	42	196
4	A	20.000-25.000	33	159
5	A	15.000-20.000	37	179
6	B	1.000-5.000	31	160
7	C	<1.000	60	321
8	B	35.000-40.000	28	137
9	B	>40.000	36	164
10	B	1.000-5.000	27	139
11	A	5.000-10.000	36	168
12	A++	30.000-35.000	23	126
13	A	15.000-20.000	17	61
14	B	>40.000	43	204
15	A	20.000-25.000	30	164
16	A++	1.000-5.000	26	186
17	A++	>40.000	33	170
18	B	35.000-40.000	35	167
19	B	25.000-30.000	40	198
20	A	35.000-40.000	38	197
21	A	1.000-5.000	28	142
22	A+	5.000-10.000	39	155
23	B	1.000-5.000	29	176

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3 Results for the whole LCAs

In a first step the results for the whole LCA were analysed for each indicator independently. All specific values are aligned to the net floor area, according to the requirements in the DGNB system. Figure 1 shows the boxplots for each indicator. The whiskers of the boxplot are defined by the lowest and largest observation within 1,5 IQR (interquartile range). All outliers are marked by an x.

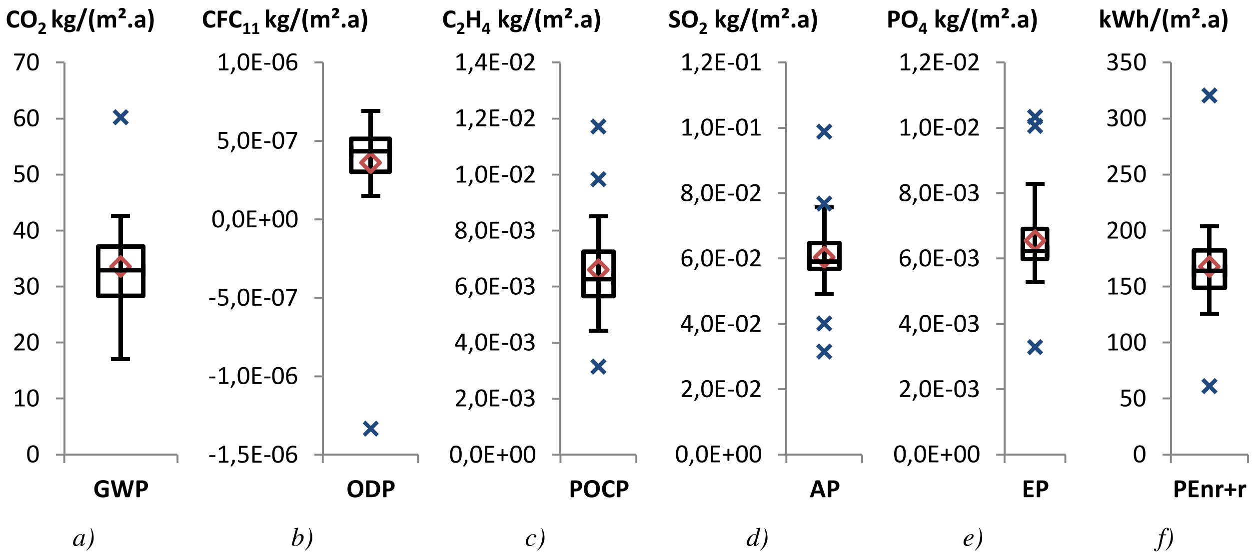

Fig. 1: Boxplots of the results for the whole LCA for the indicators a) global warming potential b) ozone depletion potential c) photochemical ozone creation potential d) acidification potential e) eutrophication potential f) primary energy input renewable and non-renewable; all values are aligned to net floor area

The mean value for the global warming potential is around 34 CO_2 kg/(m².a) over all buildings and quite close to the median. A closer look on the global warming potential is found in section 5 of this paper. Except the ozone depletion potential the results show inconspicuous boxplots with outliers in both directions. The descriptive statistic of the ozone depletion potential shows a mean value of 3,6E-07 CFC_{11} kg/(m².a) with an extreme outlier. This value is definitely wrong, as a building can't contribute positive to the environment over its reference service period.

For this study one important goal was to identify the most important phase of a building's LCA. In a first step all parts of the LCA were counted to the construction related impact on the one hand and to the operational related impact on the other hand. In a second step the average value of all indicators was calculated, whereby each indicator was weighted as equal important. Figure 2 illustrates the result for each building separately. The mean value for the construction related impact over all buildings is about 35 % and for the operational related impact about 65 %. But there are wide differences between the several indicators. This issue will be detailed in section 4.

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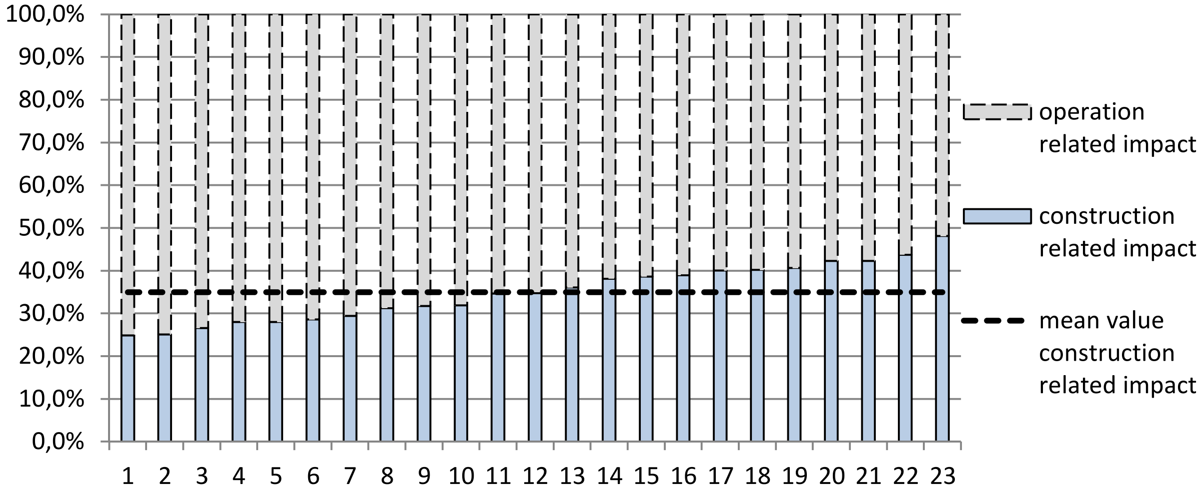

Fig. 2: Bar diagram of the share of the construction related and operational related environmental impact as well as the mean value of the construction related impact; all investigated indicators are weighted as equal important

4 Results for the construction related LCA parts

The construction related impact for all investigated indicators is illustrated in figure 3. The mean values of the share range from 8 % for the PE_r and 77 % for the ODP. The boxplots show different variation types of normal and non-normal distributed samples. Also three outliers for the GWP and PE_{nr} are negative. A possible explanation for the negative values of the GWP and the PE_{nr} can be a wrong dataset combination for the materials regarding raw and recycled materials as well as (double) counted benefits during the end of life scenario.

Especially for the GWP and all PE indicator is the energy mix, used to assess the consumption of electricity, very important. In this study the electrical energy mix of Austria was used, as the buildings are mainly located in Austria. An electricity mix with more or less fossil energy will result quite different.

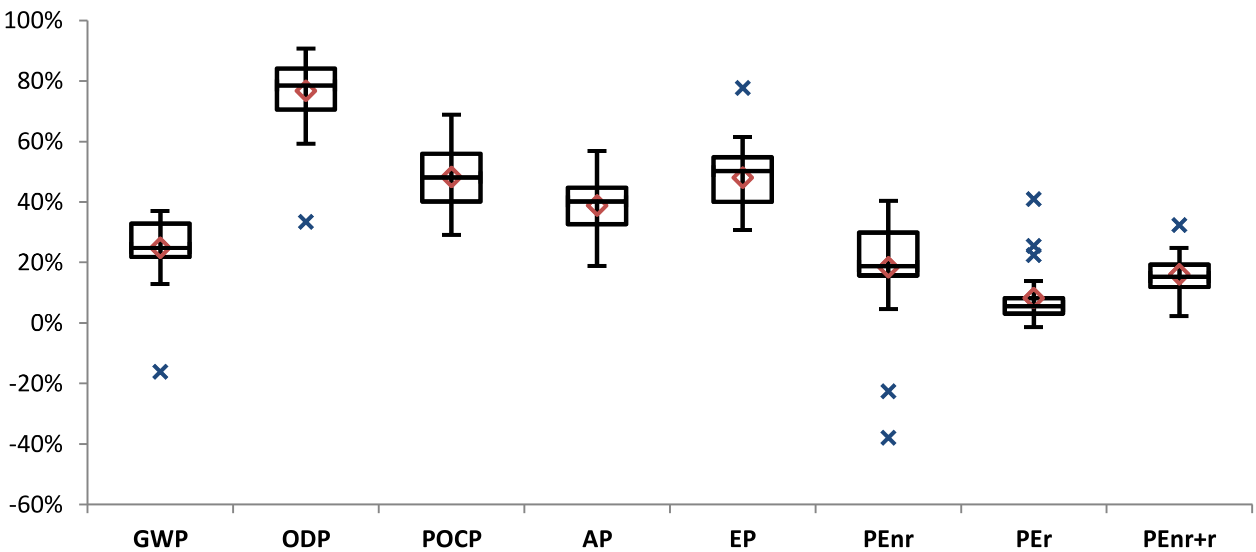

Fig. 3: Boxplot of the share of the construction related environmental impacts for all investigated indicators within the DGNB system

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5 Results for the selected GWP indicator over all LCA parts

A comparison of all LCA parts was done for all indicators. In this paper the GWP is described as an example. Figure 4 a) shows the result for the total LCA with a mean value of 34 CO_2 kg/(m².a) and one upper outlier. 4 b) illustrates the construction related GWP impact with a mean value of 8 CO_2 kg/(m².a) and one upper outlier as well as a wrong negative value (see also fig. 3). The operational GWP impact is demonstrated in 4 c) with an mean value of 25 CO_2 kg/(m².a).

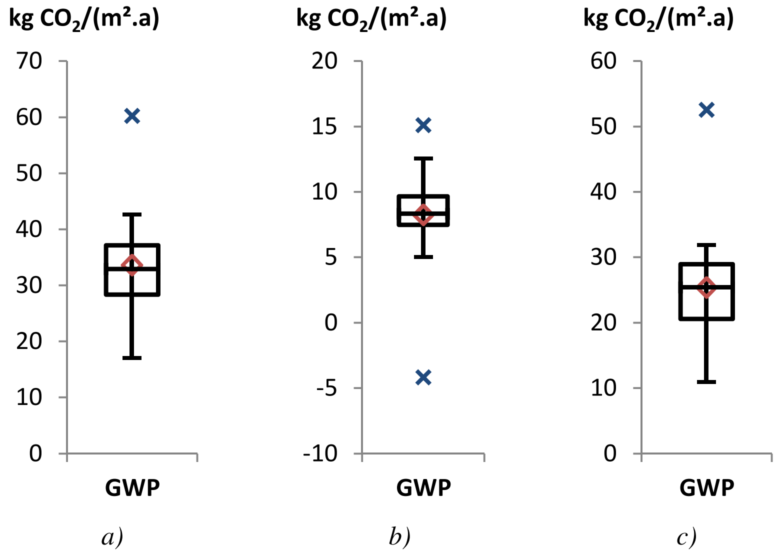

Fig. 4: Boxplot of the empiric analysis of the Global Warming Potential for a) the LCA in total; b) the LCA construction related only and c) the LCA for the operational phase; all values in in kg CO_2/(m².a)

6 Conclusions and Outlook

One of the main finding is the important role of the operational related impact over all indicators considering them as equal important. But there are wide differences taking each indicator independently. The most relevant indicators for the operational related impact are GWP, PE_{nr+r}, PE_r and PE_{nr}. Also, these indicators have a 2 to 3 times higher weighting as the other indicators in the final assessment within the DGNB system. So the results of the assessment emphasis the operational relevance even more.

The method to calculate the operational related impact is not consistent in Austria. The energy calculation doesn’t include energy demand values for basement garages, but the net floor area, used for specific values, includes the basement garage. So the importance of the operational phase would increase another time as the values for GWP and PE indicators would rise, if taking energy demand values for the operation of basement garages.

The analysis shows a good implementation of the LCA method into the environmental building assessment within the DGNB system. As recommendation for a further development of the system it seems to be feasible to reduce the weighting for GWP and PE indicators and give all indicators equal consideration. Similarly the energy demand for basement garages should be included and counted. The comparison between the buildings reveals some wrong

LCA calculations also. It might be a good idea to state some standard of practise on how to deal with recycled materials and end of life scenarios for specific product groups or building elements in the criteria description.

7 Acknowledgement
We would like to thank the Austrian Green Building Council ÖGNI for the good cooperation and providing the data sample for this investigation, as well as the BOKU - University of Natural Resources and Life Sciences, Vienna and the ETH Zuerich for the scientific support.

References

[1] Zabalza Bribián, Ignacio ; Aranda Usón, Alfonso ; Scarpellini, Sabina: Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. In: Building and Environment vol. 44 (2009), Nr. 12, pp. 2510–2520.

[2] Malmqvist, Tom ; Glaumann, Mauritz ; Scarpellini, Sabina ; Zabalza , Ignacio ; Aranda, Alfonso: Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. In: Energy vol. 36, Elsevier B.V. (2011), pp. 1900–1907.

[3] Passer, Alexander ; Kreiner, Helmuth ; Maydl, Peter: Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings. In: The International Journal of Life Cycle Assessment vol. 17 (2012), Nr. 9, pp. 1116–1130.

[4] Zabalza Bribián, Ignacio ; Valero Capilla, Antonio; Aranda Usón, Alfonso: Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. In: Building and Environment vol. 46 (2011), pp.1133–1140.

[5] Ferreira, Joaquim ; Pinheiro, Manuel Duarte ; Brito, Jorge De: Portuguese sustainable construction assessment tools benchmarked with BREEAM and LEED : An energy analysis. In: Energy & Buildings vol. 69, Elsevier B.V. (2014), pp. 451–463.

[6] Wu, Huijun ; Yuan, Zengwei ; Zhang, Ling ; Bi , Jun: Life cycle energy consumption and CO2 emission of an office building in China. In: The International Journal of Life Cycle Assessment vol. 17 (2012), Nr. 2, pp. 105–118.

[7] ISO 14044:2006 Environmental management -- Life cycle assessment - Requirements and guidelines.

[8] EN 15643-2:2011 Assessment of buildings – Part 2: Framework fort the assessment of environmental performance.

[9] Austrian Green Building Council: ÖGNI Steckbriefe 1 to 5 and 10 to 11. ÖGNI Scheme Office Buildings 2009. Linz, 2010.

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Session 64:

Which should the main goals in building renovation be?

Chairperson:
Miguel Mitre, Emilio
GBCe, Madrid, Spain

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Solutions for energy efficiency and renewable energy use in buildings: Basics and results of a stakeholder-oriented economic asessment

Speakers[1]:
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Abstract: *A substantial share of resource depletion and air emissions is caused by energy use in buildings. Building systems incorporating energy efficiency and renewable energy offer technical potential for environmental impact reduction. However, the exploitation of this potential is hampered by non-technological barriers, especially lacking evidence of the respective economic advantages. In a first step, the information needs of stakeholders involved in new construction and refurbishment projects are discussed according to the results of an online questionnaire. Subsequently, a methodology and indicators are developed that aim at the stakeholder-oriented economic assessment of energy efficiency and renewable energy measures. Special attention is given to the presentation form of these indicators to the respective stakeholders. The methodology is illustrated using concrete examples, based on data that has been collected in 58 pilot projects in 23 countries. The contribution concludes with recommendations for the data collection and analysis in future research projects.*

Key words: Energy efficiency, renewable energy, building, economic assessment

1. Introduction

In the European Union a substantial share of resource depletion as well as greenhouse gas and air pollutant emissions is caused by energy use in buildings. Already existing as well as newly developed building systems incorporating energy efficiency and renewable energy offer technical potential for environmental impact reduction. Although single buildings have only a small absolute potential for environmental impact reduction, the building stock as a whole offers a significant one because of the large number of buildings in Europe. Compared to other sectors like industry, transport and energy supply, in the building sector the economic advantageousness of a large share of this potential is often emphasised by different stakeholders like policy makers or environmental organisations.

However, the exploitation of this potential is hampered by a plethora of non-technological barriers, including behavioural, institutional/organizational and market-related barriers and failures [1]. In particular, evidence of the respective economic advantageousness is needed in order to persuade the relevant stakeholders of the benefit of applying energy-related measures. This is a complex task because of the heterogeneity of the building stock, the building owners and the other stakeholders involved in energy efficiency and renewable energy projects. In addition, statements about the economic advantageousness react sensitively to changes in key parameters like planning horizons, share of the total investments contributing to the energetic modernization, energy price expectations and interest rates, as well as the specific stakeholder perspective. This enables contradictive interpretations of the economic advantageousness by

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different stakeholder groups and hinders the comparibility of calculated performance indicators. For example, the construction industry could try to keep minimum requirements low in order to maximize their profit, whereas environmental organizations could try to strengthen these regulations, both by varying the mentioned key parameters. This reveals the need for a *transparent* and *stakeholder-oriented* economic assessment of energy efficiency and renewable energy measures in the building sector.

In this context, further research is needed to reveal an optimum tailoring of information to individual stakeholders. Therefore, in section 2 stakeholders and their information needs are discussed. Section 3 presents a methodology for satisfying these information needs via indicators. This methodology is exemplarily applied in section 4. The paper concludes with a summary and recommendations.

2. Stakeholders and their information needs

Several typologies of stakeholders involved in new construction and refurbishment projects are used in literature (e. g. [2], [3], [4]). An analysis of stakeholder-specific information needs based on an online questionnaire applied in the project CONCERTO Premium showed that the information needs vary strongly between stakeholders [4]. On average, the stakeholders show the highest interest in the economic dimension of energy efficiency and renewable energy measures, followed by the environmental, social and technical dimension. Focusing on buildings owners because of their significant influence in the decision making process in case of refurbishments and new construction projects confirms, in general, a high interest in economic issues. Building owners can be differentiated into (1) individual owner-occupiers, (2) owners/leaseholders/freeholders associations, (3) commercial owner-occupiers, (4) public authorities as owner-occupiers, (5) small-scale private landlords, (6) large private sector landlords, (7) housing cooperatives and (8) state-owned or social housing providers. These stakeholders are characterized by different roles (e.g. investor, owner, user), occasions (e.g. new construction, refurbishment, sale or purchase of building), questions, activity-related characteristics (e.g. level of professionalism, capital availability), knowledge level (e.g, knowledge about energy efficiency and renewable energies, complexity of understandable visualization) and factors impeding or supporting energy efficiency and renewable energy use. Thus, a variety of information needs and the need for different presentation forms result.

3. Methodology for satisfying information needs via indicators

In order to provide the different building owning stakeholders with the relevant information required for an economic assessment, adequate indicators are proposed and assigned to them, as shown in Table 1. The presentation form of these indicators is adapted to the stakeholder characteristics. The reliability of the proposed indicators is ensured by meta-information describing the indicator and the object of assessment context. The following inputs serve as an information base for this methodology: (1) questionnaire results [4], i.e. the information needs stated by these stakeholders, (2) stakeholder-specific system boundaries, which are relevant for the economic assessment, as well as (3) expert knowledge.

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Economic indicators: For the economic assessment of energy efficiency and renewable energy measures in both new construction and refurbishment projects incl. renewable energy technologies, the indicators presented in Table 1 are proposed. They cover short-term (e.g. capital costs), mid-term (e.g. payback period) as well as long-term planning horizons and have different complexities.

Table 1: Assignment of stakeholders to economic indicators and diagram types (not exhaustive); X: yes; (X): partly; -: no; +: high; (+): medium; 0: low; Sources: [4], authors' assumptions/expert judgement

Stakeholder		Economic Indicator						Diagram type			
		Capital costs	Payback period	Equivalent price of saved energy	Energy production costs	Net present value	Acceptable complexity of presentation form	Bar charts	Line chart	Boxplot	Several axes
Owner-occupiers	Individual owner-occupiers	X	X	(X)	(X)	-	0	X	(X)	-	-
	Owners/leaseholders/freeholders associations	X	X	(X)	(X)	-	0	X	(X)	-	-
	Commercial owner-occupiers	X	X	(X)	X	-	(+)	X	X	-	(X)
	Public authorities as owner-occupiers	X	(X)	(X)	X	(X)	(+)	X	X	-	(X)
Landlords	Small-scale private landlords	X	X	-	(X)	(X)	(+)	X	X	-	(X)
	Large private sector landlords	X	(X)	(X)	(X)	X	+	X	X	X	X
	Housing cooperatives	X	(X)	(X)	(X)	X	+	X	X	X	X
	State-owned or social housing providers	X	(X)	(X)	(X)	X	+	X	X	X	X
Complexity of indicator/diagram type		0	0	+	(+)	++		0	(+)	++	++

Assigning indicators to stakeholders: These indicators are assigned to the building owning stakeholders accounting for their individual characteristics (cf. Table 1). The complexity of the indicators played a crucial role in the assignment process, i.e. less complex ones were assigned to stakeholders with assumedly less knowledge regarding energy topics.

Stakeholder-oriented presentation form of indicators: The complexity of a presentation form is determined by the complexity of the indicators and the diagram type. E.g. the equivalent price of saved energy[1] is more complex than the capital costs (cf. Table 1). Regarding the diagram types, complexity increases from bar charts over line charts to boxplots and diagrams with several axes. Table 1 shows per stakeholder the assumed acceptable complexity and in addition to the adequateness of indicators the adequateness of the diagram types**.**

Reliability of indicators: The reliability of indicators depends on their transparency and comparability, an issue often neglected in international research projects. In order to achieve a high transparency and enable statements about the comparability of indicator values each indicator value has to be supplemented by easily accessible information concerning (1) the monitoring rules applied in order to collect the data used to calculate the indicators, (2) the calculation procedures, i. e. the mathematical formula, behind the indicators and (3) meta-information referring to the indicator and the object of assessment. Meta-information encompasses (1) a characterization of the object of assessment and (if applicable) the reference object (general object type [new building/refurbished building/energy supply unit];

[1] This indicator illustrates how expensive it is to save one kWh of final energy, e.g. by an insulation [5].

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detailed object type [building/energy supply unit type]; energy carriers/flows; technologies, floor area etc.), (2) economic key parameters (interest rate, planning horizon, energy prices, annual energy price increase, incl./excl. VAT, price level etc.), (3) environmental parameters (emission/primary energy factors etc.) and (4) additional parameters (climate zone, country, system boundary, demand/consumption based energy flows etc.). Comparability between indicator results requires accordance in several meta-information categories. These categories depend on the indicator type and on the decision the indicators shall be used for.

4. Results & Discussion

The methodology is illustrated using three concrete examples focusing on (A) energy efficient new construction, (B) energy-related refurbishments and (C) use of renewable energy sources. These examples are based on data that has been collected in 58 pilot projects in 23 countries and merged in the cross-analysis project CONCERTO Premium. The data, formula and monitoring guidelines applied are available at www.concerto.eu for all three examples.

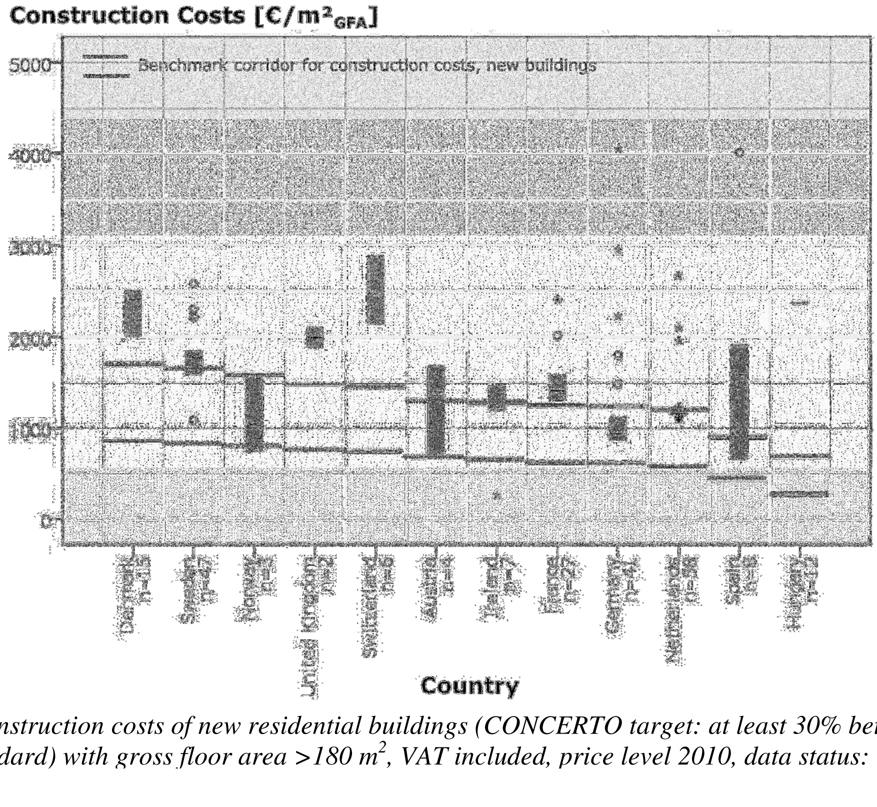

Figure 1: Construction costs of new residential buildings (CONCERTO target: at least 30% better than national standard) with gross floor area >180 m^2, VAT included, price level 2010, data status: 8.10.2013 [6]

Example A – energy efficient new constructions: A state-owned or social housing provider (**stakeholder**) aims at constructing new buildings (**occasion**). Because of pressure from the public shareholders he targets not only housing affordable for low-income tenants but also energy efficient. As affordable housing is still his primary interest and his budget is limited, he wants to know if it is possible to construct energy efficiently within the usual budget (**question**). Thus, capital costs are selected as an **indicator**. As he is used to economic and energy-related diagrams complex **presentation forms** are adequate and an integrated boxplot-bar-chart with benchmarks is used. Figure 1 shows the capital costs of new constructions funded in the CONCERTO initiative. The energy demand of these buildings had to be at least

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30% below fictive new buildings constructed according to the national minimum requirements (**reference**) and can therefore be regarded as “energy efficient”. For Norway, Austria and Germany these buildings show a clear overlap between energy efficient building capital costs and the usual range of capital costs. As the state-owned or social housing provider aims to construct several identical buildings, his situation is comparable to the usual CONCERTO situation, in which economies of scale have been used. However, as not each CONCERTO building is within the usual budget a careful, perhaps integrated planning approach is required. Furthermore, checking the **meta-information** is indispensable for a final judgement regarding comparability. As the figure bundles the information of a variety of buildings only some meta-information can be provided: buildings with a gross floor area exceeding 180 m² are analysed; total construction costs incl. VAT (value added tax) with price level 2010 are referred to the gross floor area. Especially the meta-information characterizing the exact energy efficiency measures depend on the specific building and have to be analysed separately.

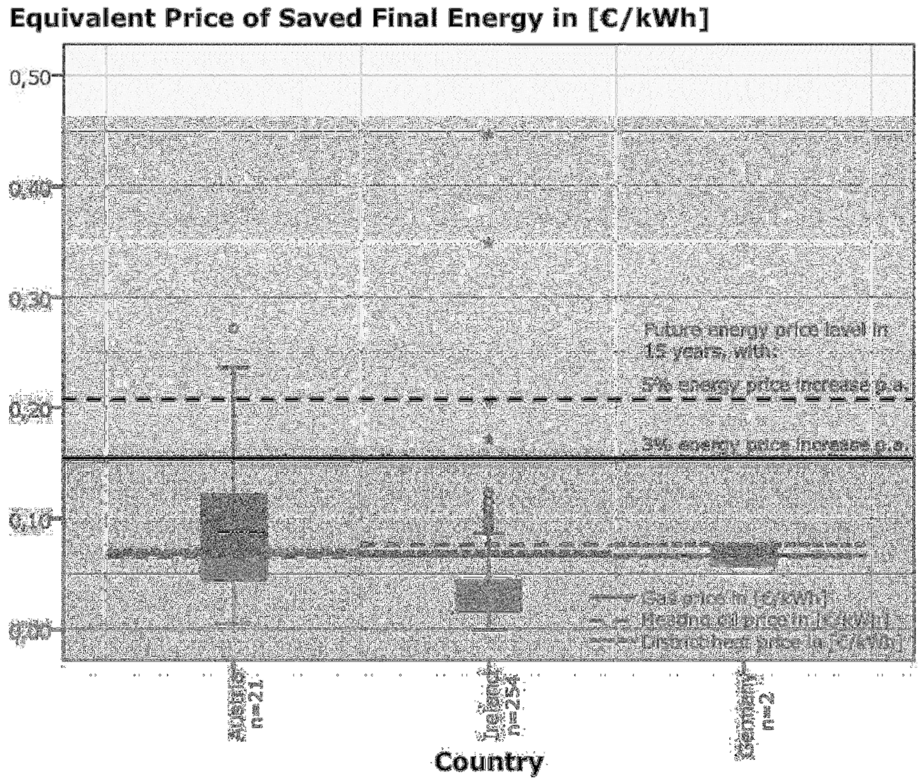

Figure 2: Equivalent price of saved (final) energy, based on calculated demand reductions by refurbishments of residential buildings with a gross floor area < 180 m², energy-related investment costs, no grants considered, VAT included, price level of 2010, 3% discount rate, planning horizon: 30 years, data status: 9.10.2013 [6]

Example B – energy-related refurbishments: A large housing sector landlord (**stakeholder**) owns several single-family houses that are due for refurbishment (**occasion**). He wants to know if he should target a non-energy-related or an energy-related refurbishment (**question**). As the large housing sector landlord is used to complex diagrams a high complexity is acceptable concerning presentation form and indicators. He is aware that the

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energy price strongly influences economic assessments and is difficult to forecast. Furthermore, he assumes that his tenants are willing to participate in refurbishments if the rent incl. heating is not increased. Therefore, the equivalent price of saved energy is chosen as **indicator**. As the economic assessment varies strongly between energy refurbishment packages, a boxplot is used as the **diagram type** in order to present the plethora of potential scenarios. Figure 2 shows the equivalent price of saved energy for energy saving measures in single family houses in Austria, Ireland and Germany, which have been energetically refurbished to new construction level. Assuming constant current energy prices the majority of the energy-related refurbishments in Ireland (n=254) and Germany (n=2) enables a constant or decreasing rent incl. heating. In addition, tenants would be hedged against increasing energy prices. Meta-information shows that grants, which could be applied for, are not considered in the calculation. The discount rate and the planning horizon seem adequate to the landlord.

Example C – use of renewable energy sources: An individual owner-occupier (**stakeholder**) wants to invest in a renewable energy measure. Several years ago, his neighbour invested in PV modules because of promising grants, but the situation changed dramatically since then. Continuously, grants have decreased, PV modules become cheaper, the European industry rapidly declines and the future grant situation is uncertain. He wants to know if it is economically feasible to install PV without grants (**question**). He is no expert, but he knows, what he has to pay for electricity to the local energy supplier (0.24 €/kWh in 2010). Therefore, he wants to know if the electricity production costs (**indicator**) have already dropped to this level. As he is interested in the development of the electricity production costs, a simple line chart is chosen, a **diagram type** with low to medium complexity. Figure 3 shows that in 2010 even if 100% self-consumption, an annual energy price increase of 5%, an interest rate of only 3% and a planning horizon of 20 years is assumed, it was not yet economically feasible to install PV without grants, but with an assumed analogue development throughout the following years it will be. More actual data finally convince the owner-occupier to invest in PV.

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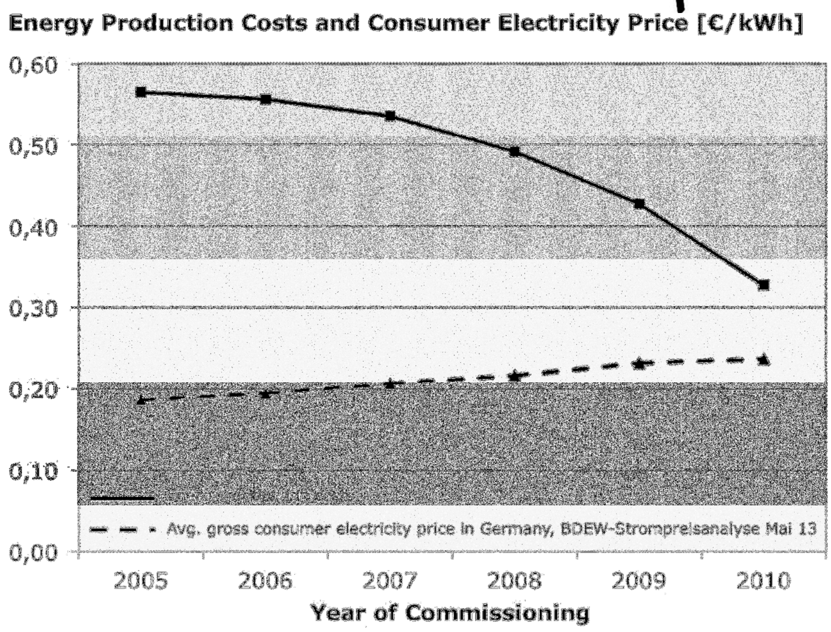

Figure 3: Energy production costs of small PV systems grouped by years, 3% interest rate, 20 years planning horizon, no grants considered, design values used, VAT included, data status: 15.9.2013 [6]

Whilst the framework developed in Table 1 and the exemplary indicators shown above enable the presentation of tailored information to different stakeholders, this information will not necessarily lead to more "rational" behaviour according to "homo oeconomicus", especially if other barriers remain. In addition, the framework and assumptions in Table 1 would benefit from additional validation with empirical data before being further applied. Hence, future work should focus on these two aspects, as well as, on enabling the collection of harmonized datasets across diverse projects/regions and transferring some of these insights to other stakeholders/groups.

5. Summary & Conclusions

A methodology for satisfying information needs of building owning stakeholders has been presented and illustrated with three examples. The paper focused on the economic assessment of energy efficiency and renewable energy technologies. However, the methodology can be applied to other stakeholders, as well as, for the technical, environmental and social assessment dimension. Comparability and transparency have been highlighted as crucial issue. Therefore, data collection and analysis in future research projects should be performed based on a harmonized data collection strategy encompassing meta-information as an obligatory component.

Acknowledgements The authors thank all partners of the CONCERTO Premium consortium and the European Commission that has enabled this work.

References

[1] Sorrell, S.; O'Malley, E.; Scott, D. S. & Schleich, D. J. (2004). *The Economics of Energy Efficiency: Barriers to Cost Effective Investment,* Edward Elgar, Cheltenham.

ISBN: 978-84-697-1815-5

[2] Jahnke, K. (2009). *Analyse der Mesoebene – Praxisakteure im Blickfeld nachhaltigen Wärmekonsums*, Bremen: Bremer Energie Institut.

[3] Lützkendorf, T.; Graubner, C.A. & Löhnert, G. (2008). *Fortsetzung des Dialogs Bauqualität – Erarbeitung von Lehrmodulen zum Nachhaltigen Bauen zur Unterstützung der Aus- und Weiterbildung der am Bau Beteiligten – Phase I: Analyse von Schlüsselakteuren und des Bedarfes an Lehrmodulen & Entwicklung von Handlungsanleitungen für Planer*, Berlin, Bonn: Bundesministerium für Verkehr, Bau und Stadtentwicklung; Bundesamt für Bauwesen und Raumordnung.

[4] Seitz, K.; Fath, K.; McKenna, R.; Stengel, J.; Fichtner, W. & Schultmann, F. (2013). Information needs for community-level energy investments: some insights from a CONCERTO questionnaire. *Eceee Summer Study proceedings*, Rethink, renew, restart. pp. 845–854.

[5] Lützkendorf, T & Platt, E. (2013): *Evaluation of (Smart) Solutions – Guidebook for Assessment Part I – Methodology*. Karlsruhe, www.concerto.eu.

[6] Lützkendorf, T.; Platt, E.; Kleber, M.; McKenna, R.; Merkel, E.; Seitz, K. & Stengel, J. (2013): *Evaluation of (Smart) Solutions – Guidebook for Assessment Part II – Final Assessment Report*. Karlsruhe, www.concerto.eu.

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Interventions in old city centres: assessing the sustainability of rehabilitation actions

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Abstract: *This paper presents a sustainability assessment system for the built environment, specifically addressing urban centres with historic features and consisting of a built environment with high cultural value but often marked by dereliction and constructive degradation. The system was designed based both on the analysis of other assessment systems worldwide and the analysis and characterization of the urban areas, mainly through a comprehensive survey work of the 'old town' of Coimbra (Coimbra's downtown).*

The results achieved by applying this methodology allow defining a profile intervention that clearly shows the performance in each area assessed. The main objective was to create a decision support tool that guides the activities of designers and engineers involved and to guide the user's attitude in face of the occupation and building maintenance, specifically attending the level of resource consumption and waste generation.

Sustainable rehabilitation, urban sustainability, traditional construction

1. Introduction

Rethinking intervention in the built legacy can represent one of the paths to the achievement of sustainable development. To endorse processes, methodologies, materials and solutions assessment are key factors to change the approach of this intervention, in order to promote sustainable practices able to lead to rational use of resources, reduction of waste production, the encouragement of local activity, respect for the individual or the creation of new opportunities to reduce social disparities. [1] [2] [3]

Almost all Portuguese cities have an old city centre that was the cradle of the urban expansion. These areas are characterized for specific materials use and constructive solutions and techniques applied, completly different from the modern patterns of construction. The interventions in old urban areas have been marked for replacement of materials and solutions for current ones; in the cases in which they come together we can observe the discare about the behaviour compatibility among materials that normally result in future pathologies. [4]

All these aspects need to be taken into account during interventions in old cities in order to preserve the heritage and to grant the usability of these urban areas, in some cases completely abandoned and left to their own luck.

2. A Model to Assess the Sustainability of Rehabilitation Actions in Old Areas

Before designing the model it was necessary to study three issues related to it:

- The characteristics of old city centres (for this purpose it was used the example of Coimbra's downtown);
- The sustainable principles and its implementation at the urban and building level;
- The existing sustainability assessment systems that are used in other countries in order to analyse examples and practices that could be replicated in our study.

To go on with the first aspect, a deep study about Coimbra's downtown was carried out by the University of Coimbra, in the area called "Baixa". In this work, around seven hundred buildings were inspected and observed by workgroups from different faculties, as architecture and civil engineering. The profound knowledge acquired allowed to know exactly how these buildings are and what is the performance expected according to its characteristics. The result of this approach was the bottom line to settle the measure levels used to assess the criteria in the model. [5]

The second aspect was developed through research about the main aspects of sustainability that were used as guidelines for the models. The main areas of the model were defined according to the main principles related with the environmental, economical and social aspects. The environmental aspect is the one wich includes more areas and criteria, and this becomes important once it is expected the model properly assess physical interventions and answer users' needs and it is intended to be used by technicians and urban decision makers.

Regarding the third aspect some existing sustainable assessment tools, used in other countries, were analysed, as SBTool (the global model), BREEAM (UK), LEED (USA) and LiderA (Portugal). In the cases of BREEAM and LEED, tools for new and existing buildings were analysed in order to understand the main differences in areas and criteria. Some criterion could be fundamental in one approach and disregarded in other, attending the characteristics of the site's use of land (something very important for new buildings, namely when the construction is done in a new area, but it is not applicable when we are assessing rehabilitation, as it occurs in existent buildings in constructed areas). [5]

The designed model has nine main areas and each one has its related criteria to be analysed and assessed acoording to the sustainability of the intervention: Local, Transport, Water, Energy, Materials, Exterior Environment, Interior Environment, Use and, finally, Cultural, Economic and Social. As mentioned before, each area has specific criteria to assess sustainability and this paper closely deals whith the three areas related to sustainability in resources: water, energy and materials.

The criteria for these areas are showned in the following tables: Table 1 for sustainability in water, Table 2 for sustainability in energy and Table 3 for sustainability in materials.

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Table 1 – Criteria for sustainability of resources – Water

Sustainability of Resources - Water				
Supplying		Criteria 1	Criteria 2	Criteria 3
SA1	Potable water consume	SA1.1 Monitoring	SA1.2Awareness actions	
SA2	Efficency of supply housing network	SA2.1 Before/After interventions	SA2.2 Equipments	
SA3	Internal supplying systems separated	SA3.1 Double supply systems		
SA4	Using reainwater for irrigation and other non potable uses	SA4.1 Outer spaces	SA4.2 Inner spaces	SA4.3 Public spaces
Drainage				
SA5	Wastewater treatment for reuse	SA5.1 Type of system	SA5.2 Recycled flow	

Table 2 – Criteria for sustainability of resources – Energy

Sustainability of Resources - Energy				
Efficiency		Criteria 1	Criteria 2	Criteria 3
SE1	Defining minimum performance levels	SE1.1 U envelope	SE1.2 Expected performance levels	
SE2	Type of used equipments	SE2.1 Energetic and ecological efficiency		
SE3	Type of building's exterior and interior lighting	SE3.1 Interior lighting	SE3.2 Natural lighting	
SE4	Monitoring energetic consume	SE4.1 Monitoring		
Renewable resources				
SE5	Using renewable resources	SE5.1 Type of systems	SE5.2 Monitoring	
SE6	Strategies to improve the solar potential	SE6.1 Used strategies		

Table 3 – Criteria for sustainability of resources – Materials

Sustainability of Resources - Materials				
Consume		Criteria 1	Criteria 2	Criteria 3
SM1	Reusing existente main elements	SM1.1 Walls	SM1.2 Floor	SM1.3 Roof
SM2	Using local materials	SM2.1 Materials origin		
SM3	Using material with recycling potential in refurbishment and maintenance actions	SM3.1 Volume of materials		
Residues				
SM4	Availability of devices to collect residues	SM4.1 Ecopoint distance		
SM5	Reducing waste from refurbishment and maintenance actions	SM5.1 Volume of non-recycable waste / Recycable		
Recycling				
SM6	Recycling domestic waste	SM6.1 Awareness actions	SM6.2 Recycled waste in the area	
SM7	Recycling wast from refurbishment and maintenance actions	SM7.1 Monitoring SM5		
SM8	Management of non-recycable waste	SM8.1 Collecting and storing		

Each criterion has measurement standards defined and indicators that match defined grades. The model has three measurement indicators: the lowest level is A and is graded with -3 points, the medium level is B with 1 point and the highest level is C with 3 points. In some criteria it is possible to increment the grade with 1 extra point when inovative solutions are used [what is called innovation point (identified in Figures 1, 2 and 3 with a star)].

Other criteria were acknowledged in the model as Management Criteria (GU) and its assessment depends of the decision maker’s strategies and urban area structure. Thus, this criteria are not directly related with the project technician’s choices and solutions.

The measurement criterion are complementar, meaning that to reach the maximum grade C, with the equivalent 3 points, the conditions of lowest levels A and B are also filled.

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As an example, in Table 4, the measurement indicators of the criteria related with the Area of Sustainability in Resources - Water are presented. In this Area it is possible to find five criteria and each one has from 1 to 3 indicators, graded from -3 to 3.

Table 4 – Measure indicators for criteria in the Area Sustainability of Resources – Water

	Assessment -	A	B	C
	Grade -	-3	0	3
SA1	Potable water consume			
SA1.1	Monitoring	Same	Reduction < 15% anual consume	Reduction > 15% anual consume
SA2.1	Awareness actions	Ocasional information	Systematic information	Implementation of a strategy
SA2	Efficency of supply housing network			
SA1.1	Before/After	Same losses	Reduction < 10% losses	Reduction > 10% losses
SA2.1	Equipments	Using water efficiency equipments	Double flushing equipments	Using equipments with sensors
SA3	Internal supplying systems separated			
SA1.1	Double supply systems	Non use of separate systems	Separate systems using rainwater for toilet	Separate systems using rainwater non potable uses
SA4	Using reainwater for irrigation and other non potable uses			
SA4.1	Outer spaces	Without system	System supply 100% outer needs	System provide all exterior needs
SA4.2	Inner spaces	Without system	System supply <50% non-potable needs	System supply >50% non-potable needs
SA4.3	Public spaces	System supply <50% public spaces needs	System supply >50% public spaces needs	System supply 100% public spaces needs
SA5	Wastewater treatment for reuse			
SA5.1	Type of system	Without system	Treatment of gray water from bathrrom	Treatment of gray water from kitchen and/or brown from bathroom
SA5.2	Recycable flow	Waste flow non recycle	Recycling <50% housing flow	Recycling >50% housing flow

3. Examples of Model Application

The model was applied in these three domains in a rehabilitation project that took place in Coimbra's downtown. This rehabilitation was done by the Historical Centre Office, the organism responsible for managing the old city centre and that reports directly to Coimbra's townhall.

The first obstacle to overcome by the model implementation was the lack of information in the project, with no specifications about the systems used or specific projects (water supply, electricity, and structure). Describing this rehabilitation project briefly we can mention that the main structure of the old house was preserved, just the roof was replaced due to its bad conditions. In general, it is a traditional project where the original solutions were maintained but updating it for new materials. As the house doesn't have an exterior space, mainly due to the land occupation pattern, the criteria related to exterior spaces couldn't be considered. Some specific aspects, as the type of equipment or lighting devices were not identified in the project, so the grade considered was the worst one, i.e. A, with -3 points.

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Figures 1, 2 and 3 show the model system applied to the intervention project analysed. The global performance is quite poor as sustainable actions were not taken into account or were considered as a strategic approach to define the intervention.

In the Area Sustainability of Resources –Water, the main goal delt with the racionalization of the potable water consume using several strategies.

		Minimum	Maximum	Result	
	SA1.1	1	3	-3	
GU	SA1.2	1	3	-3	
	SA2.1	1	3	-3	
	SA2.2	1	4	-3	⋆
	SA.3	1	4	-3	⋆
	SA4.1	1	4	1	⋆
	SA4.2	1	4	-3	⋆
GU	SA4.3	1	3	-3	
	SA5.1	1	4	-3	⋆
	SA5.2	1	3	-3	

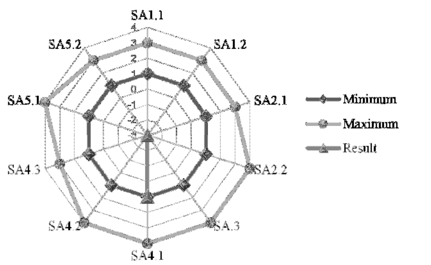

Figure 1. Example of system use in Sustainability of resources – Water

In the area Sustainability of Resources – Energy, the two indicators related to criteria SE5 – use of renewable resources were assessed with 1 point as its use is not mandatory in old city centres according to the Portuguese energetic certification system. The model stated that criteria that can’t be assessed for some reason should be considered with 1 point.

	Minimum	Maximum	Result	
SE1.1	1	4	-3	⋆
SE1.2	1	4	-3	⋆
SE2	1	4	-3	⋆
SE3.1	1	4	-3	⋆
SE3.2	1	4	-3	⋆
SE4	1	3	-3	
SE5.1	1	4	1	⋆
SE5.2	1	3	1	
SE6	1	4	1	⋆

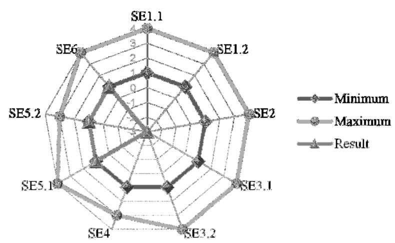

Figure 2. Example of system use in Sustainability of resources - Energy

In the area Sustainability of Resources – Materials, it is intended to carry out an analysis to the different materials used during the building’s rehabilitation phase. Contruction materials show high intrinsic energy, associated with the energy needed to produce such elements. The use of recycled materials could provide a significative reduction of these energy levels. The origin of these materials or the existence of collection points are also assessed in this area.

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		Minimum	Maximum	Result	
	SM1.1	1	4	1	⋆
	SM1.2	1	4	1	⋆
	SM1.3	1	4	-3	⋆
	SM2	1	4	-3	⋆
	SM3	1	4	-3	⋆
GU	SM4	1	3	-3	
	SM5	1	4	-3	⋆
GU	SM6.1	1	3	-3	
GU	SM6.2	1	3	-3	
	SM7	1	3	-3	
GU	SM8	1	3	-3	

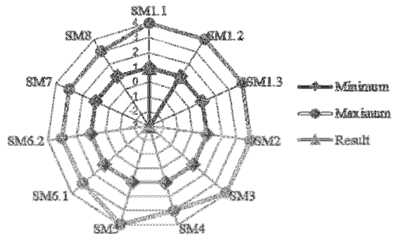

Figure 3. Example of system use in Sustainabilityof resources - Materials

As can be observed, the assessement of the majority of criteria were awarded whith C, the lowest grade. It hapened due to lack of information existing in the technical file of the intervention analysed, following the atribution of the lowest level according to the model. Thus, taking into account that the only source of information is the existing documents, the assessment should be base on them, but it doesn't mean the impossibility of some other solution existence that could be implemented in the intervention action. This situation took us to the main challenge for aplication of a sustainability assessment model: the lack of information.

4. Conclusions

The approach of sustainable principles in a Project it is a strategy that must be considered since before the Project phase starts. This phase is the most important one, where solutions and methodologies can be set in order to promote a better interior and exterior environment. The knowledge about sustainability principles and about systems and solutions related to its application is the only way to reach an aceptable result in sustainability assessment methods.

The benefits of using the model to drive technician and decision makers in interventions are central elements in overall strategies of development and sustainability of urban areas and can be used as a way to change the actions and practices. The relationship between the site and construction is one of the factors that are lost over time, due to technological improvements. The mastery of technologies that meet the comfort through the use of equipment was one of the reasons that motivated some satisfaction regarding the relationship between the environment and the building.

The rehabilitation of the built environment is, in fact, an asset for sustainability because it engages the decrease of requirements for new buildings. Promoting interventions in degraded urban areas is a key factor in renewing the urban environment and reduce its spreading.

The model designed is accurate with the old city centres characteristics and this is fundamental for creating an objective and executable system, with reachable goals: the existent conditions are known and the values defined in the indicators can be achieved with solutions adapted to the buildings conditions.

5. Acknowledgements
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6. References

[1] KIBERT, Charles J., "Sustainable Construction: Green Buildings Design Delivery", 2nd Edition, John Wileys & Son: New Jersey, 2008.

[2] HALLIDAY, Sandy, "Sustainable Construction", Oxford: Butterworth-Heinemann, 2008.

[3] GRAHAM, Peter, "Building Ecology – First Principles for a Sustainable Built Environment", Oxford: Blackwell Science Ltd, 2003.

[4] AGUIAR, José, CABRITA, António Reis, APPLETON, João, "Guião de Apoio à Reabilitação de Edifícios Habitacionais", Vol. 2, Laboratório Nacional de Engenharia Civil (LNEC): Lisboa, 2001.

[5] RAMOS, Ana Ferreira, "Os Custos do Desenvolvimento Sustentável para a Arquitectura, Engenharia e Construção nos Processos de Reabilitação" [Sustainable development costs for Architecture, Engineering and Construction in rehabilitation processes], PhD Thesis, Coimbra: Universidade de Coimbra, 2010.

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Is building renovation truly sustainable? The need for applying a multi-criteria assessment through life cycle approach

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Abstract: The aim of the present research is to characterise the international scene in the field of building refurbishment, by thoroughly reviewing the literature relating to building renovation and systematising the results according to the different aspects considered by the authors. Even though there is certain consensus with respect to the criteria for the selection of energy efficiency measures, the assessment criteria differ broadly and widely. The present work highlights the lack of consensus on the assessment criteria and the need of harmonization. A holistic view is required in order to identify the most sustainable strategies in each particular case, considering social, environmental and economic impacts from a life cycle perspective.

Building renovation, energy efficient retrofits, assessment method, sustainability, energy efficiency.

1. **Introduction**

Buildings worldwide account for 16-50% of total energy consumption, while the corresponding value in Europe is 40%. Although over 70% of the existing building stock is inefficient, the replacement rate of existing buildings is just around 1.0-3.0% per year. The challenge is now to act on this stock, the result of the heavy need for housing in the middle of the last century, after the devastation of World War II.

Nowadays, the need to promote energy efficiency in the building sector is widely recognized. Following the European commitment of "Horizon 2020", many governments and international organisations have made significant efforts towards energy efficiency improvement in existing buildings. In a previous work, an analysis of over 50 renovated residential buildings in Madrid was carried out, with the conclusion that the same energy efficiency strategies had been applied in buildings with different features. Furthermore, only the reduction of thermal transmittance values was evaluated. Since as yet there has been no deep analysis of the same, further study is needed together with fixing the priority of evaluation of the sustainability of measures applied.

The aim of the present research is to characterise the international scene in the field of building refurbishment, by thoroughly reviewing the literature relating to building renovation and systematising the results according to the different aspects considered by the authors. Even though there is certain consensus with respect to the criteria for the selection of energy

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efficiency measures, the assessment criteria differ broadly and widely. Some authors consider solely environmental aspects, others analyse exclusively economic factors and others develop multi-criteria methodologies considering both environmental and economic aspects. However, the life cycle approach is not considered in either the economic or the environmental assessments. Apart from this, there is a highly limited number of authors who evaluate the social dimension.

2. Building renovation: is it truly sustainable?

The amount of research carried out in building refurbishment has significantly increased over recent years. In the present work, a systematic classification has been done in order to identify the most common energy-efficient strategies concluding that retrofit strategies implemented are quite similar in all the case studies analysed. One central question that should be addressed is: is building renovation truly sustainable? The assessment criteria and methodologies differ broadly and widely. For the purpose of this study, sustainability assessment works have been classified according to the evaluation criteria: environmental, economic and multi-criteria.

2.1. Environmental assessment

During the past decade several studies have researched the efficiency of energy saving measures for residential buildings. Annual energy savings and CO_2 emission reduction were only considered until a few years ago (1,2). More recently, the whole life of the building has been included in the environmental analysis, as well as a broader range of environmental impacts, through the Life Cycle Assessment (LCA) method (3,4).

2.2. Economic assessment

When analysing retrofit strategies from an economic perspective, several approaches are considered, such as savings-to-investment ratio (SIR) (5), cost-benefit analysis (6), relation between investment cost and annual energy cost (7) and net present value (NPV) approach (8). The NPV approach is used for determining the present values of the costs that would occur in the remaining life of a building; it is the most common method for calculating Life Cycle Cost (LCC), as LCC represents the sum of the present value of investment and operating costs for the building and service systems, including those related to maintenance and replacement, over a specified life span. In Sweden, LCC analysis of renovation measures for all multifamily buildings is required as part of the national implementation of the first EU energy performance of building directive (EPBD) (9).

2.3. Multi-criteria assessment

Multi-criteria analysis methodologies (MC) have increasingly been developed in order to achieve sustainable assessment; economic and environmental impacts are generally considered, while social impacts are still put aside. Jaggs and Palmar (10), Rey (11), and Alanne (12) proposed MC-based approaches for the evaluation of retrofitting scenarios. Diakaki et al. (13) investigated the feasibility of applying multi-objective optimization techniques to the problem of improving energy efficiency in buildings. Juan et al. (14)

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developed a genetic algorithm-based decision support system for housing condition assessment that suggests optimal refurbishment actions considering the trade-off between cost and quality. Wang et al. (15) reviewed multi-criteria/objective decision making (MCDM) methods used in sustainable energy field, namely in the selection of energy supply systems. Chantrelle et al. (16) developed a new tool, MultiOpt, for the multi-criteria optimization of renovation operations, with regard to building envelopes, HVAC systems and control strategies. Asadi et al. (17) presented a multi-objective optimization model to quantitatively assess technology choices in a building retrofit project. Brown et al. (9) proposed a method for assessing renovation packages drawn up with the goal of increasing energy efficiency; the method included calculation of bought energy demand, life-cycle cost (LCC) analysis and assessment of the building according to the Swedish environmental rating tool Miljöbyggnad (MB). All mentioned studies are however limited to the evaluation of energy consumption, costs and/or CO_2 emission reductions. It is remarkable that the overall life cycle environmental impact and cost of housing renovation have not been considered in an integrated way in the aforementioned works.

More recently, Allacker et al. (18) proposed an integrated assessment of the life cycle environmental impact and cost methodology for sixteen representative dwellings in Belgium, both existing and newly built dwellings. The environmental impact was estimated based on a life cycle assessment (LCA), while a life cycle costing (LCC) analysis was used for the cost aspect; the investment cost was also considered in terms of affordability. Vrijders and Wastiels (19) evaluated the renovation of a building in Belgium considering different scenarios through the LCC and LCA methodologies. In this case, cost efficiency and environmental impact are compared separately. De Angelis et al. (20) analyzed a multi-story residential building located in Northern Italy in order to evaluate different renovation alternatives, considering LCA and LCC approaches. Ostermeyer et al. (21) proposed a multidimensional Pareto optimization methodology, using LCC and LCA, combined with first stages of a social assessment in a feasibility study but potentially later full SLCA; LCA and LCC were used to analyze a case study from an EU project named BEEM-UP in which solutions for large scale uptake of refurbishment strategies are developed. Cetiner and Edis (22) defined an environmental and economic sustainability assessment method to evaluate the effectiveness of existing residential building retrofits for reducing their space heating energy consumptions and the resulting emissions.

3. Towards a sustainable building renovation

As innovative technologies and energy efficiency measures for buildings are well known, the main challenge is to identify those that will prove to be the more effective and reliable in the long term. A limitation observed in this review study is the difference in the appraisal criteria. The wide variety on assessment methods and tools and the lack of uniform criteria, make impossible to compare results from different research works. Table 1 shows a compilation of multi-criteria methodologies that consider both economic and environmental approaches over the whole life cycle.

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Allacker et al. (18)

Economic criteria

Life cycle cost (€/m^2)

Initial cost (€/m^2)

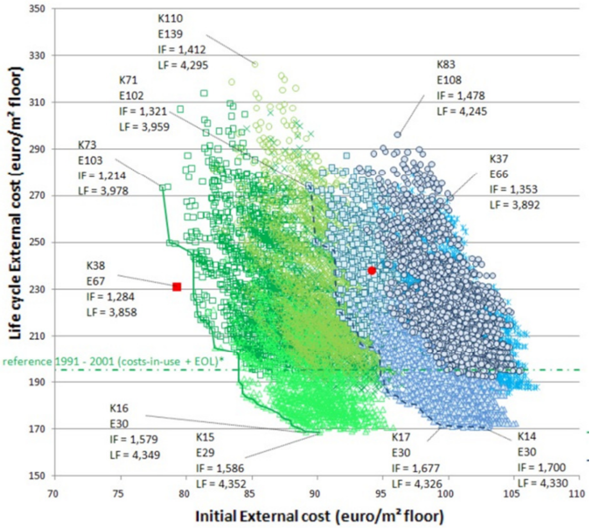
Environmental criteria

External cost (€/m^2)

External initial cost (€/m^2)

Optimization method

Pareto optimization



De Angelis et al. (20)

Economic criteria

Life cycle cost (€/m^2)

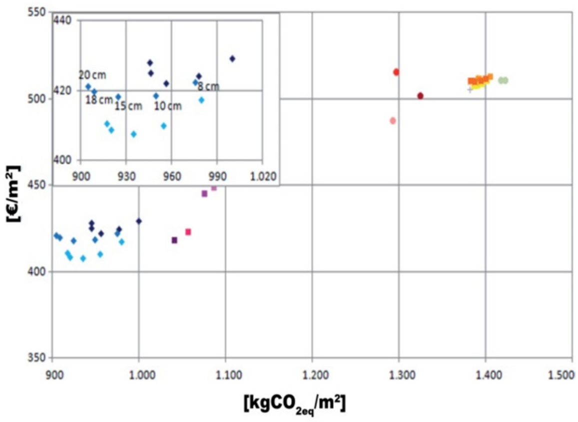
Environmental criteria

Cumulative Energy Demand (MJ/ m^2)

CO_{2eq} emissions (kgCO_{2eq}/m^2)

Optimization method

Pair-wise ranking method



Ostermeyer et al. (21)

Economic criteria

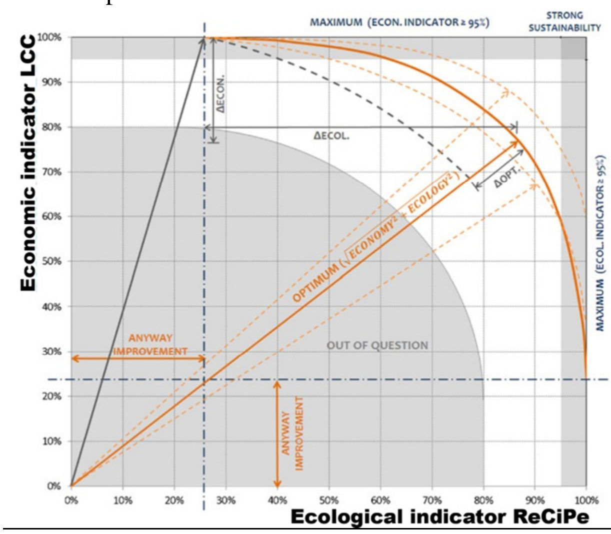
Life cycle cost

Environmental criteria

ReCiPe

Optimization method

Pareto optimization



Cetiner and Edis (22)

Economic criteria

$CR_{i,j} = (CI_i - CI_j) \times CI_i$

CR: economic performance; *CI*: economic impact (TRY); i, j: building type and retrofit alternatives.

Environmental criteria

$NR_{i,j} = (NI_i - NI_j) \times 100/NI_i$

NR: environmental performance; *NI*: environmental impact (eco-points); *i,j*: building type and retrofit alternatives.

Optimization method

Weighted-sum method

$$SP_{i,j} = \left(\frac{(NR_{i,j} \times m_n) + (CR_{i,j} \times m_c)}{100}\right)$$

SP: sustainability performance (−); *NR*: environmental performance (−); *CR*: economic performance (−); *m*: is the importance ratio (%).

The indices *i* and *j* are the building type and the retrofit alternative planned to be used respectively.

The indices *n* and *c* indicate the environmental and economic performances respectively. The sum of m_c and m_n is 100.

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Table 1. Comparison of multi-criteria methodologies of environmental and economic assessment applied to residential sector.

In order to achieve sustainability, the whole life cycle must be considered. In buildings with high-energy consumption, operational energy represents a high percentage compared to the total life cycle energy use. Nonetheless, there is currently an increasing trend towards low energy houses and, as energy consumption decreases, energy involved in the rest of the life cycle phases become more and more important.

One major concern is that social performance is not considered yet in these methodologies. Ostemeyer et al. (21) discussed the potential for including Social Life Cycle Assessment (SLCA) as a third dimension in the methodology proposed. However, they concluded that the development in the field of social indicators in the building sector has to be strengthened in order to come up with a holistic picture and respectively with appropriate responses to current challenges. Although LCA and LCC methodologies are used in the four cases, output indicators differ significantly as do optimization methods, which prevent the comparison of different studies.

There is therefore a great need for harmonization in this area. The technical committee ISO TC 59 in parallel and in coherence with its European counterpart, CEN TC/350 Sustainability of construction Works, are working on the development of the standards for the sustainability assessment of buildings, including the assessment of environmental, economic and social performance. The framework under development applies to all types of buildings and it is relevant for the assessment of the environmental, social and economic performance of new buildings over their entire life cycle, and of existing buildings over their remaining service life and end of life stage.

4. Conclusions

This paper presents a critical review of the works related to the energy-efficient housing renovation and discusses the sustainability assessment methods used in building retrofits. Firstly, assessment methods have been classified into environmental, economic and multi-criteria. Multi-criteria methodologies has been deeper analyzed, briefly describing those that cover the entire life cycle (Table 1).

The concluding remarks in this area are as follows:

- There is a certain degree of consensus about energy-efficient strategies in housing renovation. Envelope insulation and windows replacement are the most common measures, as they are good passive strategies in order to reduce heating energy demand.
- There is not any unanimity on the sustainability assessment criteria. Although multi-criteria methodologies have become increasingly popular, they do not consider economic, environmental and social issues simultaneously in the entire life cycle.

- The different normalization and weighting methods not only reduce the transparency of the study, but also make the results uncertain and subjective. Moreover, results cannot be compared.

To sum up, more research should be developed on multi-criteria methodologies, as a decision tool in order to compare the sustainability of alternative solutions on refurbishment projects.

5. References

(1) Goldman, C. A., Greely, K. M., Harris, J. P. (1988). Retrofit experience in U.S. multifamily buildings: Energy savings, costs, and economics. *Energy,* 13(11): 797-811, doi:http://dx.doi.org/10.1016/0360-5442(88)90085-0.

(2) Stovall, T., Petrie, T., Kosny, J., Childs, P., Atchley, J., Sissom, K. (2007). An exploration of wall retrofit best practices. *Thermal Performance of the Exterior Envelopes of Buildings X, Proceedings of ASHRAE THERM X,* Clearwater Beach, FL, USA.

(3) Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M. (2013). Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits. *Renewable and Sustainable Energy Reviews,* 27: 283-293, doi:10.1016/j.rser.2013.05.040.

(4) Cellura, M., Di Gangi, A., Longo, S., Orioli, A. (2013). An Italian input–output model for the assessment of energy and environmental benefits arising from retrofit actions of buildings. *Energy and Buildings,* 62(0): 97-106, doi:http://dx.doi.org/10.1016/j.enbuild.2013.02.056.

(5) Gorgolewski, M. (1995). Optimising renovation strategies for energy conservation in housing. *Building and Environment,* 30(4): 583-589, doi:http://dx.doi.org/10.1016/0360-1323(95)00011-T.

(6) Goodacre, C., Sharples, S., Smith, P. (2002). Integrating energy efficiency with the social agenda in sustainability. *Energy and Buildings,* 34(1): 53-61, doi:10.1016/S0378-7788(01)00077-9.

(7) Martinaitis, V., Kazakevičius, E., Vitkauskas, A. (2007). A two-factor method for appraising building renovation and energy efficiency improvement projects. *Energy Policy,* 35(1): 192-201, doi:http://dx.doi.org/10.1016/j.enpol.2005.11.003.

(8) Desogus, G., Di Pilla, L., Mura, S., Pisano, G. L., Ricciu, R. (2013). Economic efficiency of social housing thermal upgrade in Mediterranean climate. *Energy and Buildings,* 57(0): 354-360, doi:http://dx.doi.org/10.1016/j.enbuild.2012.11.016.

(9) Brown, N. W. O., Malmqvist, T., Bai, W., Molinari, M. (2013). Sustainability assessment of renovation packages for increased energy efficiency for multi-family buildings in Sweden. *Building and Environment,* 61(0): 140-148, doi:10.1016/j.buildenv.2012.11.019.

(10) Jaggs, M., Palmer, J. (2000). Energy performance indoor environmental quality retrofit — a European diagnosis and decision making method for building refurbishment. *Energy and Buildings,* 31(2): 97-101, doi:http://dx.doi.org/10.1016/S0378-7788(99)00023-7.

(11) Rey, E. (2004). Office building retrofitting strategies: multicriteria approach of an architectural and technical issue. *Energy and Buildings,* 36(4): 367-372, doi:http://dx.doi.org/10.1016/j.enbuild.2004.01.015.

(12) Alanne, K. (2004). Selection of renovation actions using multi-criteria "knapsack" model. *Automation in Construction,* 13(3): 377-391, doi:http://dx.doi.org/10.1016/j.autcon.2003.12.004.

(13) Diakaki, C., Grigoroudis, E., Kolokotsa, D. (2008). Towards a multi-objective optimization approach for improving energy efficiency in buildings. *Energy and Buildings,* 40(9): 1747-1754, doi:10.1016/j.enbuild.2008.03.002.

(14) Juan, Y., Kim, J. H., Roper, K., Castro-Lacouture, D. (2009). GA-based decision support system for housing condition assessment and refurbishment strategies. *Automation in Construction,* 18(4): 394-401, doi:http://dx.doi.org/10.1016/j.autcon.2008.10.006.

(15) Wang, J., Jing, Y., Zhang, C., Zhao, J. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews,* 13(9): 2263-2278, doi:http://dx.doi.org/10.1016/j.rser.2009.06.021.

(16) Chantrelle, F. P., Lahmidi, H., Keilholz, W., Mankibi, M. E., Michel, P. (2011). Development of a multicriteria tool for optimizing the renovation of buildings. *Applied Energy,* 88(4): 1386-1394, doi:http://dx.doi.org/10.1016/j.apenergy.2010.10.002.

(17) Asadi, E., da Silva, M. G., Antunes, C. H., Dias, L. (2012). A multi-objective optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB. *Building and Environment,* 56(0): 370-378, doi:http://dx.doi.org/10.1016/j.buildenv.2012.04.005.

(18) Allacker, K., De Troyer, F. (2013). Moving towards a more sustainable Belgian dwelling stock: the passive standard as the next step? *Journal of Green Building,* 8(2): 112-132, doi:10.3992/jgb.8.2.112.

(19) Vrijders, J., Wastiels, L. (2013). Nearly Zero Energy Renovation of houses : Life cycle costs and environmental impact. *International Sustainable Building Conference,* Graz. 87-94.

(20) De Angelis, E., Dotelli, G., Pittau, F., La Torre, A., Porcino, C., Pansa, G., Villa, N. (2013). LCA and LCC based Energy Optimization of Building Renovation Strategies. *International Sustainable Building Conference,* Graz. 77-86.

(21) Ostermeyer, Y., Wallbaum, H., Reuter, F. (2013). Multidimensional Pareto optimization as an approach for site-specific building refurbishment solutions applicable for life cycle sustainability assessment. *International Journal of Life Cycle Assessment,* 18(9): 1762-1779, doi:10.1007/s11367-013-0548-6.

(22) Cetiner, I., Edis, E. (2014). An environmental and economic sustainability assessment method for the retrofitting of residential buildings. *Energy and Buildings,* 74: 132-140, doi:10.1016/j.enbuild.2014.01.020.

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Sustainable Renovation of Buildings

Speaker:
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Abstract: *The new Energy Efficiency Directive (EED) includes a requirement for Member States to establish long-term strategies for mobilising investment in the renovation of the existing building stock. A first version of these strategies was due to have been published by 30 April 2014. These national strategies could and should be a key vehicle for accelerating the rate, and increasing the depth, of building renovation throughout the EU, in order to achieve 90% CO2 savings in the building stock by 2050 compared to 2010 levels. It is vital that these renovation strategies are ambitious in their scope and coverage, and that they take full advantage of the state of the art, in terms of technology, policy, financing and institutional arrangements.*

Key words: sustainable renovation, Energy Efficiency Directive, financing, renovation strategy, deep renovation, state-of-the-art, dwellings, commercial buildings

Legislative Context for Sustainable Building Renovation

Across Europe and other developed nations and regions, buildings represent the largest potential for cost effective carbon emission reduction and with it, improvement in energy security, as well as a myriad of other benefits - fuel poverty alleviation, improved air quality, increased comfort, increased property values, energy system benefits, as well as energy bill savings (1). Yet historically, deep renovation of buildings to significantly improve their energy performance has not been a priority, either for policy makers or building owners and investors.

Progressive waves of EU legislation over a period of 20 years have sought to address different aspects of energy use in buildings, starting with hot water boilers and household appliances, until, in the early 2002, the first comprehensive policy addressing building energy performance was enacted (Figure 1). The Energy Performance of Buildings Directive (EPBD 2002) (2) required EU Member States to implement a number of measures, including the introduction of Energy Performance Certificates and inspection of heating, ventilation and air conditioning (HVAC) systems, as well as energy performance requirements for new as well as existing buildings. Many of these requirements were strengthened in the 2010 recast of the Directive (EPBD 2010) (3), which most notably introduced the requirement for all new construction to be nearly zero energy buildings from 2021 (2019 for buildings owned and occupied by public authorities).

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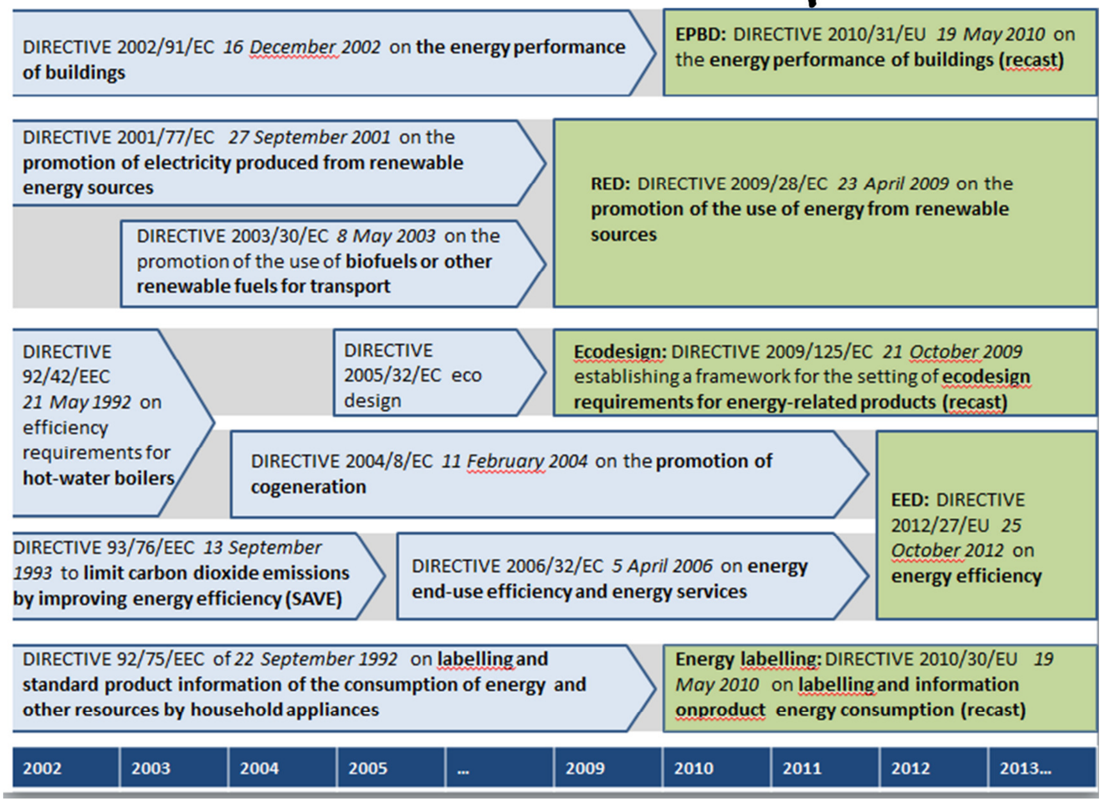

Figure 1 – Timeline of Key EU Legislation Affecting Energy Use in Buildings (4)

However, despite 20 years of legislation, the provisions for existing buildings have remained weak, relative to the requirements on new buildings. To a large degree, this is understandable, since a new building must secure approval from the relevant authorities before being constructed, and it is therefore easier to impose obligations. There are also fewer technical restrictions as to the installation of energy saving measures, other than those imposed by location, the plot of land and its immediate vicinity, and access to different energy carriers.

That said, EPBD does require certain energy performance requirements to be met when a building is undergoing a major refurbishment, though this leaves the vast majority of existing buildings not subject to any obligation to refurbish. In a similar fashion, the Renewable Energy Directive (5) requires the use of minimum levels of energy from renewable sources in existing buildings that are subject to major renovation.

Building Renovation Strategies – Compliance with Directive Requirements

The latest addition to the EU legislative framework in 2012 is the Energy Efficiency Directive (EED) (6). Among its many provisions is the requirement for Member States to develop national building renovations, describes in Article 4 of the EED:

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Member States shall establish a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings, both public and private. This strategy shall encompass:

(a) an overview of the national building stock based, as appropriate, on statistical sampling;

(b) identification of cost-effective approaches to renovations relevant to the building type and climatic zone;

(c) policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations;

(d) a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;

(e) an evidence-based estimate of expected energy savings and wider benefits.

A first version of the strategy shall be published by 30 April 2014 and updated every three years thereafter and submitted to the Commission as part of the National Energy Efficiency Action Plans.

Figure 2 – Energy Efficiency Directive Article 4

Whilst stopping short of mandatory requirements, Article 4 is nevertheless a potentially powerful lever that could result in actions being taken that significantly increase the level of activity in building renovation, by virtue of requiring each Member State to undertake a strategic assessment of the potential for renovation of the building stock. The question is – has it done so?

In order to answer that question, the author has undertaken a preliminary assessment of the strategies that have been published on the European Commission's website as of 25th May 2014, i.e. nearly one month after the deadline set in EED of 30th April 2014.

The first metric to consider is simply the number of strategies submitted. To date, only 10 have been officially published, out of the 28 that should have been. This is a very disappointing result, given that Member States have had 18 months since the EED was introduced in October 2012 to prepare for this date.

The next level is to consider whether the published strategies have met the minimum requirements set out in Article 4 (figure 2).

> *(a) overview of the national building stock* - For the most part, the strategies have covered this aspect reasonably well, though the level of detail varies by country. Malta, however, has only covered the residential and commercial (office) sector, and not the entire building stock. A number of Member States have commented that information on the non-residential sector, with its much greater heterogeneity of building types and uses, is not available to the same level of disaggregation as the residential stock. This is similar to the finding of the Buildings Performance Institute Europe (BPIE) when undertaking its assessment of the energy performance of

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buildings across Europe (EU27 + Norway and Switzerland) in 2011 (7), with the results published online at www.buildingsdata.eu.

(b) identification of cost-effective approaches to renovations - The degree to which opportunities for renovating national building stock were identified varied enormously, from a generic statement about cost optimality levels, through to a detailed enumeration of the number of measures that could be installed in different building types.

(c) policies and measures to stimulate cost-effective deep renovations of buildings - Perhaps the most important component of a strategy is the extent to which it identifies the opportunities, but then proposes and puts in place specific policies and measures. A number of Member States, among them the UK, Austria and Germany, have not introduced any new policies, the implication being that existing polices are fit for purpose. Others, like Malta and Denmark, plan to introduce a significant number of initiatives.

(d) a forward-looking perspective to guide investment decisions of all stakeholders - This is perhaps the weakest area of the strategies examined to date, with hardly any Member States providing a quantification of investment requirements, or a forward plan on which stakeholders could base their own investment decisions.

(e) an evidence-based estimate of expected energy savings and wider benefits - Several strategies identify benefits in general terms, such as job creation, fuel poverty alleviation, reducing the need for supply side investment and improved energy security, yet for the most part, these benefits are not quantified to any significant degree.

Some of these benefits accrue to society at large (e.g. energy security) and are not valued by the potential investor. However, others, such as improved comfort and indoor air quality, are perceived in a general sense by the building owner, yet are difficult to ascribe a financial value to and hence rarely factored into the economic appraisal. As a result, the true economic, societal and environmental benefits arising from building renovation are significantly undervalued.

Overall, it can be seen that the renovation strategies do not fully meet the basic requirements set out in EED. This is a matter of some concern, since it suggests that there is little policy significance at a national level applied to the role that building renovation can play in terms of a nation’s energy and climate change agenda. However, one needs to look beyond mere compliance to take a view as to whether strategies embody ambition levels which suggest a higher degree of importance. To do this, the author examined three strategies in detail representing different countries in terms of size, climate and economic development: Malta, Czech Republic, and the UK. The analysis is described in the next section.

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Ambition Levels of Three National Renovation Strategies

In overall terms, Malta**'s renovation strategy (8) lacks sufficient detail in a number of areas for it to be considered compliant. To start with, the strategy only covers residential and office buildings, and not the entire stock as required by EED Article 4. In terms of cost effective opportunities for renovation, it refers to the cost optimality studies undertaken for EPBD, and compares cost optimal levels with current building energy performance. For residential buildings, the opportunity to utilise renewable sources is identified as having the ability to bring primary energy consumption down drastically, to close to zero or in some cases, negative – i.e. energy positive buildings. Whilst commercial buildings (offices) also have significant saving opportunities, their generally higher consumption means they cannot get close to zero primary energy use. The table below illustrates the scale of potential for a selection of building types.**

Building Type	Primary Energy Consumption of Existing Reference Building (kWh/m2/a)	Cost Optimal Primary Energy Consumption (kWh/m2/a)	% Reduction
Detached villa	196	10	95%
Post war Terraced House	163	4	98%
Pre-war top floor Flat	240	-32	113%
Detached – Cellular Offices	560	89	84%
Terraced – Cellular Offices	804	154	81%
Mixed Use – Cellular Offices	1,287	189	85%

Figure 3 – Cost optimal opportunities for energy saving in selected building types in Malta

Whilst the strategy does not set out to achieve the level of savings identified, it does introduce a number of initiatives (some of which extend or replace previous ones) designed to stimulate the market.

There is no investment profile mapping out the amounts required to achieve the potential savings, nor any explanation of the level of finance provided for the proposed initiatives. Neither is there a quantification of the savings potential. Wider benefits are described in general terms, but not quantified.

In conclusion, the **Maltese renovation strategy** fails to meet a number of the article 4 requirements. On a positive note, it identifies the very large cost effective energy saving potential from sustainable renovation of buildings, and recognises this leads to numerous benefits for the constrained island energy system, as well as for consumers. A number of policies are proposed, yet they lack coherence or any indication of scale, which begs the question as to whether they are sufficiently ambitious to achieve the savings potential.

The **Czech** renovation strategy (9) covers all aspects of Article 4, and can therefore be considered a compliant strategy. The building stock is described in detail, together with a

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quantification of the measures, costs and benefits from renovating to various levels of ambition. These are presented as five scenarios out to 2050, showing the impact in energy consumption of the building stock over time. The most ambitious scenario achieves more than 50% reduction. 17 initiatives are identified that aim to deliver the renovation potential.

The ambition can also been seen in the opening paragraph of the strategy, which describes the wider benefits – *"Energy efficient building renovation represents an opportunity for the Czech construction and energy sectors. Implementation of this strategy will create new jobs […] across the country. It will increase the living comfort and improve the use of buildings. Households, institutions and businesses will have more funds available for the purchase of non-energy services and goods. An energy efficient construction sector has a strong multiplier effect on the Czech economy and it can thus significantly contribute to its growth. It will also allow saving energy and thus decrease the need to use fossil fuels, which will in turn reduce local pollution and greenhouse gas emissions and increase energy security.*

Meanwhile, the **UK** strategy is the most comprehensive of the three strategies examined. It covers the building stock in some detail, as well as identifying the potential for uptake of renovation measures. Barriers to renovation are identified, and the suite of existing policies presented as a coherent package of solutions addressing the renovation agenda, as illustrated in figure 4 for the residential sector (a similar figure is presented in the strategy for the non-residential sector).

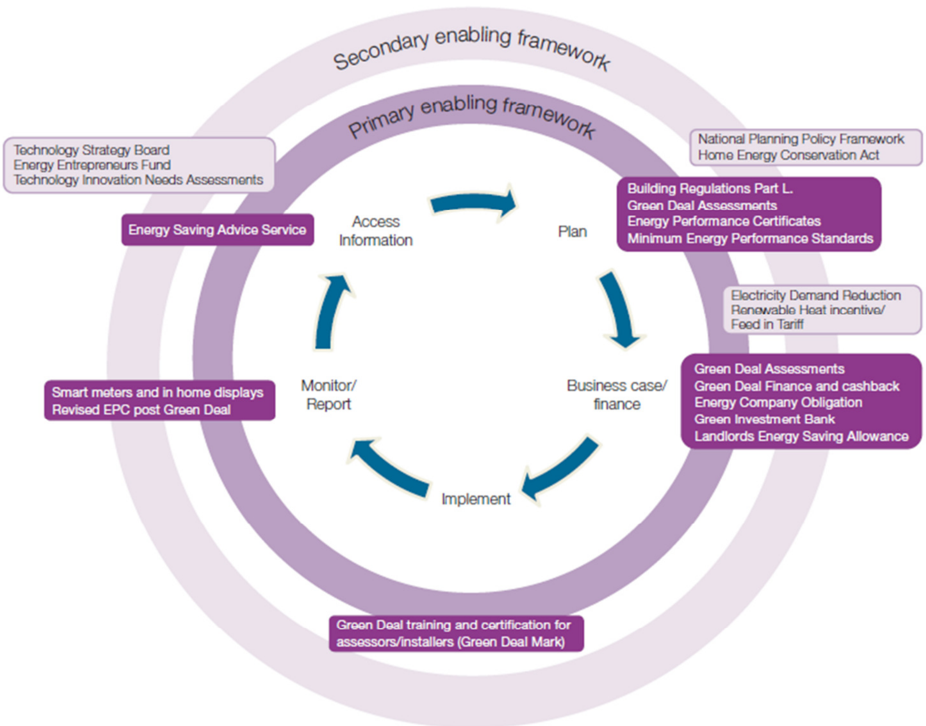

Figure 4 – Mapping of UK policies on the Renovation Cycle for the Residential Sector

Despite the technically proficient drafting of the UK strategy, it remains the case that it largely restates previous policies, and does not seek to introduce any new initiatives, yet these do not provide a framework for delivering the sustainable and deep renovation of the UK building stock.

Conclusion

Based on this preliminary assessment of a limited selection of published national renovation strategies, it can be seen that there is a wide range in terms of the quality of the strategy, the extent to which it meets the requirements of the Energy Efficiency Directive, and the level of ambition. The strategy published by the Czech Republic contains the greatest level of ambition, with numerous policy initiatives identified to support the transformation of the building stock. It remains to be seen the extent to which the Czech government, and those of the remaining Member States, deliver on their commitments and thereby lead to the sustainable renovation of Europe's buildings.

References

1 Buildings Performance Institute Europe (2013). A Guide To Developing Strategies for Building Energy Renovation.

2 Official Journal of the European Communities (2002). Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings.

3 Official Journal of the European Communities (2010). Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (recast).

4 Staniaszek & Kunkel (2014). EU policy for improving the energy efficiency of the existing building stock. *EU Law Series Volume VII: Energy Efficiency in the EU.* Claeys & Casteels Law Publishers. Deventer, Netherlands.

5 Official Journal of the European Union (2009). Directive 2009/28/EC of the European Parliament and of the Council on the energy performance of buildings (recast) on the promotion of the use of energy from renewable sources.

6 Official Journal of the European Union (2009). Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency.

7 Buildings Performance Institute Europe (2011). Europe's Buildings Under The Microscope.

8 Government of Malta (2014). Malta's Long-Term Strategy for Mobilising Investment in the Renovation of the National Stock of Residential and Commercial Buildings.

9 Government of the Czech Republic (2014). Národní akční plán energetické účinnosti ČR.

10 Department of Energy and Climate Change (2104). UK National Energy Efficiency Action Plan.

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Session 65:

What should new structures for ZEB be like?

Chairperson:

Bragança, Luis
Director. Energiehaus scp

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Comparative lifecycle energy and carbon footprint analyses of wood building systems designed as conventional or passive house

Ambrose Dodoo

Leif Gustavsson

Abstract: *In this study, we analyze and compare the primary energy and carbon footprint over the lifecycle of three wood-based building systems using either cross laminated timber or beam-and-column or modular structural systems. We analyze scenarios where the building systems are designed either conventionally or to the passive house criteria and heated with cogeneration-based district heating or electric-based ground source heat pump. Our analysis includes the entire energy chains from the extraction of fuels to the delivered end-use energy and encompasses the production, operation and end-of-life phases of the buildings. Our results show that final energy use is significantly lower when the building systems are constructed as passive house. Large amounts of biomass residues are produced due to the use of wood framing material for the building systems. The energy content (lower heating value) of the residues is significant compared to the primary energy used for production of the buildings. A passive house with cogeneration-based district heating gives low lifecycle primary energy use and carbon footprint. This study shows the importance of a system-wide lifecycle perspective and the choice of heating system in reducing primary energy use and carbon footprint in the built environment.*

Keywords: Lifecycle, primary energy, carbon emission, passive house, conventional house

Introduction

The growing dependence on fossil fuels is one of the primary challenges facing humanity in recent decades. Increasing body of knowledge suggests that using wood-based building material instead of non-wood alternatives reduces building production energy and lifecycle climate impact (Lippke et al., 2011). Wood-based materials from sustainably managed forest can play an important role both as means to reduce energy use and to mitigate climate change (IPCC, 2007). Relatively small energy input is needed to manufacture wood products compared with alternative materials (Gustavsson and Sathre, 2006). Wood-based building materials mainly use biomass residues for processing energy (e.g. kiln drying) and have lower carbon and primary energy balances than alternative materials (Gustavsson et al., 2006). The storage of carbon in wood materials and the increased availability of forest and woody by products for energy purposes are other dynamics by which the use of wood-based material affects climate (Gustavsson et al., 2006). Significant quantities of biomass residues are produced from the wood product chain and can be used to replace fossil fuels (Gustavsson et al., 2006; Lippke et al., 2011). Using wood-based material for direct substitution of fossil fuel intensive materials provides permanent and cumulative reduction in CO_2 emission, while sequestration of carbon is typically temporary (Schlamadinger and Marland, 1996). Efficient use of wood products involves material and energy flows in different economic sectors, including forestry, manufacturing, construction, energy, and waste management. The closer integration of these flows can improve the overall lifecycle environmental performance of wood-based products (Sathre, 2007). A thorough understanding of the relative impacts caused by different products over their entire lifecycles is needed to design effective strategies to reduce carbon footprint and to minimize climate impacts of the built environment.

In this study, we analyse the primary energy use and carbon footprint over the lifecycle of three modern wood construction systems for a multi-storey residential building. The construction systems use either cross laminated timber (CLT) or beam-and-column or volumetric modular structural systems. We compare versions of the buildings designed either conventionally to the Swedish building code or to the passive house criteria.

Method

This analysis covers all lifecycle phases of the buildings, including production, operation and end-of-life.

Production phase

Primary energy

The production phase primary energy is calculated as the primary energy used for material production and building construction. The net energy (lower heating values) of biomass by-products that can be recovered and made available for external use during the material lifecycle is calculated and shown separately. Our calculation of the primary energy for material production, building construction and the net energy of by-products are based on the method of Gustavsson et al. (2010).

Carbon footprint

The carbon footprint is calculated as the CO_2 emission to the atmosphere from fossil fuels used to extract, process and transport the materials, and from industrial process reactions of cement manufacture. The carbon stock in wood building materials and avoided fossil CO_2 emission if biomass residues replace fossil coal are calculated and given separately. The calculation of the CO_2 emission for material production and building construction, and carbon stock in wood building materials and avoided fossil due to biomass residues are based on the method by Gustavsson et al. (2006). The industrial process reactions of cement manufacture include calcination and carbonation and are calculated with data from Dodoo et al. (2009).

Operation phase

We calculate the operation final energy use for space heating, ventilation, domestic hot water heating and household electricity with the VIP+ dynamic energy balance program (Strusoft, 2010). The space heating demand is modeled for climate conditions of Växjö, Sweden, assuming indoor temperatures of 22^{o}C for the living areas and 18^{o}C for the common areas of the buildings. The primary energy needed to provide the final energy for the operation activities, and the associated carbon footprint, are calculated with the ENSYST program (Karlsson 2003). We calculate the primary energy use and carbon emissions for cases where

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the buildings are heated with bedrock heat pump with 95% electricity supply from stand-alone plants using biomass steam turbine (BST) technology and the remaining from light-oil gas turbine. We also analyze the buildings heated with district heating from combined heat and power (CHP) plant and heat-only boilers (HOB). We assume that 80% of the district heat is supplied from the CHP plant using BST technology, and 16% and 4% are supplied by biomass and light-oil HOB, respectively (Gustavsson et al., 2011). We allocate the cogenerated electricity using the subtraction method, assuming that the cogenerated power replaces electricity from a stand-alone plant using a similar technology (Gustavsson and Karlsson, 2006).

End-of-life phase

The buildings are assumed to be dismantled after their service life, with the demolished concrete, wood and steel materials recovered. We assume that the concrete is recycled into crushed aggregate, the steel is recycled into feedstock for production of new steel, and wood is used for energy. The end-of-life primary energy use and carbon footprint are calculated considering the energy use to demolish the buildings and to recover and transport the concrete, steel and wood materials contained in the buildings. We follow Dodoo et al. (2009) method and assume that 90% of each material is recovered.

Data

The mass of materials in the buildings are estimated based on drawings and data provided by the building systems manufacturers. The thermal characteristics of the building envelopes are shown in Table 1. The CLT and the beam-and-column building systems each has living areas of 928m^2 while the living area for the modular building system is 935m^2, due to configuration of this system. Otherwise the building systems have the same architectural details, for both conventional and passive house designs.

Table 1. Thermal properties for buildings designed to different energy standards

Building system	U-value (W/m^{2}K)					Air leakage at 50 Pa (l /s m^2)	Water taps	Mechanical ventilation
	Ground floor	External walls	Windows	Doors	Roof			
Conventional								
CLT	0.124	0.154	1.20	1.20	0.087	0.40	Standard	Exhaust air
Beam & column	0.124	0.152	1.20	1.20	0.086	0.55	Standard	Exhaust air
Modular	0.124	0.154	1.20	1.20	0.084	0.55	Standard	Exhaust air
Passive								
CLT	0.124	0.104	0.80	0.80	0.08	0.20	Efficient	Heat recovery
Beam & column	0.124	0.111	0.80	0.80	0.08	0.40	Efficient	Heat recovery
Modular	0.124	0.111	0.80	0.80	0.08	0.40	Efficient	Heat recovery

The specific end-use fossil fuel and electricity data for extraction, processing, and transport of materials is primarily from a Swedish study by Björklund and Tillman (1997). For steel we assumed that the production is based on 50% ore and 50% scrap steel. Feedstock energy value is not included in the energy content of the materials. The fuel cycle energy input, including extraction, transport, processing, conversion and distribution of the energy carriers are taken to be 10% for coal, and 5% for oil and natural gas, of the delivered fuel (Gustavsson and Sathre, 2006). Fuel-cycle carbon intensity of the fossil fuels are assumed to be 0.11, 0.08 and 0.06 kg C/kWh for coal, oil, and fossil gas, respectively (Gustavsson et al., 2006).

Results

The production phase primary energy use for the building systems are shown in Table 2 and the corresponding carbon footprint are shown in Table 3, divided into different end-use energy carriers: fossil fuels, biomass and electricity. Significant quantities of biomass residues are available due to the large quantities of wood-based materials in the buildings. The negative numbers represent energy available from recovered biomass residues or avoided emission to the atmosphere due to the replacement of fossil energy. The total production primary energy use is lowest for the CLT building systems, followed by the modular and the beam-and-column systems. When the buildings are built as passive house instead of as conventional house the material production primary energy increases by 10%, 5% and 4%, for the CLT, beam-and-column and the modular building systems, respectively. The passive beam-and-column building system has 18% and 8% higher material production emission than the CLT and modular alternatives, respectively. The net carbon emission of all the building systems is negative if the carbon temporarily stored in the wood-based materials and avoided emission due to the recovery and use of biomass residues are taken into account assuming conservatively that the carbon stock is not increasing.

Table 2. Primary energy balance during the production phase of the building systems

Description	Primary energy use (kWh/m^2 [living area])					
	CLT system		Beam-and-column system		Modular system	
	Conventional	Passive	Conventional	Passive	Conventional	Passive
Energy use						
Material production						
Fossil fuels	307	341	404	418	359	370
Electricity	233	252	283	307	295	306
Bioenergy	144	156	136	139	116	122
Total	684	749	823	864	770	798
Building construction						
Fossil fuel	14	15	16	17	16	16
Electricity	14	15	16	17	15	16
Total	28	30	32	34	31	32
Total	**712**	**779**	**855**	**898**	**801**	**830**
Energy benefit						
Biomass residues						
Forest harvest	-268	-287	-259	-267	-161	-174
Wood processing industries	-721	-759	-724	-744	-300	-335
Construction site	-66	-72	-60	-63	-51	-55
Total	**-1055**	**-1118**	**-1043**	**-1074**	**-512**	**-564**
Overall balance	**-343**	**-339**	**-188**	**-176**	**289**	**266**

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Table 3. Production phase carbon footprint for the building systems

Description	**Carbon emission (kg CO_2-eq/ m^2 [living area])**					
	CLT system		Beam-and-column system		Modular system	
	Conventional	Passive	Conventional	Passive	Conventional	Passive
CO_2 emission						
Material production						
Fossil fuels	96	108	127	132	112	116
Electricity	9	10	11	12	11	12
Net cement reaction	9	9	13	13	9	9
Total	114	127	151	157	132	137
Building construction						
Fossil fuel	5	5	6	6	6	6
Electricity	1	1	2	2	1	2
Total	6	6	8	8	7	8
Total	**120**	**133**	**159**	**165**	**139**	**145**
C stock / CO_2 avoided						
Carbon in wood material	-213	-231	-197	-204	-166	-178
Biomass residues						
Forest harvest	-108	-116	-105	-108	-65	-71
Wood processing industries	-283	-298	-284	-292	-117	-131
Construction site	-26	-29	-24	-25	-21	-22
Total	**-630**	**-674**	**-610**	**-629**	**-369**	**-402**
Overall balance	**-510**	**-541**	**-451**	**-464**	**-230**	**-257**

Table 4 shows the annual final operation energy for the building systems in Växjö, including space heating, tap water heating, ventilation electricity and household and facility electricity. Space heating dominates the final operation energy for the conventional buildings and household electricity dominates for the passive house buildings.

Table 4. Annual final energy use (kWh/m^2 [living area]) for operation for buildings in Växjö

	CLT system		**Beam-and-column system**		**Modular system**	
Description	Conventional	Passive	Conventional	Passive	Conventional	Passive
Space heating	71.0	24.5	72.1	29.9	71.8	29.4
Tap water heating	28.5	17.1	28.5	17.1	28.5	17.1
Ventilation electricity	3.0	5.8	3.0	5.8	3.0	5.8
Household electricity	35.9	35.9	35.9	35.9	35.9	35.9
Facility electricity	15.0	15.0	15.0	15.0	15.0	15.0
Total from operation	**153.5**	**98.5**	**154.4**	**103.9**	**154.3**	**103.4**

Figure 1 shows the annual primary energy use for space heating and ventilation of the conventional and passive house versions of the buildings. Primary energy use is considerably reduced when the buildings are constructed as passive house compared to when they are constructed as conventional house. The differences in final energy for space heating and ventilation for the conventional building systems are very minor. For the passive version of the buildings, the CLT system has much lower primary energy for space heating and ventilation compared to the beam-and-column or the modular building systems.

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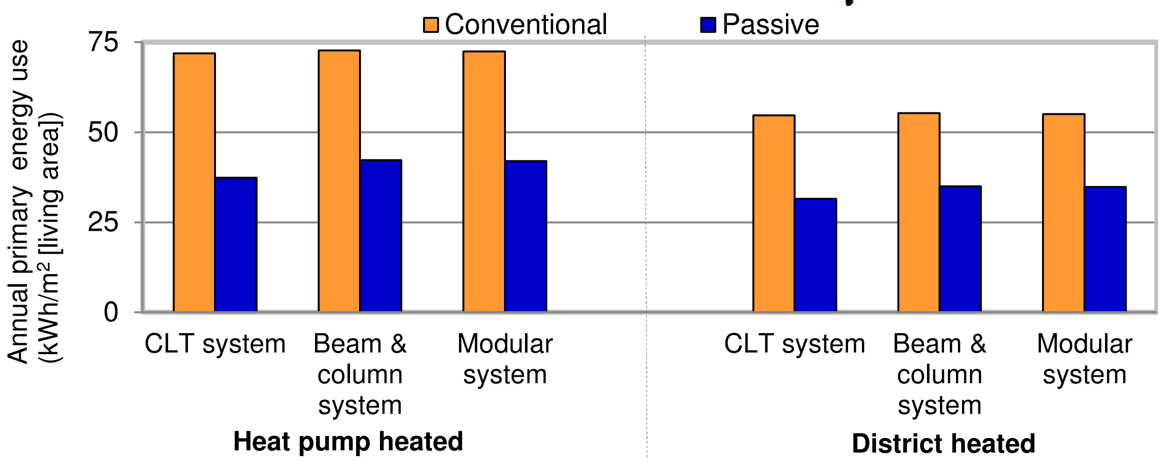

Figure 1. Annual primary energy use for space heating and ventilation for buildings in Växjö

Figure 2 shows the primary energy and carbon emission for production, operation during 50 years, and end-of-life for the buildings, respectively. The buildings are district heated and the energy supply is based on BST technology. The operation phase dominates the lifecycle primary energy use for both the conventional and the passive house versions of the building system. Material production accounts for a large share of the lifecycle GHG emission for the buildings as energy supply is based on biomass-based district heating. Overall, the CLT building systems have slightly lower lifecycle primary energy use and carbon footprint compared to the beam-and-column or the modular building systems.

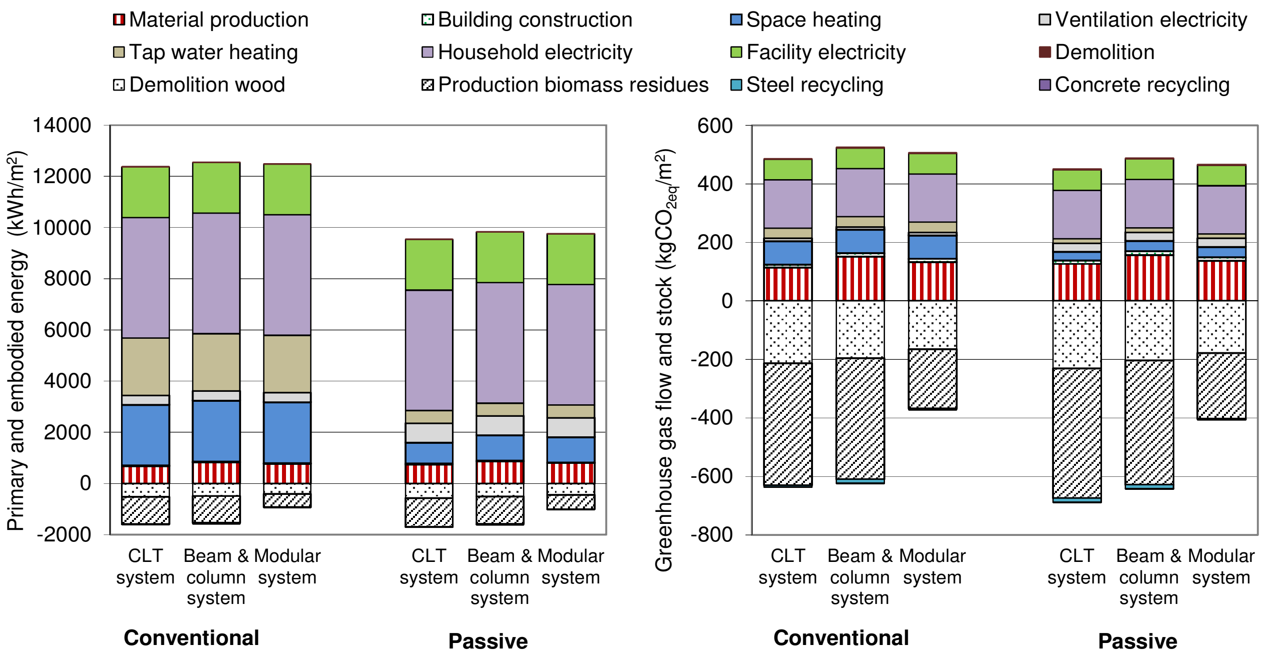

Figure 2. Primary energy use (left) and carbon footprint (right) for the lifecycle phases of the district heated buildings with assumed lifespan of 50 years. Positive numbers denote energy use or carbon emission to the atmosphere. Negative numbers denote lower heating value of recovered biomass residues or carbon emission avoided if fossil coal is replaced

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Conclusions

In this study we have explored the role of wood in carbon efficient construction and analyzed the climate implications of three wood building systems with different levels of energy-efficiency. The building systems comprise CLT, beam-and-column and modular systems. Our results show the importance of a system-wide lifecycle perspective and the choice of heating system in reducing primary energy use and carbon footprint in the built environment. An efficient energy supply system is also of great importance for a low energy building and may be an integral part of the effort to create a low energy built environment. Final energy use is significantly lower when the building systems are designed as passive house. In summary, wood-frame passive houses with district heating based on CHP production seem to be an effective means of reducing primary energy use and carbon footprint in the built environment.

References

Dodoo, A., Gustavsson, L. and Sathre, R. 2009. Carbon implications of end-of-life management of building materials. Resources, Conservation and Recycling 53(5): 276-286.

Gustavsson L., Dodoo A., Truong N.L. and Danielski I. 2011. Primary energy implications of end-use energy efficiency measures in district heated buildings. Energy and Buildings, 43 (1), pp 38-48.

Gustavsson L., Joelsson A. and Sathre R. 2010. Lifecycle primary energy use and carbon emission of an eight-story wood-framed apartment building. Energy and Buildings, 42 (2), pp 230–242.

Gustavsson, L. and Karlsson, Å. 2006. CO2 mitigation: On methods and parameters for comparison of fossil-fuel and biofuel systems. Mitigation and Adaptation Strategies for Global Change, 11(5-6): 935-959.

Gustavsson, L. and Sathre, R. 2006. Variability in energy and carbon dioxide balances of wood and concrete building materials. Building and Environment, 41(7): 940-951.

Gustavsson, L., Pingoud, K. and Sathre, R. 2006. Carbon dioxide balance of wood substitution: comparing concrete- and wood-framed buildings. Mitigation and Adaptation Strategies for Global Change, 11(3): 667-691.

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the IPCC, Geneva, Switzerland, IPCC.

Karlsson, Å. 2003. ENSYST Version 1.2. Lund University, Lund, Sweden.

Lippke, B., Oneil, E., Harrison, R., Skog, K., Gustavsson, L. and Sathre, R. 2011. Lifecycle impacts of forest management and wood utilization on carbon mitigation: Knowns and unknowns. Carbon Management, 2(3): 303-333.

Sathre, R. 2007. Life-cycle energy and carbon implications of wood-based products and construction. PhD dissertation, Department of Engineering, Physics and Mathematics, Mid Sweden University, Östersund, Sweden.

Schlamadinger, B. and Marland, G. 1996. The role of forest and bioenergy strategies in the global carbon cycle. Biomass and Bioenergy, 10(5-6): 275-300.

Strusoft. 2010. Overview of VIP-Energy. Accessed at www.strusoft.com on June 13, 2011.

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Environmental product declaration of ready-mix products. A practical application

Abstract: *this paper presents the calculation of Environmental Product Declaration, EPD, of functional units consisting in concrete waffle and flat slabs, from the environmental profile of its constituents: cement, concrete and steel, by applying the Product Category Rules that are being developed by the European Technical Committee CEN TC 104 Concrete.*

The implementation of module B(use), C (end of life), and D where carbonation, use of resources and thermal mass are involved, is presented. Some conclusions on the reliability of the information provided in cradle to grave DAPs at both, product and building level, are also provided.

Key words: Environmental Product Declaration, concrete, functional unit, Product Category Rule.

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Introduction.

The Environmental Declaration of Products has the explicit purpose of assessing and comparing product reliably from an environmental point of view and from a Life Cycle Analysis approach. This information can de considered as an input regarding the purchase decision-making, whether public or private. To this purpose, many evaluation schemes have proliferated internationally. Only in relation to the carbon footprint, 62 different initiatives in this field have been identified by the European Commission. Initiatives that do not evaluate the same parameters, use different criteria and weight the indicators in different ways.

The solution proposed by the EC seems to be the Product Environmental Footprint, PEF (1). This scheme, designed to calculate, report and compare the environmental footprint of any product, evaluates 14 environmental impact categories.

However, construction products have their own assessment methodology, based on the EN 15.804 (2) European Standard, since 2012. The reasons why these products have a particular method are well known and can be summarized in the fact that comparison only makes sense if we know exactly the function in which they were designed for. Its environmental performance becomes full meaning in the context of the building in which they are going to be installed. EN 15.804 evaluates seven impact categories plus 17 auxiliary indicators.

On the other hand, the Construction Products Regulation, CPR, (3) lays down conditions for the placing or making available on the market of construction products by establishing harmonized rules on how to express the performance of construction products in relation to their essential characteristics and on the use of CE marking.

This means that the free choice of a construction product for a given function or technical requirement, takes into account the Declaration of Performance (DoP) and the existence of the CE marking on it.

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In addition, CPR establishes a new Basic Work Requirement of sustainable use of the resources, BWR7: which will be included in the DoP of construction products. CPR itself establishes that the tools to do so are the Environmental Product Declarations.

If the DoP must include, in a near future, information on the BWR7, this environmental information will be taken into account at the time of the purchase decision. It is, therefore, extremely important to identify the comparability criteria of the environmental information provided in the DoP when is required and when environmental impacts are included.

This article presents EPDs of functional units of structural concrete and aims to highlight the difficulties mentioned regarding the comparability and interpretation of results of EPDs. Finally, proposes, at the light of the results, specific proposals to clarify, under which conditions, environmental information can be transmitted and used in a meaningful efficient and reliable way, particularly in the case of functional concrete elements.

Foreword.

According EN 15.804, EPD communicates verifiable, accurate, not misleading environmental information for the products and their applications, thereby supporting scientifically based, fair decision-making and stimulating the potential for market-driven continuous environmental improvement.

EPDs of declared (4) and functional units are very different conceptually. It is not possible to compare declared units because the precise function of the product or scenarios for its life cycle stages at the building level are not stated or are unknown. Examples of declared units are usually basic construction materials as 1 ton of cement or 1m3 of concrete.

In this article EPDs of functional units are calculated. For a complete definition of these units, the quantified, relevant functional use or performance characteristics of the construction product when integrated into a building, shall be provided.

In these cases, the FU supplies the basis for the addition of material flows and environmental impacts for any stage of life cycle. This means that information of the components of a construction system can be added in a bottom-top approach.

Comparability of EPDs.

From our point of view, a EPD of a functional unit in a cradle to gate approach is highly reliable. In this case, the uncertainty is minimal because it is no necessary to establish hypothesis out of the production process itself.

Extrapolation of EPDs to the construction and use phases can only be done in a generic way, and with limitations that need to be highlighted.

For example, a concrete flat slab serving as slab in a building, is a functional unit whose environmental loads can be fully known in a cradle to gate approach. At building level the prominence moves to the building´s functional equivalent, like intended use of the building, location, orientation, compactness, insulation systems etc. Only when generic scenarios defined at product level are particularized at building level in a certain and specific project, all the information necessary to perform the evaluation cradle to grave, becomes fully reliable. This is absolutely clear in cases where the functional unit considered has implications on the

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operational energy consumption in the building, for example, due to the high thermal inertia of concrete walls and slabs, or due to the type of insulation of the building.

In the following sections, the scenarios and assumptions for concrete functional units according Product Category Rule developed by the CEN Technical Committee 104 Concrete will be analyzed.

Concrete product category rules.

The latest available version of PCR that are being developed by CEN TC 104 Concrete has been used in the calculations. These specific RCPs will be published as a European Standard and will constitute the harmonized way in which DAPs of concrete products shall be declared in the future.

The scope of the Standard includes how the parameters of EN 15.804 can be particularized for concrete and, therefore, driven by the concrete RCP and not by the Standard. These parameters are: boundary limits, modeling and evaluation of specific characteristics of the constituents of concrete, allocation rules in the production chain, rules for the definition of the Inventory and calculation of ACV itself etc.

Modularity approach.

Modular scheme of EN 15.804 is the basis to develop scenarios for any construction product.

The most remarkable feature of the concrete PCR is, from our point of view, the end of waste criteria, the consideration of Module D and the influence of operational energy consumption at, either, product and building level.

Regarding the end of waste condition, figure 1 summarizes the different possibilities considered. These alternatives involve module C, with three subcategories directly linked to four possible destinations of concrete as a waste: reuse in recovered concrete elements, land restoration, substitution of primary material, use as aggregate in fresh concrete. The figure shows when the end of waste boundary is reached and the relations between module C and D in each case.

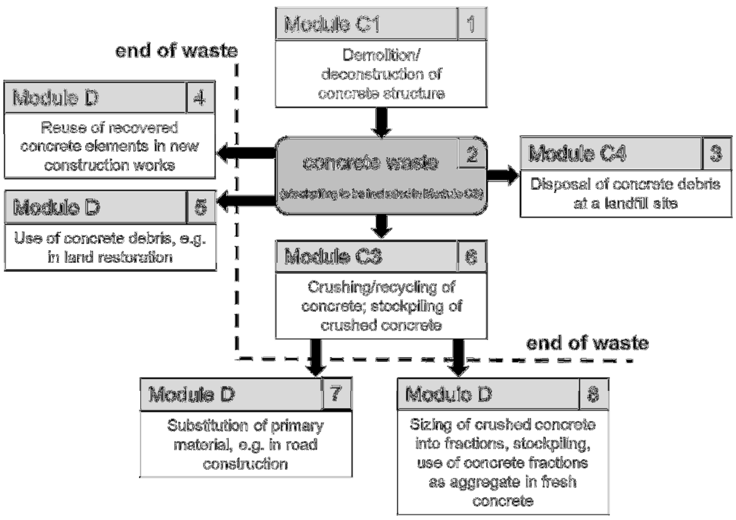

Figure 1. Typical processes at the end-of-life of concrete and concrete product and their attribution to the life cycle modules C1-C4 and D.

Module D can include the environmental benefits of concrete recycling (cells 3, 4, 5, 7 and 8). The benefits from the substitution of primary materials shall be included in this module. In our case disposal of concrete debris at a landfill site has been selected as reference scenario, therefore no benefits from substitution of primary materials have been accounted to module D.

On the other hand, carbonation of concrete is a benefit that shall be allocated in the stage in which the process takes place. Carbonation is a natural process by which concrete absorbs carbon dioxide from the atmosphere. Atmospheric carbon dioxide reacts with particular cementitious compounds in concrete to form solid products that are either precipitated on the surface or within the matrix. In terms of EN 15804, carbonation may be considered as a negative emission, and as a consequence it should be allotted to the range of life cycle stages in the same way as other emissions. Carbonation of concrete can occur during the use stage (B1) and during the end of life stage (C3 or C4). In this article both contributions have been calculated.

Concrete PCR includes a chapter of guidance requirements and guidance on calculation of carbonation impacts. The carbonation front progresses from the surface into the concrete with a speed that can be calculated by the equation d=k*SQR(t). k-factors are chosen depending on the strength class, exposure conditions, degree of carbonation and type of structural concrete according to the criteria set in the guidance chapter of the PCR.

Description of Functional Units: reinforced concrete waffle slabs and flat slabs

1m^2 of waffle slabs and flat slabs has been considered as a functional unit, FU. Table 1 presents the constituents and main characteristics of these FUs.

Constituents	Flat slab	Waffle slab
Concrete HA25/B/20/IIa (m^3)	0,252	0,163
Corrugated steel UNE EN 10080 BS500 S (kg)	22	15
Formwork system (m^2)	1,1	1,1
Separators (ud)	3	1,2
Demoulding agent (l)	0,05	0,05
Concrete block (ud)	--	3,495
Electro welded wire mesh ME 20X20 Ø 5-5 B 500 T 6X2,20 (m^2)	--	1,1

Table 1. Main constituents of functional unit expressed as per m^2

Where the environmental loads of the constituents are summarized in table 2.

Impact category	Unit	(5) Concrete per m^3	(6) Steel per tonne	(7) Cement per tonne
Global warming potential	[kg CO_2eq]	2,25E02	1735	7,56E02
Depletion potential of the stratospheric ozone layer	[kg CFC-11eq]	8.19E-06	1,39E-07	7,27E-05
Acidification potential of land and water	[kg SO_2eq]	3,86E-01	3,52	1,83
Eutrophication potential	[kg PO_4^{3-} eq]	8,27E-02	3,7E-01	4,44E-01
Formation potential of tropospheric ozone photochemical oxidants	[kg C_2H_4eq]	1,41E-02	6,98E-01	1,98E-01

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Abiotic depletion potential for non fossil resources	[kg Sb eq]	5,51E-01	2,85E-04	1,02E-04
Abiotic depletion potential for fossil resources	[MJ]	1,30E03	17000	5,17E03

Table 2. Main impact categories of constituents expressed as declared unit.

The concrete considered is a HA25B20IIa with the following key characteristics:

Units in kg/m^3	Data
Water	170
Additive	3
Gravel	1025
Sand	875
Cement CEM II	280
Water cement ratio	0.6

Table 3. Main characteristics of concrete expressed in kg/m3 as declared unit

Definition of Scenarios

According the PCR, the main topics to be included in the appropriate life cycle stages are the following: A1-A3 production phase, downstream transport (A4); reinforcement type and quantity (A5); method of installation on site (A5); Reference Service Life for the Unit and relevant in-use conditions (B1 to B7); finally, if the case, % of re-use of demolition concrete (C1 to C3).

Regarding the in-use stage, some important considerations are established by the PCR. As a general rule, there are no environmental impacts related to the normal use of concrete or concrete products other than the potential release of substances, the carbonation process and the consequences of the thermal mass provided by concrete elements on the overall energy consumption of the building.

Tables 4 and 5 present the scenarios provided by the PCR for concrete slabs (per m^2):

	Production stage	Construction stage		End of life			
Scenario	**A1-A3**	**A4**	**A5**	**C1**	**C2**	**C3**	**C4**
Structural concrete or concrete elements for buildings (interior)	Flat slab and waffle slab	With A2	• Energy consumption during in site construction. 20,06 MJ/m^2 • Water consumption in curing: 3l/m^2	Demolition	Transport to the landfill	Crushed and stockpiled	Landfiled Carbonation [kg CO_2eq] Flat slab:-42,9 Waffle slab:-27,7
Flat slab	Adapted from its constituents at impact level (see table 1)	With A2	Waste generated (kg) • Wood: 0,66 • Steel: 1,10 • Waste concrete: 5, 45				
Waffle slab	Adapted from its constituents at impact level (see table 1)	With A2	Waste generated • Wood: 0,85 • Steel: 0,91 • Waste concrete: 14,18 • Plastic: 0,015 • Package: 0,020				

Table 4. LCI and LCA data by module and by functional unit.

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And the selected scenario for use phase according the PCR:

		USE STAGE						
Module	**RSL**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
Structural concrete or concrete elements for buildings (interior)	ESL: 100 years	Carbonation process	Maintenance. According Article 103.2 of EHE 08, article 8 part I of CTE and, DB-SE of CTE, no maintenance activities are considered	Repair. According PCR, no repair activities have been considered	Replacement According PCR, no repair activities have been considered	Refurbishment According PCR, no repair activities have been considered	Energy used for operating heating and cooling systems integrated in the element	Water used for operating heating and cooling systems integrated in the element**.
	Result	Recarbonation [kg CO_2eq] Flat slab:-4,16 Waffle slab:-4,16			-			

Table 5. LCI and LCA datas by module and by functional unit.

The analysis of the functional units for the seven main impact categories is the following:

Impact category	Unit	Flat Slab A1-A3	Waffle slab Module A1-A3
Global warming potential	[kg CO_2eq]	9,49E+01	6,83E+01
Depletion potential of the stratospheric ozone layer	[kg CFC-11eq]	2,07E-06	1,48E-06
Acidification potential of land and water	[kg SO_2eq]	1,75E-01	1,26E-01
Eutrophication potential	[kg PO_4^{3-} eq]	2,90E-02	2,08E-02
Formation potential of tropospheric ozone photochemical oxidants	[kg C_2H_4eq]	1,89E-02	1,37E-02
Abiotic depletion potential for non fossil resources	[kg Sb eq]	1,39E-01	9,92E-02
Abiotic depletion potential for fossil resources	[MJ]	7,02E+02	5,06E+02

Table 6. LCA results by module and by functional unit for seven impact categories.

As expected more significant results for the assessment are those related to the production stage and not so to the use phase. The durability of concrete has a strong influence in the advantages of being virtually free of maintenance and, therefore, free of the corresponding environmental loads during the use stage. The extension of the study to B and C modules has always to take into account ESL upto 100 years and how to the end of waste condition is reached.

Regarding the LCA results, it can be highlighted that the contribution of environmental loads from cement and steel per m^2 to the functional unit is approximately 60/40% in both cases for GWP. In the case of other impact categories, the relative contribution may vary strongly depending on the order of magnitude of each basic material.GWP is the impact category which has a significant variation between the slabs due to their different content of steel and concrete. Data for carbonation allocated to B1 and C3 are also in line to the figures recently shown in the literature (8) an in the PCR itself.

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Nevertheless, it can be stressed that when elements as concrete slabs or concrete walls may have an influence in the thermal inertia of the entire building, this effect can assessed carefully at building level. The benefits from enhanced thermal mass in buildings can reduce the overal energy consumption by 16% (9) in passive systems and up to 40% in active walls and slabs (10).

Conclusions.

Environmental declarations of functional units are the natural step forward from the construction basic materials to assembled systems. As long as EPDs of functional units become more close to a particular project or building, the combination of the Standard 15.804, at product level, and the EN 15.978, at building level, provide the more accurate and actual results. Meanwhile, the product category rules that are being developed by product TCs across Europe represent a major breakthrough in order to modeling the environmental performance of FUs without knowing the specific project/building.

The knowledge and experience in the context of CEN product TCs, allow environmental declarations of functional units developed under harmonized PCRs, to go beyond the product stage retaining the quality of the results and modeling in a proper way the use and end of life phases of LCAs.

PCRs involving scenarios for functional units, like concrete slabs and other elements of structural concrete, provide a good approximation to the environmental performance in a real building. In our view, if a cradle to grave approach is required, the combination of EN 15.804 and EN 15.978 into a specific building is the best option to assess the environmental performance of a functional unit, especially when operational use of energy is involved even at product level.

In other cases, the second best option is modeling the behavior of functional units according the scenarios predetermined in PCRs developed by product TCs as has been stated in this paper.

References

(01) http://ec.europa.eu/environment/eussd/smgp/product_footprint.htm.
(02) EN 15.804 Sustainability of construction works; Environmental product declarations; Core rules for the product category of construction products. The standard has been developed in the CEN/C 350 sustainability of construction works.
(3) Regulation (EU) nº 305/2011 Of The European Parliament and of the Council of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.
(4) As defined in EN 15.804
(5) Source: own elaboration, data from ANEFHOP.
(6) Source: Institut Bauen und Umwelt e.V. (IBU), structural steel. BAUFORUMSTHAL e.V
(7) Source: own elaboration, data from OFICEMEN. Spanish Association of Cement Producers

(8) Galán García, Andrade Perdrix, Prieto Rábade, Mora Peris, López Agüí, San Juan Barbudo, Study of the CO_2 (2010). Sink Effect of Cement Based Materials. IETCC, OFICEMEN, IECA
(9) Tenorio, J.A.; Vega, L.; Turmo, J.; Burón, M.; Alarcón, A.;Martín Consuegra, F.; Burón, A.; D'Andrea, R.: Los requisitos del Código Técnico de la Edificación. Eficiencia energetica e incremento de la sostenibilidad. Aplicación a los edificios de hormigon. Cemento Hormigon no 937, marzo abril 2010.
(10) http://www.echormigon.es/construccion.html

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Comparison of GHG emissions from concrete alternatives for a zero emission office concept

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Abstract: *This paper presents the method and results from a GHG emissions analysis of different types of concrete used in a zero emission office building concept. Further, the paper presents an emission comparison of different exterior wall constructions. Energy simulations have been performed to compare energy use and thermal mass for the wall types. Use of low carbon concrete resulted in a significant reduction in material emissions. An increased amount of concrete used in exterior walls had a minor heat saving effect. Temperatures where stabilized in the building over the day and year as a result of the heat capacity in the concrete; however thermal mass of other building elements reduced the effect of the exterior wall.*

Zero emission office building, GHG emissions from concrete, thermal mass

Background

The European performance of buildings directive (EPBD) defines a nearly-ZEB as "*a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site*" [1]. This definition does not include the total life cycle aspect but refers to the operational energy use. The concept of life cycle ZEBs, including the concepts of annualized initial embodied energy and annualized recurring embodied energy have been introduced by [2] and [3]. The work presented here aims to go beyond compensating for the operational emissions of greenhouse gases (GHG) measured in CO_2 equivalents and include emissions from materials that occur in the product phase and for material replacements over the estimated life cycle of the building. This is defined as the ambition level called ZEB-OM by [4], where the "O" stands for operational emissions and the "M" stands for material emissions. All of these emissions should be compensated for with on site renewable energy production. The work presented here is based on a ZEB office concept study presented in [5] and [6] where the results showed that emissions from materials were higher than the operational emissions, and that the emissions from the concrete constituted a large proportion of those emissions. The ambition level of ZEB-OM was far from reached. However, the first phase only considered the material emissions of traditional material use, using mostly the Ecoinvent v.2.2 database [7] with no efforts to minimize them. The sensitivity analysis presented in this paper is a step forward to increase the understanding of emission contributions from different concrete and concrete exterior wall choices for the ZEB

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office concept model. The work presented has been conducted at the Concrete Innovation Centre, COIN in Norway based on work at the Research Centre for Zero Emission Buildings.

ZEB concept building model and design

The "Building Information Model", abbreviated BIM, is a virtual digitalized model of the actual building. The model can be utilized in the early design phase of the envelope, choosing technical installations and furthermore in management over the building's lifespan. The BIM model, see Figure 1, was designed using Revit, version 2011 [8]. Studies show that BIM can significantly impact decisions made in the early design stages, thus contributing to reduce a building's life cycle environmental impact [9]. The BIM-model, provides information on material quantities used for the different construction alternatives.The building is a typical Norwegian 4 storey office building with additional underground parking facilities.The heated floor area is 1980 m^2. The basic design is based on the current Norwegian building codes TEK 10 [10] but the energy concept is based on the Norwegian passive house standard [11] and the building is estimated to have a service life time of 60 years. The model is designed for Oslo climate. Detailed descriptions of the building physics and energy concepts can be studied in [5].

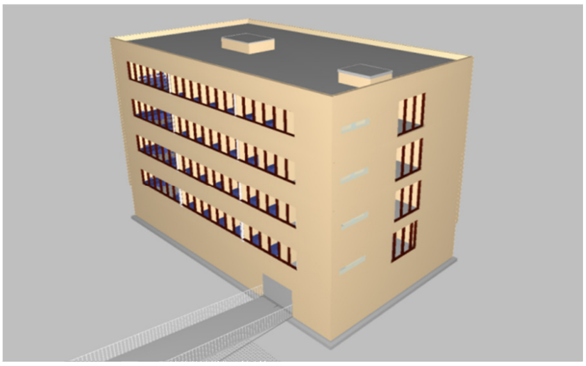

Figure 1 Office concept model

Walls structures and U-values

The exterior wall used for the base case of the calculations is a well insulated timber frame wall shown left in Figure 2, with mineral wool insulation of 350 mm and a fibre cement board for the exterior façade. The alternatives introduced here are three concrete sandwich elements with the same buildup, Figure 2, (right). The concrete sandwich elements have different thicknesses of the inner concrete slab while the outer concrete is constant, 60 mm. The alternative concrete sandwich elements can be used for both bearing and non-bearing facades. A 300 mm expanded polystyrene (EPS) choosen for the insulation is most commonly used in these kinds of sandwich elements.

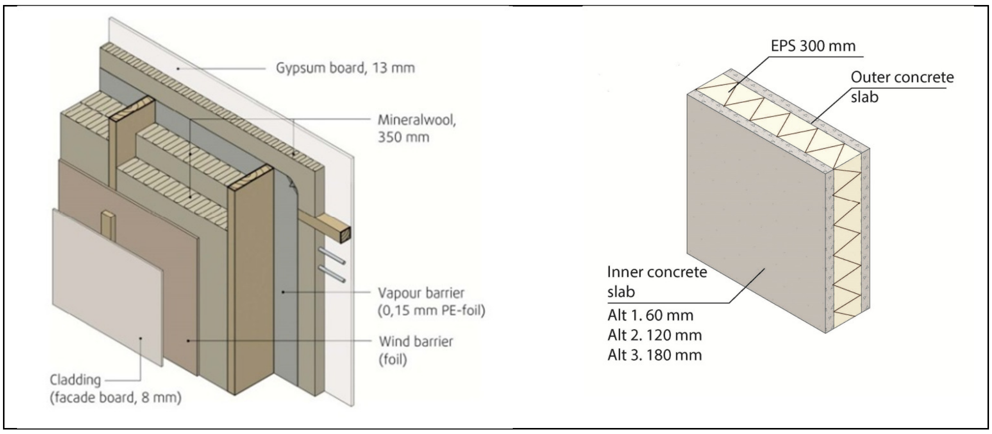

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Figure 2 External wall - base case (left) and the basic structure of the concrete elements (right)

The U-values of the alternatives analysed are 0.12 [W/m^{2}K] for the base case with mineral wool (λ 33) and 0.13 [W/m^{2}K] for the sandwich walls with EPS (λ 38).

Material use

The amount of concrete used in the whole office concept for the base case is shown in Table 1, as well as the concrete amounts for the different concrete sandwich elements.

Table 1 Amount of concrete in different construction parts for the base case and the concrete sandwitch elements

Construction part	Concrete [m^3] (base case)	Concrete [m^3] alt. 1.	Concrete [m^3] alt. 2	Concrete [m^3] alt. 3
Fundaments	104	104	104	104
Bearing outer wall	109	109+**99**	109+**145**	109+**191**
Bearing columns	4,5	4,5	4,5-	4,5
Inner bearing walls	134	-134	134	134
Slab structures	524	524	524	524
Total use of concrete	875,5	**974,5**	**1020,5**	**1066,5**

For the concrete elements, materials for interior and exterior cladding become unnecessary, as well as cladding maintenance. Thus emissions from other materials such as the interior gypsum plates, the outside fibre cement plates and the timber used are subtracted when these walls are placed into the concept model. However reinforcement steel is needed for the concrete wall elements. It has been calculated that the additionl steel needed is 3963 kg for alternative one, 5795 kg for alternative two and 7628 kg for alternative three.

Alternative types of concrete

The emission factors for the emission sensitivity analysis of the concrete types are listed in Table 2. A reduction in emissions from concrete is gained by using suplimentary cementitious materials (SCM) like fly ash or waste silica fume replacing clinker. A mixdesign method also contributes to reducing cement paste volume. The density of the concrete types is around 2400 kg/m^3. The emission factor used in the base case was from Ecoinvent (concrete at plant) 261 kg CO_2 eq /m^3 for the concrete. The low carbon concrete A can be delivered in Norway up on special requests and low carbon concrete type B is readily available according to the producer Norbetong [12]. The EcoCrete emission factor is based on a study performed in the Masdar City project [13]. The EcoCrete emission calculations have not been verified by third party as the recipe for this concrete is for demonstration production in Abu Dhabi. The larger portion of the clinker in the cement has been replaced with SCM, i.e. waste silica fume from a ferro silicium production plant in Iceland, fly ash from India and blast furnage slag from Japan. The carbon footprint from the SCM, which are all waste materials varied from 100 to 160 kg CO_2 eq/ton which stems predominantly from the transportation. The emission factor for the processing of the waste silica fume in Iceland has been calculated to be 4 kg CO_2 eq/ton without transportation. The paste volume is significantly lower in the EcoCrete than the other concrete wich is mainly obtained with different particle size distribution of the aggregates [14]. The industry average for UK is from the UK concrete center [15] and the Norwegian industry average is based on calculations from Norbetong [12].

Table 2 Emission factors for different types of concrete

Alterative concrete type	[Kg CO_2 eq/m^3] (C25/30)	Reference
Industry average UK	400	UK concrete centre
Industry average Norway	363	Norbetong
Norbetong (Environmental product declaration)	270	Norbetong, EPD
Ecoinvent (concrete at plant)	261	Ecoinvent, 2010
Norwegian Low carbon concrete type B	235	Norbetong
Norwegian Low carbon concrete type A	205	Norbetong
EcoCrete	99*	Masdar city concrete

*Carateristic strength of the the EcoCrete is C35/40 according to EN206.

Even though different concrete types are used for different construction parts, this analysis is simplified and applies the same emission factor for all of the concrete in the constructions. In reality the fundament plate does not have to have the same strength as for example the concrete used in the bearing columns.

Method and results from simulations on energy use and heat capacity

Energy simulations have been carried out using the software SIMIEN [16]. The thermal mass in a building has a potential of saving heating and cooling and reducing over temperatures. The base case wooden frame wall is a light-weight construction with very low heat capacity compared with the concrete sandwich elements. As a result of high heat capacity in other components, as in the concrete slabs, the differentiation of heat capacity in the cases decreases for the whole building. The values are shown in Table 3.

Table 3 Heat capacity of the different walls and for the total building

Case	Heat capacity of wall	Total heat capacity of building
	[Wh/m²K]	[Wh/m²K]
Base case	4	83
Alt 1	38	98
Alt 2	75	114
Alt 3	113	130

The heating and cooling need for the building is depended of the u-value of the wall. The Base case has a slightly better u-value than the sandwich wall. For comparison, a scenario with a wooden frame wall with the same u-value as the sandwich wall is therefore also presented in Figure 3. Replacing a wooden frame wall with a sandwich wall, with the same u-value, reduces the heating need with 0,1 kWh/m². The same impact has the addition per

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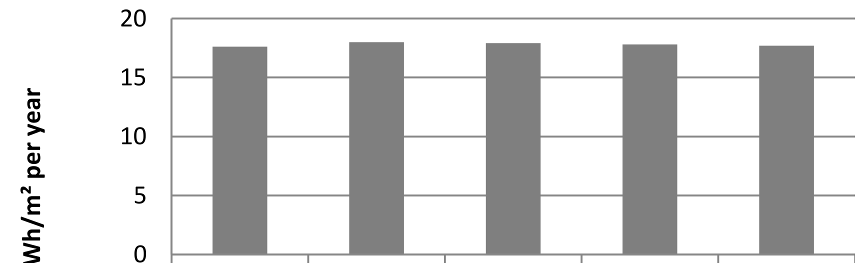
60mm concrete for the sandwich wall. The reduction of 0,2 kWh/m² from alternative 1 to alternative 3, is compatible with a reduction of the u-value from 0,13 to 0,125 W/m²K in alternative 1. The cooling is not reduced, but the indoor temperature is affected by the thermal mass, over-temperature can occur. With the emissions factor of 0,132 kg CO_2 eq/kWh (electricity) the emission savings amount to 0,04 kg CO_2 eq/m^2 year [17] from the base case to alt.3.



	Base case U=0,12	Base case U= 0,13	Alt. 1	Alt. 2	Alt. 3
Heating [kWh/m²]	17,6	18	17,9	17,8	17,7

Figure 3 Required heating energy per m^2 for the different alternatives

Over-temperature is defined as an operative temperature exceeding 26 °C. The centralized cooling system has a modest installed capacity of 10 W/m^2, and is sufficient when using ventilation for night cooling to reduce the temperature peaks. For the analysis of the over temperature, no night cooling is used.

For the whole building, the base case has 40 h over 26 °C and 156 hours over 25 °C during working hours, whereas alternative 3 has 11 h and 112 h over 26 °C and 25 °C, respectively. The base case, as shown has sufficient indoor temperature. The effect of the thermal mass is a reduction of over temperature hours and a stabilization of the temperature during the day.

Results from material emission analysis

The results of the concrete and exterior wall scenarios made are shown in Figure 4. The first phase of a the material emission analysis of the ZEB concept showed that the emissions from the concrete amounted to approximately 1.9 kg CO_2 eq/m^2 per year of the total material emissions of around 8.5 kg CO_2 eq/m^2 per year. The results show that by using Norwegian low carbon concrete in all the concrete structures, the embodied emissions from concrete can be reduced from the baseline of 1.9 kg CO_2 eq/m^2 per year to around 1.5 kg CO_2 eq/m^2 per year. This amounts to around 21 % reduction of the concrete emissions. The use of EcoCrete can further reduce the emissions significantly. It is also interesting to see that the base case emission factor is low, and that if the concrete used was the Norwegian industry average, the emissions would significantly increase.

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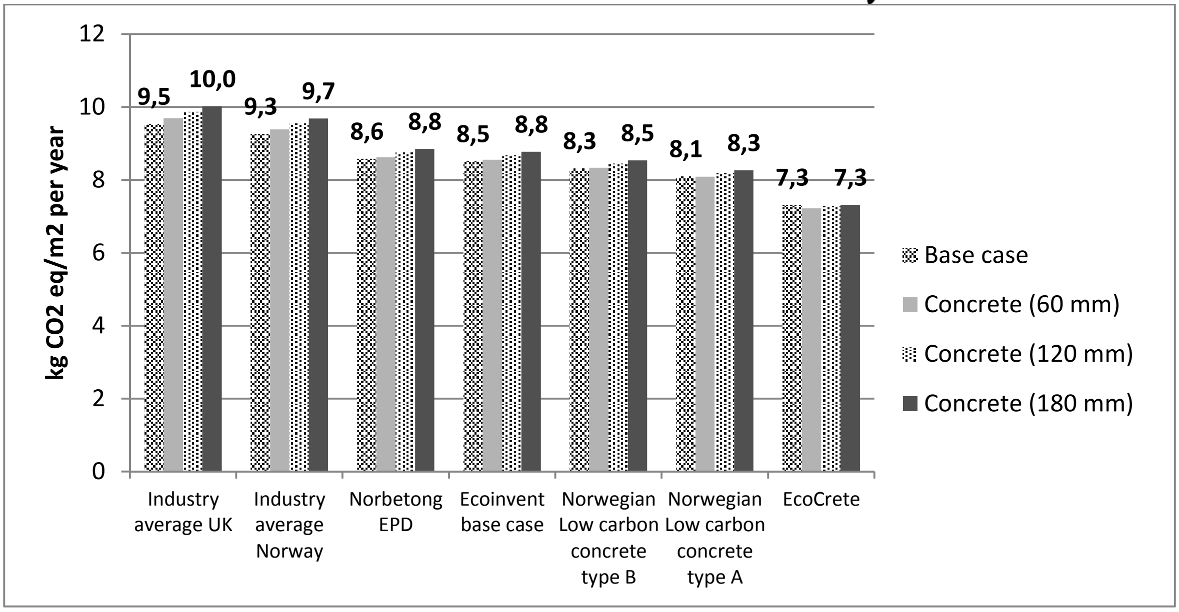

Figure 4 Results of the embodied emission for the base case with the sensitivity analysis of different concretes and for the four different exterior wall alternatives

Conclusions

This simplified study shows that differences in the types of concrete can have significant impact on the embodied emissions for a ZEB office concept. Also, the analysis shows that there are benefits of thermal mass, but only up to a certain level. The operational energy and thermal mass benefits of using concrete sandwich exterior walls, show that there are some minor benefits with respect to the reduction of energy use and the reduction of number of days with over-temperatures, but the significant increase in material emissions seam to outweigh the benefits, especially for the concrete walls with 120 and 180 mm inner concrete walls.

Simplification, uncertainty and further work

The calculations are simplified and not all material and construction details are included. Here it is assumed that the same type of concrete is used in all the construction parts, this is not the case and an optimization of the quantities and necessary strengths of the concrete structures should be analysed further. It could also be interesting to look further into where it is optimal to place thermal mass in a ZEB building with resepct to minimize embodied emissions.

References

[1] European Performance of Buildings Directive (2010). *European performance of buildings directive* 2010/31/EU.

[2] Hernandes, P. and P. Kenny (2010) From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings*, 2010, volume 42(6):p. 815-821.

[3] Cellura, M., Francesco, G., Longo, S. and Mistretta, M. (2014) Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study. *Energy and Buildings*, 2014, volume 72:p.371-381.

ISBN: 978-84-697-1815-5

[4]Dokka, T.H., Sartori, I., et al. (2013). A Norwegian Zero Emission Building Definition. *In proceedings from Passivhus Norden*, 15-17 October 2013; Göteborg, Sweden.
[5]Dokka TH, Kristjansdottir T., et al. (2013). A zero emission concept analysis of an office building. *The Research Centre on Zero Emission Buildings (ZEB*), Technical Report. www.zeb.no
[6] Kristjansdottir, T., Mellegård, S., et al. (2013) The first phase of a zero emission concept for an office building in Norway in *Portugal SB13, Contribution of sustainable buildings to meet EU 20-20-20 targets*. L. Bragança, M.Pinheiro, and R. Metaus, Editors, Guimarães, Portugal.
[7] Ecoinvent. (2010). Ecoinvent version 2.2. Swiss, Centre for Life Cycle Inventories, Dübendorf, Switzerland
[8] Autodesk, Revit Architecture Suite version (2011). Autodesk, Inc., California, USA.
[9]Basbagill, J., Flager, F., et al. (2013) Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Building and Environment* nr 60 (2013): p. 81 to 92.
[10]KRD, Kommunal og regionaldepartementet (2010) Forskrift om tekniske krav til byggverk (Byggteknisk forskrift – TEK10, FOR-2010-03-26-489). Technical Building Regulations (TEK10, FOR-2010-03-26-489, in Norwegian).
[11]Standard Norge. (2012) Kriterier for passivhus og lavenergibygninger - Yrkesbygninger (Criteria for passive houses and low energy buildings - Nonresidential buildings) NS 3701:2012.
[12] Norbetong, Heidelberg (2012) Lavkarbonbetong– et bevisst valg for lavere utslipp (Low carbon concrete- a concious choice for lower emissions)
[13] Saleem, F. and M.Konrad.(2011) Masdar embodied carbon table: The table of Embodied Carbon of products and materials. *Abu Dhabi Future Energy Company*, Masdar City.
[14] Wallevik, O.H. (2003) Rheology – A Scientific Approach do Develop Self-Compacting Concrete, in *3rd Int. Symposium on SCC*, Rilem. Reykjavik Iceland.
[15] UK Concrete Centre, Table 7 (2013). Embodied carbon in concrete used in buildings. Sustainable Concrete Forum.
[16] SIMIEN 5.11. (2012). SIMulation of Indoor climate and ENergy use.
[17] Graabak, I. and Feilberg, N. (2011). CO2 emissions in different scenarios for electricity generation in Europe. *Technical report from SINTEF Energy for the Research Center on Zero Emission Buildings.*

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Multi-Performance Indicators for Sustainability Evaluation of Concrete Structural Systems

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Abstract: *This paper aims at advancing on the validation of indicators for sustainability evaluation of concrete building structural systems from an integrated life cycle perspective. A case study approach investigates (i) the feasibility of comparing sustainability performance of different concrete slab systems; and (ii) the similarity between environmental indicators trends for a typical floor and the corresponding whole superstructure. Five residential and five commercial vertical buildings are analyzed, using either prestressed or reinforced concrete slabs with or without beams exposed to a marine environment. SimaPro 7.3 supports calculation of the environmental indicators. Service life estimation is used to ensure functional equivalence and to form a basis for life cycle costing. Analytic Hierarchy Process was used to establish relative importance among indicators. PCF slabs showed best functional-technical and economic results, while no particular trend among prestressed and reinforced concrete slabs was observed concerning environmental results.*

Key words: Indicator, Sustainability, Structural System, LCA, LCC

Introduction

Environmental, economic and social performances should be considered in the sustainability assessment of buildings. However, many unsolved difficulties regarding integration of social aspects to environmental lifecycle assessment are pointed out in literature [1] [2]. Data regarding functional, environmental, economic and social performance integrated evaluation within a building and its subsystems life cycle are practically inexistent in the Brazilian construction sector, where concrete buildings predominate [3]. Furthermore, life cycle-based studies have shown the structural system and envelope as major contributors to material environmental loads of a building [4] [5] [6]. Despite that, most sustainable buildings assessment systems available so far have not given enough attention to service life, durability, and the role played by structural systems.

In order to facilitate the integration of technical/functional indicators to environmental and economic dimensions of sustainability, and allow consideration of important life cycle aspects into the design decision-making routine for concrete structural systems selection, [7] proposed a core set of multi-performance indicators, which were subsequently validated in different studies. This particular paper focuses on its validation at slabs systems level (usual reinforced and prestressed concrete technologies) of ten case studies of vertical buildings.

Method and Approach

Table 1 comprises technical- functional, environmental and economic metrics. The technical-functional indicators are based upon recommendations of [8] [9] [10]. As the latter does not

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detail the requirements for environmental performance compliance, the environmental indicators were then defined according to [11] for buildings environmental assessment and [12], which regulates environmental product declarations (EPDs) of construction, in accordance with [13]. Life cycle cost (LCC) was chosen to describe economic performance. LCC is obtained through life cycle costing technique, standardized by ISO 15686-5 [14]. In this paper LCC calculation profited from the use of Life-365 v.2.1.1 software approach [15].

Table 1 – Functional-technical, environmental and economic indicators assessed

	Performance Indicators of structural systems / elements
Technical / functional (associated to structural safety, constructability, adaptability, maintenance and durability requirements)	***1. Concrete volume over structural area ratio (concrete consumption),*** $[m^3/m^2_{SA}]$ ***2. Steel mass over structural area ratio (steel consumption),*** $[kg/m^2_{SA}]$ ***3. Height over span ratio (h/ℓ) per structural floor area,*** $(h/\ell)/m^2_{AE}$, $[m^{-2}_{SA}]$ ***4. Column density: number of columns over structural floor area ratio,*** n^o/m^2_{AE} $[m^{-2}_{SA}]$ ***5. Beam over slab height ratio, [m/m] per structural floor area,*** $(hb/hs)/m^2_{SA}$, $(m/m) / m^2_{SA}$, $[m^{-2}_{SA}]$
Environmental (associated to environmental adequacy requirement: encompassing environmental aspects (intensity of resources use) and environmental impacts (LCA impact categories).	***1. Embodied carbon equivalent*** (ECO_{2e}) $[kgCO_{2\text{-}eq}/ fu/ m^2_{SA}]$ ***2. Embodied primary renewable energy*** (EE_{ren}) $[MJ/ fu/ m^2_{SA}]$ ***3. Embodied primary non renewable energy*** $(EE_{n\ ren})$ $[MJ/ fu/ m^2_{SA}]$ ***4. blue Water Footprint*** (bWF) $[m^3/ fu/ m^2_{SA}]$ ***5. Material resources consumption*** (Mc) $[kg/fu/ m^2_{SA}]$ (steel + concrete + plywood formwork). ***6. Non renewable raw material content (Abiotic Content***) (NRc) $[(kg_{total\ material} - kg_{recycled} - kg_{reused}) / fu/ m^2_{SA}]$ ***7. Acidification Potential*** (AP) $[kg\ SO_{2\text{-}eq}/ fu/ m^2_{SA}]$ ***8. Eutrophication Potential*** (EP) $[kg\ (PO_4)_{3\text{-}eq}/ fu/ m^2_{SA}]$ ***9. Depletion potential of the stratospheric ozone layer*** (ODP) $[kg\ CFC11_{\text{-}eq}/ fu/ m^2_{SA}]$ ***10. Formation potential of tropospheric ozone*** (POCP) $[kg\ C_2H_{4\text{-}eq}/ fu/ m^2_{SA}]$
Economic (associated to the economy requirement: life cycle monetary flows)	***1. Life cycle costs,*** LCC $[\$/m^2_{SA}]$: Initial costs of design and construction (***acquisition costs***) and ***maintenance and repair costs.*** Obs.: end of life costs (recycling and reuse; demolition and final disposal) were not considered in this LCCA.

EN 15804 [12] breaks down a building's life cycle into three main stages. In this study, the indicators considered cover phases I (pre-use stage) and II (in-use stage), and the environmental indicators did not consider the construction process for Phase I. Phase III (end of life stage) was not considered due to lack of reliable environmental data for end-of-life alternatives, as well as of cost records for design for disassembly and post-use alternatives in the Brazilian context.

The indicators were calculated for five residential and five commercial buildings, varying from 6 to 30 floors, using either prestressed concrete flat (PCF) and waffle (PCW) slabs with flat beams or reinforced concrete waffle (RCW) and solid (RCS) slabs with beams exposed to a Brazilian southeast marine environment, subject to chloride attack. The class of concrete specified in the design is C25 for CS5, C35 for CS6 and C30 for all other case studies. Case studies description and quantitative design data collected for calculation of indicators are shown in Table 2.

Table 2 - Case studies description and design data collected for indicators' calculation

Case Study	Typical floor slab system	Concrete volume	Reinforcing steel - CA-50	Prestressing steel - CP 190 (unbonded tendons)	Cast iron anchorages (unit = plate + edge anchor) 0.5kg/unit	Plywood formwork area [a] (17mm-thick) [m^2]	Structural area of the typical floor [m^2]	Number of columns at typical floor [unit]	Slab span - ℓ,[m]	Slab thickness - h_l [mm]	Beam height - h_v, [mm]	Total structural area [m^2]	Number of floors
		m^3	kg	kg	unit	m^2	m^2	unit	m	mm	mm	m^2	
1-R	RCW	121.1	10657.0	0	0	197.5	784.83	44	6.8	275[b]	275	5470.0	6
2-R	PCF	80.9	2927.0	1566	112	92.6	458.40	15	7.3	180	180[c]	7105.0	15
3-R	PCF	131.9	4465.0	2100	136	185.8	773.20	39	6.0	180	180[c]	4640.0	6
4-R	RCS	39.1	3801.4	0	0	110.8	247.17	22	6.2	120	700	2444.7	7
5-R	RCS	51.4	4952.6	0	0	107.8	249.02	16	6.4	120	600	4180.7	16
6-C	PCF	251.4	16052.0	4266	246	351.8	1222.0	68	5.5	180	180[c]	21203.5	18
7-C	PCF	146.2	10447.0	1897	99	127.3	626.35	20	6.8	180	180[c]	20406.7	18
8-C	PCF	77.1	5958.82	1550	102	55.6	331.43	15	6.5	200	200[c]	7986.1	17
9-C	PCF	105.3	10798.8	1293	128	63.5	476.11	18	5.9	180	180[c]	17382.7	30
10-C	PCW	168.5	11888.3	2280	134	209.5	25344.1	22	8.6	280	280	25344.1	21

R=residential; C= commercial; RCW = reinforced concrete waffle slab and flat beams; PCF = prestressed concrete flat slab RCS = reinforced concrete solid slab with normal beams; PCW = prestressed concrete waffle slab and flat beams

[a] considering maximum of five formwork reuse cycles | [b] waffle slab concrete volume equivalent to a 147mm-thick solid slab | [c] for the flooring systems with no beams, beam height is taken as slab height | concrete cover = 20 mm.

To form a basis for meaningful comparison, quantified functional/technical requirements for a building or a system assembly are expressed in terms of the functional equivalent [11]. In this study, functional equivalence of different designs was expressed in terms of $m^2_{\text{structural area}}$ (m^2_{SA}) of residential and commercial vertical concrete buildings exposed to a marine environment with 50-year design life (DL). This DL is the minimum required service life of a residential building according to the Brazilian performance standard [10].

Calculation of the environmental indicators was supported by software SimaPro 7.3. The performed LCAs followed ISO 14040 [16] methodological guidelines. The defined system boundaries characterize a cradle to gate analysis, which disregards transportation and building construction, use and end of life stages. Data for materials production cycle modeling were taken from national literature or adapted from processes within Ecoinvent or ELCD international databases, after switching into the Brazilian energy mix. Data obtained from the Worldsteel Association for prestressing steel could not be edited. Table 3 shows the materials, their units and data sources used for LCA modeling of the considered production processes.

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Data for computing the functional indicators were extracted from structural design shop drawings according to [17] provided by the responsible structural design practices. Service life estimated by Life-365 v.2.1.1 software triggered the maintenance program defined to allow all case studies to reach a minimum of 50-year DL and ensure functional equivalence for both LCA and LCC calculations. The default 10-year interval between repairs was considered to reasonably represent current practice. LCC calculation by the software was adapted to also follow ISO 15686-5 [14] guidelines. A 10 % extra volume of material was assumed for each predicted flooring system repair event and added to the overall material consumption of the respective floor. Foundations were disregarded to isolate the effects of soil's carrying capacity on sizing, and consequently on material consumption. These environmental indicators per m^2_{SA} were calculated for one typical floor and for the total superstructure of each case study.

Table 3 – Process name, units and inventory data sources for the materials considered in the assessments

Construction materials	unit	Data source
Concrete (fck 25,30 and 35Mpa) [a]	1 m^3	*Silva* [18]
Steel rebar, blast furnace and electric arc furnace route, production mix, at plant	1 ton	*ELCD v.2.0 (European life cycle database) (available at: <// http:www.pre.nl.>.)*
Plywood, outdoor use, at plant (BR), Sand, at mine; Gravel, crushed, at mine	1 m^3	*Ecoinvent v.2.2 (available at: <//http:www.pre.nl.>.)*
Wire Rods (prestressing steel)	1 ton	*World Steel Association* [19]
Cast iron, at plant / RER U - BR (anchorages)	1 ton	*Ecoinvent v.2.2 (available at: <//http: www.pre.nl.>.*

[a] Concrete mix with cement type CPIII-32 (66% of ggbs as clinker replacement)

LCC estimation by software Life-365 v.2.1.1 considers only concrete and rebar data. Thus, an input data adaptation was required to include plywood formwork and prestressing steel costs and labor [20]. LCC was given by the sum of the initial construction costs and the discounted future repair costs, over the design life of each flooring system. Maintenance cost estimation considered the same schedule and assumptions established for LCAs. The four economic parameters input in Life-365 v.2.1.1 were: 50-year DL as the reference period; 2013 as the reference year; annual inflation rate of 6.59% and real discount rate of 7.5%, which respectively represented the Price index to consumer rate (IPCA), defined by the Brazilian Institute of Applied Economic Research (IPEA), and the special system of liquidation and custody rate (SELIC) established by the Brazilian Monetary Policy Committee in April 2013.

For relative importance among technical/functional indicators, analytic hierarchy process (AHP) was applied with consultation to a panel of experts, whilst an adaptation of the Ecoindicator 99 method was used for weighting the environmental indicators. Before that, all indicators results were normalized by the results of the case study with greater fck (CS6). In order to reflect stakeholders' perspectives, three different scenarios were set among the dimensions.

Results and Discussion

Table 4 shows the originally predicted service life and LCC results for all case studies, after selection of a repair schedule to acomplish the minimum 50-year DL. LCC results varied

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circa 76% between the best and worst performances. The prestressed concrete flat slabs system of CS3 presented the best LCC result, which is ~14% lower than the best reinforced concrete slab system of CS1. Considering the LCC median values (RC=US$423.26/$m^2_{SA}$; PC=US$375.09/m^2_{SA}), PC slabs performed ~13% better than RC slabs.

Table 4 - Predicted service life and LCC results for all case studies

Case Studies	Acquisition costs (A) [US$/$m^2_{SA}$]	Maintenance /Repair costs* (MR) [US$/$m^2_{SA}$]	LCC = (A)+(MR) [US$/$m^2_{SA}$]	Predicted service life [yrs]
CS1 - RCW	87,52	254,03	341,55	11,7
CS2 - PCF	75,65	236,24	311,89	11,2
CS3 - PCF	72,41	227,94	300,35	11,2
CS4 - RCS	104,75	318,44	423,26	11,9
CS5 - RCS	126,76	401,26	528,01	10,4
CS6 - PCF	87,66	287,42	375,09	11,2
CS7 - PCF	124,46	315,40	439,86	11,2
CS8 - PCF	135,09	282,57	417,67	12,1
CS9 - PCF	143,22	301,66	444,89	11,2
CS10 - PCW	106,62	243,76	350,38	11,5
*** four repair events (present worth basis)**				

Figure 1 shows the technical/functional indicators' results normalized by CS6 and weighted by AHP. Considering the medians of results for RC and PC slabs systems, the first ones performed better for consumption of concrete and steel, while the latter presented better performance with respect to all other indicators. The presence of normal beams reflects the poor functional performance of CS4 and CS5.

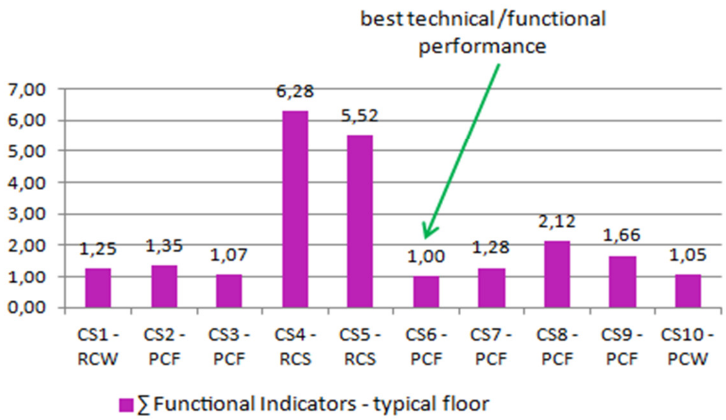

Figure 3 – Technical/functional indicators results normalized by CS6 and weighted by AHP

The environmental indicators results normalized by CS6 are presented in a radar type graph in Figure 4. It shows the greater variability of POCP results among case studies followed by EEren and ODP. Calculated for a typical floor and the whole superstructure, these indicators were weighted by an adaptation of the hierarchist version of Eco-indicator 99 Life Cycle Impact Assessment (LCIA) method and aggregated. They presented different trends when calculated at both levels – pointing to CS1 and CS7 as best environmental performance

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structures at a typical floor, and to CS3 when calculated at the superstructure level. Once normalized by CS6 and weighted, the indicators results of each dimension are aggregated. To simulate some stakeholder's perspectives, three weighting scenarios among the dimensions were defined. The multi-performance indicators results presented in Figure 5 show CS3 as the top performance solution for scenarios 1 and 2, and CS1 when privileging the environmental dimension (scenario 3).

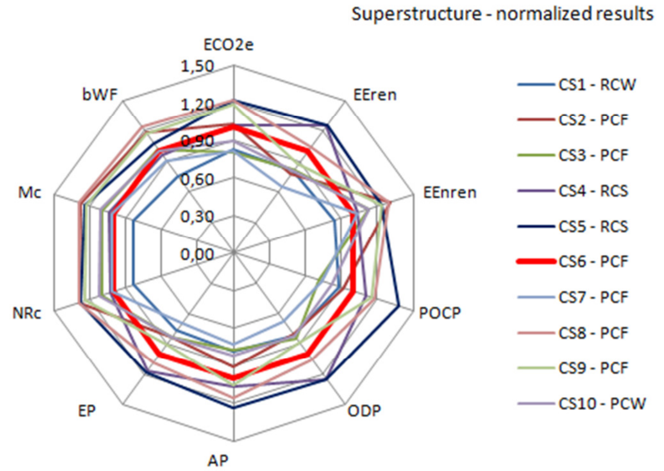

Figure 4 – Environmental indicators results of the ten case studies normalized by CS6

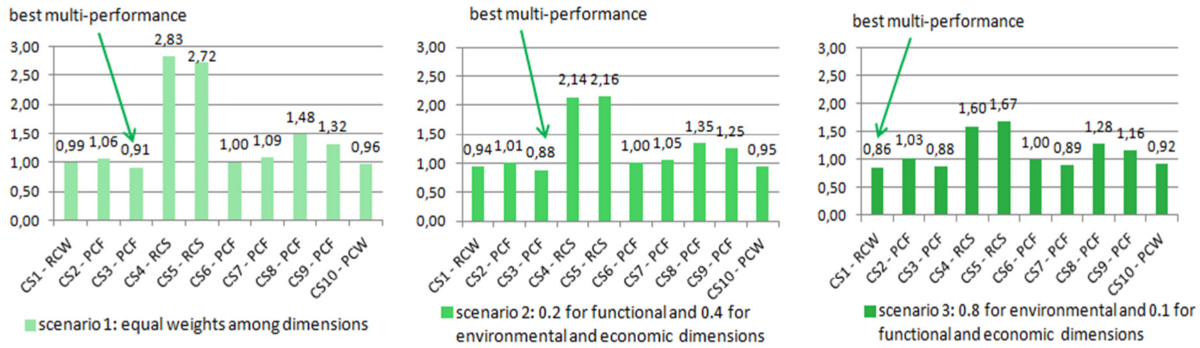

Figure 5 - Multi-performance indicators results of case studies for three different scenarios of importance among technical-functional, environmental and economic dimensions

Final Remarks

In this study, PCF slabs showed best results for the economic and most technical-functional indicators, but concerning the environmental results, no particular trend was observed between reinforced and prestressed concrete slab systems. Full quantitative superstructure data shall be collected to calculate environmental indicators, as a similar trend was not found for typical floors and their corresponding whole superstructure. Finally, weighting scenarios simulating stakeholder's perspectives may streamline identification of a top performing solution.

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References

ISBN: 978-84-697-1815-5

[1] Reap, J.; Roman, F.; Duncan, S.; Bras, B. (2008) A survey of unresolved problems in life cycle assessment. Part 1: goal and scope and inventory analysis. International Journal of Life Cycle Assessment, v.13, p.290-300.
[2] Heijungs, R.; Setanni, E.; Guinée, J. (2012). Toward a computational structure for a life-cycle sustainability analysis: unifying LCA and LCC. Int. J. LCA. DOI: 10.1007/s11367-012-0461-4.
[3] Oliveira, F. R. M.; Silva, V. G.; Silva, M. G. (2013). Indicators to Support Sustainability and Performance-Based Selection of Structural Frame Alternatives in Concrete: Preliminary Validation at Element Level. In: SB13 Munich. Munich, 2013. Proceedings, Germany, v.1, p.1-8.
[4] Dobbelsteen, A.A.J.F.; Arets, M.; Nunes, R. (2007). Sustainable design of supporting structures. Optimal structural spans and component combinations for effective improvement of environmental performance. Construction Innovation, v.7, n.1, p.54-71.
[5] Haapio, A.; Viitaniemi, P. (2008).Environmental effect of structural solutions and building materials to a building. Environmental Impact Assessment Review, v.28, n.8, p.587-600.
[6] Kellenberger, D.; Althaus, H. (2009). Relevance of simplifications in LCA of building components. Building and Environment, v. 44, n. 4, p. 818-825.
[7] Oliveira, F. R. M.; Silva, V. G.; Silva, M. G. (2011). Towards Integration of environmental, functional and economic indicators for envelope and structural frame selection: proposal for discussion at the conceptual design stage. In: SB11 HELSINKI, Proceedings, theme 4, p.502-509, Finland.
[8] International Organization For Standardization - ISO. Performance standards in building - Contents and presentation – ISO 6240, Geneve, Switzerland, 1980.
[9] International Organization For Standardization - ISO. Performance standards in building - Principles for their preparation and factors to be considered. ISO 6241, Geneve, Switzerland, 1984.
[10] Associação Brasileira De Normas Técnicas - ABNT. Edificações habitacionais – Desempenho, NBR 15.575, Part 1, Rio de Janeiro, 2013.
[11] European Committee For Standardization. Sustainability of construction works — Assessment of buildings. Part 2: Framework for the assessment of environmental performance. Incorporating corrigendum February 2012. EN 15643-2, Brussels, 2011.
[12] European Committee For Standardization. Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products. EN 15804:2012. Brussels, 2012.
[13] British Standard. European Committee for Standardization. Environmental labels and declarations. Type III environmental declarations. Principles and procedures. BS EN ISO 14.025. Brussels, 2010.
[14] International Organization For Standardization - ISO. Buildings and constructed assets. Service life planning – Part 5: Life Cycle Costing - ISO 15686-5, Geneve, Switzerland, 2008.
[15] Ehlen, M. A. (2012). Life-365 Service life prediction model, v.2.1 – Users Manual. USA.
[16] International Organization for Standardization - ISO. Standard14.040. Environmental management – Life-cycle assessment: Principles and framework. 2006. Genève, Switzerland.
[17] Associação Brasileira De Normas Técnicas - ABNT. Projeto de Estruturas de Concreto - Procedimento. NBR 6118, Rio de Janeiro, 2007.
[18] Silva, M. G. (coordinator) (2006). Concreto de Alto Desempenho com Elevados Teores de Escória de Alto Forno: Estratégia para consolidar o Mercado da Escória de Alto Forno. Projeto Desempenho. Technical report. Universidade Federal do Espírito Santo. 254p.
[19] Finkbeiner, M., Dowdell, D., Inaba, A., Young, S. B. World Steel Association. Life Cycle Assessment Methodology Report, 2011. Available at: http://worldsteel.org/dms/internetDocumentList/bookshop/LCA-Methodology-Report/document/LCA%20Methodology%20Report.pdf >. Assessed on March, 2012.
[20] Labor/Ct-Ufes. Tabela custos referenciais (ls=129,88%; bdi=28%) Labor/Ct-Ufes padrão IOPES fev/2013 (Available at: http://siteiopes.no-ip.info/ [assessed on 3/15/2013].

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Session 66:

Does innovation really exist in the Spanish construction sector?

Chairperson:

Oteiza, Ignacio

Instituto de Ciencias de la Construcción Eduardo Torroja- CSIC

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Sustainable low energy buildings using innovative heat storage solutions

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Abstract: *The framework of the research presented in the paper is a project oriented to promote the use of concrete solutions in buildings based on maximizing the benefits of its thermal inertia for both heating and cooling periods.*

The constructive solution developed has to configurations, one for summer (cooling mode) and another for winter (heating mode). In the cooling mode, the constructive solution is similar to a ventilated facade that is formed by a thermally insulated outer layer of concrete, an intermediate air layer and an inner layer of concrete. The inner layer is cooled at night by forced ventilation using an outdoor - outdoor scheme. The heating mode is reached by the addition of a crystal layer in front of the outer of concrete, creating an attached solar space.

The aim of this paper is to show the preliminary results about the potential of special concrete walls as solutions to reduce energy demand in residential buildings by heat storage and thermal offset in Spanish Mediterranean climates.

In summer, the concrete building facades are used as heat sinks. The aim is to cool the inner layer of concrete moving outdoor air through the air layer during night taking advantage of the low nigh-time air temperatures. The cool stored is released to the interior spaces when the maximum peak load of the space takes place.

In winter, the inner layer of concrete is heated moving hot air coming from the attached solar space created by adding an external glass to the solution. The heat stored is released to the interior space during evening and early night hours when heating is typically required.

With the aim of select a proper design of the innovative element, the influence of the thickness of the inner layer, the air velocity in the chamber and control lays to activate the ventilation are analysed. Simulations show that the use of this element is very promising for reducing energy demand in residential buildings in the Spanish climates. Experiments will be performed during summer 2014

Keywords: Energy saving heating and cooling needs, thermally active walls, building thermal inertia, concrete walls.

Introduction

The framework in which this study takes place is the " Service Contract R + D + i Relating to Competence Scope of the Ministry of Public Works and Housing " with the research project

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entitled "Analysis of the energy performance of closures concrete based on maximizing the benefits derived from the thermal inertia".

Meeting the "20-20-20" targets [(1)] for reduction of CO_2 emissions necessarily involves a drastic reduction of energy consumption in buildings.

However the particular climatic conditions of Andalusia make it very special since there is a wide thermal radiation in summer and in the cold winter seasons that are not exploited by existing buildings[(2)] in the rest of Europe this circumstance is given, and therefore have not developed studies in this regard.

For reducing energy consumption and therefore CO_2 emissions, it is previously necessary to decrease energy demand through passive building insulation systems and materials with high thermal inertia[(3)].

The walls of building should have a double thermal paper: one related to be a heat transfer resistance and the other one related to its inertia. The last one is the most overlooked by building designer o energy standards, so it is very difficult to use for reducing energy consumptions.

A simple definition of thermal inertia would say: “it's the ability to keep the mass of thermal energy received and gradually releasing it”. Because this ability, including thermal inertia of the walls of a building, can be decreased the energy needs with the consequent reduction of energy consumption and pollutant emissions.

When building is exposed to high outdoor temperature and solar radiation, indoor air will increase but a different way in function of thermal inertia of the building. The evolution of temperature of exterior face has a maximum (maximum amplitude) in a particular time of day depending on the location and orientation of the enclosure. This wave is damped outdoor temperature, in amplitude, crossing the enclosure, also emerging a time lag between the instants at which a peak temperature is produced. And finally, the effect of phase shift and damping increase number of hours that buildigs is in the comfort zone without additional energy expenditure. Then it produces free savings.[(4)]

The physical characteristics of the concrete gives it a high thermal inertia , which allows to predict optimum energy performance of the building in the event that this material forms the inner core (structure) and external (walls and roofs) thereof. The use of concrete as façade cladding and covered in the building:

- Reduce the energy consumption of heating.
- Softens variations in internal temperature.
- Delay maximum temperatures in offices and commercial buildings to the exit of the occupants.
- Reduces peak temperatures (maximum and minimum) and can make the air conditioning unnecessary.

- Maybe employed with nocturnal ventilation to eliminate the need for cooling during the day.
- Makes better use of sources of low temperature heating such as heat pumps for underfloor heating.

Overall, effect of thermal inertia in enclosures is a variable not usually considered in the design of the building. In addition, buildings energy performance tools have model not sensitive to this parameter. So, knowledge of the technical and scientific community about this potential benefit is poor (actual buildings, experiments…).

The main objective of the project is to identificate fundamental variables that characterize thermal inertia of buildings by means of measurements. This objective generates two important products: the improvement of energy procedure to analyze influence of thermal inertia in buildings, and demostrate energy savings in real prototype from the thermal inertia of buildings with enclousure and concrete structure. All results would be instrumental to value role of concrete solutions as part of improving energy efficiency

Materials and method

This study have been developed and adapted for specific reference models that are based on the contour and the structure of the building, and use to analyze energy performance.

These models are able to improve buildings energy performance, since they include:

- Interaction of inertia and solar radiation (that influences the use of free solar gains in winter and undesirable modulation of solar charging in cooling mode).
- Treatment of inertia night ventilation strategies to pre-cool the structural elements of the building and reduce cooling requirements at next day.

Reference models are based on analytical and numerical behaviour of the phenomena studied. They are based on balance equations and heat transfer. The model used in this article is based on the previous developed by Ruiz-Pardo (5). These models can be used independently for energy characterization applications, or like a starting point for developing anothers simplified models. It is important since simplied models are the most efficiency to be integrated into the simulation tools, for example, official tools. Besides, simplied models have been developed for specific reference based on innovative elements of the building envelope, mainly two:

> Glazed Spaces. Like greenhouses with the positibily to have connection or no with the building. The space between exterior cladding and glazed element is heated by sun. Heat is stored inside the wall, and later it is transferred to interior space.
>
> Thermally active walls. The enclosure is cooled using low outdoor air at night (lower temperature that indoor air). The wall is cooled and building begins next day more confortable.

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This innovative element is a combination of the mechanisms of Trombe-Mitchell and Constantine walls. It can be classified as an opaque solar facade, in the group of active elements accoding to the classification presented by [(6)]

The variables studied in models that are thickness of the inner layer of concrete (10-15-20 cm.), thickness of the internal air chamber wall (2-5-10 cm.) and air speed flow inside the chamber (0.5-1-2 m/s). The operational parameters of system have been optimized for winter or summer depending on location within the existing climate variability in the autonomous community of Andalusia, of which has focused on Granada, Seville and Cadiz for their thermal differences winter / summer.

In the next months (may-december 2014), research group is going to validate previous models by testing on the test cells are described in the following section. They are reinforced concrete cubicles 3.0 x 3.0 x 3.0 m. to which he included a special front face south to investigate several special construction solutions:

A planned two sheets of concrete and an air façade, which will be circulated in the summer evenings by cold air extractors (see Figure 1) is included first.

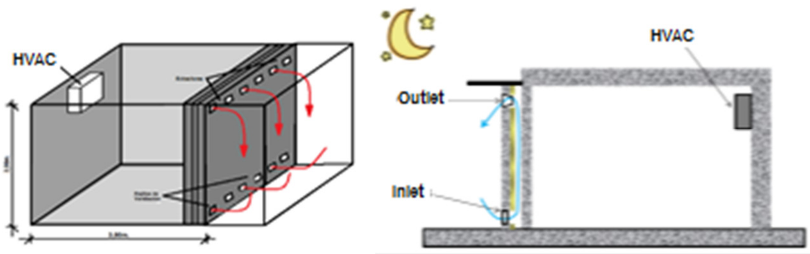

Figure 1: module test for the analysis of the influence of nocturnal cooling of the concrete wall through the chamber ventilated by forced ventilation.

Secondly, is studied the influence of the thickness of the glass chamber. Includes a glass cubicle in the main face, facing south , you can travel around by the width of the inner chamber between 0.10 and 0.50 meters, as shown in Figure 3.

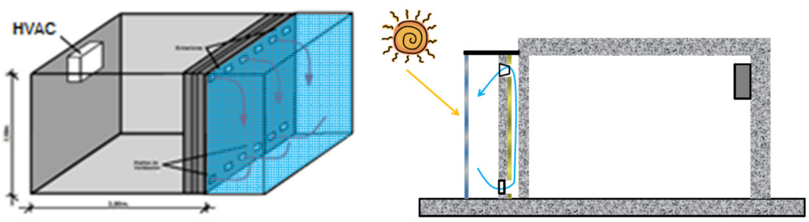

Figure 2: test module for analyzing the influence of thickness of the chamber.

Results and discussion

In order to select a proper design of the innovative element, several simulations were performed with different designs in the three selected localities. In Sevilla and Cádiz the

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design was optimized for summer period because in these cities cooling demand is dominant. In Granada, the design was optimized for winter.

The process performed in the three localities can be described in the next points:

- Nine options were initially tested: three air velocities insite the camber and three thicknesses for the inner wall.
- The results define the best solution to obtain the highest energy savings for the selected localities (table 1).
- For the best solution, it necessary to study some variations in operational condition. The objective of this work is maximizing its behavior for winter season when it is optimized for summer. The opposite procedure is performed if the optimization was performed for winter.

For the three cities considered, it was found that the optimal design was the same. This result was not expected, since they are very different climates, and in addition, the solution for Granada was optimized for heating season. The only difference in the design is the optimum temperature to operate, since the optimum for Cadiz is 25°C and for Granada and Seville 23ºC. The main descriptive parametes of the optimal desing are shown in Table 1.

Table 1. Studied solutions to find a proper design of the innovative element in Seville

	Inner wall thickness	*Air layer velocity*	*air layer convective heat transfer coefficient (air in circulation)*
solution 5	*15cm*	*1 m/s*	*5 W/m^{2}K*

The overall results for these three cities are shown in Table 2. It can be seen that the innovative element performs cooling in summer and heating

Table 2. Gross heating gains for the innovative element in the three studied cities. Negative values means heating losses (desirable behaviour in cooling season) and positive values means heating gains (desirable behaviour in heating season). All values are in kWh/m^2

	Summer			*Winter*		
	month	*Monthly heat losses kWh/ m^2*	*Total heat losses kWh/ m^2*	*month*	*Monthly heat gains kWh/ m^2*	*Total heat gains kWh/ m^2*
Seville	*Jun*	*-7.57*	*-13.12*	*Dec*	*11.80*	*37.06*
	Jul	*-3.04*		*Jan*	*14.18*	
	Aug	*-2.51*		*Feb*	*11.08*	
Cadiz	*Jun*	*-19.81*	*-36.07*	*Dec*	*19.41*	*52.02*
	Jul	*-9.71*		*Jan*	*18.60*	
	Aug	*-6.54*		*Feb*	*14.01*	
Granada	*Jun*	*-32.08*	*-72.85*	*Nov*	*8.64*	*26.42*
	Jul	*-20.77*		*Dec*	*3.51*	
	Aug	*-19.99*		*Jan*	*3.55*	
				Feb	*4.34*	
				Mar	*6.39*	

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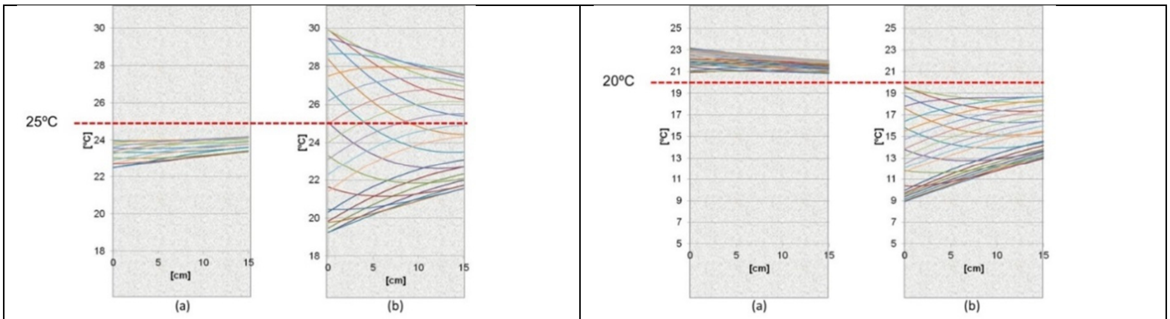
The results of Table 2 show that in the three localities studied, the innovative element removes heat in summer and introduces heat in winter. In addition when it is compared with a conventional wall its benefit is increased, since the behavior of conventional wall is opposite that the innovative element: conventional wall transfers heating in summer and cooling in winter, namely, it increase energy demand into the space.

Figure 4 shows behaviour of the innovative element in comparison with a conventional wall, the temperature profiles are shown for the interior layer of the innovative element and for a conventional wall. These profiles were calculated for one typical day of cooling season and for a typical day of heating season.



Cooling season	Heating season
(a) Interior layer of the innovative element (b) Conventional wall	

Figure 3: Temperature profile in: (a) the innovative element and (b) in a conventional wall.

The amplitude of temperature oscillation obtained in the innovative element, is much lower than that obtained in the conventional wall. Additionally, it is seen how in the cooling season, temperatures of the innovative solution are always lower than the indoor temperature (assumed as 25°C), while the conventional wall is oscillating around that temperature. In the heating season, temperatures of the innovative element remain above the indoor temperature, while in the conventional wall; temperatures are always below the indoor temperature.

The expected savings for the innovative element are obtained from the comparison with a conventional wall. The results of this comparison are shown in Table 3.

Table 3. Heat gains comparison between the innovative element and a conventional Wall having the same U-value in the three tested localities

	Summer			*Winter*		
	Innovative element Heat gains	*conventional wall heat gains*	*difference (savings)*	*Innovative element Heat gains*	*conventional wall heat gains*	*difference (savings)*
	kWh/ m²	*kWh/ m²*	*kWh/ m²*	*kWh/ m²*	*kWh/ m²*	*kWh/ m²*
Seville	*-13.1*	*12.6*	*-25.8*	*37.1*	*-17.9*	*54.9*
Cadiz	*-36.1*	*4.2*	*-40.3*	*52.0*	*-10.4*	*62.4*
Granada	*-72.9*	*3.4*	*-76.3*	*26.4*	*-45.0*	*71.4*

In the comparison shown in table 3, it can be seen that in Granada (the coldest locality) savings in both, heating and cooling, are higher than in the other two localities. This is because in summer the potential of nighcooling provided by the innovative element is big while the conventional wall is almost neutral around the day. By contrast, in winter, it is

Granada where innovative element provides the least amount of heat input, however, as the conventional wall shows high losses, the difference between the heat input of the innovative element and the heat losses of the conventional wall, is greater than in the other two locations.

Conclusions

The results show that the innovative element provides cooling in summer and heating in winter. In the three locations where the simulation were performed, energy savings are high, being highest in the coldest locality, but more simulations are required to establish if this is a continuing trend.

The levels of expected savings in both, heating and cooling show a promising performance in energy savings. For these reason the investigation of this element is justified to be continue in an experimental set up, in order to confirm the actual potential is as high as predicted.

Acknowledgements

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References

1. European Commission. Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and ahe Committee of the Regions. Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage. 2010.
2. Knowles RL. The solar envelope: Its meaning for energy and buildings. Energy Build. 2003 1;35(1):15-25.
3. Aste N, Angelotti A, Buzzetti M. The influence of the external walls thermal inertia on the energy performance of well insulated buildings. Energy Build. 2009 11;41(11):1181-7.
4. Ruiz-Pardo Á. Ahorro energético mediante el uso de elementos de doble envolvente transparente-opaco [dissertation]. Tesis Doctoral, Sevilla: Universidad de Sevilla, ETSI; 2008.
5. Ruiz-Pardo Á, Domínguez SÁ, de la Flor, Francisco José Sánchez, Lissen JMS. Simulation model for some types of double envelope elements. International Journal of Ventilation. 2010;9(3):227-39.
6. Quesada G, Rousse D, Dutil Y, Badache M, Hallé S. A comprehensive review of opaque solar facades. Renewable and Sustainable Energy Reviews. 2012 6;16(5):2820-32.

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Housing prototypes: industrialized and efficient with renewable energy

Abstract: *In recent years the construction of efficient and sustainable housing has experienced significant development and in the near future these criteria will be required for most new construction.*

This research is based on the prototype housing "Patio 2.12" presented to the international competition Solar Decathlon Europe 2012, awarded the second prize in the general ranking, the first prize in energy efficiency and the second prize in sustainability and innovation.

This paper presents a study of an "open industrialized system" that comes from a spatial and constructive prefabricated modular system or prefabricated "kits parts" system. Different architectural models are analyzed that integrate the use of solar PV in the building envelope and "passive systems".

The main topics discussed:
- The construction process and assembly system
- Sustainability and energy efficiency
- The habitability and comfort

The innovations presented can be applied in, ecological tourist housing and export of manufactured housing emergency.

Industrialization, assembly, self-sufficient, integration

1. Background: Competition Solar Decathlon Europe 2012. House Patio 2.12.

House Patio 2.12. is a proposal for a self-sufficient prefabricated modular house using renewable energies. It is a project that develops a type of construction without a landscape footprint; it combines low energy consumption on its fabrication with the cultural identity where it is inserted. The main features are to set a **flexible housing** type and its **technological patio** that plays multiple functions in the house. The house is generated by the addition of living modules to a variable space, the patio, allowing a new type of house prefabrication. The **living modules** are fixed prefabricated spaces whose dimensions allow to be transported by road, incorporating all the housing systems and facilities. They are based on the medium scale prefabrication concept. The **patio** is an intermediate space, covered by a pergola, which is used for living, thermal regulation and energy generation. It is a **technological patio**, that uses the new technologies and which is based on the traditional knowledge about passive cooling and spatial comfort of the Mediterranean house.

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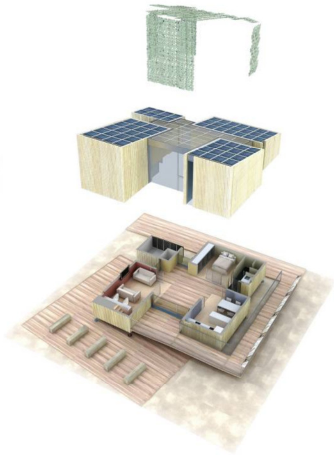
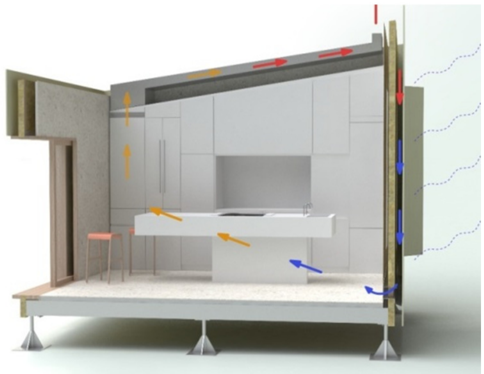
Picture 1



Picture 2



Picture 3

The prototype is based on three main components which add up to create a complete house. This components are totally premanufactured in a workshop and assembled at the user's will, allowing thus for a higher user's personification, normally missing in premanufactured housing. The three components are: Skin, Closets and Isles.

The **skin** *(Picture 2)* is completely prefabricated in workshop. It includes all the materials needed to create the comfort necessary in a house. It is made up of the exterior and interior envelopes, the bearing structure and is prepared to have any type of system installed in it.

The **closets** *(Picture 4)* are also premanufactured and are thought to contain the necessary elements for any system to work properly. The lighting points, sockets, air conditioning grilles, etc. can be found inside of them.

The **isles** *(Picture 4)* help qualify the space by giving it a use (kitchen and bathroom). These are prefabricated "furniture" containing everything needed to qualify a space. These concepts, closets and isles, can also be used in any other space, for example, building´s refurbishment.

Picture 4

Picture 5

1.2. Industrialization: medium scale prefabrication (complete modules)
Medium scale prefabrication is the basis for this new model, which allows the living modules to be made completely in factory, to be taken later on to its final destination by road transportation.

Traditional construction materials are technologically reinterpreted and applied to the prototype. For example, ceramic and timber. They are suitable from an environmental perspective because they improve the passive performance of the spaces and need little energy consumption for the construction.

The constructive system of the envelope consists of a '**balloon frame**' timber structure, with ceramic claddings to the outside and timber sandwich panels filled with insulation inside. Each module is autonomous from the structural perspective and connected to the ground through a reduced number of supports.

The **assembly process** is very simple: First, the living modules are set in place. The foundation is minimal thanks to the reduced weight of the modules, the plots are based on a few small cubes of concrete *(Picture 5).*

The patio floor is independent from the living modules and is connected to the ground through a support system similar to the module´s one. Therefore, the house floor is elevated, ventilated and insulated. The pergola´s structure of the patio rests on the living modules. Lastly, all the systems are connected using the systems ring found underneath the patio´s air chamber.

Once the prototype has been assembled, it will be completed with the implementation of exterior ramps, carpets and water repositories.

1.3. Sustainability, ecology and energy efficiency
The prototype achieves the best architectural **integration** of **photovoltaic** solar system through the house shape. Photovoltaic panels are integrated in the modules, placed on the roof to create a ventilated air gap on little supports. The living module´s roofs have the appropiate inclination to get the higher efficiency. Therefore, the photovoltaic system has a double function: roof cover and electricity generation.

The innovative systems of this prototype decrease the need of air-conditioning during a great part of the year. This is possible through the use of different **bioclimatic** strategies: passive systems.

- **The technological patio like "buffer space"** *(Pictures 6-7)*: an intermediate space damper outdoor climate that allows control of solar incidence and generating drafts. It is constructed in two layers, a glazed and mobile that can be opened or closed and the other layer consisting of adjustable blades that provide shade. In winter causes a greenhouse effect and in summer favors a cross ventilation.
- **Passive cooling by evapotranspiration or "jug Effect"**: the envelope can become an

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"active material", in this case the skin is breathable ceramic and incorporates an irrigation system that humidifies the ceramic pieces evaporating the water contained outside. When water evaporates it absorbs the energy of the air chamber and the cold air is recirculated into room through automated gates.

- **Passive ventilation by solar chimney**: it works by heating a volcanic rock on deck that generates a convection current that ventilates the module. It is not just to acclimatize the inside of the room it is to regulate the air quality as well.

Picture 6

Picture 7

2. Industrialized Prototype: Highly Efficient Tourist Housing

As another alternative of Patio 2.12 we propose a prototype of temporary housing for tourism. It consists of two bedroom modules with bathroom and a livingroom/diningroom module with kitchen. The three prefabricated modules *(Picture 9)* are related through the patio that is a versatile space that contains the access. The original technical module has been deleted, to integrated facilities technical spaces have been provided over the kitchen and bathrooms.

Picture 8

Picture 9

This application is actually a set of elements of the original project, this is possible because it is an open and flexible industrial system, which can be extended or reduced by adding or removing modules and patio pieces. In this particular case, one of the four prefabricated

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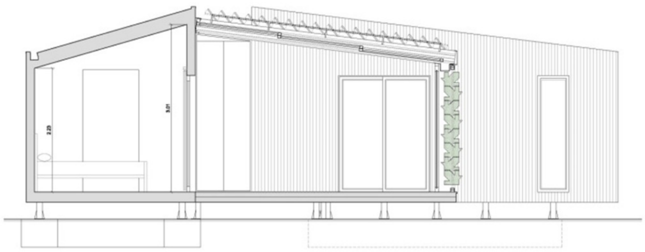
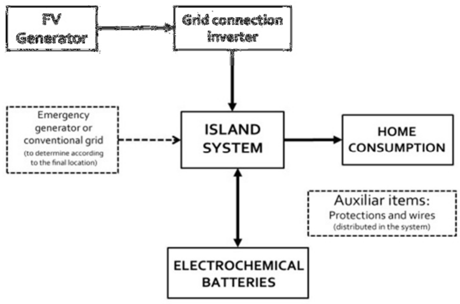
modules has been deleted and the patio has been reduced. It remains the same system but adapted to a different use.

The photovoltaic system *(Picture 11)* generates electricity from solar energy and it can incorporate a backup system for emergencies. The system will be located in a place where there is no access to conventional power grid. This is the concept of "energetic self-sufficiency". It can be connected to the general grid, with other houses to form a micro-generation grid or incorporate a generator. The Island System is the fundamental component and an innovation in renewable energy used at homes. It feeds a complete equipment: high-efficiency appliances, conditioning system, etc.



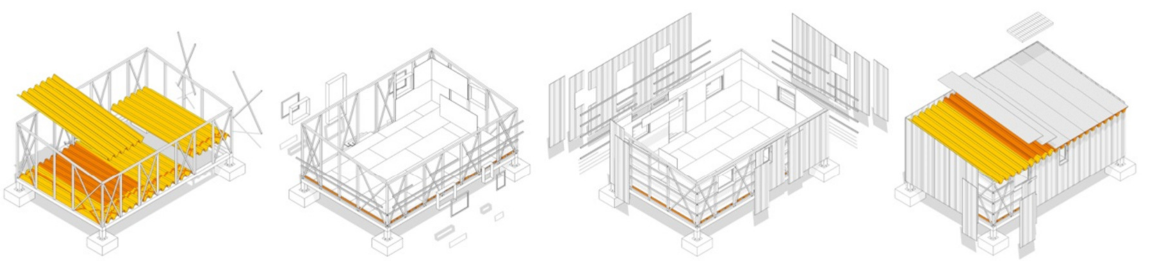
Picture 10



Picture 11

3. Industrialized Prototype: Emergency Housing

This research deals with various systems of emergency housing, self-sufficient housing industrialized with a very low cost, including renewable energies. Space requirements are set at a minimum housing for four people: living area with kitchen, two bedrooms and a bathroom. The prototype can optionally incorporate a front porch.



Picture 12

3.1. Industrialization: prefabricated "kit of parts"

The connection between industry and architecture is exploited to transform traditional building processes and to come closer to industrial manufacturing systems, which provide greater speed, quality control, lower costs, greater flexibility and efficiency. We start with a basic premise that we call "open industrialized building" based on compatible,

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interchangeable and renewable resources. (1) For items that are interchangeable must take into account the factor of compatibility of the pieces.

The kit house concept refers to the sale of packages precut pieces that allows user input, possibly by self-build parts with dry mounting following a "manual". Peter Cook (2) takes an architectural research that falls in housing and the possibilities of a variety of kits to choose from. Structural kit, surround kit + woodworking kit, facilities kit + Photovoltaic kit.

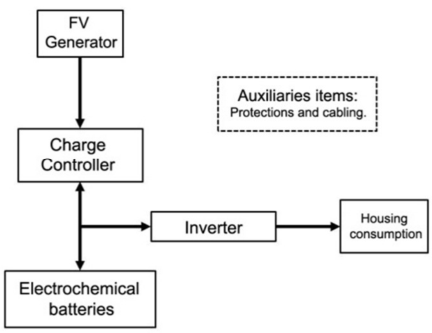
The structural and construction *(Picture 12)* design are linked to the functional organization; in the case of prototypes studied the structure is formed by standard linear elements prefabricated in a workshop. A metallic system, reminiscent of the balloon frame, regular and orderly calculated to be resistant to earthquake and wind.

The main advantage is that this house is designed to be sent anywhere in the world, exporting the packaged components contemplated by road in trucks or by sea in containers in a port that can carry two complete houses.

3.2. Sustainability, ecology and energy efficiency
The prototype consists of a single compact volume with an optimal ratio between the volume of the interior space and the surface contact with the outside. Thus the maximum performance is achieved at the lowest cost.

By the "photovoltaic kit" *(Picture 14)* we obtain a self-sufficient house, which generates its own electricity through a solar panel, an inverter and a battery. The installation includes elements for storing and supplying electrical energy when required. It will feed point lighting (LED technology) and small appliances.

Picture 13



Picture 14

The prototype is composed by sustainable materials (steel structure and wood surround OSB boards, sandwich panels, plates or ceramic, Onducober, etc.), considering the energy balance and the life cycle. Sustainability is extended to the use of materials of rapid regeneration, low environmental impact and high durability (for possible reuse), along with the implementation of recycling solutions.

Once removed, the prototype can be refitted wholly or partly, or may even use its components to expand or repair other prototypes. The prototypes can be recycled or reused once their housing mission has finished. The possible adaptation to other uses responds to economic sustainability demanded by today's society.

Industrialization allows the transformation of spaces over time, according to user needs and changing the boundaries of the property, thus incorporating as exclusion areas by aggregating elements. In an industrialized house both the elements and components such as the spatial organization will be flexible as long as the mounting system allows. Industrialization systems offer flexibility to the organization and allow any constructive or formal provision that supports adaptation to certain ways of occupying the prototype.

4. Habitability and comfort

The integration of industrialization in the process of architectural design should not prevent the creation of pleasant and comfortable spaces, where there is a thermal, acoustic and light balance. The walls are energy accumulators; the transmission of heat through the wall in variable conditions is affected by the thermal inertia, which is a direct function of their weight (3). The thermal and acoustic comfort is a subjective and personal sensation that makes us feel good in the environment where we are. Make the difference between a house and a home.

5. Conclusion

The construction sector due to its size and branches is the slowest to incorporate innovations offered by contemporary industry. Industrialized architecture linked to residential use, which has the largest impact on the construction sector by volume, still anchored in tradition with great difficulties in applying existing systems and components on the market.

"You have to combine architecture as art and a humanistic science with the possibilities of the great contemporary industry" (4)

A restructuring of the construction industry where the architectural design allows create more effective linkages between technologies production and assembly is required. This requires developing a methodology of teamwork that provides the basis for greater coordination between architecture and industry and all those involved in the construction process agents.

References:

(1) Águila, A. (2006) La industrialización de la edificación de viviendas. Madrid. Mairea Libros
(2) Cook, P. (1971) Arquitectura: planeamiento y acción. Madrid. Ediciones Nueva Visión
(3) Serra, R. (2002) Arquitectura y climas. Barcelona. Gustavo Gili
(4) Leoz, R. (1981) Arquitectura e industrialización de la construcción, La Fundación, Madrid

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Thermal energy storage in sustainable buildings: passive and active systems

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Abstract: Energy use from the building sector has become an important amount of the global energy consumed in Europe. This fact gives importance to the research and development of technologies focused on the energy demand reduction in buildings, in order to achieve zero or nearly zero energy buildings. Thermal energy storage implementation in buildings is one of the main research issues which are carried out in this study. Two types of storage systems can be defined, the passive alternatives which consist of giving thermal inertia to the envelope, and the active ones where it is possible to decide when to store and/or release the energy depending on the weather conditions and energetic requirements of the building. Some of these systems are studied under real conditions and compared. Finally, not all these technologies are able to operate under summer and winter periods. The benefits and limitations of each system to operate under specific conditions are also analysed.

Keywords: thermal energy storage (TES), buildings, thermal inertia, passive system, active system, phase change materials (PCM)

1. Introduction

In recent years, 40 % of the global energy consumed in the European Union corresponds to the building sector, being the use of the HVAC systems an important fraction of this energy consumed [1]. Since, the Horizon 2020 programme implemented the objective of 20% reduction of the greenhouse gas emissions by 2020 as one of the main statements, professionals of the building sector must take into account the energetic performance in their designs [2]. In this context, researchers are working on improving a critical issue related with the energy consumption in buildings, the thermal enery storage.

It is well known that there is a high potential in energy demand reduction with the improvement of building envelopes [3-5]. Thermal insulation layer is considered the most effective protection from the external conditions, however, the design parameters of the constructive systems have to be not only focused on the thermal resistance but in the thermal inertia, as well [6,7].

Many researchers have focused their studies on the increase of the heat storage capacity of building envelopes or components for reducing the energetic consumption of HVAC systems. Phase change materials are widely studied for this purpose due to their high storage capacity during its phase change process [8-10].

In this paper, some passive and active systems for energy savings in buildings are presented and their thermal performance are analysed and compared.

2. Experimental set-up

An experimental facility (located in Puigverd de Lleida, Spain) consisting of 21 cubicles was built to study the energetic performance of several constructive systems and building materials under real conditions. In order to obtain comparable results, all the cubicles have the same internal dimensions (2.4 x 2.4 x 2.4 m), orientation (N-S, 0º), and configuration design with an insulated metal door and without windows (Figure 1). The area corresponds to the climate Cfa/Csa according to the Geiger climate classification [11]. The facility includes cubicles built with traditional brick system with an insulation layer, alveolar brick walls and a sustainable constructive system such as rammed earth walls. The common target of the different envelopes studied, apart from insulation, is to store thermal energy in order to reduce the energetic demand and therefore the energy consumption of HVAC systems. Two types of storage systems can be defined in these cubicles, the passive alternatives which consist of giving thermal inertia to the envelope, and the active ones that store and release the energy depending on the energetic demand of the building.

All cubicles are fully instrumented and data is registered at five minutes intervals to evaluate their thermal performance. Surface and ambient temperatures were measured using Pt-100. In addition, the weather data was also registered. Two Middleton Solar pyranometers SK08 are used to capture horizontal and vertical global solar radiation, outer air temperature and humidity are measured using an ELEKTRONIK EE21 with a metallic shield to be protected against radiation, and wind speed and direction is provided by a DNA 024 anemometer.

2.1 Passive systems

The cubicles used to study passive systems for energy demand reduction are presented next. All of them have different constructive systems in their walls, and a flat roof built with precast concrete beams and 5 cm of concrete slab, 3 cm of polyurethane placed over the concrete which is finished with a double asphalt membrane and a drainage layer of grave. Rammed earth cubicle is finished with a green roof following sustainable criteria.

- Traditional Mediterranean brick cubicles
    - Reference brick cubicle (BRICK): It consist of a perforated brick layer (29x14x7.5 cm), an air chamber of 5 cm, hollow brick layer (50x20x7 cm), with a structure made of 4 mortar pillars with reinforcing bars, one in each edge of the cubicle. There is no thermal insulation in this cubicle. The brick facades are finished with mortar coating on the exterior and plaster lining on the interior face.
    - Polyurethane cubicle (PU): The same structure and layer distribution than the reference cubicle but with 5 cm of polyurethane sprayed foam between the perforated bricks and the air chamber.
    - Polyurethane PCM cubicle (PU-PCM): A PCM layer was added to the same constructive system than the polyurethane one. Macro-encapsulated panels of

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RT-27 are placed on the internal face of the insulation, in the roof, south and west walls.

- Alveolar brick cubicles
  - Alveolar brick cubicle (ALV): The constructive system is formed by alveolar brick facades (30x19x29 cm) finished with mortar coating in the exterior and plaster lining in the interior, which have a structural function as load-bearing walls. The alveolar brick has a special design which provides both thermal and acoustic insulation. No additional insulation was used in this cubicle.
  - PCM cubicle (ALV-PCM): Same structure and layer distribution than the alveolar cubicle. The addition of a layer of macro-encapsulated hydrated salts (PCM) in the roof, south and west walls is the only difference between them. No additional insulation was used in this cubicle.
- Rammed earth (RAM): It is composed of a 29 cm thickness mix of clay (38% in volume), sand (52%), and straw (10%), which has been mechanically rammed. There is no internal or external coating. Rammed earth has a structural function as load-bearing walls. The roof is built with wooden beams and wooden board, and it is finished with a green roof with 5 cm of puzolana drainage layer and 4 cm of substrate.

Figure 1. Experimental set-up located in Puigverd de Lleida (Spain). Up: general view. Down: cubicles during their construction, from left to right: BRICK, PU, PU-PCM, ALV, ALV-PCM, RAM.

2.2 Active system

The use of passive systems presents some limitations, one of them being the impossibility of releasing the stored energy when desired. In order to overcome this barrier, the use of active systems integrated in the building structure is analysed.

A ventilated facade (FAC) with PCM (macro-encapsulated panels incorporating SP-22) inside the air channel is implemented in the south wall of a double high cubicle (Figure 2). The use of latent heat storage inside the ventilated chamber allows the system to store solar radiation during winter and be used as a cold storage system during night, using the low temperatures at night to solidify the PCM. In order to test and compare the thermal benefits of the system a

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reference cubicle (REF) was built with the same dimensions and constructive system. The constructive system used in the walls of both cubicles is based on alveolar bricks (30 x 19 x 29 cm) with an external cement mortar and inner plaster coating. Both roofs were made using concrete pre-cast beams, 3 cm of polyurethane and 5 cm of concrete slab. The polyurethane is placed over the concrete and it is protected with a cement mortar roof with an inclination of 3%, a double asphalt membrane and 5 cm of gravel.

The ventilated facade is equipped with three fans (FCL 133 Airtecnics) located at the bottom of the air channel to provide mechanical ventilation when needed. Six gates were installed at the different openings of the channel giving versatility to the system to operate under winter and summer conditions.

Figure 2. Experimental set-up located in Puigverd de Lleida (Spain). Left: ventilated facade and double height reference. Right: macro-encapsulated PCM inside the air cavity.

3. Methodology

The experimental set-up offers the possibility to perform two kinds of tests: free-floating temperature and controlled temperature. All cubicles are equipped by a heat pump (Fujitsu Inverter ASHA07LCC) and its electrical energy consumption is also registered (Circutor MK-LCD). In free floating experiments the air and surface temperatures of the cubicles are analysed under free oscillating conditions. On the other hand, in controlled temperature experiments the same set point temperature is fixed in all the cubicles and the energy consumption of the different heat pumps is compared.

3.1 Passive systems

The comparison of the benefits of using insulation and thermal inertia is evaluated. On one hand, the effect of thermal insulation is evaluated with the BRICK and PU cubicles; on the other hand ALV and RAM cubicles will reflect the thermal inertia effect. Both effects are compared under both winter and summer conditions.

Moreover, the effect of PCM incorporation in the building envelope as a passive cooling system was studied by Castell et al. [12]. The addition of phase change materials gives higher thermal inertia to the building envelope, since PCM stores high amount of heat within the

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phase change range. In this passive application, PCM will store the heat of the high temperatures of summer days and then released to outdoors during night-time.

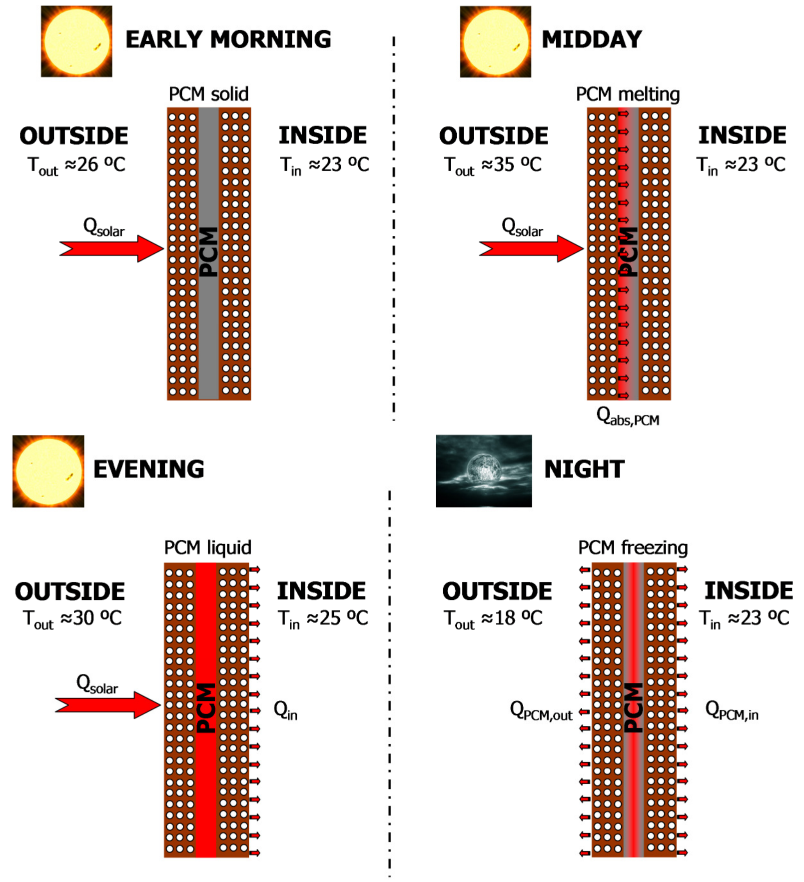

Figure 3. Operating principle of PCM in buildings.

3.2 Active system

The sequence of operation during winter period is shown in Figure 4 [13]. The ventilated facade acts as a solar collector during the solar absorption period (Figure 4a) and all its gates are closed. Once the PCM is melted and heating demand is needed, the heat discharge period starts and the openings drive the air flowing from the inner environment to the facade cavity, where is heated up by the PCM panels and after delivered to the inner environment (Figure 4b). This discharge period ends when no more thermal energy is needed or no heating can be provided by the facade; hereafter the system closes all the openings, acting as a Trombe wall, to minimize the heat losses from this envelope to the environment (Figure 4c).

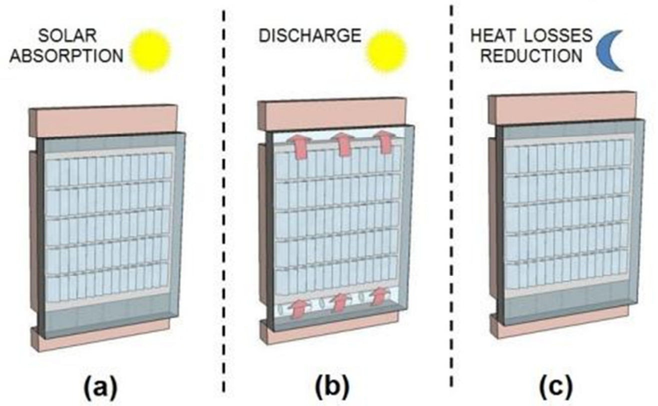

Figure 4. Sequence of winter operation of the ventilated facade.

The summer operation of the facade is studied by de Gracia et al. [14] consisting of pumping air from the outer environment to the channel to solidify the PCM during the night time (Figure 5a). Once there is a cooling demand indoor air is cooled down by the PCM and is pumped to the inner environment (Figure 5b). After the cold stored in the PCM has been released to the air, the system lets the air flow from outdoors to outdoors in order to prevent the overheating effect in the air channel (Figure 5c). Moreover, night free cooling operation (Figure 5d) can also be done once the PCM solidifing period is finished.

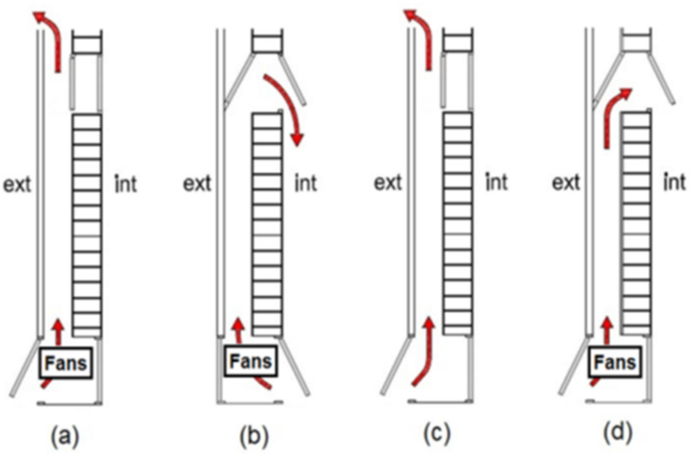

Figure 5. Sequence of summer operation of the ventilated facade.

4. Results

4.1 Passive systems

Figure 6 presents the results of a controlled temperature experiment using a set point of 24ºC. The accumulated energy consumption of the BRICK cubicle is higher than that of all the other cubicles. The PU-PCM cubicle is the one with the lowest energy consumption while the ALV-PCM cubicle is the second one, consuming even less energy than the PU cubicle. Finally, the ALV cubicle consumes slightly more energy (10%) than the PU cubicle because

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of his lack of insulation, however it consumes significantly less than the BRICK cubicle (46%) because of his higher thermal energy storage capacity.

It can be observed that both PCM cubicles reduced the energy consumption compared with the same cubicle without PCM. PU-PCM cubicle achieved a reduction of 15% compared to the PU cubicle, while the ALV-PCM cubicle reached a 17% of energy savings compared to the ALV one. Moreover, ALV-PCM cubicle presents lower energy consumption than the PU cubicle.

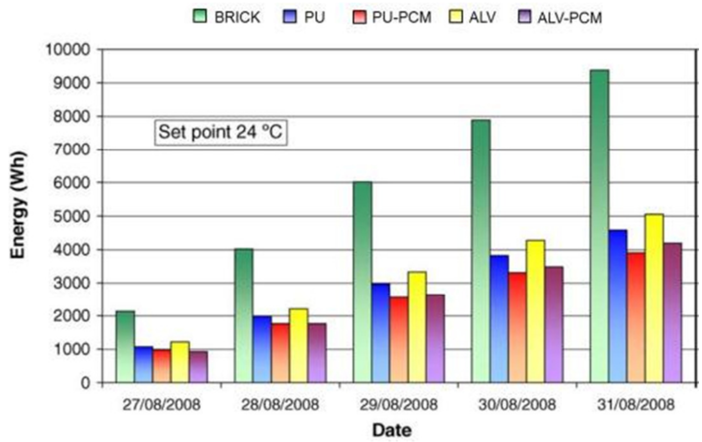

Figure 6. Accumulated energy consumption, controlled experiment Set point 24ºC.

On the other hand, rammed earth (RAM) cubicle is experimentally compared with the alveolar brick (ALV) cubicle and brick with and without polyurethane (PU and BRICK, respectively). Temperature profiles of internal ambient of cubicles are measured for winter (Figure 7) and spring-summer in free floating conditions. In both periods, RAM cubicle presents the highest oscillations of inner temperature, while PU cubicle has the lowest oscillations. Moreover, ALV and BRICK cubicles have a similar thermal oscillation along both periods, but with slightly higher temperature peaks of temperature in the hollow brick facade. The comfort temperature range is not achieved by any of the cubicles without heating system during winter period.

4.2 Active system

Experimental mesurements during winter period have been carried out with different set point temperatures, schedules (depending on different demand profile), and operational modes (with or without the use of fans). In Figure 8 two controlled temperature experiments where presented with the same set point (21 ºC) and the same schedule operation but with a difference on the ventilation mode (natural and mechanical). As it was previously mentioned the ventilated facade cubicle (FAC) is compared to a reference (REF) one with the same constructive system but without the facade. The system operating under naturally ventilated mode (Figure 8, right) reduced the electrical energy consumption of the HVAC in 18.7% in

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comparison to the reference cubicle, while the mechanically ventilated mode has similar energy reduction having 19.1% of energy savings.

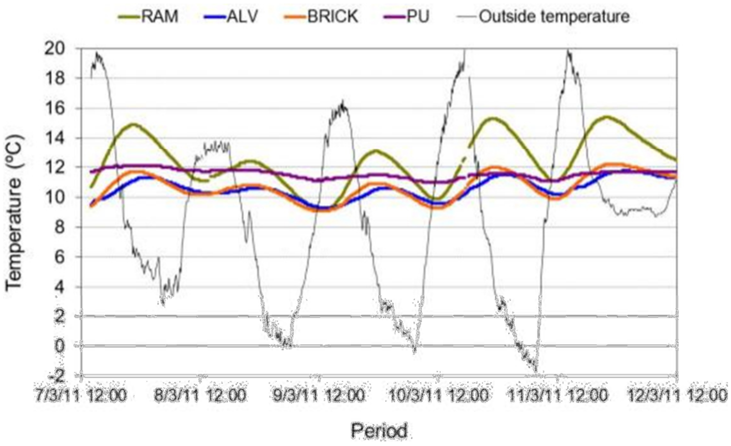

Figure 7. Indoor temperature of the rammed earth (RAM), alveolar (ALV), reference brick (BRICK) and polyurethane brick (PU) cubicles and outside temperature, along March 7th to 12th, 2011.

These experiments highlight that the use of fans is not necessary unless a fast heating supply is needed, since the fans implies an extra energetic consumption that needs to be compensate by the energy provided by the facade.

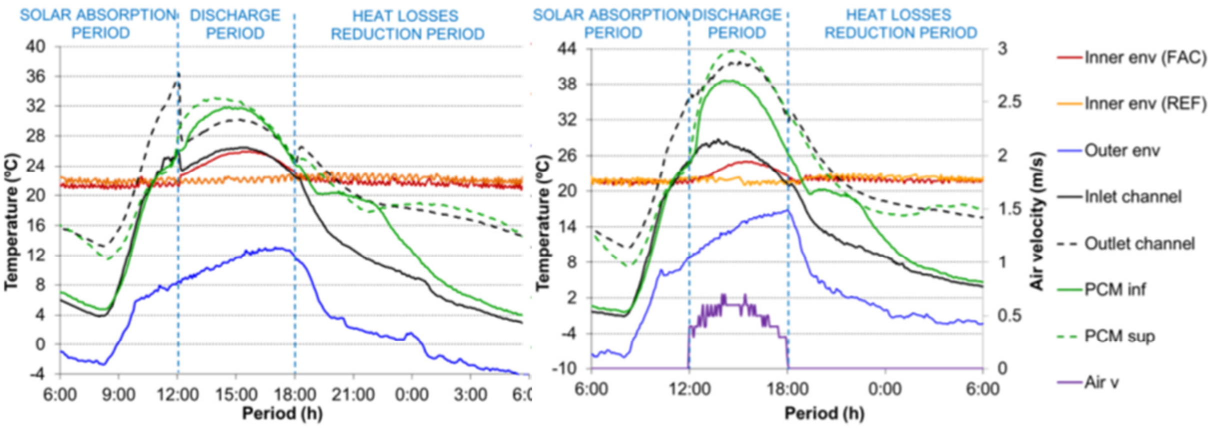

Figure 8. Thermal profiles of PCM, air flow, and inner and outer environment of controlled temperature (21ºC) experiment with mechanical ventilation (left) and natural ventilation (right).

Moreover, experiments during summer period were performed and some results are presented. In Figure 9 (left), a controlled temperature experiment (25 ºC) with cold storage sequence under sever summer conditions is presented. Electrical energy consumed by the heat pump installed at the FAC cubicle presents a reduction of 16% in comparison to the REF during this experiment. On the other hand, Figure 9 (right) shows a controlled temperature experiment (25 ºC) where outer temperature at night was higher and the PCM could not

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solidify. However, the versatility of the ventilated facade permits the use of night free cooling effect. In such case, although the cold storage system was almost useless and the night free cooling was not optimized, the electrical energy consumption of the heat pumps was reduced by 23.1% during this experiment.

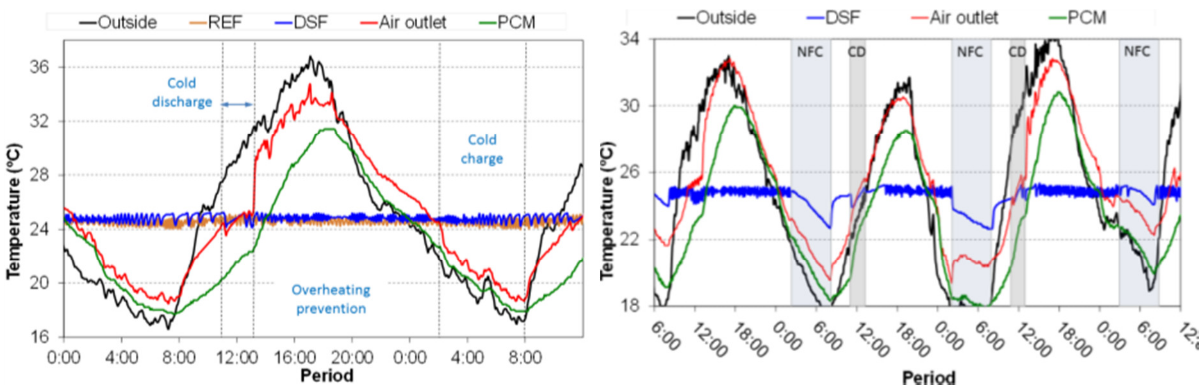

Figure 9. Thermal profiles of PCM, inner and outer environment of controlled temperature (25ºC) experiments with cold storage (left) and cold storage and night free cooling (right).

5. Conclusions

An experimental facility located in Puigverd de Lleida (Spain) where several house-like cubicles with different constructive systems are studied is presented. A comparison between conventional systems and the implementation of new technologies to reduce the energy demand in buildings is done.

Thermal inertia increase in building envelopes was experimentally studied as a passive system for energy consumption reduction. Benefits of thermal inertia have been enhanced by its combination with thermal insulation, since results from thermal inertia alone (rammed earth) show higher temperature fluctuations. On the other hand, the incorporation of PCM in building envelopes and its combination with thermal insulation showed significant potential for energy savings and thermal comfort management during summer.

Furthermore, an active system consisting of a ventilated facade with PCM was presented. The use of the ventilated facade during winter reduces significantly the electrical energy consumptions of the installed HVAC systems. In addition, experimental mesuarements during summer period demonstrated the high potential of the night free cooling effect in reducing the cooling loads of a building. On the other hand, the cold storage capacity of the system is very sensitive to the outer night temperature, since temperatures below the phase change are needed to solidify the PCM.

Although passive systems are demonstrated to reduce the energetic demand of the cubicles, active systems provide energetic reductions on the energy consumed by the HVAC systems. Moreover, energy supplied by active systems is used depending on the weather conditions and the requirements of the building. A combination of both types of systems (passive and active) and their appropiate implementation depending on the weather conditions and the climate would reduce drastically the energy consumption of the HVAC and therefore, the CO_2 emissions.

Acknowledgements
This work was partially supported by the "Corporación Tecnológica de Andalucía" by means of the project "MECLIDE-Soluciones estructurales con materiales especiales para la climatización diferida de edificios" with the collaboration of DETEA. The work is partially funded by the Spanish government (ENE2011-28269-C03-01 and ULLE10-4E-1305). The authors would like to thank the Catalan Government for the quality accreditation given to their research group (2014 SGR 123) and the city hall of Puigverd de Lleida. The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° PIRSES-GA-2013-610692 (INNOSTORAGE).

References

[1] Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings. Available from: http://www.epbd-ca.eu.

[2] Horizon 2020, The EU Framework Programme for Research and Innovation. Available from: http://ec.europa.eu/programmes/horizon2020/en/ (April 2014).

[3] Castell, A., Martorell, I., Medrano, M., Pérez, G., Cabeza, L.F., (2010). Experimental study of using PCM in brick constructive solutions for passive cooling. Energy and Buildings, 42: 534-540.

[4] Papadopoulos A.M., (2005). State of the art in thermal insulation materials and aims for future developments. Energy and Buildings, 37(1): 77-86.

[5] Kossecka, E., Kosny, J., (2002). Influence of insulation configuration on heating and cooling loads in a continuously used building. Energy and Buildings, 34: 321–331.

[6] de Gracia, A., Castell, A., Medrano, M., Cabeza, L.F. (2011). Dynamic thermal performance of alveolar brick construction system. Energy Conversion and Management, 52: 2495–2500.

[7] Al-Sanea, S.A., Zedan, M.F., Al-Hussain, S.N., (2012). Effect of thermal mass on performance of insulated building walls and the concept of energy savings potential. Applied Energy, 89: 430–442.

ISBN: 978-84-697-1815-5

[8] Cabeza, L.F., Castell, A., Barreneche, C., de Gracia, A., Fernández, A.I. (2011). Materials used as PCM in thermal energy storage in buildings: A review. Renewable and Sustainable Energy Reviews, 15: 1675-1695.

[9] Khudhair, A.M., Farid, M.M. (2004). A review on energy conservation in building applications with thermal storage by latent heat using phase change materials. Energy conversion and Management, 45: 263-275.

[10] Farid, M.M., Behzadi, S. (2010). Energy storage for efficient energy utilization in buildings, in: 1st International High Performance Buildings Conference, 12–15 July, Purdue University, USA, 2010.

[11] Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., (2006). World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15: 259-263.

[12] Castell, A., Martorell, I., Medrano, M., Perez, G., Cabeza, L.F. (2010). Experimental study of using PCM in brick constructive solutions for passive cooling. Energy and Buildings 42: 534–540.

[13] de Gracia, A., Navarro, L., Castell, A., Ruiz-Pardo, A., Álvarez, S., Cabeza, L.F. (2012). Experimental study of a ventilated facade with PCM during winter period. Energy and Buildings, 58: 324-332.

[14] de Gracia, A., Navarro, L., Castell, A., Ruiz-Pardo, A., Álvarez, S., Cabeza, L.F. (2012). Thermal analysis of a ventilated double skin facade with PCM for cooling applications. Energy and Buildings, 65: 508-515.

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Success factors for the Multi-Comfort House standard in warm climates: last generation products and solutions to achieve a better energy performance, economical and management tools on job-site

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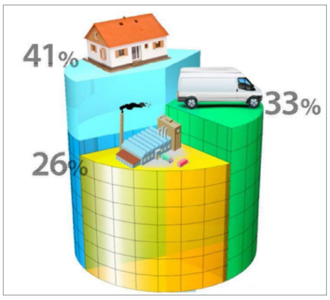
Everybody talks about more and more extreme weather events, but only few take action. With their signature under the Kyoto Protocol, more than 140 industrial nations have made a commitment to reducing their CO2 emissions drastilacy. This means: top priority for using energy saving technologies and thus top priority for saving our natural resources. Each and every one of us should contribute to more economical house keeping by living comfortable and making most efficient use of energy.



On the current context, 40% of the total energy compsumtion on UE is owing to building sector. Is a key factor design strategies to reduce this consumption in order to achieve the requirements of European Directive 2010/31 focused on reduce greenhouse effects thorough nearly zero energy buidings.

By this, a single-family house has been built in Calicanto, Valencia, as a successful case of Multi-Comfort House (based on the Passive House Standard) in hot climates. It has been built with all thermal and acoustic comfort, and at the same time it gains energy with the objective of creates at home a snugly warm in winter and a comfortable cool in summer.

It is going to present the key points of this case:

1. *"Multi-Comfort House" requirements.*
2. *Comfort at home in hot climates.*
3. *Design principles & Strategies applied in Calicanto.*
4. *Management on job-site.*

Energy-savings, CO2 emissions, nearly zero energy buidings, Multi-Comfort House, Passive House Standard.

1. "Multi-Comfort House" Requirements.

The Passive House concept was developed in Germany in 80's as an evolution of the nearly zero energy buildings because of the high quality of the insulation materials for the envelope of buildings, internal heating systems, reduces of energy loses, and a controlled ventilation, provides to the family a sufficient amount of warmth remains in the house in the cold season, there is normally no need for heat supply by traditional space heating.

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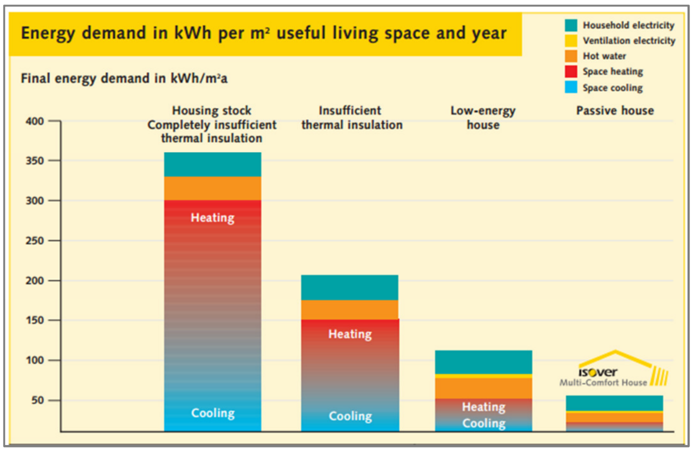
In hot periods, the perfect thermal insulation and the windows with outside shading keep most of the heat and solar radiation outside. The cooling demand for a pleasant indoor temperature is reduced by up to 90%, with a heating and cooling demand less than 15kWh/m2 per year.

These energy and cost savings are all the more important in view of the steadily increasing world market prices for all kinds of energy.

The Isover Multi-Comfort House is based in the same concept of energy savings and it also considers the multiple dimension of comfort:



- Thermal comfort
- Acoustic comfort
- Healthy indoor air
- Safety from fire
- Lower energy bills – more money for enjoying life
- Use of local and renewable energy sources
- Independence from external energy suppliers
- Active environmental protection
- Higher property value

Heating and cooling energy demand of a typical single-family house	kWh/m²a 300-250	kWh/m²a 200-150	kWh/m²a 90-60	kWh/m²a ≤ 15
Heating	270-230	185-140	80-55	≤ 10
Cooling	30-20	15-10	10-5	≤ 5
BUILDING STANDARD	**Completely insufficient thermal insulation** Structurally questionable, cost of space conditioning no longer economical (typical of rural buildings, non-modernized old buildings).	**Insufficient thermal insulation** Thermal renovation is clearly worth the trouble (typical of residential houses built in the 50s to 70s of the last century).	**Low-energy houses**	**Very low energy houses** (passive houses need to meet this parameter as part of the requirement profile)
BUILDING ELEMENT	Typical U-values and insulation thicknesses			
External walls (massive wall of 25 cm) Insulation thickness	2.45 W/(m²K) 0 cm	1.0 W/(m²K) 2 cm	0.50 W/(m²K) 6 cm	0.20-0.45 W/(m²K) 20-10 cm
Roof Insulation thickness	1.38 W/(m²K) 0 cm	0.54 W/(m²K) 4 cm	0.28 W/(m²K) 10 cm	0.15-0.25 W/(m²K) 25-15 cm
Cellar ceiling Insulation thickness	1.66 W/(m²K) 0 cm	0.85 W/(m²K) 2 cm	0.57 W/(m²K) 4 cm	0.35 W/(m²K)* 8 cm
Windows	5.1 W/(m²K) Single glazing, thin wooden frame	5.1 W/(m²K) Single glazing, thin wooden frame	2.8 W/(m²K) Double glazing, standard frame	1.0-1.5 W/(m²K) Double low-e glazing, insulated frame, or triple glazing if nessesary
Ventilation	Leaky joints	Window ventilation	Exhaust air unit	Comfort ventilation with heat recovery
CO_2 emission	75 kg/m²a	30 kg/m²a	12 kg/m²a	4.5 kg/m²a
Energy consumption in liters heating oil per m² living space and year	30-25 liters	15-10 liters	5-4 liters	1.5 liters

** If the average temperature of the outside air is not below 15 °C, insulation to the ground is not so important.*

The Isover Multi-Comfort House, as same as the Passive House concept, does not define itself by outer appearance but by its inner values. Therefore any type and size of building can be realized. This is testified every year by a growing number of examples, including one-family houses and industrial estates, schools, churches and mountain shelters. Not only new buildings comply with this future-oriented building standard. There are even increasing numbers of old buildings whose refurbishment is based on passive house principles. The use of wellselected passive house components achieves ecologically and economically sensible results.

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Thermal requirements:

Thermal insulation of envelope: average U-value than (Avoid thermal bridges)	<0.2 W/m2K.
Blower Door Test: (n50) at 50 Pa pressure difference	<1.0 1/h acc.
Glazing with U-values from	1.0-1.5W/m2 K
Windows with average area weighted U-value	1.0-1.5 W/m2K
Compact design V/A (volume to surface ratio)	1-4
Efficient ventilation (heat recovery at least 80 % acc. to Passive House Institute Certificate combined with low specific electricity consumption of the fans).	

Acoustic requirements:

Class	"Music"	"Comfort"	"Enhanced"	"Standard"
Airborne sound insulation between flats DnT,w + C (dB)	≥68	≥63	≥58	≥53
Airborne sound insulation between the rooms of one flat (without doors), also incl. one-family houses DnT,w + C (dB)	≥48	≥45	≥40	≥35
Impact sound insulation between flats LnT,w +C (dB)	≤40	≤40	≤45	≤50
Impact sound insulation within a flat, also incl. ome-family houses LnT,w +C (dB)	≤40	≤40	≤45	≤50

2. Comfort at home in hot climates.

The single-family house is based in Calicanto, a residential area owned by three small villages Chiva, Torrente and Godelleta, near to Valencia.

Climatic zone: B3
It means an average temperature above 10 °C in warmest months, and an average in the coldest between 16 to –3 °C.
It is an area without shade provided by mountains or surrounding trees.

In the warm climates of Southern Europe, heating is less of a problem than in Central and North Europe cliamtes, in this case the main compsumption to contro is energy used by

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cooling systems. With minimal total energy consumption, buildings can be kept comfortable all year round. Both heating and cooling requirements need to be considered when defining insulation levels and glazind specifications in Southern Europe. Of course, a detailed planning and engineering as well as expert installation are essential for an excellent energy performance.

But, do we really need so much energy for comfort?

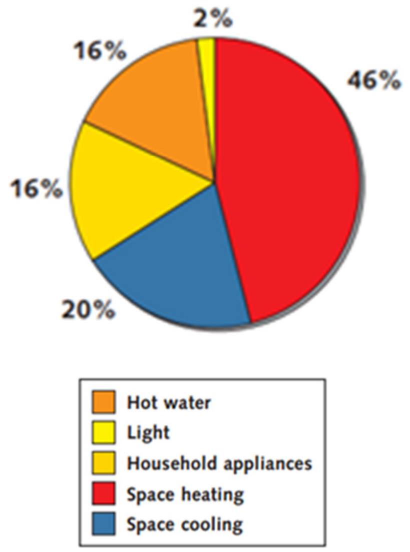
Passive house design is a strategic approach in different locations and climates. Its objective is to minimize energy consumption for heating, ventilation, lighting and cooling. In Northern Europe, the demand for heating energy is still quite high.
Naturally, it is lower in Southern Europe where the demand for mechanical cooling has been increasing rapidly. Recently, there is a growing interest in strategies to achieve passive house performance for both heating and cooling, i.e. to reduce total heating and cooling demand to less than 15 kWh/m2 a according to the Passive House Planning Package (PHPP).

Location: 39º 28’17’’N 0º 43’ 11’’O
High: 270msnm.
Distance to the coast: 30km

Although Southern European homes still need to be heated in winter, there is a predominant need for cooling in summer. We at ISOVER have therefore recently adapted our Multi-Comfort House concept to warmer climates.

The mix of energy consumption has been calculated for a typical existing single-family house with an indoor temperature of 22 °C. The values can vary depending on the user habits and the selected indoor temperature.

Characteristic energy mix for a conventional house in Valencia (Calicanto).



3. Design principles & Strategies applied in Calicanto.

Premium rule for the building design: “Where a heating energy demand of 15 kWh per square meter and year is achieved, economy, building physics and design are are in perfect harmony”.

A meticulous planning is indispensable: to achieve a comfortable ambient and good conditions at home of 20-23ºC air temperature and a relative air humidity of 30-50 %.

Basic features to be considered:

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Primary factors

• Maximum thermal insulation, structural compactness and freeness of thermal bridges: All components of the building envelope are insulated at a U-value below 0.15 W/(m2K), achieved by insulating thicknesses between 60 and 80 cm, depending on the thermal coefficient of the insulation layer.

• The windows must have triple glazing and insulated frames. Aim: a U-value of < 0.80 W/(m2K), including the frame, and a g-value of 0.5 (total solar energy transmittance) for the glazing.

• Airtightness of the building: The result of the Blower Door Test must be < 0.6 air changes per hour.

• Heat recovery from the exhaust air: Over a counterflow heat exchanger, the major part of the warmth from the exhaust air is fed again to the fresh air supply – heat recovery rate above 80 %.

Secondary factors

• Pretreatment of fresh air: Fresh air can be pre-heated in winter and pre-cooled in summer via a geothermal heat exchanger (energy well).

• South orientation and freedom from shadows in winter: Passive use of solar energy saves heating energy.

• Domestic hot water generation: The required energy can be produced with solar collectors (energy demand for the circulating pump 40/90 watts per liter) or by air-to-water heat pumps (average coefficient of performance 4). In summer, the heat pump can also be used for energy-efficient cooling. Dishwashers and washing machines should be hot-water connected to save the energy needed for the heating process.

• Energy-saving household appliances: Fridge, oven, deep-freezer, lamps, washing machine etc. as efficient power savers are yet another useful constituent of the passive house concept. But this is something the occupants must take care of themselves.

Southern orientation and shading: the shape of the building has been considered carefully.

In summer, south-facing windows receive less solar radiation than those facing east or west. This is due to the fact that during summertime the midday sun is high in the sky whereas the morning and evening sun shines at a lower angle. Its rays can therefore penetrate deep into east- and west-facing windows, causing them to heat up.

In order to reduce the energy demand of the house, designers have applied this strategy and they also have combined ventilated façade on the southeast facades and an ETICS system on the northwest facades, to maximize the performances of each one:

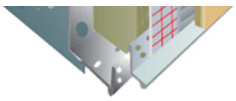
North and west facade:

External Thermal Insulation Composite System (ETICS) based on an acrylic render made of mortar and an insulation layer of mineral wool, particularly developed for this application. Advantages of a jointless façade:

- Thermal performance: U=0,10W/m2K
- Acoustics: Ra>56dBA.
- Fire reaction: A1 Euroclass. Totally fire-resistance >2h for 100mm of thickness.

This system takes advance of the thermal inertia of the façade. And the mineral wool it is able to absorp light structural movemnets of the building.

Easy to install by the size and weight of the panels.



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South and east façade:

This ventilated façade is only made of Saint-Gobain materials.

The insulation layer is made of mineral wool panels ("arena") facing to improve the resistance to traction of anchors on the
wall, durability with wind, rain, heat and moisture, and reduce the convection in the mineral wool layer.
Excellent durability with rain and UV (sometimes the job site has to wait a few months before the installation of the cladding).
Thanks to their diffusibility, they support the rapid drying of damp walls.

- Thermal performance: U=0,20W/m2K
- Acoustics: Ra>64dBA.
- Fire reaction: A2-s1,d0 Euroclass. Partially fire-resistance.

Thermal bridge rupture anchors.

Ventilated facades and ETICS ensured a good tratement of the thermal bridges. Thermal bridge free construction is a precondition for passive houses and ensures that the building is not damaged by moisture condensation on the inner surface of the building envelope.

Obviously, it is very important to design an energy-efficient window glazing and frames with an U-values of windows should be between 1.0 to 1.5 W/m2K for the whole window (glazing and frames) with a solar heat-gain coefficient above 50 %.

Flat Roof with gravel:

Walkability (supports the weight of workers) without any deformation.

- Thermal performance: U=0,27W/m2K
- Acoustics: Ra>50dBA.
- Fire reaction: A1 Euroclass. Totally fire-resistance.

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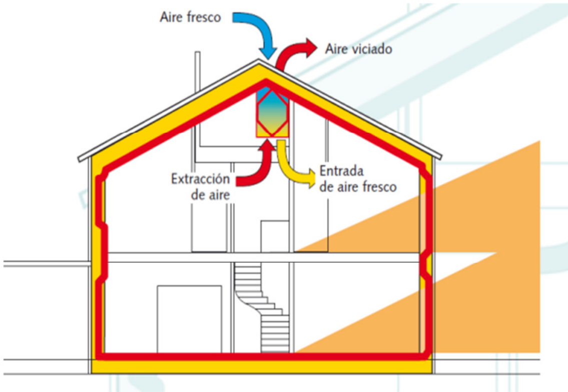
4. Management on job-site.



Call for tenders and awarding of contracts

• *Plan for quality assurance measures in the contracts.*

• *Set up a construction schedule.*

Assurance of quality by the construction supervision

• *Thermal bridge free construction: schedule on-site quality control inspections.*

• *Check of airtightness: airtight penetration of all pipes and ducts by proper sealing, plastering or taping.*

Electrical cables penetrating the building envelope must be sealed also between cable and conduit.

Flush mounting of sockets in plaster and mortar.

• *Check of thermal insulation for ventilation ducts and hot water pipes.*

• *Seal window connections with special adhesive tapes or plaster rail. Apply interior plaster from the rough floor up to the rough ceiling.*

• *n50 airtightness test: Have a Blower Door Test performed during the construction phase. Timing: as soon as the airtight envelope is complete but still accessible. This means: before finishing the interior work, but after completion of the electricians' work (in concert with the other trades), including identification of all leaks.*

• *Ventilation system: ensure easy accessibility for filter changes.Adjust the air flows in normal operation mode by measuring and balancing the supply and exhaust air volumes. Balance the supply and exhaust air distribution. Measure the system's electrical power consumption.*

• *Quality control check of all heating, plumbing and electrical systems.*

Final inspection and auditing

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Session 67:

Improvements on an urban scale. How can buildings and public spaces help each other?

Chairperson:

Wadel, Gerardo

Socio fundador. Societat Orgànica Consultora Ambiental SL

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On the improvement of urban regeneration processes from more than thirty years of rehabilitation experiences

Speakers: Matesanz Parellada, Ángela (DUyOT/UPM)[1]; Hernández Aja, Agustín (DUyOT/UPM)[2];

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Abstract: *At this moment of extended economic, social and environmental crisis within which new interventions on the consolidated city are being set out, it is essential to count on the acquired experience in urban rehabilitation processes that were carried out in Spain during the last thirty years. Despite the complexity of this kind of processes and the diversity of the situations and actions that happened, this paper addresses the analysis of common patterns in twenty urban rehabilitation experiences. Different stages of the processes were studied, from the management to the regenerated areas in order to ease the design of new intervention initiatives.*

Regeneration, management, rehabilitation processes, stakeholders, urban areas.

Introduction

The extended crisis and its close relation with the unlimited urban growth has led technicians, politicians and academics to take up the interest on the intervention in the consolidated city as well as on urban rehabilitation. That interest, in line with the revival of citizen's demands of public space, has its reflection in the implementation of initiatives for the rehabilitation of buildings or neighbourhoods as well as in the arising of new laws. That is the case of the *Ley 8/2013, del 26 de junio, de rehabilitación, regeneración y renovación urbanas*. These interventions are often aimed at introducing new techniques that optimize some aspects, such as energy consumption, or that improve processes or plans. However, in many cases these actions do neither lay on previous experiences nor improve developed processes.

The urban department of Instituto Juan de Herrera (DUyOT/ETSAM/UPM) developed in 2011 the project *'National and European policies analysis regarding urban regeneration and neighbourhood renovation'* (*Análisis de las políticas estatales y europeas en materia de regeneración urbana y rehabilitación de barrios*[1]). This study has its roots in the belief that the only way to improve the efficiency of urban process management and to pose new ways of intervention is taking advantage of the knowledge and the experience acquired along more than thirty years of urban rehabilitation actions. This research covers the analysis of twenty urban rehabilitation cases in Spain, the policy framework and the identification of Areas of

[1] Study directed by Agustín Hernández Aja and carried out thanks to the collaboration agreement between the IJH and Ministerio de Fomento. (http://www2.aq.upm.es/Departamentos/Urbanismo/blogs/re-hab/)

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Integrated Rehabilitation programmes (ARI) that were developed from 1992 to 2010 in cities with more than 50.000 inhabitants as well as in province capitals.

The analysed experiences, selected among all ARI and URBAN processes that were conducted between 1992 and 2010, are located in several geographical areas (17 autonomous regions) and have different backgrounds, form of urban growth and typology. The study attempted to cover a wide and a representative range of the diversity of developed actions.

The research was conducted through office work, field research and interviews with stakeholders and it analysed the complete rehabilitation processes building up 20 intervention chronologies. According to the proposed methodology, the stakeholders as well as the focus of the interventions (urbanism, environment, building and socioeconomics) were identified. This approach enables not only a general overview of the evolution of urban rehabilitation in Spain but the understanding of the established relations between the regenerated areas and the stakeholders who were involved in the processes. This is the main issue this paper deals with.

Rehabilitation processes analysis. On the relation between the areas and the stakeholders

In general terms, it can be said that the complexity of the treated issues and the development of actions through time make the 20 study cases to have their own singularities with a different management model each (1). Furthermore, there is not a unique plan or programme evolved in time for every case. Instead of that the majority of them resulted from the addition of actions that were not conceived as a global plan but as a response to the needs that were detected in every moment or to the actions that were founded by the available aid scheme. However, it must be highlighted that in many cases these added actions did not even coincided within the same urban physical limits.

These differences and the lack of homogeneity and continuity between programmes make necessary a global vision of the processes so as to understand the established relations between the areas subject of actions and the institutional stakeholders who managed the interventions as well as the used tools. Figures 1 and 2 show the structure of the analysis. It is divided into the three studied decades with the total number of actions according to the issues they dealt with and the stakeholders who were involved in each.

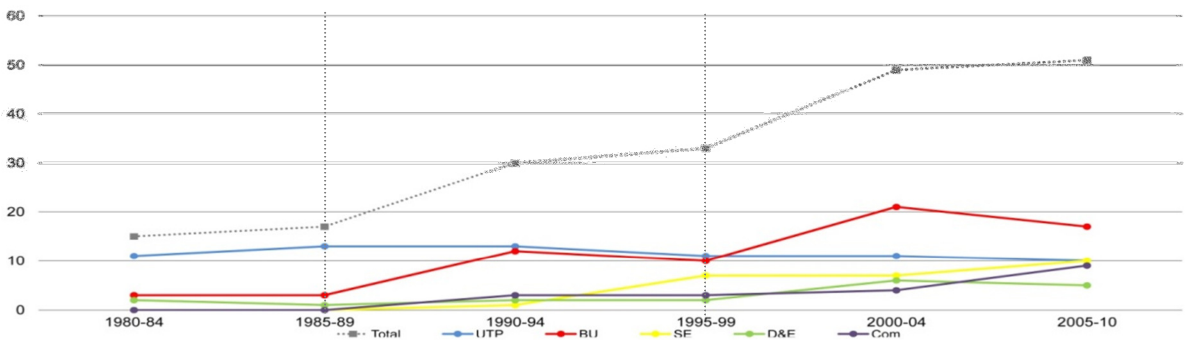

Figure 1. Number of programmes/plans that were launched by year according to the periods of National Housing Plans. They are classified by main area for the 20 studied cases. Source: personal compilation. Caption: Total: total number of conducted actions; UTP: Plans/Programmes regarding Urban and Territorial Planning area; BU: Plans/Programmes regarding building area; SE: Plans/Programmes regarding Socioeconomics area; D&E: Plans/Programmes regarding Urban Design and Environment area; Com: Plans/Programmes with a comprehensive character.

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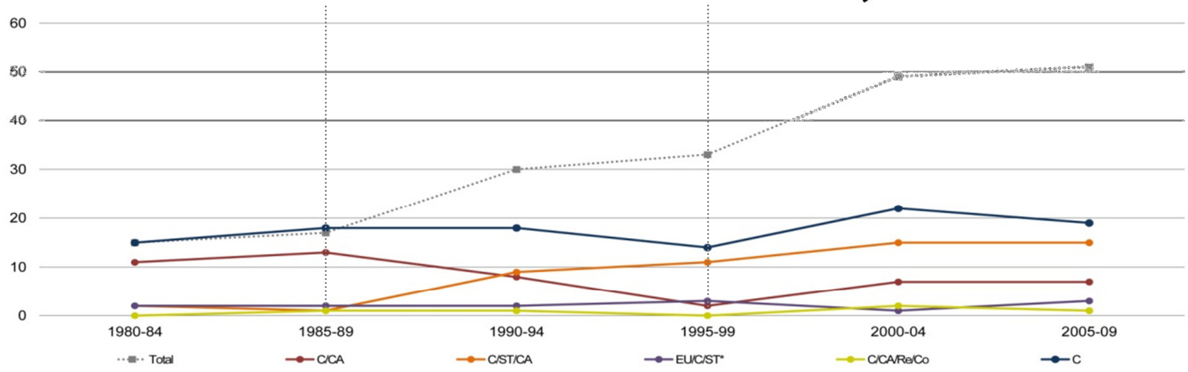

Figure 2. Number of programmes that were launched by year and the administration that is involved in each according to the periods of National Housing Plans. They are classified by its main area for the 20 studied cases. Source: personal compilation. Caption: C: Plans/Programmes with the participation of council; ST: Plans/Programmes with the participation of the State Government; AR: Plans/Programmes with the participation of the Autonomous Region Government.

First analysis stage (1980-1990). The beginnings of urban rehabilitation

First interventions, amongst the 20 analysed experiences, that can be considered as the beginnings of rehabilitation processes took place between the last 70' and the early 80' in historic districts. These districts were usually involved in processes of abandonment, they were inhabitated by low income population and gathered a relevant presence of social problems. In addition, these neighbourhoods had been deeply transformed by simultaneously and complementary actions of heritage conservation and destruction (2). These processes had expelled a part of the population and had contributed to make urgent to take action on buildings in bad conditions. Despite that, the analysed cities had suffered from an important and mostly unstructured growth product of speculation. Thus, they presented problematic lacks of facilities and infrastructures in historic districts as well as in recently developed outskirts. Within this period, three important factors met: the strong presence of community movements that claimed the improvement of their neighbourhoods and housing conditions, a new political class that had been involved in these mobilisations, that had raised from an economic crisis that stemmed the construction activity, and an urban European context and urban culture (3) had arisen standing for rehabilitation.

Within this context, the rehabilitation processes that began in this period came from the planning (UTP in Figure 1) or from Special Interior Reform Plans (PERI in Spanish) that were gathered in master plans that were developed by first democratic councils. However, it can be considered that some of these processes had been implemented before that as in the case of Trinidad Perchel. Due to the political and social context added to the municipal technicians' character, deeply influenced by the urban culture of the time (3), master plans dealt with the "re-balance" of the whole city regarding urban, social and economic fields. Furthermore, they integrated PERIs in the functionality of the city as a whole, with a strong understanding of the necessary integration of these neighbourhoods in the city.

Along with these PERIs, the national legislation of urban rehabilitation emerged. This law, mainly through the Royal Decree 2329/1983, would lay the foundations of national founding for rehabilitation and the partnership procedures among councils, newly created Autonomous Regions and the State. Also, the recently created ARIs, in line with the developing processes of that moment, used to found the rehabilitation of the physical support, mainly the buildings but the settlement of rehabilitation offices as well (4), even though the eligibility criteria was referred to more complex issues. These rehabilitation offices along with incipient public organizations such as trusts or land companies led by technical council services were the responsible for the rehabilitation works in this period.

This first stage of historic district rehabilitation, although being a few number of interventions, laid the foundations of the management and development of rehabilitation in each municipality or region. The principles established then, partly common but with variations in each case, were maintained in time or became the starting point for the new systems. Despite these variations, it can be said that within this period rehabilitation works were launched through planning and building works (without social, economical nor environmental programs) and were founded by the state through agreements with autonomous regions and municipalities. They were managed by council technicians, rehabilitation offices, trusts and public companies and, in some occasions they were supported by technical social services personnel.

Second analysis stage (1990-2000). The introduction of the comprehensiveness concept
During the 90', afterwards the economic recovery in the middle 80' and the brief economic crisis of 1992, the urban sprawl set again the development of the economy and the cities. Having solved part of the problems from previous period (lack of facilities, infrastructures, housing conditions...) and with practically non-existent social movements, the municipalities, in line with the European context, were concerned about positioning their cities and the existence of 'blackspots' that could damage their image (5). Among the rehabilitation policies of the time it must be highlighted the arise of the Pilot Urban Programmes in 1989 of the European Union which were consolidated in 1994 with the URBAN I programme and the National Housing Plan in 1992 that would consolidate the ARI programme.

All the rehabilitation processes that had already been implemented continued either through already launched initiatives or incorporating new actions of another type. Even though some physical shortfalls had been solved, many of the problems that motivated first interventions, like the socioeconomic ones, remained though time. Despite the fact that urban planning was still the main driver for rehabilitation actions, building interventions (BU in Figure 1) were increasingly more important concurrently with the consolidation of ARI programme. Although in former stage ARIs were almost non-existent, thanks to European programmes, what were called *comprehensive* operations emerged (Com in 1), with plans than brought in different work fields and different administrations or departments within them. Some municipality programmes were added to all this and were mainly focused on promoting economic activities (SE in Figure1). There were also some initiatives promoted by councils or neighbours aimed at gathering their claims or complaints, in a moment that was characterized by the limited presence of neighbourhood movement. In addition, some programs focused on

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environmental improvement (not only redevelopment) were launched, although they were an exception.

On the other hand, although councils and companies or local consortium, the collaboration among municipality, autonomous region and state was increasingly more relevant, the municipality was the responsible for the execution. The emergence of URBAN programmes, posed in a first stage the collaboration among different areas of the council, however, although programmes presented several actions, their execution was usually independent. The arise of new municipality companies and public or private-public consortium, that were in some cases only linked to rehabilitation processes, enabled to present new shapes of intervention although they were usually slowed down by coordination shortfalls between administrations.

Third analysis stage (2000-2010).
First decade of XXI century, that was marked by an unlimited urban development which was encouraged by an out of control real estate bubble since the adoption of the law 6/1998, was still focused on the creation of city instead of being concern about the problems of the existing one. The EU followed up previous programmes with URBAN II (2000-2006) and the speech of rehabilitation was not intensified till the advent of the economic crisis in 2008. In Spain, ARI programmes were still on force in national housing plans, some legislation and programmes of autonomous regions with a *comprehensive character*[2]. These programmes were added to the former rehabilitation ones and were mainly focused on housing but also on neighbourhoods that had been developed in previous stages.

The interventions in the studied neihgbourhoods kept on increasing from 64 up to 108. Although it can be pointed out a take-off in outskirts actions, historic districts still gathered the majority of interventions. Just as previous stages, despite the fact that some aspects had been improved, mainly the building ones, many of the problems were still remaining despite the fact that programmes or foundlings had already finished. Within this stage two tendencies can be noted. The first one gathered interventions which brought up complementary actions to those that were already launched. These were generally social, economic or what were called comprehensive plans or programmes that were still working in a non coordinated way with previous programmes. The second tendency consisted of plans with a comprehensive character due to the problems dealt or to their management. These plans were led by a management figure that posed new ways of organization based on the coordination between administrations and on the engagement of stakeholders through forums such as roundtables with neighbours. These actions were in general promoted by the municipality but used to bring up national or European aids.

Nevertheless, comprehensive programmes and those that brought in social, economic or environmental issues were still inferior in number to those with a purely physical subject matter. Within this stage, in contrast with former ones, interventions in the building area

[2] Appearance of the Llei 2/2004 de millora de barris and others and the programmes that were linked to them.

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involved the largest number of actions with a decrease in those regarding urban planning (UTP in Figure 1).

Conclusions: a proposal to improve processes

Through the analysis of these 20 experiences it can be established a general evolution in the development of rehabilitation processes that were influenced by previous programmes shortfalls. These can be related to the position and weight of the stakeholders, to the European and national tendencies and the derived programmes from the political and mainly economic context.

This evolution in the management of plans and programmes is directly linked to the issues that were developed by them (Table 1). Municipalities have been the main responsible figure for executing these programmes, regardless of the tendency of founding addition from superior administrations. However, the shape of management figures has evolved in time from the independence of planning technicians or rehabilitation offices to a coordinated cross-area organization that was formed by a group which was specifically created to guide the rehabilitation action. This management group which needs citizen and political support through the agreement of all groups tries to integrate politicians, technicians and citizens which, in many occasions, is a tough and slow task. This evolution in management has gone along with the incorporation of other programmes, with an environmental, social or economic character, as well as with the involved areas' integration that was encouraged by European programmes. However this tendency has not wiped out the predominance of physical interventions. Furthermore it has been accompanied with the abandonment of planning which in first general urban development plans and PERIs was based on a more complex vision. To add more, former intentions used to move away from the European vision of 'blackspots' understanding the problems in these neighbourhoods as a matter of balance and global distribution shortfall.

Table 1 Plans, programmes or interventions that were launched by area and institution in the eighties.

	1980s							**1990s**							**2000s**						
	C	CA	ST	EU	Co	O	T	C	CA	St	EU	Co	O	T	C	CA	ST	EU	Co	O	T
UTP	24	1	0	0	0	0	24	23	1	0	0	0	0	24	21	2	0	0	0	0	23
BU	0	0	4	0	0	2	6	1	2	18	0	0	0	21	8	1	31	0	2	0	42
D&E	0	0	0	0	0	2	2	2	1	0	0	1	3	8	8	2	0	0	2	0	12
SE	0	0	0	0	0	0	0	4	1	0	0	0	0	5	6	4	1	0	0	8	19
Com	0	0	0	0	0	0	0	1	0	0	5	0	0	6	1	5	2	4	0	0	12
Total	23	1	4	0	0	4	32	32	4	19	5	1	3	64	45	14	34	4	4	8	108

Caption: Total: total number of launched initiatives by area and institution; C: Council; CA: Council and Autonomous Region; ST: Council, Autonomous Region and State; EU: Council, Autonomous Region, State and EU; Co:companies O: Other entities: UTP: Urban and Territorial Planning; BU: Building; D&E: Urban Design and Environment; SE: Socioeconomic; Com: interventions called comprehensive. Source: personal compilation.

After the study of the 20 experiences it can be stated that despite the progress presented by the introduction of new techniques in some specific aspects, the level of success of each intervention relied on the establishment of local action plans with coordinated measures for the different areas of intervention (planning, building, environment and socioeconomic). These plans must be based on a deep knowledge of the social and environmental problems of each community meeting neighbours' demands. Furthermore the solution will pose an efficient response to the social and environmental global challenges that should be managed from the local scale as well as proposed, assumed, defended and agreed by citizens, technicians and politicians. In any case, the efficiency of the process (understood as the achievement of better quality of life for citizens), has been slowed down by a lack of evaluation methodologies.

In punctual cases innovative initiatives led to a raising of new organization ways and to the development of plans with a real comprehensive vision. However it can be doubted whether this vision can be achieved. These interventions, which were carried out in long-term problematic neighbourhoods, are long and imply the engagement of a multidisciplinary team which in some occasions belongs to different areas or administrations. Furthermore their results are not immediately visible in contrast to those that derive from only physical interventions which, to add more, have visible effects on economy. Present times are marked by cuts in public founding, rehabilitation is thought to be the new possible economy booster, urban planning as an equal distribution tool has practically disappeared and with it the idea of the right to the city. Are these kind of processes possible nowadays in neighbourhoods that do not pose an opportunity for real estate business? And, to add more, are these processes possible without the initial impulse and autonomy of citizens? (6) Given that we are immerse in a moment of global change and despite the arising doubts, it seems appropriate to generate new tools (for evaluating and guiding future plans) from old experiences that enable to keep on moving towards a better quality of life for citizens through urban regeneration.

References

1. Hernández-Aja, A, García-Madruga, C (2014). Magnitudes de 20 años de planes y programas de rehabilitación y regeneración urbana. *Por la rehabilitación, la regeneración y la renovación urbanas. Ciudad y Territorio. Estudios Territoriale*s, XLVI (179):184-191.

2. Álvarez-Mora, A (1995). *Conservación del patrimonio, restauración arquitectónica y recomposición elitista de los espacios urbanos históricos: Opening lecture of academic course 1995-96*. Available at: <http://uvadoc.uva.es/handle/10324/4309>

3. Castrillo, M (2013). La réhabilitation urbaine: une politique impossible? En Coudroy de Lille,L.,Vaz, C., Vorms, Ch. (Dir.) L'Urbanisme espagnol depuis les années 1970. La ville la démocratie et le marché.(pp113-126). Rennes: Presses Universitaires de Rennes.

4. Hernández-Aja, A, Matesanz-Parellada, A, Rodríguez-Suárez, I, García Madruga, C, Evolución de las políticas de rehabilitación en Áreas de Rehabilitación Integrada en España (1978-2012). En *Informes de la construcción*. (66):535 (not yet published).

5. Committee of the Regions European Union.(1990) *Green Paper on Urban Environment.*

6. Castrillo, M., Matesanz, A., Sánchez,D.,Sevilla, A. (2014) ¿Regeneración urbana? Deconstrucción y reconstrucción de un concepto incuestionado. *Papeles 126. FUHEM* (not yet published).

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Reconquest of public space through a managerial approach, case of Constantine and its new town Ali Mendjeli

Speakers:
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Abstract: *The public space is a key element of the urban environment and its image. The master of its management, its production, its environmental dimension and its urban organization constitute the major challenge of the work on the city within the framework of the requalification of urban spaces. Indeed, public space is essential like a keystone of success of any urban improvement operation carried out in the context of the sustainable development of the city in particular the town of Constantine with its medina, the colonial city then the new town Ali Mendjeli.*

Public space with its components: squares, channels of communication: boulevards, avenues, which structure the cities, constitute the background frame making the city perceptible. This urban component allows the orientation, the comprehension of the organization and the functioning of the city. The intervention on the layout, the environmental quality, the treatment… of public spaces, requires an adequate managerial approach.

Keywords: public space, environmental dimension, colonial city, new town, sustainable development, managerial approach.

Use and practical of public space

Fundamental component of urban fabric, public space is the support of the social life. Indeed, it constitutes the privileged place of the social practices, of the meetings… reflecting the perceptible image of the urban environment. Therefore, any action or operation of improvement unquestionably passes by that of public space as space of articulation and junction between the various urban functions.

Facing the effects of contemporaneity, public space knew significant changes as for its use, its environment, its dimensions, its treatment… With the increase of the vehicle use, public space accommodated a new use, which transformed its use, its dimensions, its treatment…, generating negative effects on the urban environment. if certain foreign countries has managed to master these changes, others such as Algeria, are facing problems where public spaces and their treatment escape to the decision makers, to the designers, to the citizens.... Indeed, public space in Algeria knew problems where its design, its environmental quality, its materialization, its treatment, its management… are relegated to the second plan considering the most pressing challenges to which the country is facing. These problems of public space result in the lack of taking in charge, management, design, environmental treatment…, such as: the absence of differentiation in the treatments of spaces, of signaling to ensure a segregation between pedestrian and mechanical flows, the non-respect of the hierarchy principles of public spaces facilitating their appropriation and contributing to structure the city and to ensure the safety and its image.

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Public spaces between old city and new city

Today, Constantine, city of bridges and the eastern capital of Algeria is suffering from pollution and degradation of public spaces (old and new) touching even the recent public spaces built in its new town Ali Mendjeli (image n° 1,2,3), whose design was supposed to be done in the context of sustainable development and environmental protection. Moreover, the situation of Constantine's public spaces is critical pushing the authorities to think and to undertake effective actions in order to find the appropriate solutions for these problems.

The public space in the traditional fabric is reduced in its forms and dimensions. It is limited to the alley "ruelles", Dead Ends and placettes. Its location meets the laws of the hierarchy of spaces (from public to private) imposed by the concept of intimacy.

Urban public space of the medina

Image N°1

Source : authors, 2014

With its culture, the colonization introduced a new type of public space. The latter is characterized by its location pondered according to the principles of french urbanism: constituting openings in the fabric with regular geometric shapes, of large dimensions.

Image N°2

Colonial urban public space

Source : authors, 2014

After independence, Algeria was concerned with the construction of buildings neglecting the public space.Thus, the public space consists of Residual spaces between the built spaces. In this case, the public space constitutes the weak link in the production of the built environment.

Urban public space of the new town

Source : authors, 2014

Image N°3

Thus, with the A.P.W "Assemblée Populaire de la Wilaya" (city council) and in collaboration with the Commission "aménagement du territoire et urbanisme " (urban planning and urbanism) of the city of Constantine, a survey[3] -in March, 2014- was carried out among the citizens of this city concerning public spaces, their state even after the operation of the urban

[3] This survey was done by two 2nd year PhD student in sustainable urban project management, its questionary was divided in two parts: the first part was about concertation and public spaces, the second one concerned accesibility and disabeled people. The surveyed persons live in Constantine city. In the end, more than three handred peaople were surveyed (62 % of them were men).

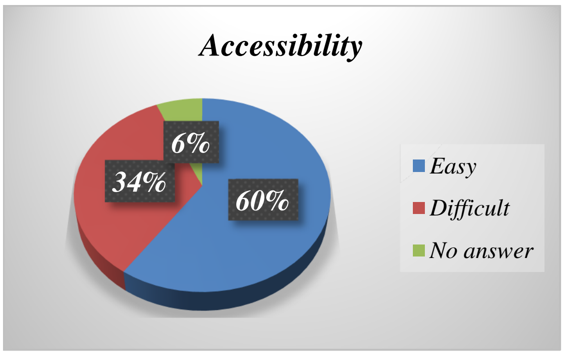
improvement experienced by this city. The report supported by the survey reveals what follows:

- The absence of positive impact of the urban improvement ;
- Nullity of actions and operations ;
- The absence of quality in the results of the urban improvement work especially on the environmental quality ;
- Dissatisfaction of the inhabitants as to the result of the urban improvement in particular environmental quality at the level of their districts;
- The non-appropriation of improved spaces;
- The non-accession of civil society because there is no dialogue or participation process of the citizens in the operation, this neglect gives them a feeling of discomfort, insecurity, faintness and great frustration ;
- Inexistence of the specifications worked out by the control of work ;
- Space cutting in areas and inconsistency of the interventions ;
- The inexistence of coordination between the various actors generating a discordance between their various actions ;
- A restricted operational culture towards the great operations that include the urban improvement work on public space, also, with the logic of the great operations.

The summary of the results of the survey

Concerning public spaces, the survey shows the following points:

- Not equity: public spaces do not exist and even if they exist, several districts have no public space. The inhabitants complain about the long way that they must make to go there: the public spaces are far from the places of residence. For this reason, the 34% of surveyed people answered that the access is difficult in these spaces (graph n° 1). In addition, the average time put to reach that point is 15 minutes, but it should be noted that a significant number of 25, 5% make a ride of more than half an hour to arrive at these spaces (graph n° 2).



It seems that the majority of public spaces (when they exist) are inaccessible.

Source: BOUHADJAR KHALIL, MOUHOUBI NEDJIMA, April 2014.

Graph N°1

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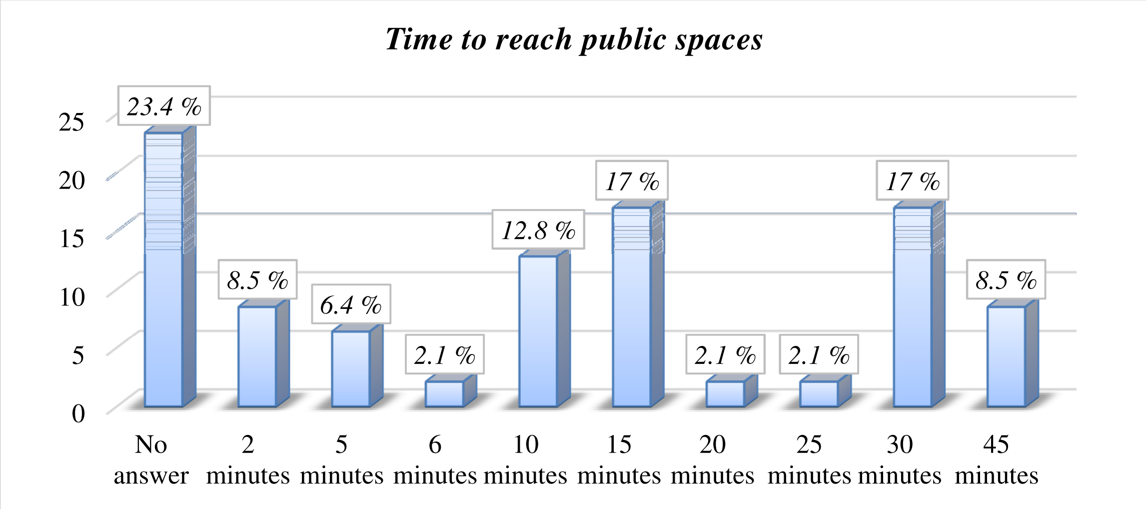
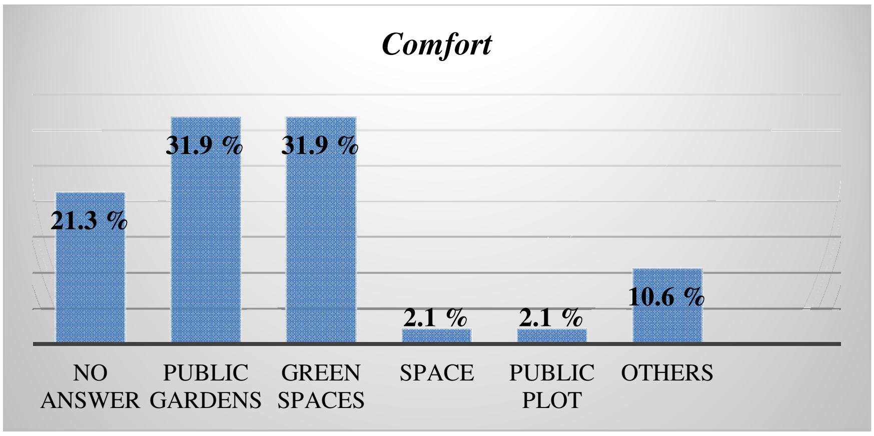


Graph N°2 *Source: BOUHADJAR KHALIL, MOUHOUBI NEDJIMA, April 2014.*

Public spaces are far away from the places of residence. The distance represent the principal cause.34% of the surveyed mentioned that the access is difficult to these spaces.

- Discomfort and insecurity: transport, circulation and the immediate environment of these spaces constitute the major difficulty that the citizens are facing (graph n° 3). Safety is one of the principal causes, which make the access difficult to public spaces especially for women.



Green spaces and gardens represent most attended public spaces by surveyed persons. They feel comfortable in this type of public space, but, it should be noted that 21,3% did not answer affirming that they feel comfortable only in their houses.

Graph N°3 *Source: BOUHADJAR KHALIL, MOUHOUBI NEDJIMA, April 2014.*

- Management and maintenance: the best way of promoting and improving the accessibility to public spaces is to make them safe, to change citizens' mentalities by ensuring animation and attractivity through ongoing maintenance actions of this type of spaces. It is also question to reduce the circulation and organize transport in order to decrease the distance between these spaces and residences without forgetting parking areas beside these spaces (graph n° 4).

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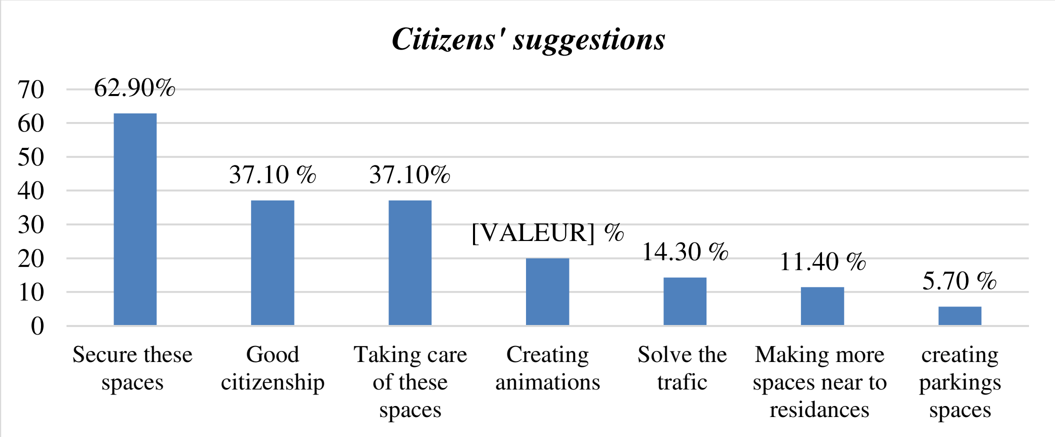

Graph N°4 Source: BOUHADJAR KHALIL, MOUHOUBI NEDJIMA, April 2014.

Security constitutes a precondition to the use of these spaces by the surveyed persons Changing mentalities, take in charge the urban space assuring animation, they become more attractive such are the actions that the appropriation of public spaces requires so that the citizens go and visit them.

Concertation and public space

The fieldwork revealed the fact that the inhabitants are ready to take part in the operations of urban improvement of their public space: they propose several participative initiatives in the form of real actions led by associations of district in order to improve their space of life. They express a frustration as they are totally out of this important project concerning their space which is it gradually taken from them.

Environmental dimension

The law 03-10 of July 19 th, 2003 relating to the environmental protection within the sustainable development sets up the PPNAEDD [4] introduced legislative dispositions about protection of the living environment with a classification of spaces of leisure, parks and any space of collective interest. In this law, we find that the protection of the environment in a context of sustainable development aims to:

- To fix the basic principles and rules of environmental management ;
- To promote a sustainable national development by improving the living conditions and working to ensure and guarantee a healthy living environment ;
- To prevent any pollution form or negative effects on the environment by guaranteeing the safeguard of its components ;
- To restore the damaged areas ;
- To promote for a rational ecological use of available natural resources and the use of more suitable technologies ;
- To strengthen the information with mediatisation, the sensitizing and the participation of the public and the different actors to the protection measures of the environment.

[4] Plan National d'Action Environnementale et de Développement Durable (National plan of environmental action and sustainable development).

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Proposals and suggestions

The taking into account of environmental dimension is guarenteed by the overall improvement of the environmental quality of spaces of life.... Only the urban planning of green spaces can improve and guarantee the quality of urban ecosystem by attenuating the problems of harmful effects and stress. At the level of the residential areas, the green screens in the form of dense and tight vegetation, can constitute landscapes embellishing the urban space while creating a microclimate and ensuring the soundproofing. Gazonnement and plantation of trees can contribute to the absorption of dust, and the attenuation of the microbes.

1. Energy and climate: supporting an adequate urban planning, energy effectiveness by taking in consideration topography, orientation and green species (contextualization);
2. Water: a good water management processes makes it possible to decrease the extension of the networks and the building oversizing. Such a management process contributes also to the quality of public spaces:
   - Allow the natural infiltration of rain water and to slow down their streaming ;
   - Implement techniques for the treatment of waste water and the re-use of rainwater.
3. Displacement: to develop public spaces which support means of soft transport ;
4. Biodiversity and landscapes: conceive green spaces giving them a function and an ecological maintenance procedures ;
5. Waste: optimize installations to facilitate and improve the collection of waste ;
6. Polluted soils and sites: reinvest spaces in wasteland (evident depollution) ;
7. Noises and harmful effects: take into account sound dimension in the installations and materials used for the horizontal and vertical coatings ;
8. Risks: preserve the sectors with strong ecological value (slopes, wooded surfaces...) and to take into account the exposed areas to the various risks (flood, update…);
9. Project management and management: provide control of work (supervision and services decentralized of the state) with **managers** specialized in the management of public spaces who master the following requirements:
   - Takes part and attends the development and the refinement of the project from the mental idea to the operational exploitation of the site ;
   - Collects and processing the data whether economic, social, political, architectural, urban, environmental, scientific and cultural of the concerned site ;
   - Knows, understands and implements the bases of the PMBOK, Conventions and recommendations of the international organizations (PMI…) as well as the charters, laws and other legal texts in relation with the project site and the implication of all actors ;
   - Knows the operators of public spaces as well public as private too;
   - Gives an opinion based on deontology principals relating to the management of public spaces while being based on the ten (10) fields of project management and on a sustainable urban development vision ;
   - Is able to collaborate, mobilize and put in synergy all the required professionals by the operational chain which will be indicated to them (landscape town planners, architects , managers, engineers, administrators, planners) as well as the groups of

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population (citizens) in order to propose to the users and to the public authorities several assumptions of project related to the principles of public spaces management and to the possibilities, the resources and the local needs (project stakeholders and communications management) ;

- o Understands the history of the site and the techniques of construction employed, in order to define the identity of it, to take into account measures of conservation relating to the contents, the surrounding and the landscape in which it is integrated (project integration management) ;
- o Conduct the project as a complex system which associates human, financial and technical data (project human resource, cost and procurement management) ;
- o Understands the process of conduct, of control, of development, of construction and project management "stage of diagnosis, stage of assembly, stage of preliminary studies, stage of file constitution , stage of installation and the stage of management " (project scope management) ;
- o Understands and gives an opinion about the technical of maintenance and future management techniques in order to ensure the environmental sustainable dimension by ensuring the global management of the concerned site.

Conclusion

Initially the causes of the destructuration of the Algerian public space are related to the country's history especially colonization. The latter introduced new public spaces generating social, cultural confrontation between the two models: traditional and colonial. Today, the lack in managing public spaces is essentially linked to political choices: first, all the government's efforts are focused on how to solve the problem of the housing crisis, secondly, the threat of public space for authorities if it should play its full role in the establishment of a democratic state. So the urban improvement operations done by the authorities do not meet the expectations of citizens and their results are not satisfactory. The will to control the movement of population and the absence of communication project management between the citizens and the authorities (project main stakholders) constitutes the main obstacle to produce suitable urban space. Moreover, these barriers can be overcome if the management of such projects is based on the application of the 10 fields of project management without forgetting the international and the local experiences' results of similar projects that we must take in consideration keeping in mind that the context is never the same (history, traditions, culture,….).

Refrences

- Christian Brodhag. (2004). *Dictionnaire de développement durable*. Editions AFNOR ;
- Jean-Yves Moine. (2012). *Management de projet 3D : le cube projet*. Editions Cépaduès ;
- HAROLD KERZNER. (2013). *Project management: A systems approach to planning, scheduling and controlling Ed. 11*. JOHN WILEY & Sons Editions ;
- Aurélien Ragaigne. (2013). *L'essentiel du management des organisations*. Editions Gualino;
-Souad SASSI BOUDEMAGH, Yasmina AMIRECHE, Mouloud ANNAB, Khalil BOUHADJAR, Nedjima MOUHOUBI. (2014). *l'espace public et l'amélioration urbaine : évaluation et orientation*. Commission aménagement du territoire et urbanisme, session ordinaire de l'A.P.W. Constantine, Algérie.

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Seeking systems for sustainable higher-density housing in Australian cities

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Abstract Summary: *Decades of expanding, low-density urban sprawl has shaped the form of Australian cities as well as housing construction and finance systems. Current metropolitan plans promote urban consolidation and increased housing densities in suburbs. Such densification challenges the perceived ideal of the free standing suburban family home and existing methods of housing provision and construction. Higher-density housing is viewed as a compromise to the Australian housing dream and remains primarily an investment market rather than a desirable owner-occupied housing option. This scenario has generated a miss-match between household desires and the higher-density housing products available. This paper examines the existing higher-density housing provision systems to determine social, systemic and institutional barriers to change. Removal or reduction of the identified barriers may assist in reducing the identified miss-match, supporting the implementation of urban consolidation promoted by metropolitan plans as a significant tool for improving urban sustainability and resilience.*

Keywords, medium-density, housing provision, consolidation, owner-occupied, Australia

The context of the Australian consolidation challenge

Recent decades have seen the introduction of an assortment of metropolitan planning policies across Australian cities promoting development within existing urban boundaries through urban consolidation(1). Among other attributes, these policies have a collective ambition to generate more ‘sustainable’, ‘equitable’ and ‘liveable’ future urban environments. Commentators have criticised these plans as containing little more substance than marketing documents, “confusing physical phenomena with social relations”(2). Forster(3) observes a continuing disparity between planning ambitions and urban reality resulting in two parallel urban universes: that of the planning authorities and that of the *“realities of the increasingly complex, dispersed, residentially differentiated suburban metropolitan areas most Australians live in”*(4). The majority of growth in Australian cities continues to occur outside of policy designated growth areas consists of large single family housing with little variation(5). Scholars suggest this mismatch between policy intent and urban reality results from the persistence of existing urban infrastructure and form, doubts regarding the ‘worth’ of proposed change and the lack of comprehensive policies or programs for effective implementation.(6).

This paper reviews existing literature regarding housing preferences and whether these are addressed by current housing provision systems. It aims to outline the significant social, systemic and institutional barriers which perpetuate existent mismatches and discourage the implementation of urban consolidation plans. Examples of alternative medium-density housing solutions are then described to illustrate emerging trends and opportunities.

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Social barriers: medium-density housing perceptions

Historically medium density housing in Australia has been associated with inner urban workers accommodation and low socio-economic rental housing (both private and publically owned). In parallel with the post WWII increases in personal mobility and rapid urban expansion, the low-density single family suburban house became the dominant housing form, acquiring the descriptor of 'The Great Australian Dream.' Both medium and high density housing became viewed as a temporary arrangement for young households as they worked toward achieving the common dream. To this day media and researchers continue to reinforce the perception that medium and high density housing is an inappropriate environment to raise children(7). The 2011 Australian census shows three quarters of Australian privately-owned houses are free-standing suburban dwellings(8). Of these, 77% are owner-occupied with the remainder privately rented. In contrast, privately-owned multi-unit housing has an owner-occupier rate of just one third(9). Only 13% of people in rental housing are likely to reside at the same address as they did five years prior compared to 71% of owner-occupiers(10). These tenure and mobility differences between low density and medium/high-density housing have steered the evolution of two distinct provision systems over time. The resultant built form perpetuates the entrenched perception of medium-density as an inferior housing alternative and as undesirable in one's neighbourhood due to high rental rates. Until this perception is transformed the planning policies promoting consolidation have limited chance of success and public objection to consolidation of existing urban areas is likely to continue.

Given the apparent negative perception of medium-density housing it is valid to enquire as to whether there is a demand for the housing types promoted by urban consolidation plans. Two recent studies have investigated this matter. Focusing on Sydney and Melbourne a 2011 study(11) sought to understand the 'trade-offs' households were willing to make given decreasing housing affordability. In comparing 'trade-off' preferences with actual and new housing stock a significant unmet desire for medium-density(up to 3 storey) housing was identified in both cities, with only 41% of Sydney residents and 48% of Melbourne residents preferring to live in detached housing given current market prices. Another 2011 study in Adelaide(12) demonstrated similar outcomes, finding that one third of respondents were not averse to living in medium-density housing with children. However, it also identified that those attracted to living in higher-density housing did not view the housing product available as meeting their lifestyle needs. These two studies reveal a notable shift in public acceptance of medium density housing partially driven by financial constraint and household purchasing power. They also show this shift is not accommodated by existing housing provision systems.

Systemic Barriers: provision and purchasing systems

Low-density speculative housing construction is uncommon in Australia; most construction is undertaken on a contractual basis with individual homes built to the chosen specifications of a household on their selected allotment. Nonetheless, each new region of suburban growth tends to be constituted of remarkably similar houses. Burke and Hulse(13) describe low-density housing as providing as 'wrap-around' housing tenure. That is, the ability for households to wrap their chosen lifestyle and leisure activity around the built form of the house, adapting the generic form of suburban homes to outwardly express their individuality. As Australia moves toward higher-density housing advocated by city plans, the relatively simple contractual construction tradition familiar to new home purchasers shifts to a more complex 'modern' or 'industrial' one(14). Unlike low-density housing, medium-density townhouses and multi-dwelling units are typically offered for purchase 'off the plan.' Predesigned for an assumed occupant, constructed with generic fittings and finishes, and often identical to other dwellings in the development, they offer little room for occupant intervention. In particular, they significantly constrain the potential for the 'wrap-around' housing tenure. Designed by developers, architects and builders with a view to maximum financial return, this shift in procurement precludes a significant portion of the population from engaging in medium density housing either through inappropriate design, inflated cost, or perceived impersonalisation of space.

A number of recent reports have highlighted the significant influence of speculative developers and property investors in the provision of medium-density housing(15). The increased risk (both real and perceived) taken by developers to deliver speculative medium-density developments in comparison to contract based greenfield building is compensated in most cities by higher profit margins(16). In addition, different staging of payments by purchasers places greater financial holding costs on the developer which are subsequently passed on to the purchaser. Both of these factors combine (with other increased construction impositions not discussed here) to increase the cost to purchasers(17). To minimise risk developers wisely target their product to meet demand, which is predominately from property investors, not owner occupiers. Investor demand in the 'off-the-plan' apartment market has remained at around 70 per cent over time(18). The Australian property investor is typically a middle to high income earner (or household) who either owns outright or is purchasing their own home. They seek to use this second or subsequent property as an investment, building value in capital and accessing government tax incentives to increase personal wealth. Investors seek a balance between financial outlay and return, both in the long term in relation to capital growth, and in the short term through property rental. Hence a typical medium-density design and dwelling size has become entrenched based on the ideal financial outcomes for investors, rather than on the needs and lifestyles of the occupants. Regardless of the fact that one third of medium-density housing is owner-occupied it is typically constructed to meet the needs of this dominant purchaser group, entrenching the perception of medium density housing as a rental tenure solution and requiring those who select to owner-occupy to compromise their person lifestyle to fit within that determined by the investment market.

Both academics and industry practitioners express concerns about investment dominance in the Melbourne higher-density housing market regarding the quality of housing being produced, particularly in relation to the social legacy which may result(19). Keck predicts the creation, in the near future, of two distinct higher-density housing typologies: one meeting the needs of investors and another for owner-occupiers. In making this prediction he also notes that further construction of dwellings for rental purposes will increase the miss-match between available dwellings and household preferences. The small proportion of developments currently aimed at the owner-occupier tends to be targeted to high income households to achieve maximum return. Hence, medium to low income households are effectively excluded from engaging in the owner-occupied urban re-generation market, limiting housing choice and losing the opportunity to deliver lower cost housing through consolidation. The existing developer-led method of medium-density housing provision has, like its detached predecessor, become 'locked-in': it has gained an 'early lead' to 'corner the market' and as a result other options become 'locked out'(20).

Institutional Barriers: the risk of innovation
The major instruments through which government is able to influence housing size and type are the Local Government Development Plans, made by local councils to comply with State Government Planning Legislation. Focusing on systems in place in the state of Victoria March(21) highlights the role of existing planning policies as restricting undesirable development on a case by case basis by ensuring all development complies with the applicable Development Plan and poses minimal risk to the community. This risk adverse structure limits urban outcomes to a set of (re)combinations of existing, know urban solutions and fails to promote or encourage innovative opportunities which may present themselves.

The rate of change in existing urban environments is further limited by the relatively high rates of private home and land ownership. The vast majority of residents view their housing and its surrounds not only as a home, but also as a significant financial investment. Having selected a location and dwelling to invest in existing residential owners are reluctant to see their locale change over time. In a study of inner suburban areas of Melbourne with high rates of public protest to change Alves concludes that the main issues limiting the provision medium-density housing in existing urban areas are *"the highly dispersed nature of residential property ownership, and the conflict this engenders around the competing development and use rights that accompany an interest in property."*(22)

The complexity of financial, legislative and construction contract systems associated with medium and high density housing provision requires a degree of expertise to ensure housing development is effectively implemented. The proven success of the developer and investor driven development model described above provides a financially successful model for stakeholders, promoting the continuation of the status quo due to the perception that alternatives may pose a greater risk. A number of scholars have made efforts to describe the complex interactions between these financial, legislative and construction systems and how they inform built outcomes. Burke(23) describes the Australian housing system as comprised of four subsystems: Production, Exchange, Consumption and Management, all of which are influenced by economic, legal, political, environmental, administrative, and social and demographic factors. As seen from the above discussions a disjunction currently exists between those stakeholders engaged in the production and consumption subsystems, with occupants not provided an opportunity to engage in the production of medium-density dwellings. Franklin(24) provides a conceptual framework of built form production relating cultural processes to built form through structural processes(social, spatial and conceptual) and the agency of stakeholders. Franklin's model(Figure 1) demonstrates that the removal of agency of occupants(individuals and groups) from the production subsystem removes the opportunity for built form to represent the occupants' concepts of meaning, identity, perception and use; to reflect the needs and preferences of the individuals lifestyle. Conceptual processes become distanced from built form as the inputs of myth, ritual, metaphor and symbol become interpreted through the (financially focussed) lens of spatial processes by designers and developers. It therefore illustrates the dominant influence of institutions and construction/ development systems which occurs when the occupant is removed from the process of housing production, feeding the mismatch between household preferences and available housing.

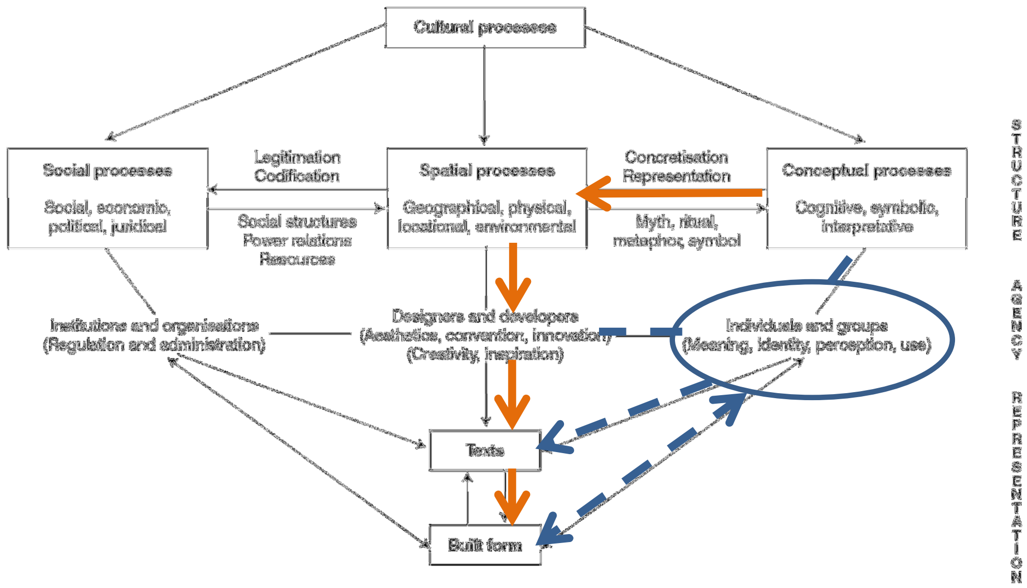

FIGURE 1: A model to illustrate the contextual framework of built form from Franklin 2006, p.27.Adapted to demonstrate the effects of removing occupant agency from the process of housing production. Occupant influence (blue dashed arrows) is severed, and conceptual processes become distanced from built form(orange).

Alternative Cases

A small number of innovative examples of medium-density housing provision have been pursued in recent time by individuals and groups seeking to navigate an alternative to the existing system and enable owner-occupier input in design. Each of these examples varies the extent and location of risk in the development process and hence the magnitude of developers profit. Four examples from Melbourne, both built and in progress, are described in Table 1 with an emphasis on how they differ from the existing provision model, the degree of owner input in design enabled, the relocation of risk, and the motivations of the project instigators. These four examples illustrate that viable options do exist for user input in design and development in medium-density housing in Australia. Each takes a different approach and requires individual engagement ranging from relatively minor time commitment in examples 1 and 2 to a high level of personal investment in examples 3 and 4. The level of personal time commitment directly reflects the amount of design input enabled and cost savings realized. It is also notable that where high levels of design input are achieved the group has benefitted

Table 1: A comparison of alternative provision projects

Example 1. 'On-Line dating service' Commenced 2013. Groups currently being formed, no completed projects.	
Differences	Combines crowd sourcing and smart marketing in on-line platform to form groups of like-minded households. Groups formed are paired with an architect and developer to realise the project.
Extent of design input by owners	Moderate. Interested parties indicate personal preferences via on-line platform. The group formed meets with designers 3 times during design development. Some personal choices in finishes. The intention is to avoid excessive input or 'design by committee' due to possible time delays resulting
Risk & Cost	Risk to financial institutions and developers reduced as purchasers are pre-committed, effectively representing adequate pre-sales for financial approval for development. This should represent a saving through reduced marketing and financing costs. Additional costs incurred to utilise the service.
Instigators Motivation	Architects seeking a means of enabling innovation in the medium-high density housing market by side stepping the restrictive developer driven brief.
Example 2. 'Mediation and Design' Commenced 2013. Early project stages, no completed projects.	
Differences	A client group is formed through registration of interest prior to site selection. Client group formulates project brief. Design team acts as 'mediator' between the client group and the financing developers.
Extent of design input	Moderate. Client group formulates project brief. Designers provide a range of options or possibilities within the budget. Group selects common options. Individual selection of interior finishes.
Risk & Cost	The usual developer model of finance is not significantly altered. The risk which would normally be associated with an atypical design is avoided through pre-sales. Use of independent project manager proposed to limit construction risks. Marketing costs removed.
Instigators Motivation	Young architects and property specialists seeking more collaborative living environments. Focus on 'good design', small living spaces and the inclusion of shared facilities.
Example 3. 'Collective Development' Initial Project completed 2013.	
Differences	A group of individuals form a company which purchases land and acts as a private developer. At completion of project the company is dissolved and individual dwellings sold to members.
Design input	Highest possible level of design input into brief, site design, building and individual interiors.
Risk & Cost	Company, composed of the individual members, takes 100% risk. Owners personally realise the profit usually paid to developer. No marketing costs. No stamp duty tax payable. Resultant property values in the initial project greatly exceeded costs, realising a significant profit(or saving) for members.
Instigators Motivation	The intent was to build properties for rent as part of personal property portfolios. Unexpectedly, all units are occupied by owners.
Example 4. 'Cohousing collective in partnership with community housing provider(CHP).' In design.	
Differences	Group formed well in advance of site selection. CHP acts as developer, accessing finance through large portfolio. Rental community housing combined on site with owner-occupied residences. Co-housing members contribute an equal share of land purchase expenses at time of purchase. At completion individual units sold to group members except those retained by CHP.
Design input	High, including group design of shared external facilities and gardening spaces.
Risk & Cost	CHP partnership provides access to cheaper finance. Developer profits and marketing costs avoided.
Instigators Motivation	A group of mid aged professionals seeking an alternative to the developer designed model of city living, including collaborative use of space and gardens.

from professional members, such as architects, planners and property consultants, working in the interests of the project. If such processes for owner input in design are to be main-streamed it is not realistic for all owner groups to have access to such expertise and implementation programs would be needed to support participation and minimize risk. The main attribute these examples all have in common is that they exist within the established financial, institutional and contractual systems of development. They seek alternative financial and contractual solutions within boundaries which have evolved to meet the needs of the existing developer led system of provision. If they had the freedom to move beyond these constrictions more innovative solutions may be possible.

Conclusion:

Discussing housing in the UK Franklin argues for smaller scale community/ collective action. She highlights the potential for active (individual and collective) investment (physical,

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emotional and financial) in housing design and provision to increase household acceptance of medium-density housing and commitment to local community and neighbourhood. Such owner-occupier investment in medium-density housing provision may provide a key to more effective implementation of consolidation policies, avoiding the confusion of “physical phenomena with social relations”. The literature discussed has demonstrated that a new direction in medium-density housing provision is required in Australia if the needs and desires of those households seeking an alternative to low-density suburbia are to be adequately met and perceptions of medium-density housing as undesirable are to change over time. The examples described show new provision directions are possible within the Australian context and can provide a level of owner-occupier design input suitable to the individual. However, it remains clear that to effectively implement the urban consolidation proposed by existing planning policies a more cohesive approach to alternative provision is required to simplify processes and avoid design input becoming a privilege available only to those with financial capital or professional expertise. Further study of these examples as they mature is needed to identify how they can assist in facilitating an industry and community shift from a predictable risk-adverse (market led) future to a culture of active participation in the generation of prescriptive and desirable urban environments to meet future needs.

References

(1) Such documents include the Metropolitan Strategy for Sydney to 2031(in draft), SEQ Regional Plan 2009–2031(2009), Directions 2031 for Western Australia(2010), 30-Year Plan for Greater Adelaide(2010) etc.

(2) Dodson, J.(2012). Transforming Australia's 'housing solution': how we can better plan suburbia to meet our future challenges. *Australia's unintended cities*. In R. Tomlinson(Ed). Collingwood, CSIRO: 19-32, p.28.

(3) Forster, C.(2006). The Challenge of Change: Australian Cities and Urban Planning in the New Millennium. *Geographical Research, 44*(2), 173-182. doi: 10.1111/j.1745-5871.2006.00374.x

(4) Ibid. p.180

(5) Goodman, R., Buxton, M., Chetri, P., Taylor, E., & Wood, G.(2010). Planning and the characteristics of housing supply in Melbourne *AHURI Final Report no. 157*. Melbourne Australia: AHURI.

(6) Gleeson, Dodson & Spiller 2012; Dodson 2010; Buxton, Goodman & March 2012.

(7) Birrell, B., & Healy, E.(2013). *Melbourne's High Rise Apartment Boom*. Melbourne: Centre for Population and Urban Research, Monash University.

(8) Australian Bureau of Statistics.(2013). *Quickstat household composition*. Retrieved 24/06/2013

(9) Troy, P. N.(2012). *Accommodating Australians: Commonwealth government involvement in housing*: Federation Press.

(10) Australian Bureau of Statistics.(2010). *Australian Social Trends December 2010: Moving house.*

(11) Kelly, J.-F., Weidmann, B., & Walsh, M.(2011). *The Housing We'd Choose*. Melbourne: Grattan Institute.

(12) Fischer, H., & Ayturk, D. G.(2011). *Residential Density(Liveable Communities) Market Perceptions. Adelaide*: Adelaide Thinkers in Residence program.

(13) Burke, T., & Hulse, K.(2010). The Institutional Structure of Housing and the Sub-prime Crisis: An Australian Case Study. *Housing Studies, 25*(6), 821-838.

(14) Turner, J. F. C.(1976). *Housing by people: towards autonomy in building environments.* London : Marion Boyars.

(15) Rowley, S., & Phibbs, P.(2012). Delivering diverse and affordable housing on infill development sites *Final Report no. 193*. Melbourne: AHURI; Nathan, S.(2012). Melbourne Apartment Market V2.0. *The Asian Executive,* 6-11.

(16) Ibid; Kelly(2011) op. cit.; Newton, P. et.al. .(2011). Towards a new development model for housing regeneration in greyfield residential precincts *AHURI Final Report; no.171*. Melbourne, Australia: AHURI

(17) Urbis.(2011). *National Dwelling Cost Study*.

(18) Keck, S.(2013). The Value of Good Design. *Charter Insight, July 2013*.

(19) Ibid; Birrell and Healy(2013) op. cit.

(20) Arthur, B.(1989). Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal, 99*, 116-131. p. 116.

(21) March, A.(2012). *The Democratic Plan: Analysis and Diagnosis*. Surrey: Ashgate.

(22) Alves, T.(2006). *Managing Medium Density Housing Development: A Municipal Case Study.*(Doctor of Philosophy), Swinburne University of Technology.

(23) Burke, T.(2012). The Australian residential housing market: institutions and actors. In R. Tomlinson(Ed.), *Australia's unintended cities*(pp. 35-49). Collingwood: CSIRO.

(24) Franklin, B.(2006). *Housing transformations.* New York: Routledge.

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Market Drivers on the Transformation of Green Buildings in Hong Kong – The Green Buildings Roadmap

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Abstract: Hong Kong Green Building Council's HK3030 is a demand-side management initiative to building energy consumption, with the target of 30% reduction in building electricity consumption by 2030. This approach involves classifying building stocks according to their potential for adopting energy efficient strategies, as well as tailoring strategies that specifically target the sweet spots in each of them. Using Hong Kong as an example, readers are encouraged to deliberate, debate and resolve the urgent challenge of green buildings transformation faced by cities worldwide.

The paper reports the on-going process in identifying necessary actions, policies and potential costs towards achieving the HK3030. The first part outlines the quantitative analyses in assessing Hong Kong's building stock; while the second part presents the roadmap for transformation of green buildings in Hong Kong, which is derived by combining the quantitative analysis with the results of stake-holders engagements, and also a review on international initiatives.

Keywords: Hong Kong, Green Buildings Roadmap, Emissions Targets, HK3030

Introduction

Buildings in Hong Kong consume over 90% of the electricity and account for more than 60% of the GHG emitted citywide, and hence has great potential in contributing to the city's GHG reduction target [1]. Hong Kong Green Building Council (HKGBC) was established in 2009 to lead the market transformation to a sustainable built environment. Over the last 5 years, the council has played a major role in guiding the transformation by developing industry standards and best practices, as well as delivering educational programs and initiating research in green buildings.

Recently, the council launched the HK3030 Campaign, an initiative to focus and coordinate the demand-side management approach to electricity consumption [2]. The objective of the campaign is to enable a reduction of 30% to the absolute building electricity consumption by 2030, as compared to the level of 2005. Taking into account the projected increase in building stocks and higher energy consumption per capita, HK3030 Campaign is equivalent to a reduction of 52% in absolute electricity consumption compared to a Business-As-Usual (BAU) scenario, as illustrated in Figure 1.

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Quantitative Analyses on Building Energy Consumption and Reduction Potential
To understand the current building energy consumption in detail, buildings are categorized into two main segments: residential and commercial. The two types have significantly different energy consumption intensities and patterns. They are further divided into several subcategories to highlight particular characteristics.

The potential for energy reduction in each building category and sub-category are estimated through energy modelling. To ensure the models are of appropriate levels of accuracy, they are calibrated against measured data in actual operation. The overall reduction potential is thus built from bottom up by analysing the energy saving measures for each type of building, and assessing their cumulative effect on the entire building stock.

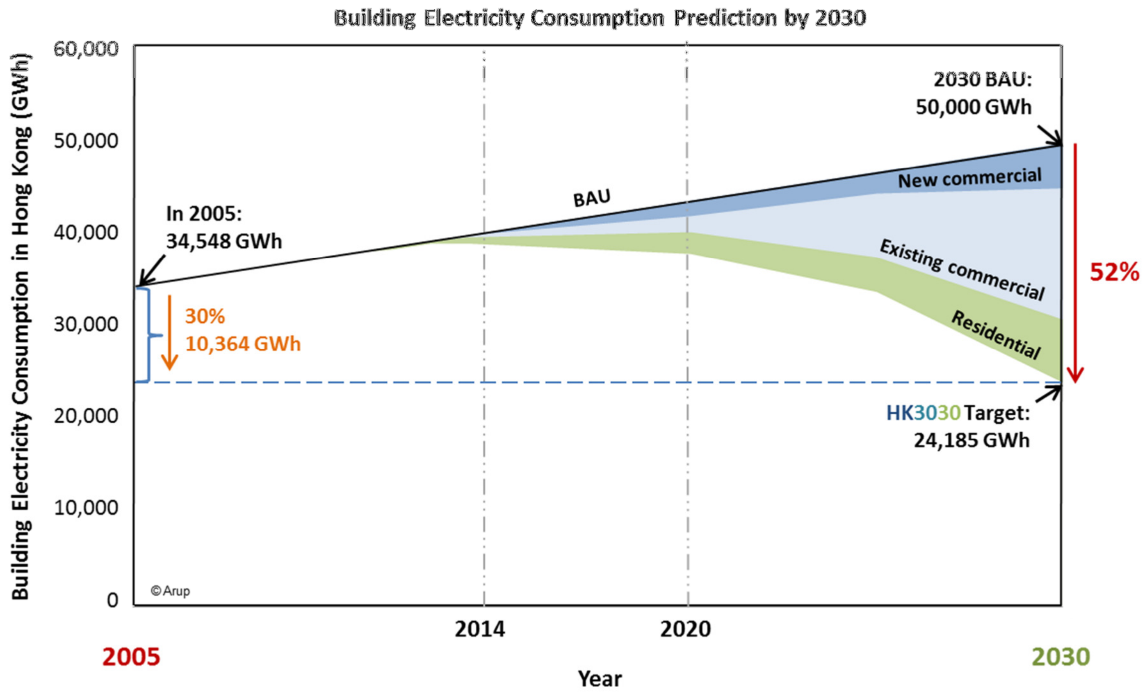

Figure 1 Electricity consumption of building stock in Hong Kong

Energy consumption is not only dependent on the type/sub-category of buildings, but also their conditions. In order to identify a realistic pathway towards HK3030, an extensive study on buildings with different conditions is essential. For this study, buildings are divided into the following categories:

- Existing commercial buildings – developed before the year of 2015
- New commercial buildings – constructed in 2015 onwards
- Residential buildings

The projected energy consumption level and possible target for each building category are shown in Figure 2. New commercial buildings have the highest potential for energy intensity reduction. They are governed by the latest building codes and also have more flexibility in

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design for adopting innovative systems. However, their impact on overall reduction is relatively small since they only account for 15% of building electricity demand in 2030.

On the other hand, 58% of the building electricity demand in 2030 comes from existing commercial buildings that have already been built; they account for most of the building energy consumptions in Hong Kong. Therefore, the energy reduction initiatives for existing buildings are crucial for the achievement of the HK3030 target. Lastly, residential buildings make-up the remainder of the demand.

The study considered many scenarios in the evolution of building stock performance that have the potential to deliver the energy reduction required for HK3030 campaign. In this document, we focus on one particular scenario to highlight some features that are essential when developing an action plan for future energy reduction.

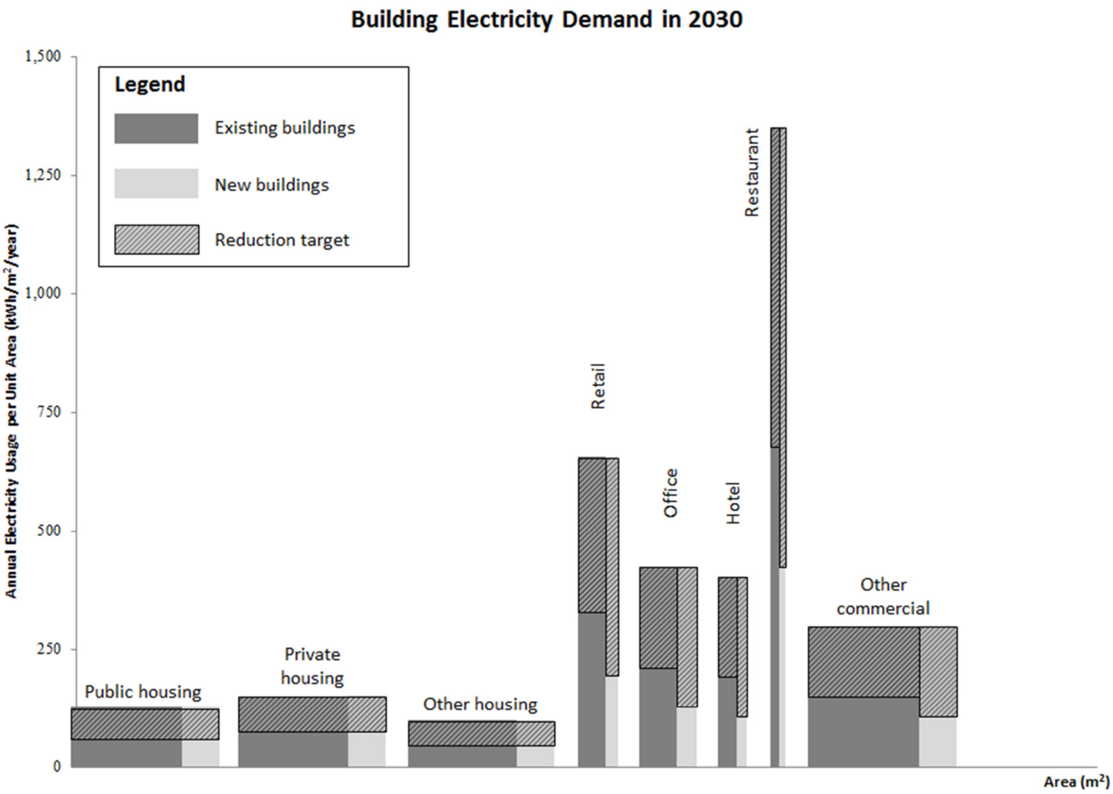

Figure 2 Projected building electricity consumption levels and possible reduction targets

Existing commercial buildings is the category of building stock with largest energy consumption. Given the significant consumption of this category and will have to play a significant role in the overall reduction. Under this scenario, existing commercial buildings contribute over half of the total reduction in building electricity consumption. This is a daunting target and requires a sequential modular approach to break it down into a number of manageable interim steps – this is further discussed in the next section.

For existing commercial buildings, there are two different strategies (summarized in Figure 3):

- Retrofit and retro-commission 70% of existing buildings – improving energy performance of buildings by replacing the existing equipment with energy efficient ones. The energy reduction target for retrofitted buildings: 60%, as compared to the consumption level in 2005
- Retro-commission 30% of existing buildings – examining actual building equipment systems operation and maintenance procedures for comparison to intended or design procedures. The associated energy reduction target for retro-commissioned buildings: 30%

In contrast, the strategies for residential buildings are mainly dependent on behavioural change and existing Mandatory Energy Efficiency Labelling Scheme (MEELS), which grades appliances based on their energy performances. The assessment criteria of MEELS will have to be made increasingly stringent, such that the scheme could contribute to 25% of energy savings in residential buildings. This is accompanied by progressive behaviour change that is both facilitated by design (natural ventilation and facade design) and education (energy conservation).

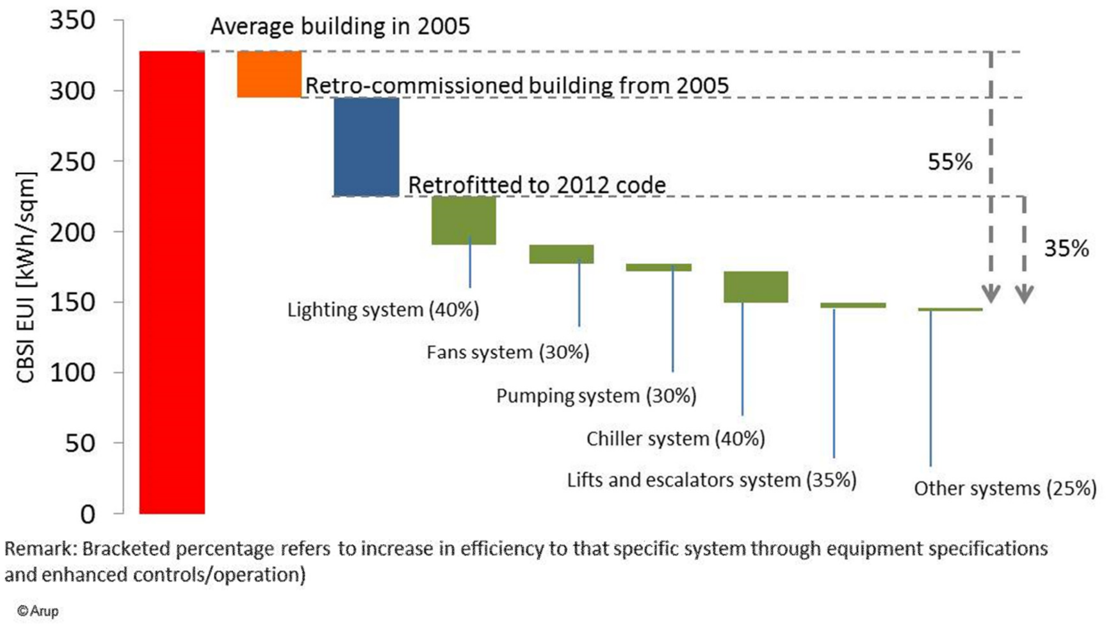

Figure 3 Overall strategies for enhancing energy performances of centralized equipment in existing commercial buildings

The implementations of proposed strategies could reduce building electricity consumption by 53%, allowing the HK3030 target to be attained. The effort reduces Hong Kong's GHG emission by 30% or 15 million tonnes of CO_2-e (compared against BAU scenario), which is equivalent to carbon sequestered by 4,000 sqm of forests in one year.

The Hong Kong Green Buildings Roadmap

Using the data derived from our quantitative analyses, combined with views collected at stake-holders engagements, and reference to international best practices, an action plan for market transformation of green buildings in Hong Kong was derived. The objective is to provide an overview of the truly critical initiatives on the road to HK3030, how they are interlinked, the interim milestones, the quantitative impact, and to do it in a way that is devoid of "greenwash" [3].

The major outcome of this research is the Hong Kong Green Buildings Roadmap for the implementation of the *critical initiatives*, showing the linkage between events, and the interim milestones along the way. The roadmap is in turn constructed out of a series of inter-linked modules, including roadmaps for existing buildings, reporting and benchmarking, regulatory drivers, BEAM Plus (i.e. Hong Kong-based green buildings assessment system), new buildings, GFA incentive scheme, green buildings financing, carbon markets and education. Such a modular and sequential approach is essential when tackling a campaign of such magnitude, as the daunting target can be broken down to a web of manageable interim actions and milestones.

The focus of this roadmap is on the critical initiatives, they are the outcome of the various stake-holders consultation and further shortlisted; while there are many initiatives discussed, only *those that serve as waypoints, without which other initiatives cannot proceed, are considered critical*. As such, many initiatives, though of great importance, are not given top billing in this action plan. This is a conscious decision on the part of the authors, and helps focus the discussion on most pressing matters.

As shown in Figure 4, the roadmap can be thought of in 2 stages, including:

- First stage: Paving the way – is the preparation work necessary before the extensive physical changes in achieving significant energy reduction, these includes initiatives such as reporting, benchmarking, legislation, and assessment. A comparatively small portion of energy reduction occurs at this first stage, but at the same time, also requires relatively little investment in resources.

- Second stage: Realising Change – with the ground work of the first stage in place, Hong Kong will be ready to tackle the tougher problems of significantly improving the operation (retro-commissioning) and hardware (retrofitting) of our buildings. The majority of the energy reduction will occur in this stage with accompanying significant investment in resources.

The roadmap is constructed based on the following principles:

- **Impact of existing buildings** – greater portion of the energy reduction will come from upgrading our existing buildings. *58% of building electricity demand in the year 2030 will come from existing commercial buildings that have already been built. On average, these buildings will need to reduce their energy use intensity by 50%.*
  To enact such a level of energy reduction, a number of sequential steps must be pursued: the process starts by enlisting a significant portion of the existing building stock into a program of reporting, the data gained can then be used for consistent benchmarking, which in turn drives the low-hanging fruit retro-commissioning process in bringing the building stock up to defined performance standard, and finally the adoption of retrofitting of energy efficient systems to bring the energy consumption down to the required level. The roadmap is in a large part driven by the sequence and scheduling of these steps.

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- **Crucial role of benchmarking** – benchmarking is the hinge point on the roadmap. Firstly, *many of the initiatives of stage one are geared towards the implementation of benchmarking* – the refinement of building codes, the preparation of assessment methodology in BEAM Plus, etc. Secondly, *a significant part of stage two also requires a robust benchmarking system to succeed* – the identification of enhancement works in retro-commissioning and retrofitting, the construction of a consistent financial framework in GFA incentives, ESCOs and carbon markets.
  Currently, HKGBC has put into action two initiatives towards the successful implementation of benchmarking – a tool targeting commercial tenants, and another focusing on the landlord building management. The full action plan [3] highlights the synchronization of these tools with the roadmap.

- **Innovative design in new buildings** - represents 20% of the total building stock. Though the impact is relatively smaller, the flexibility in integrating green building features into new buildings is much greater, and often allows for a higher level of energy performance. Perhaps equally important, is that the innovative design of new buildings captures the imagination of both professionals and the public: an exciting new building serve as a beacon for demonstrating sustainable design practices, new technology, and exemplary behaviour; and hence we must capture and maximize their demonstration and education value.

- **Regulatory driven** – The emphasis is placed on regulatory initiatives. This has its origin in one of the findings in the stake-holders consultation, which *is to achieve the aggressive energy reduction required, a coherent set of regulatory measures are the most important type of initiatives.* Hence the construction of this roadmap first considers a number of regulatory policies (reporting/benchmarking/energy codes), and then subsequently seek supporting market driven initiatives to support them (voluntary initiatives/ incentives/education). While the majority of the stake-holders agree with such a regulatory driven approach, it was unrealistic to expect a complete consensus. Nevertheless, we hope that this approach serves as a useful starting point in our continued refinement to Hong Kong's roadmap.

- **Area of emphasis at different stages** – *the modular sequential approach of this roadmap highlights the shift in allocation of resources*. At the first stage, the focus is on professional training towards the realization of benchmarking. While at the second stage, it shifts towards technical implementation. Financing becomes critical in the second stage when the bulk of the investment in physical upgrade occurs. It is at this stage that we need large scale funding through GFA incentives, funds, loans, ESCOs, which will also require professionals fluent in the finance of green buildings. The potential for energy/carbon markets (tax/rebates/trading) at this stage after a consistent framework of benchmarking is established.

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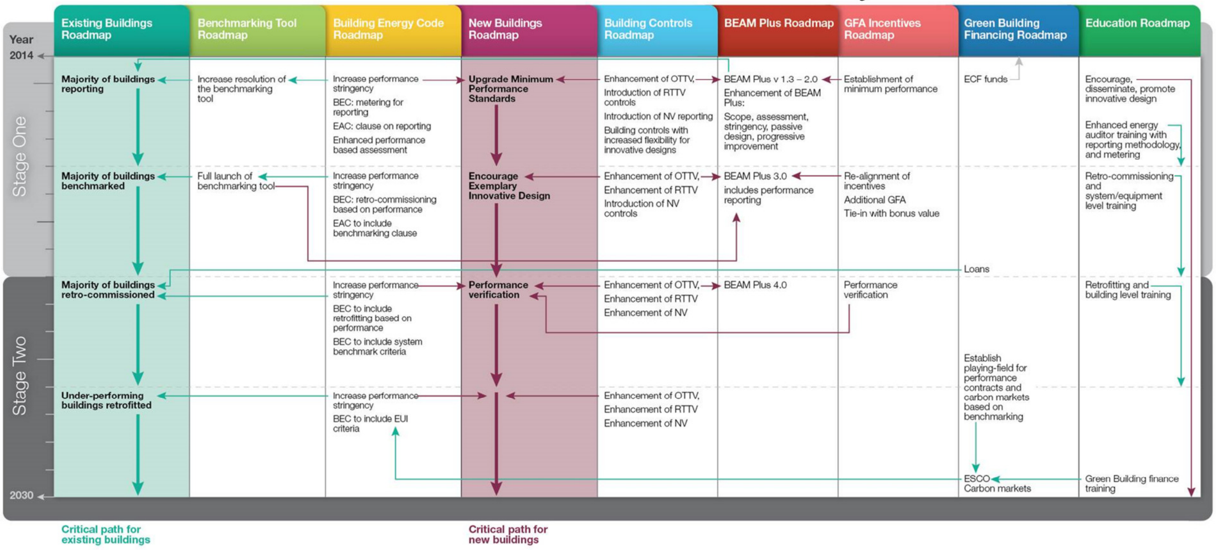

Figure 4 Hong Kong Green Buildings Roadmap

We hope that the stake-holders can use this roadmap to gain a better appreciation of the scale and impact in the challenge of achieving HK3030. Laid out in this form, we see how the "*critical path*" shifts as we progress into the campaign, and can prepare for them in resource allocation and capacity building. Using Hong Kong as an example, readers are encouraged to deliberate, debate and resolve the challenge of green buildings transformation faced by cities worldwide.

Acknowledgement
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References

[1] Environmental Bureau, HKSAR Government. (2007). *Hong Kong's Climate Change Strategy and Action Agenda*. Hong Kong

[2] Hong Kong Green Building Council. (2012). *"HK3030" A Vision for A Low Carbon Sustainable Built Environment in Hong Kong by 2030*. Hong Kong

[3] Arup. (2014). *Research on Market Drivers for Transformation of Green Buildings in Hong Kong*. Hong Kong

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Session 68:

Energy efficiency and life quality: on what scale?

Chairperson:

Cárdenas, Luz

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Evaluation of reduced energy use resulting from a DHC network in the Shinjuku DHC area

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Reduced energy use and low carbon emissions by cities are important, and area-wide energy usage is an effective way to achieve these goals. District heating and cooling (DHC) is a typical form of area-wide energy usage. However, declining efficiency is a concern for heat source equipment that has been in operation for a long period of time. Therefore, facilities have to be updated or heat transfer has to be facilitated (connections to plants) in order to make an existing DHC network more efficient.

This study analyzed and evaluated how effectively the DHC network between the Nishi-Shinjuku 1-chome area and the Shinjuku Shin-toshin area reduced energy use. This network began transferring chilled water between the 2 areas in Shinjuku Ward, Tokyo starting in 2013. Results revealed that the DHC network resulted in about a 5 % reduction in the primary energy input per year in the area studied.

Keywords: DHC, DHC network, heat transfer, reduced energy use, area-wide energy usage

1 Introduction

In recent years, the use of area-wide energy has been promoted as a result of amendment of the Act concerning the Rational Use of Energy. District heating and cooling (DHC) is a typical form of area-wide energy usage. That said, declining efficiency is a concern for heat source equipment that has been in operation for a long period of time. Therefore, existing DHC networks have to be made more efficient. Heat transfer between DHC areas had previously been regulated but is now being considered as a result of measures to promote area-wide energy usage under the Kyoto Protocol Target Achievement Plan. Moreover, heat transfer started in 2 DHC areas in Shinjuku as an example of a DHC network following the creation of DHC areas around Nagoya Station.

This study estimated the reduced energy use resulting from a DHC network between the Nishi-Shinjuku 1-chome area and the Shinjuku Shin-toshin area that started in 2013.

2 Summary of the DHC areas studied

The location of the DHC areas studied and the heat transfer pipe are shown in Fig. 1 and a summary of the DHC areas studied is shown in Table 1. The Nishi-Shinjuku 1-chome area has two plants, and it further reduces energy use by accepting exhaust heat from combined heat and power (CHP) generated for Mode Gakuen. The Shinjuku Shin-toshin area is one of the world's largest DHC areas that supplies heating and cooling to buildings with a total floor area of 2.2 million square meters. The Shinjuku Shin-toshin area supplies electric power to the Tokyo Metropolitan Government Building and the Shinjuku Park Tower via CHP.

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Important aspects of the DHC network in the Shinjuku Shin-toshin area are that it supplies about 7.5 times the cooling and about 11 times the heating supplied by the Nishi-Shinjuku 1-chome area throughout the year. There is a large difference in the heating demand of the 2 areas, and most of the heat source equipment in the Shinjuku Shin-toshin plant is more efficient than that in the Nishi-Shinjuku 1-chome plant. Furthermore, upgrading of some equipment in the Shinjuku Shin-toshin plant is planned. Having the Shinjuku Shin-toshin plant provide the amount of cooling required by both areas should reduce energy use in both areas as a whole when the cooling demand is low, such as at night or during the winter or during intervening periods [between seasons].

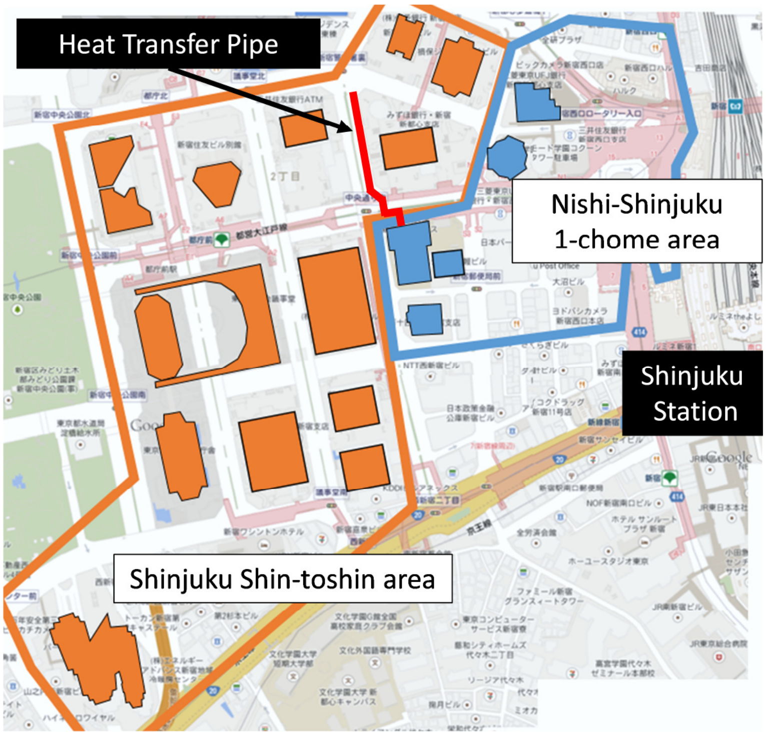

Fig. 1 Location of the DHC areas studied and the heat transfer pipe

Table 1 Summary of the DHC areas studied

Name		Nishi-Shinjuku 1-chome area			Shinjuku Shin-toshin area		
Total Floor Area		About 357,880㎡			About 2,222,630㎡		
Plant Equipment	Boiler	Flue Fire Tube Boiler	9[t/h]	×1	Water-Tube Boiler	30[t/h]	×1
			12[t/h]	×1		60[t/h]	×3
			18[t/h]	×1			
		Once-Through Boiler	2[t/h]	×2			
	Chiller	Double Effect Absorption Chiller	600[RT]	×2	Condensing Turbine Centrifugal Chiller	4,000[RT]	×1
			900[RT]	×1		10,000[RT]	×3
			1,100[RT]	×2	Back Pressure Turbine Centrifugal Chiller	2,000[RT]	×1
			1,300[RT]	×3		2,870[RT]	×1
					Double Effect Absorption Chiller	1,000[RT]	×2
						2,065[RT]	×2
		2014 March 31→			Electric Turbine Turbo Chiller	5,000[RT]	×4
	CHP				Gas Turbine CHP	4,000[kW]	×1
					Waste Heat Boiler	7.2[t/h]	×1
					Gas Turbine CHP	4,500[kW]	×1
					Waste Heat Boiler	10.6[t/h]	×1

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3 Evaluation of the DHC network

3.1 Summary of heat transfer between the Nishi-Shinjuku 1-chome area and the Shinjuku Shin-toshin area

The DHC network in the Shinjuku DHC area was intended to help reduce energy use and lower carbon emissions by the city. A pipe connects the 2 areas.

A diagram of the DHC network is shown in Fig. 2. The DHC network transfers up to 38 GJ (3,000RT) of cooling produced in the Shinjuku Shin-toshin area to the Nishi-Shinjuku 1-chome area via 3 heat exchangers and 3 cold water pumps in the Nishi-Shinjuku 1-chome area. The Shinjuku Shin-toshin area supplies cooling of 4°C and the Nishi-Shinjuku 1-chome area supplies cooling of 7°C. Because the supplied temperature of cooling differs between the areas, heat is exchanged more efficiently.

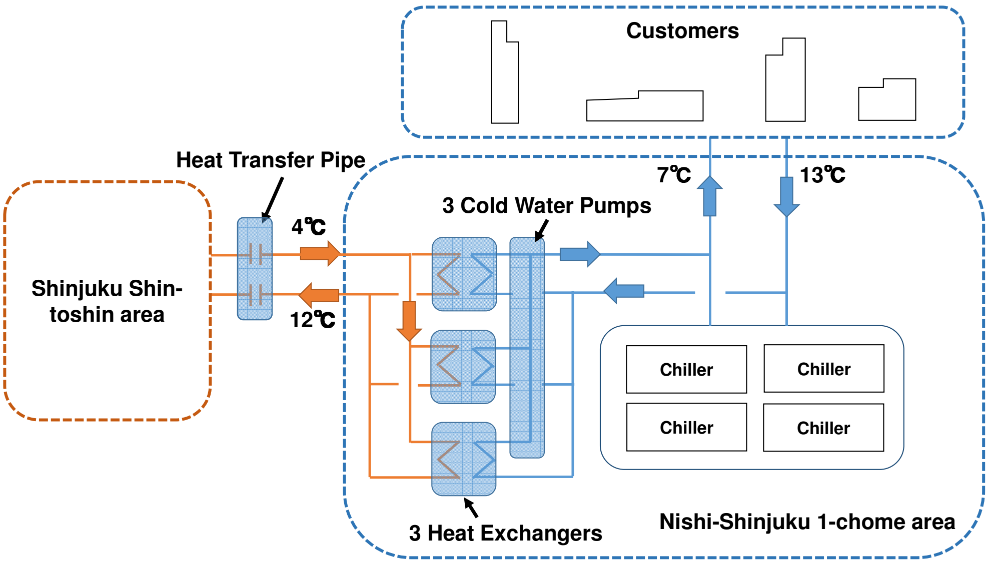

Fig. 2 DHC network

3.2 Study and analysis of heat transfer

The amount of the daily cooling supply from April to November 2013 in the Nishi-Shinjuku 1-chome area is shown in Fig. 3. Cooling transfer began in earnest in June. Cooling is produced in the Nishi-Shinjuku 1-chome area in the summer. However, most cooling that is required in the Nishi-Shinjuku 1-chome area can be supplemented by the DHC network because the cooling demand decreases after autumn.

The amount of cooling supply by time during the week in which the largest amount of cooling was transferred is shown in Fig. 4. Because little cooling is needed in the middle of the night, the total cooling that was needed in the Nishi-Shinjuku 1-chome area was supplemented by transferring cooling. Maximum cooling is not transferred at peak times since the amount of cooling that can be transferred is limited by adjustments to equipment. A study indicated that there was no transfer on August 9th at the behest of the Shinjuku Shin-toshin plant.

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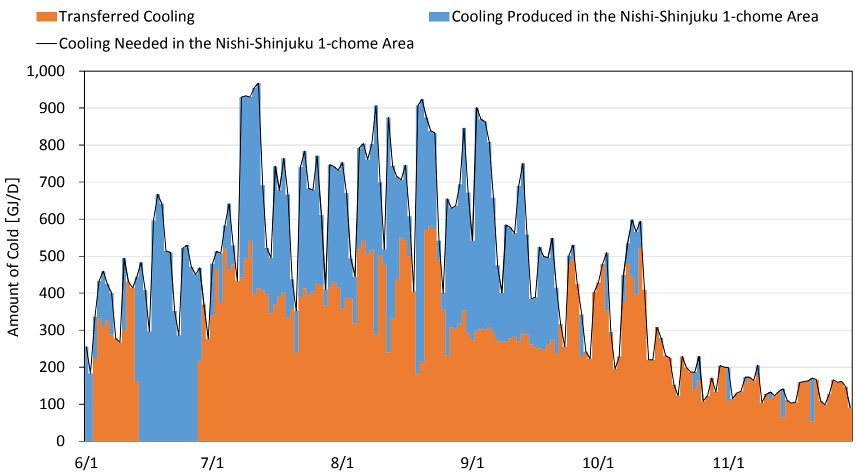

Fig. 3 Amount of daily cooling supply in the Nishi-Shinjuku 1-chome area

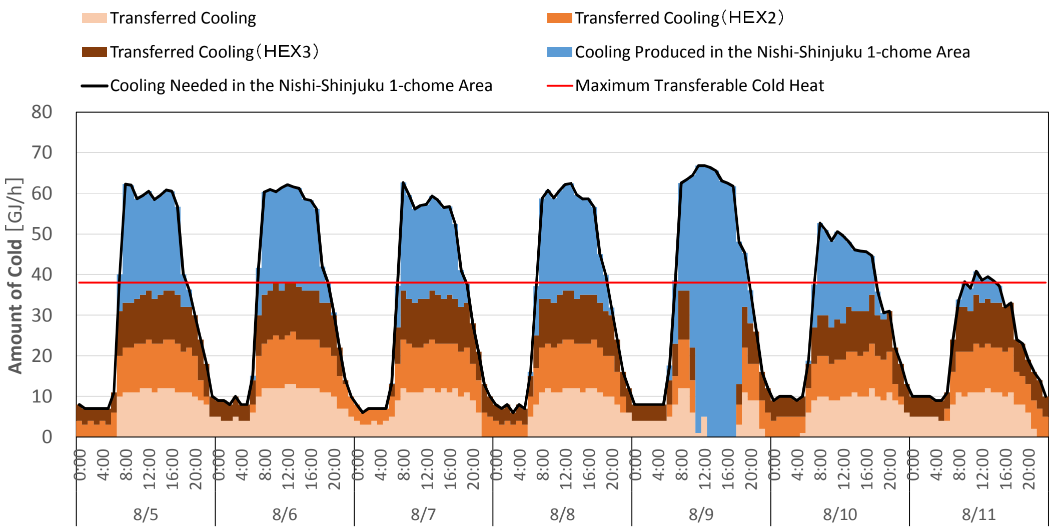

Fig. 4 Amount of hourly cooling supply in the Nishi-Shinjuku 1-chome area

3.3 Evaluation of reduced energy use resulting from the DHC network

In order to evaluate the reduced energy use resulting from a DHC network, primary energy per unit of cold supply was estimated each year from 2009 to 2013. The data from June to November in those years were used in estimates because cooling was transferred in earnest over that period in 2013. Moreover, primary energy input each year was compared. Results of the evaluation are shown in Fig. 5. In this figure, Gas for Cold Supply is the amount of gas consumed in the manufacture of steam to operate chillers. Transferred Cooling is the amount of gas and power consumption that were used to transfer cooling in the Shinjuku Shin-toshin area. Auxiliary Power is the sum of the total electrical energy of the primary cooling pump, cooling water pump, secondary cooling pump, cooling tower fan, and cooling pump for the DHC network, and the electrical energy of other equipment that was divided by the ratio of heating and cooling supplied.

Calculations indicated that the primary energy input was about 5.6% less in 2013 compared to the average primary energy input from 2009 to 2012. This indicates that gas for cold supply and auxiliary power were greatly reduced in the Nishi-Shinjuku 1-chome area.

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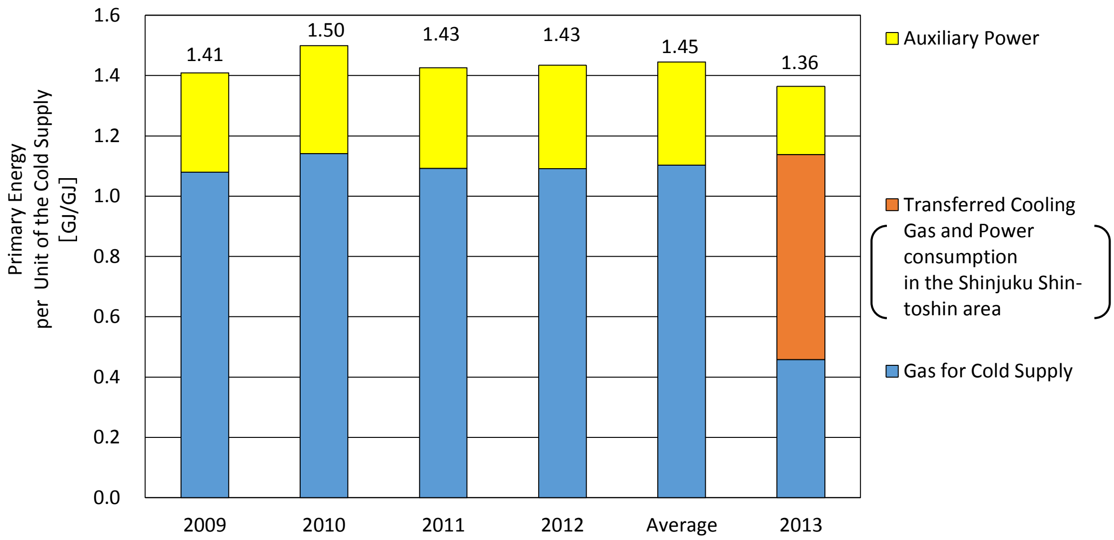

Fig. 5 Primary energy per unit of cold supply by year

4 Discussion based on simulations

Because there were times when cooling transfer was not utilized as a result of adjustments to equipment, a simulation was performed assuming there were no limits on cooling transfer. The anticipated reduction in energy use resulting from the DHC network was estimated.

The software "SPREEM-UD [1][2]" was used for simulations. Entering the heating and cooling supply per hour, COP, and partial load characteristics of each piece of equipment in the Nishi-Shinjuku 1-chome area allowed calculation of the amount of gas that each boiler consumes, the amount of steam that each boiler produces and that each chiller consumes, and the amount of cooling that each chiller produces per hour based on data provided by Energy Advance Co., Ltd. Simulations were performed using 3 scenarios with different amounts of cooling transferred, and the data from June to November (4,392 hours) were used in the simulations.

[Regular Transfer]: Scenario where the amount of transferred cooling is similar to the results in 2013.

[Limited Transfer]: Scenario where the amount of transferred cooling is limited to 60% when the amount of power received by the Shinjuku Shin-toshin plant exceeded 9 MWh/h.

[Ideal Transfer]: Scenario where all transferable cooling is transferred.

Limited Transfer is explained here. When the amount of power received by the Shinjuku Shin-toshin plant exceeds 9 MWh/h, less cooling tends to be transferred than usual. Therefore, transferred cooling is presumably limited in accordance with the amount of power received by the Shinjuku Shin-toshin plant.

The amount of transferred cooling and the amount of the cooling supply in the Nishi-Shinjuku 1-chome area in each scenario is shown in Fig. 6. In the figure, ideal transferred cold is the amount of the cooling supply in the Ideal Transfer scenario, and limited transferred cold is the

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amount of the cooling supply in the Limited Transfer scenario. An increase in the amount of cooling transferred in these scenarios is apparent in comparison to the cooling transferred in the Regular Transfer scenario. Based on the total amount of cooling transferred from June to November, the amount of cooling actually transferred was only approximately 67% of the amount of ideally transferred cooling. After the intervening period [between seasons], almost the entire amount of cooling needed in the Nishi-Shinjuku 1-chome area was covered by the amount of actually transferred cooling regardless of the scenario.

Results of each scenario are shown in Fig.7. A Limited Transfer resulted in about a 0.4 % reduction in primary energy input and an Ideal Transfer resulted in about a 5.7 % reduction in primary energy input compared to a Regular Transfer. Moreover, the Limited Transfer was predicted to reduce primary energy input about 6.0 % and the Ideal Transfer was predicted to reduce primary energy input about 11.3 % in comparison to primary energy input prior to establishment of the DHC network.

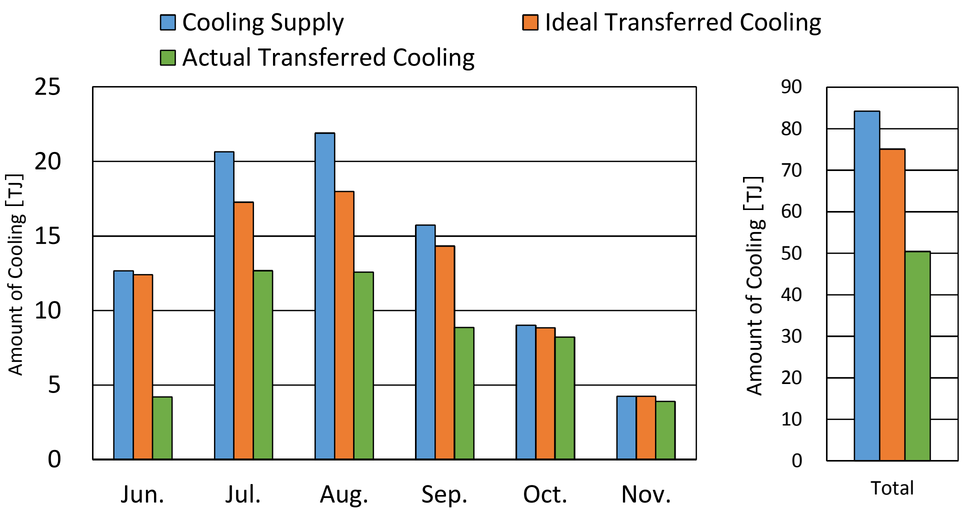

Fig. 6 Amount of cooling consumption and transferred cooling (June - November)

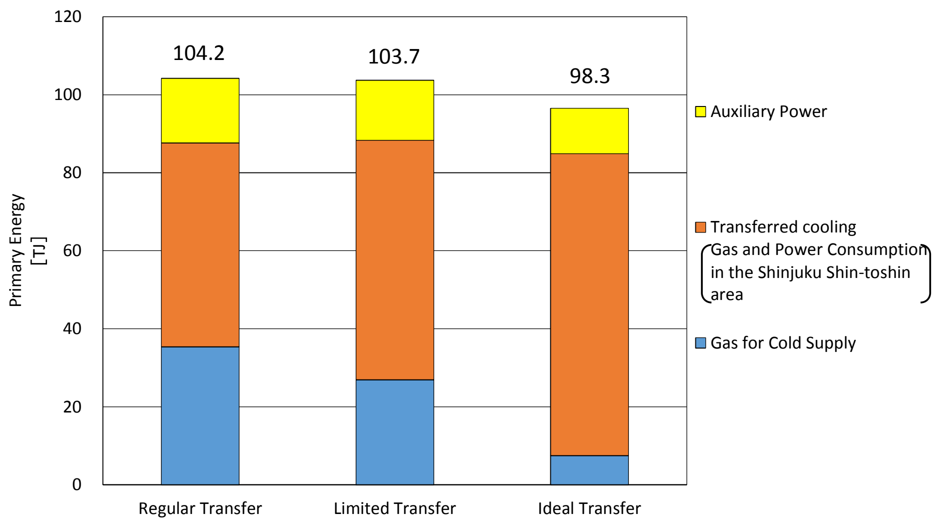

Fig. 7 Amount of total primary energy from June to November

5 Conclusion

This study estimated the reduced energy use resulted from a DHC network between the Nishi-Shinjuku 1-chome area and the Shinjuku Shin-toshin area that began operating in 2013.

As evidence of reduced energy use resulting from the DHC network, primary energy input was reduced about 5.6 % in comparison to primary energy input prior to establishment of the DHC network. In addition, a simulation revealed that primary energy input should be reduced about 0.4 % except when cooling transfer is limited as a result of adjustments to equipment. Primary energy input should be reduced about 5.7 % when all transferable cooling is transferred from the Shinjuku Shin-toshin area to the Nishi-Shinjuku 1-chome area.

Limits on transferable cooling due to adjustments to equipment should decrease in the future. Further studies will analyze and evaluate reduced energy use in DHC networks and a model of a DHC network will be created in the future.

Acknowledgment

The authors wish to thank Energy Advance Co., Ltd. for the data and suggestions regarding data processing that the firm provided.

References

[1] Hayashi et al. Development of an energy and carbon emissions simulator for urban design (Parts 1 and 2). Technical Papers from the Annual Meeting of the Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan, 2009

[2] Sugihara et al. Development of technology to optimize smart energy networks (Optimization of the configuration of a DHC and optimization of its operation). The 27th Conference on Energy Systems, the Economy, and the Environment, 2011

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Green design strategies for urban heat island mitigation in a solar optimized access Eixample via IMM® methodology.

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Abstract: *The cities are responsible up to 75% of energy consumptions and 80% of CO_2 emissions. The European Performance of Buildings Directives and the urban regulations are going towards the reduction of the energy consumptions and the minimization of the land's use. In this scenario the innovative methodology, IMM® (Integrated Modification Methodology), has been applied in order to achieve the energy standards of net zero energy districts of four Eixample courtyards in Barcelona. The city is considered as a complex system composed by heterogeneous parts influenced each other. The multi-criteria process aims to transform a consolidated urban context into a more efficient and sustainable one. The opmization of solar potential and the design of new green areas give relevant benefits in terms of energy efficiency and quality of urban environment.*

Key words: Solar potential, urban heat island, IMM® (Integrated Modification Methodology)

Introduction

Cities are and have been the epicenters of transformations and the incubators of solutions. In this century, the first urban century, world population is projected to reach 8.1 billion in 2025 and 9.6 billion in 2050 [1]. This estimated increase will occur mainly in urban areas where the urban population "is projected to gain 2.6 billion, passing from 3.6 billion in 2011 to 6.3 billion 2050. Thus, the urban areas of the world are expected to absorb all the population growth expected over the next four decades." [2]. The increase of the world population and the consequent spread of the urban areas is only one of the current and future global challenges that cities have to face. Climate change, food security, environmental pollution, loss of biodiversity, and energy over-consumption are among the most relevant. Urban agglomerations have been hit by different crises in the past centuries. Invasions, fires, epidemics, natural catastrophes, declines, resources' depletion, wars, together with internal social and power revolutions have stressed cities and forced to think about their changes. Utopian, visionary thinkers, city planners, architects, and engineers have picked up the challenges and figured out how to face the problems and look for solutions. In Europe after the Industrial Age, the challenges of urban pollution, natural resource depletion, water and air quality, and the abominable life conditions of the urban population, inspired new proposals of urban visioning and planning. Similarly almost a century after, the goal of ecological planning (grown in the 1960s and established in the 1970s) was to provide methods to deal the wordwide environmental crisis. Today, the knowledge acquired and the awareness developed about the environment, advises that is the time to approach urban and global challenges comprehensively providing new avenues to cope with them, looking at the problems from a different points of view, and through new and innovative ways of collaboration among

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different disciplines. Energy production, energy consumption[1], and energy depletion[2] are three challenges that both cities, new and consolidated, must to face in the next decades. For achieving these goals, the European Performance of Buildings Directives established the energy policy's targets of 20% emissions' reduction, the increase of 20% of renewable energy and 20% of energy efficiency by 2020. While the urban regulations are favouring the exploitation of the sites within the urban environment in order to develop a compact city model. The case study here presented demonstrates how a consolidated city could change from an energy-consumptive system to a complex able to produce its energy by itself.

The IMM® theory and methodology

The Integrated Modification Methodology (IMM®) consists in a holistic design approach founded on a specific process in which the main goal is to improve the urban energy performance working on the most influenced components of the city such as population, urban morphology, density and spatial parameters [3]. It aims to reach a more sustainable city level on both new and consolidated urban settlements, optimizing the urban aspects as transportation, solar access and green areas [4] [5]. The city is not solely considered a mere aggregation of disconnected energy consumers. The total energy consumption of the city is different from the sum of the whole building's consumption: "The whole is more than the sum of its parts" (Aristotle). The gap between the total energy consumption of the city and the sum of all consumers is related to the urban morphology of the city. In IMM®, the city has been considered as a single entity, composed by heterogeneous elements connected each other directly and indirectly. A Complex Adaptive System (CAS) is characterized by a specific ability to learn from prior occurrences. The strength of the IMM® theory is its multi-layer and multi-scale analysis approach that considers the city as a CAS [6]. System's agents adapt to improve their performance, in response to new internal and external constraints. According to the CAS, an action in one constituent of the system will produce chain reactions in the others. This means that from superimposition or symbiotic integration of CAS' subsystems another vision of system's operation emerges. The actual key of understanding the complexity of the system is to study all the one-by-one interactions.

[1] Building operations account for approximately 41% of the nation's [United States] primary energy consumption, 72 % of electricity consumption, 38 % of carbon dioxide (CO_2) emissions, and 13% of potable water use (National Trust for Historic Preservation (2011), The Greenest Building: Quantifying the Environmental Value of Building Reuse.

[2] According to the U.S. Energy Information Administration (http://www.eia.gov/tools/faqs/faq) World energy consumption by end-use sector (quadrillion Btu) and shares of total energy use, 2011 (includes losses in electricity generation, transmission, and distribution) are the following

	Energy End Use	Electricity Losses	Total Energy Use	Share of Total Energy Use
End-Use Sectors				
Commercial	29	34	62	12%
Industrial	200	66	266	51%
Residential	52	40	92	18%
Transportation	101	2	103	20%
Total End-Use Sectors	382		524	

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Figure 1. (On the left) A complex adaptive system (CAS) is composed of several subsystems; it is considered to be a superposition of products of the sub-systems' states. Superimposition is a process of integration of two or more sub-systems. Once the subsystems interact, their states are no longer independent. (On the right) Courtyards' regenerating projects: in red the four blocks under consideration. Green lines are the corridors that play the bonding role in the public spaces system. [Green corridor patter M.Gausa] (Authors: IMM®).

The work presents the transformation of four Barcelona's urban blocks courtyards toward new more efficient systems. The project is included in a greater Muncipality's urban strategy, *ProEixample*, which aims to recover about 70 courtyards located in the *Eixample blocks*. These parts of the city are currently obsolete and often occupied by old factories or underused laboratories. Their transformation is going towards innovative integrated systems improving the energy efficient and the environmental comfort of the district through the reduction of air and acoustic pollutants, the mitigation of the urban heat island (UHI) and the increment of the renewable sources' use. Simultaneously, the project is integrated in two existing strategies of a new mobility model: the *Superblock* proposed by *Agència d'Ecologia Urbana de Barcelona* [7] and the *Green corridor* plan studied by *M. Gausa* [8]. The *Superblock* strategy is based on a new hierarchy of the existing traffic grid, 400 x 400 m, with car free interior streets covered by grass and used solely by the *Superblock*'s residents and peripheral axes for the motorized traffic. The plan plays a relevent role in the environmental quality and energy performance of the city. While the *Green corridor* gave the opportunity to bond the courtyard renovation project to an overall envinronmental strategy. According to IMM®, every single element works as a multiplier of the performance of each other single component. The paper presents more in detail two of the technical evaluations, such as solar potential and the UHI analysis.

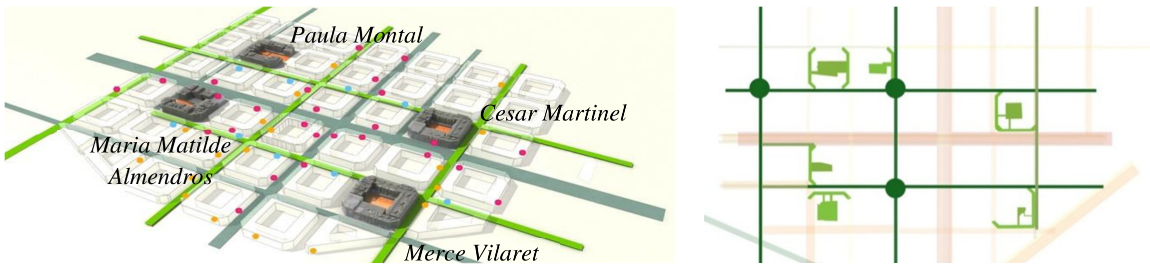

Figure 2. The location of four courtyards in the neighbourhood, administrations and services are indicated by red, while cultural and entertainment is shown with yellow and educational spaces with light blue. Actual neighbourhood diversity situation is illustrated by coloured rectangles; M.Gausa green corridors are shown by green lines when new proposed transportation lines are illustrated by orange lines (Authors: IMM® team).

Aims and analysis: solar access, solar potential, solar mapping and UHI analysis

The aim of this work is to present an application of the IMM® methodology in a case study. It consists in analysing an existing complex context, as the *Eixample blocks,* applying design strategies and analyses in order to get more efficient and sustainable urban assessment and improve the energy performance of each single part of the city. The paper presents only two aspects of a broad multi-disciplinary transformation plan of neighbourhoods of Barcelona:

- The solar access analysis for calculating the solar potential of the blocks and the solar mapping analysis in order to localize the suitable areas for installing the solar systems;
- The benefit of the green system in the urban areas for calculating the UHI's mitigation and the improvement of the quality of the environmental conditions.

The solar analysis investigated the potential of the *Eixample blocks* running dynamic simulations using *DiVA for Rhino*, a radiance-based program, validated for complex daylight calculations and solar radiation maps analysis [9]. The analysis allowed calculating the solar radiation on the building envelopes. This section aimed to localize the most irradiated areas and to estimate how much energy can be produced for achieving the standard of net zero energy neighbourhoods. While the UHI analysis was conducted using *ENVI-met*, a three-dimensional microclimate model designed to simulate the surface-plant-air interactions in urban environment [10]. Two dimensions that affect the UHI effect at the pedestrian level were analysed in order to evaluate the benefit of the green areas inside the courtyards of the *Eixample blocks*: the potential temperature (T_{POT}) and the mean radiant temperature (T_{mrt}).

Solar access, solar potential and energy production analysis by solar dynamic simulation

The initial request of the presented project was directed on the transformation of four Barcelona's urban blocks courtyards, toward sustainable public spaces, which could serve the surrounding area. The proposed approach is based on consideration of those blocks as a part of whole Barcelona's urban system. The entire system of the neighbourhood scale is defined by 41 blocks of the *Eixample* (Figure 1). Among the blocks four of them have been selected for conducting the feasibility study: Merce Vilaret, Cesar Martinel, Maria Matilde Almendros and Paula Montal (Figure 2). The solar access analysis of the blocks has been done in order to calculate their solar potential. While the solar map analyses have allowed localizing the suitable areas of the external façades, the courtyard façades and the parts of the roofs in which is more convenience installing the solar systems as photovoltaic (PV) or solar thermal collectors (STC). Two different levels of simulation have been conducted: the first is focused on calculating the total amount of the solar radiation on the block's envelope in the *isolated scenario*. This kind of analysis permitted to establish the maximum solar potential of each block. The direct radiation, setting the radiace parameters ambience bounces (ab) equal to 0, and the global radiation (ab=3) that considers the mutual solar reflections from the surrounding (ground and building) have been calculated. The same radiance parameters (Table 1) has been set for the second level of analysis in which the blocks were considered inserted in the urban environment, *context scenario*. Table 1 shows the parameters of the simulations, while the Table 2 shows the features of the materials assigned to the blocks.

Table 1. Set of "rtrace" parameters used for all radiance-based simulations. (Authors' table)

ambient bounces	ambient division	ambient super-sample	ambient resolution	ambient accuracy	specular threshold	direct sampling	direct relays
0 – 3	1000	20	300	0.1	0.15	0.20	2

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Table 2. List of radiance materials for simulation (for R,G,B values of reflectance). (Authors' table)

Element	Material	Radiance description	Number of values	R	G	B	Specularity	Roughness
Façades	Conc plaster 50%R	void plastic	005	0.549	0.549	0.549	0.00	0.00
Roofs	Plaster_Insulation_CeramicTile	void plastic	005	0.624	0.624	0.624	0.00	0.00

Table 3 summarizes the two levels of simulation. The calculations estimate both effects: the overshadowing effect that the blocks are affected when they are considered in the urban environment (ab=0) and the contribution of mutual solar reflections created by the surrounding and the ground (ab=3). The block of Maria Matilde Almendros is maily affected by the overshadowing effect (- 4.77%), while the Merce Vilaret block has the greater contribution of the solar reflections (-0.92%).

Table 3. Solar analysis: E_S: total exposed area. Isolated scenario - R_{isol}: total solar radiation on a block. R_{isolA}: average solar radiation on a block. Context scenario: R_{con} and R_{conA}; Δ% of solar radiation (Authors' table).

Blocks	ab	Sensor[m^2]	E_S m^2	R_{isol}[kWh/yr]	R_{isolA}[kWh/m^2yr]	R_{con}[kWh/yr]	R_{conA}[kWh/m^2yr]	Δ %
Merce Vilaret	0	5.74	23150	10299176.81	444.90	9974726.94	430.88	- 3.15
	3			23270206.64	1005.21	23056934.71	996.00	- 0.92
Cesar Martinel	0	3.67	24462	9925564.14	405.76	9508639.88	388.71	- 4.20
	3			23162501.02	946.88	22765912.84	930.67	- 1.71
Maria Matilde Almendros	0	3.33	24377	9731586.98	399.21	9267811.34	380.19	- 4.77
	3			22822390.02	936.23	22392460.80	918.59	- 1.88
Paula Montal	0	3.60	24216	9652950.08	398.62	9249590.55	381.96	- 4.18
	3			22708338.79	937.74	22471935.46	927.98	- 1.04

The second analysis' level was focused on the calculation of the energy production generated by the solar systems installed in the external façades, courtyard façades and roofs of the blocks. Table 3 collects the results of the direct radiation considering the blocks inserted in the *context scenario*. The solar mapping analysis individualized the best areas for installing the solar systems. Their energy production allows covering almost the entire energy demand of the blocks as shown in Table 4.

Table 4. Energy production analysis: E_S: total exposed area. R: total solar radiation on a block, R_A: average solar radiation for unit of the surface; PV: Phovoltaic - SC: solar thermal collectors (Authors' table).

Blocks	Elements	Sensor /m^2	E_S [m^2]	R [kWh/yr]	R_A [kWh/ m^2yr]	Energy production [MWh/yr]		% Energy cons. covered		% Tot energy covered
						PV	STC	PV	STC	PV+STC
Merce Vilaret	External fac.	4.16	9581	2436390	254.28	40.6	203.4	2.1	10.7	100%
	Courtyard fac.	5.60	5045	1213376	240.47	38.5	192.3	2.0	10.1	
	Roofs	10.24	8522	6324962	742.17	261	1306	12.5	62.5	
Cesar Martinel	Ext. façades	3.00	9336	2663238	285.25	45.6	228.2	2.4	12.0	92.4%
	Courtyard fac.	3,03	6667	876614	131.47	21,0	105.1	1.1	5.5	
	Roofs	6.21	8457	5968788	705.72	248	1242	11.9	59.4	
Maria Matilde Almend.	Ext. façades	2.40	9382	2181645	232.53	37.2	186	2.0	9.8	93.7%
	Courtyard fac.	3.18	7009	1418840	202.41	32.3	161.9	1.7	8.5	
	Roofs	6.65	7985	5667326	709.76	249,8	1249	12.0	59.8	
Paula Montal	Ext. façades	3.24	9720	2345175	241.27	38.6	193	2.0	10.2	93.4%
	Courtyard fac.	2.56	6422	1113476	173.39	27.7	138.7	1.5	7.3	
	Roofs	6.63	8074	5790939	717.22	252.4	1262	12.1	60.4	

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The calculation has been done considering the area of installation equal to 1000 m^2 of external façades, 1000 m^2 of the courtyard's façades and 2000 m^2 of the roof. The energy consumption of a block was calculated by multiplying the energy consumption for each person in the region per year, equal to 2.96 MWh/yr (residential sector), to the number of inhabitants living in a block, 640 [11]. For the selected case studies was obtained the annual value equal to 1900 MWh for each block. The solar mapping analysis in Figure 3 allows localizing the most suitable areas for the installation of solar systems on the buildings' envelope. The Table 4 summaries the energy production respectively for PV and STC installed on different parts of the blocks.

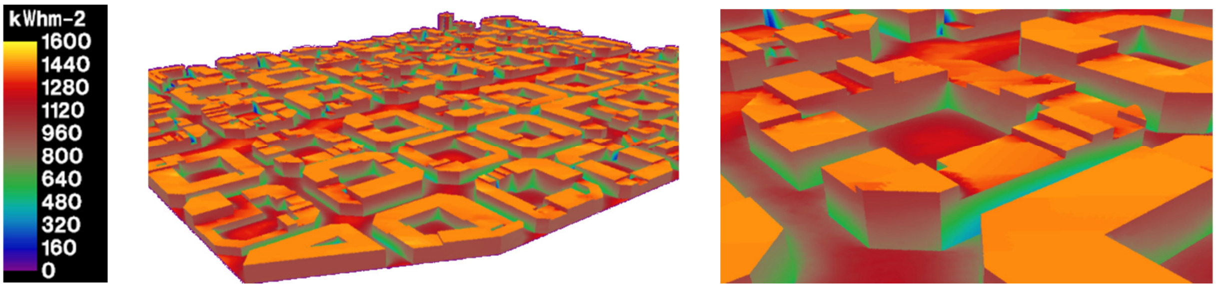

Figure 3.Solar mapping analysis: the solar irradiation of the 41 Eixample blocks (on the left); the localization of the most irradiated areas in the Maria Matilde Almendros Eixample block (on the right) (Authors'pictures).

Urban heat island mitigation

The UHI effect has been studied conducting the simulations in two scenarios: the *current scenario*, in which the soil was considered in asphalt, and the *IMM® scenario*, characterized by green corridors and green courtyards (Figure 2) constituted by grass soil. Receptors have been set in the middle of the courtyards in order to calculate the potential temperature (T_{POT}) and the mean radiant temperature (T_{mrt}) that have a strong influence in terms of UHI's mitigation. Table 5 reports the results obtained from the simulations conducted by *ENVI-met*.

Table 5.Calculation of the potential temperature (T_{POT}) and the mean radiant temperature (T_{mrt}) at level 1.5 m from the ground at 3:00 pm on the hottest day of the year, the 6th of August. (Authors' table)

Blocks	Scenario	Soil	T_{POT} [°C]	ΔT_{POT} [°C]	T_{mrt} [°C]	ΔT_{mrt} [°C]
Merce Vilaret	Current	Asphalt	29.25	/	81.57	/
	IMM®	Grass	28.81	-0.44	73.56	-8.01
Cesar Martinel	Current	Asphalt	29.30	/	81.38	/
	IMM®	Grass	28.86	-0.44	75.6	-5.79
Maria Matilde Almendros	Current	Asphalt	29.26	/	81.72	
	IMM®	Grass	28.91	-0.35	74.41	-7.31
Paula Montal	Current	Asphalt	29.22	/	83.47	/
	IMM®	Grass	28.78	-0.44	75.49	-7,98

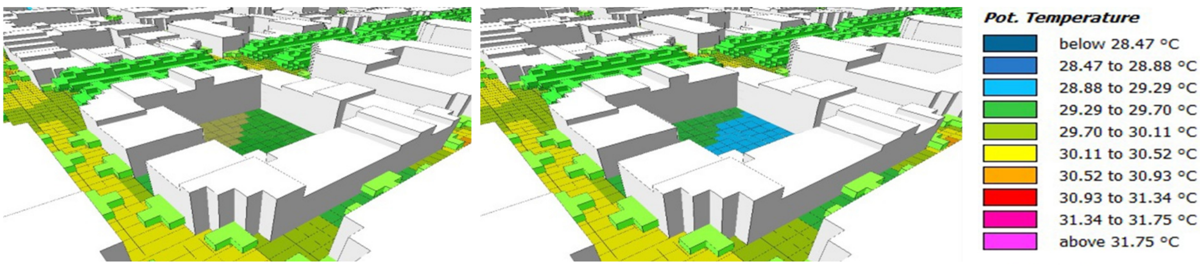

Figure 4.T_{POT} analysis: the visualization of the T_{POT} inner the of the courtyard Maria Matilde Almendros Eixample block in Currrent scenario (on the left) and in IMM® scenario (on the right) (Authors'pictures).

Conclusion

The Barcelona's case shows how the IMM® proceeds and transforms an existing urban context from its actual morphology into a more sustainable one increasing the renewable energy production in order to achieve a new level of CAS in which:

- The energy of the district is produced by the existing buildings through the installation of solar integrated systems (PV/STC);
- The green strategies at urban scale mitigate the UHI mitigation effect reducing the themal comfort at pedestrian level in four examined Eixample's courtyards.

Bibliography

[1] United Nations, Department of Economic and Social Affairs, Population Division, "World Population Prospects: The 2012 Revision, Key Findings and Advance Tables," 2013.

[2] United Nations, Department of Economic and Social Affairs, Population Division, " World Urbanization Prospects: The 2011 Revision," 2012.

[3] M. Tadi and S. Vahabzadeh Manesh, "Urban Morphological Transformation Via Urban Constituent Optimization: A Sustainable Neighborhood Design Based On Integrative Modification Methodology," in *International Conference on Green Building and Optimization*, Shenyang, 2012. ISBN 978-0-7918-6013-7

[4] M. Tadi, S. Vahabzadeh Manesh, M. Hadi Mohammad Zadeh and A. Naraghi, "Environmental and energy performances optimization of a neighborhood in Tehran, via IMM® methodology," *International Journal of Engineering, Science and Innovative Technology,* vol. 3, no. 1, 2014. ISSN No: 2319-5967

[5] M. Tadi, S. Vahabzadeh Manesh and G. Lobaccaro, "Neighbourhood Transformation via Multiscale Urban Optimization.," *Journal of Engineering Technology,* vol. 2, no. 1, pp. 1-8, 2013. DOI: 10.5176/2251-3701_2.1.34, ISSN: 2251-3701

[6] IMM® - An International Design Laboratory for Urban Sustainability, IMM® LAB, 2013. [Online]. Available: http://www.immdesignlab.com/immdesignlab.com/Home.html. [Accessed 01 07 14].

[7] BCNecologia, Complexity, Barcelona a compact and complex mediterranean city, a more sustainable vision for the future, Barcelona: A.E.U.d. Barcelona - Municipality of Barcelona, 2009.

[8] N. M. Gausa, Hacia un nuevo abordaje de la ciudad y el territorio contemporaneos. 2009., Barcelona: Multi-Barcelona, Hiper-Catalunya, 2009.

[9] "DIVA-for-Rhino," Solemma, [Online]. Available: http://www.solemma.net/. [Accessed 7 1 2014].

[10] Michael Bruse & Team, "ENVI-met," Michael Bruse & Team, [Online]. Available: http://www.envi-met.com/. [Accessed 5 1 2014].

[11] A. Behfar, M. Riyahi Alam, R. Shahmoradi, M. Tadi and S. Vahabzadeh, "Optimizing energy performance of a neighborhood via IMM® methodology: Case Study of Barcelona," *Iinternational journal of energy and environment,* vol. 7, no. 2, pp. 74-85, 2013. ISSN: 2308-1007

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Towards near zero energy buildings: energy storage, demand side regulation and renewable energy integration. "The autonomous office" case study.

Speakers:
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[1] Arup, Madrid, Spain

Abstract: The purpose of this article is to describe the energy strategy generation systems from reneweable sources, mainly from a photovoltaic and micro-wind origin, combined with the cogeneration of bio-oil. The building aims to operate with the greatest applied to an office building built in the north of Spain with the aim of achieving "near-zero energy" requirements. The building forms part of the LIFE project funded by the EU and has been designed and is being built by integrating ambitious passive strategies, low energy consuming mechanical installations and power possible autonomy through storage strategies and demand regulation, which will allow it to optimize the "intelligent" energy exchanges and balances with the electrical power network. This article describes the entire evaluation and integrated design process in detail through the means of a dynamic simulation of the set of followed energy strategies to reach the independent objectives laid out in the project.

Near-Zero Energy buildings, demand regulation, energy storage

Introduction and context

The European directive 2010/31/UE- 2010, relative to the energy efficiency of the buildings, defined the objectives and aspirations for the near-zero energy buildings, among other aspects. In line with this directive, in the focused project of this article, work has been carried out on a set of measures to improve energy efficiency of an office building in Asturias, by taking climatic conditions and local peculiarities into account whilst maintaining interior comfort environmental conditions and economic viability.

The studied building is a near-zero energy building as it has a high level of energy efficiency and thus requires very low energy. The required energy is supplied from renewable energy sources such as integrated solar photovoltaic systems complemented by micro combined heat and power fuelled by recycled oil.

The concept of energy autonomy planned for this project does not aspire to the permanent isolated operation, which in many cases would be contrary to the principles of the optimum level of profitability also established in the above cited directive. "Autonomy" is considered as the regulatory capacity of the demand for electricity from the network, that allows the management of optimum levels of profitability based on market signs and conditions. The operation of the building would be optimal within the electrical context of a "smart grid" network with a mature electrical market, truly liberalized, in which the demand is able to

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become a recognized agent for other representatives of the electric sector. However, this regulatory capacity of demand and self-sufficiency is also very useful and necessary in a less favorable regulatory framework such as the existing one in Spain. This article also describes the storage capacity of the passive building systems which will indicate the regulatory capacity and management of the balances and exchanges between local renewable production, domestic demand, and its exportation to the external network. In this sense, the project has attempted to use electricity as the main energy vector which has led to opting for efficient electric air conditioning systems through heat pumps and transmission systems embedded in structural slabs. In particular, the ability to disconnect the "load shedding" that the passive systems could impose on the studied building is analyzed.

Below, the set of strategies for energy optimization are described in detail. These have been implemented to achieve the "near-zero energy consumption" objectives.

- **Optimization of passive behaviour**

The first step in the energy optimization process has been to evaluate the passive behaviour of the building, as contemplated in the initial design. According with this objective, a simulation of the building was carried out in free evolution i.e. without mechanical air conditioning or ventilation systems. This type of simulation helps to evaluate and identify periods of the year and the various areas of the building that do not achieve the comfort conditions and to also propose the most appropriate energy improvement strategies.

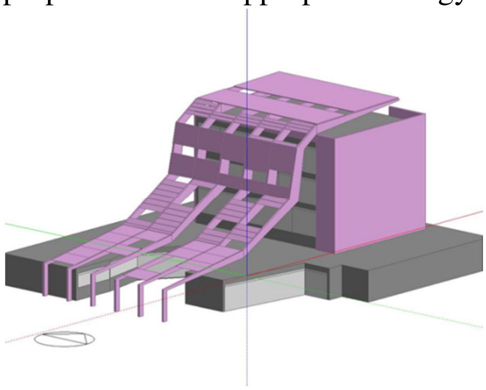

Figure 1: Model of BFC building

The energy simulation software "DesignBuilder" was used for the building simulation in free evolution. Figure 1 shows the geometric model of the BFC building. It is a four-storey building with a semi-underground floor for different uses and three floors of office space. The main façades are glazed and are oriented to the South and North.

The dynamic simulation also included the constructive aspects, modelling of natural lighting, natural cross-ventilation and photovoltaic façades to the East, South and West sides.

The following figure shows the evolution of temperature in the office area of the second floor (considered as the building's representative) and compares it to the comfort temperature band (20-26ºC). The analysis of the temperatures along with the climatic data (temperature and solar radiation) allowed to identify the various causes of discomfort in the building, in free evolution mode, as shown in figure 2.

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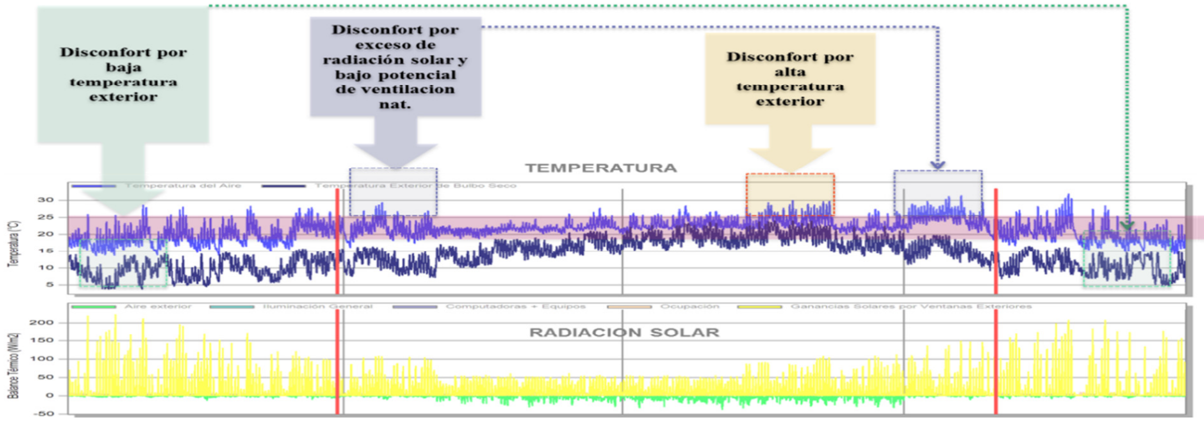

Figure 1. Behaviour of the building in free evolution. Interior temperatura of the offices.

The analysis of energy balances through the building's envelope also indicated that the glazed windows and shades are the critic element in the passive design of this building since they constitute a high percentage of the building's envelope area and also constitute thermal bridges in insulating the building to have a greater heat transmission coefficient than the opaque walls.

The first proposal to improve the thermal behaviour of the building was to optimize shading, so the photovoltaic canopy was designed in such a way that it would let solar radiation pass through in the winter months and block it from passing in the summer. An optimal design that lengthens the shading period from April to October was looked at. Shading optimization reduces the hours of discomfort in the summer by blocking solar radiation in the months to the end of August and September, however in the winter, beneficial radiation is let through. The analysis showed that the initial configuration of the shading devices was not sufficient for the adequate protection for the months at the end of the summer and beginning of autumn when solar radiation was still not beneficial despite the relatively mild summers in Asturias.

The second proposal to improve the interior comfort of the building was the change to more insulated glazed windows i.e. with a lower U-value to the one initially proposed in the Basic Project. Improvement to the heat transmission coefficient of the glass helped to improve the level of glass insulation and building insulation which resulted in less heat loss in the winter and less profit in the summer.

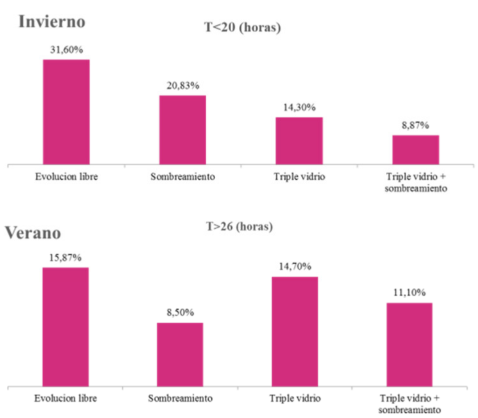

Figure 3: Hours of discomfort

The following figure shows the percentages of hours of discomfort for each of the analyzed cases. As a result of the passive proposals, it can be seen that the number of hours that the energy consuming

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installations are necessary for to maintain comfort, drastically reduce.

The following table shows the global heat transmission coefficients for the main elements of the building envelope.

	Heat transmission coefficient w/m2K
South and North façades	0,257
East and west façades	0,128
Sorth and North glazed windows	0,78
Plant cover	0,144

- **Selection and optimization of systems. Optimization of assessed active systems.**

The second step in the global energy strategy to achieve a "near-zero" building was to select the best possible mechanical systems to respond to the demand of the building. In line with the strategy to use electricity as the main energy vector for design, the use of electrical air conditioning solutions based on heat pumps combined with integrated radiant systems was proposed. The radiant systems which require moderate temperatures of warm and cold water allow the heat pumps to work very efficiently, especially in temperate climates such as in Gijon. The use of geothermal heat pumps compared to aerothermal heat pumps was analysed without justifiing the additional costs of the geothermal heat exchanger with savings derived from the relative increase in efficiency. The use of water compared to air in the building's interior allows the integration of radiant systems and the use of water to absorb residual heat from the micro combined heat and power system as well as the inclusion of possible additional elements of renewable energy accumulations and demand side regulation through water storage.

With the aim of analyzing the behavior of different radiant systems, a partial model of the building was developed in TRNSYS software. With this software, the thermal and dynamic behavior of the thermo-activated slab was analysed and a comparison was made with the behavior of conventional radiant systems (under floor heating and cooled ceiling with water tubes close to the emitting surface). The results of the simulation indicated that both systems obtained comfort conditions in the office area, although through means of different dynamics.

As under floor heating has lees inertia, it constantly turns on and off compared to the thermal behavior of the activated slab, which is more stable. Daily oscillation of average temperature of the under floor heating is much higher than that of the thermo-activated slab. This same effect was also observed in the interior temperature of the climatized rooms. The climatized spaces using a thermo-activated slabs showed lower daily thermal oscillation than the climatized spaces by means of a conventional radiant heating system.

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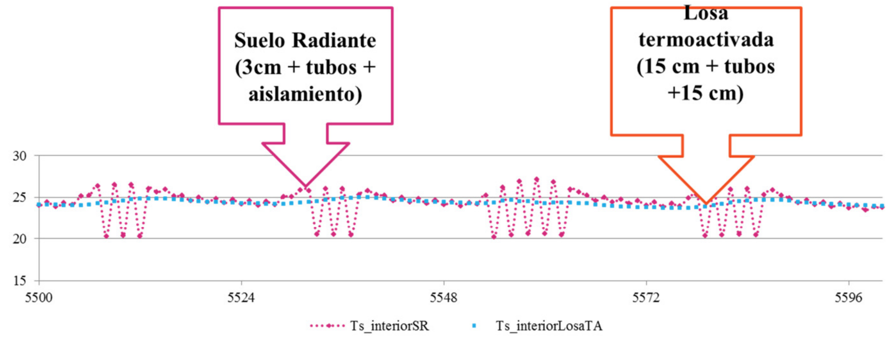
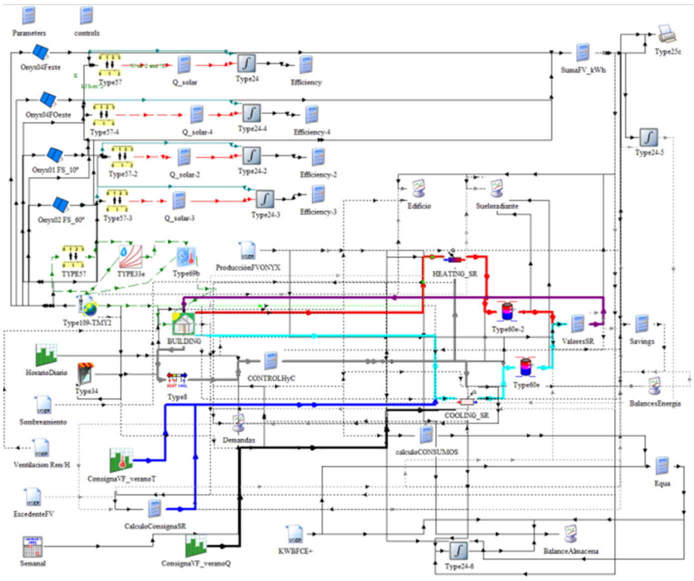


Figure 2. Surface temperatureof the transmission surfaces. Cooling mode. Evolution during 4 days of summer.

Charging time of the analysed radiante systems was calculated. The results of the simulations showed that the thermo-activated slab took about 3 days to charge (in typical office use); whilst under floor heating took less than a day.

Based on the idea that the intelligent connection between efficient production, storage capacity and demand management are requirements for any building that aspires to be energy efficient, the solution that was finally adopted to climatize the building was the use of "thermal-active tubes". This solution consists of a 30cm concrete slab which contains a system of tubes in its central part for heating and cooling, which is produced simultaneously through the floor and roof. In addition to being a high efficient system, in energy terms, the thermo-active slab provided the building with a thermal storage system integrating demand-side regulation strategies whilst active, which are essentital to achieve near-zero requirements. Finally, natural ventilation systems are combined in "mixed mode" with mechanical ventilation systems with heat recovery that guarantees the quality of air at all times of the year.

Global assessment of the building and renewable energy. Towards a"net-zero energy building".



The following step of the energy strategy, once the demand and mechanical systems had been optimized, was to evaluate the energy percentage (required or surplus) generated by renewable systems and compare this with the energy consumption of the building in order to assess the compliance level of the "net-zero energy building" requirements and propose necessary actions for its compliance.

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A model using TRNSYS software was developed for this reason which facilitated to couple the simulation of the building with the systems of renewable production (photovoltaic and mini wind turbine energy) included in the project.

The model of the building includes a second skin as a photovoltaic canopy to the south side, and also integrates photovoltaic panels in the ventilated façades to the east and west side. The building also has a small wind turbine.

The following figure represents the BFC building's annual consumption of electricity and renewable energy production. The graph shows hourly integrated values throughout the year.

Figure 3. Building consumption and photovoltaic energy production. Integrated hourly data (KWh)

The previous figure shows the difference between production and consumption as well as the annual energy balances. Although close to net-zero, it is not net-zero for the total amount of consumed energy. It should be noted that the indicated calculation for energy consumption has not only included the regulated consumptions that are included in the European directive but also the electrical consumption of the charging process (information technology and others) that are not required in the definition of the "near-zero energy consumption building" directive. With these added loads, consumption is higher than production in the winter, whilst production exceeds consumption in the summer. Preliminary calculated energy consumption shows that the comparison between production and consumption does not exceed 20MWh/year, which places the BFC building very close to the global net-zero figure, which includes all the energy consumption of the building operation.

In order to fulfill the autonomous energy requirements for the LIFE project, a micro combined heat and power system with recycled oils that is able to provide the required energy to reach a zero energy annual balance has been included in the project. However, the objective to become autonomous and self-sufficient implies that it is necessary to equip the building with different storage components and demand side regulation strategies that permits reducing and balancing out the differences between production and demand.

Storage strategies and "demand side regulation".

Incoporating storage and demand side regulation components will help to optimize the "intelligent" exchanges with the electric power network, giving the building greater flexibility. This flexibility would allow to wait for market signs in order to operate in a "cost optimal" way, and at the same time attenuate the current negative regulatory framework in Spain.

In line with the strategy to increase the building's autonomy, the ability to disconnect the loads "load shedding" that the thermo-active slab system could impose on the building has been analysed. A study has been carried out on what would happen in comfort terms, if the building became disconnected from the network during peak periods in the Spanish electricity system, for example on summer days from 15:00 to 17:00h. The dynamic simulations carried out indicate that the building could stop the air conditioning systems for two hours every afternoon, whilst maintaining interior comfort conditions. Associated regulatory capacity and savings would be of 0.25 Mwh/year. The results also indicate that the switch-off period could even extend throughout the whole afternoon if the slab load was at a lower temperature i.e. at 17ºC rather than 18ºC, producing total savings and regulatory capacities of up to 0,5 MWh/year.

This would correspond to the additional strategy to store excess energy (produced by the solar systems) in the form of subcooling the thermo active slab. Although on the scale of a single building, the associated regulatory capacity with inertia will have a limited impact (kw scale), with an adequate regulatory framework that would allow the aggregation of demand, and the office and commercial buildings could become important elements of storage and demand management. Other elements that are being analysed in the project are the inclusion of battery fuel and the possible use of batteries of electrical cars parked in the building. These technologies will become key elements in electrical systems for the future, by facilitating the integration of renewable energy sources whilst working to provide greater efficiency to the entire electric power system.

Bibliography

[1] Directiva 2010/31/UE del Parlamento Europeo y del Consejo de 19 de mayo de 2010 relativa a la eficiencia energética de los edificios (Refundición).
[2] http://theautonomousoffice.com/
[3] Design Builder Manual, V3.0 (http://www.designbuilder.co.uk/)
[4] Transient Systems Simulation program (TRNSYS) (http://sel.me.wisc.edu/trnsys)
[5] Electricity storage technologies (http://publications.arup.com/Publications)

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Study on the Establishment of Indoor Environmental Health Housekeeper System--Using Environmental Sensing and Consultation as an Example

Abstract: *The study integrates the two concepts of "health" and "intelligence" to develop a healthy environment iMOD (integrated Multi-media On Demand) sensing consultation system. By applying Android operating system and combining the intelligent tablet computer, the iMOD system interface includes: home page of environmental sensing, knowledge base of healthy environment consultation, and setting interface. The environmental sensing factors include environmental noise (Leq), illuminance, temperature and concentrations of carbon dioxide. The healthy environment consultation includes: common problems, health influence, evaluation standard, detection method, improvement method and maintenance management. The setting includes relevant parameter setting of environmental sensing and caution setting of management.*

The study is to propose an integrated environmental sensing consultation system optimizing man-machine interaction, to display sensed environmental dosage situation correctly and make it as an intelligent housekeeper system in accordance with dynamic sensory reaction of tablet computer triggered by environmental dosage information, care for users' health and improve living quality.

Key , Indoor Environmental Health, Sensing, Consultation, iMOD

Introduction

1) Research Motives

According to estimate of the World Health Organization (WHO) in the "World health report 2002", 36% of lower respiratory tract infections and 22% of chronic obstructive pulmonary diseases are due to the indoor air pollution. In 1997, the indoor environment expert, William Fisk, from the Lawrence Berkeley National Laboratory estimated that the productivity losses caused by the sick building syndrome reach 15,000 to 38,000 million USD per annum [1]. As pointed out by the American College of Chest Physicians (ACCP), most people spend more than ninety percent of their time staying in different indoor places; over one third of time of office workers stay in the office buildings, and whether the office environment is healthy or not has great impacts on the health and work efficiency of these office workers.

The research units of Taiwan government have been aware of the seriousness of the issue of indoor environment, attach importance to and conduct related studies on the indoor air quality (IAQ). According to the Environmental Protection Administration (EPA) and Environmental Analysis Laboratory, EPA has commissioned the Graduate Institute of Environmental and Occupational Health, National Cheng Kung University and Department of Architecture, National Cheng Kung University for investigations on the indoor air quality of office spaces in the north, center and south of Taiwan [2]. The results reveals that the cancer risk caused by formaldehyde in general office environment is one hundred times higher than 10-6 determined by the WHO, and the hazard index is also far larger than the standard value. 1. To summarize related factors impacting on the indoor environment, the important factors include: (1) building configuration and structure system; (2) architectural equipment system; (3) indoor decoration and use behaviors; (4) overall use management and utilization program [3].

Therefore, a lot of indoor environment problems result from bad management, such as opening and air conditioning pipeline not cleaned in office environment, too many persons, furniture and business equipment, high frequency of chemical detergent use etc. [3]. Aiming at the exposure dose in the indoor environment for offices of Taiwan people, the Executive Yuan has enacted and implemented the "Indoor Air Quality Management Law" on November 23, 2012, which establishes good regulations for preventing indoor air pollution in Taiwan.

2) Research Purposes and Significance

The present research ponders over the trend of future life and attempts to integrate the concept of environmental intelligence with the issue of health and develop an application program of "health guarantee in indoor environment", i.e. the iMOD (integrated Multi-media On Demand) of health in indoor environment, which is an environmental health management system integrating the environmental sensing and able to respond to human needs. In addition to the meaning of integration, i may also represent interior, intelligence and information. It can use the real-time information or images to remind the users, provide the information about current environmental exposure dose and help the health management in the interior environment indoors to maintain the quality of indoor environment and ensure the health of users and their high work efficiency, so that it not only improves the users' health, but also their life quality and work efficiency.

The research contains: the integration of the three domains: "intelligence", "digital" and "health". "Intelligence" refers to the construction of a logical system of triggering environmental events and responses, "digital" includes the integration of electromechanical information and image operation of user, and "health" is the essence of the research that focuses on establishing the database of healthy environment knowledge and guarantee methods, including sensing of environmental exposure dose, human body health effects. Besides mastering perception and responses of human body and selecting the proper environmental measuring methods, it also comprises the consulting services for health guarantee in indoor environment at any time and promptly provision of related healthy environment knowledge and guarantee methods; it may provide assistance to the health management of indoor environment and periodical maintenance, clean and care.

Therefore, the research takes the houses and offices as the space setting and environmental health management as the principle, with the primary purpose of constructing the application program of "health guarantee in indoor environment", so as to provide visual health management of indoor environment and create a healthy indoor environment, including: (1) environmental factor alarm and prompt of management information; (2) visualized interface according to user's need setting and use situation; (3) guiding the user to solve the indoor environmental problem by band to guarantee quality.

Literature Review

1) Related Work on Indoor Environment and Health

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According to the “Study on Comprehensive Indicators of Building Indoor Environment Health Control” for 2003, 2005 and 2006 in Taiwan, Taiwan people attach the greatest importance to the indoor air environment (22.5%), followed by thermail environment (14.2%), acoustic environment (13.7%), lighting environment (12.7%) and electromagnetic environment (11.3%). Also, people staying indoors generally encounter dry or irritated eyes or eye strain (59.4%), abnormal tiredness or drowsiness (41.6%), memory or attention deficit (38.4%), headache (30.5%), chest tightness (29.0%), and sneeze (25.8%). These symptoms are closely related to the indoor environment quality [4].

2) Environmental Sensing Technologies

At present, the environmental sensing technologies are still being develops in Taiwan by academic and civil research institutes like Industrial Technology Research Institute, Institute for Information Industry and Architecture and Building Research Institute, Ministry of the Interior. The related monitoring equipment and information integration technologies are becoming mature. Research teams has successfully integrated instruments and devices in the past [5], including monitoring of various indoor environment factors, such as temperature, relative humidity, concentrations of CO, CO_2, weather information (wind speed, wind direction, outdoor temperature, relative humidity, rainfall), as well as air conditioning equipment and electric window etc., connecting indoor sensors by wires, sending message to the transmission points of Zigbee, and transferring message of spaces through ZigBee communication module to Access Points between pipes each floor, which connect to the control panel by network wires; the small weather station outdoors is connected to the control panel by wires and the real-time environment message of all spaces is sent to the control computer. By using the program, the control computer receives all indoor and outdoor (small weather station) environment messages, computes by the program logic and drives related devices (transom window or total heat exchanger) for controlling environment, so as to achieve a healthy, convenient and comfortable environment by the intelligent techniques.

3) Human-Machine Interface and Energy Saving & Healthy Applications

The HMI (Human-Machine Interface) already develops from the Graphic User Interface (GUI) in the past and the Tangible User Interface (TUI) to, such as: Natural User Interface (NUI) using the five human senses for interaction and the Multimodal interaction interface, and the environment-perception human machine interface are being paid increasingly more attention to [6]. Related researches integrate the environmental sustainability or health issue to remind the user of economic or healthy life by intelligent life products, e.g.: the power-aware cord through ambient information display [7], use of mobile phones to remind users of maintaining the green transportation habits and achieving the effect of carbon emission reduction [8], several LED lamps replacing water meter to promote water conservation in the shower [9], and use of inAir system for sharing the indoor air quality measuring and display results and thus changing human behaviors to improve indoor air quality [10].

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Research Method

The research designs the iMOD sensing and consulting system for indoor environment health based on the results of related work. As shown in Figure 1, the system is designed in aspects of expert consulting and user operating. The visualized interfaces are operated on the Android system and the architecture includes the three main interfaces: Environmental Sensing homepage, Health Environment Consulting Knowledge Base and Settings. Environment Sensing has four different interfaces: acoustic, light, hot and air environments; Health Environment Consulting contains: Common Indoor Environment Problems, Health Impacts, Assessment Criteria, Measuring Methods, Improvements and Maintenance Management; Settings compromises the Environmental Dose Response Settings and the Environmental Device Management Settings. The iMOD sensing and consulting system uses the intelligence Pad as the terminal device to prompt the warnings of environmental factors and proper management message, and guide users to solve indoor environmental problems by their own preferences and use situations to guarantee the quality.

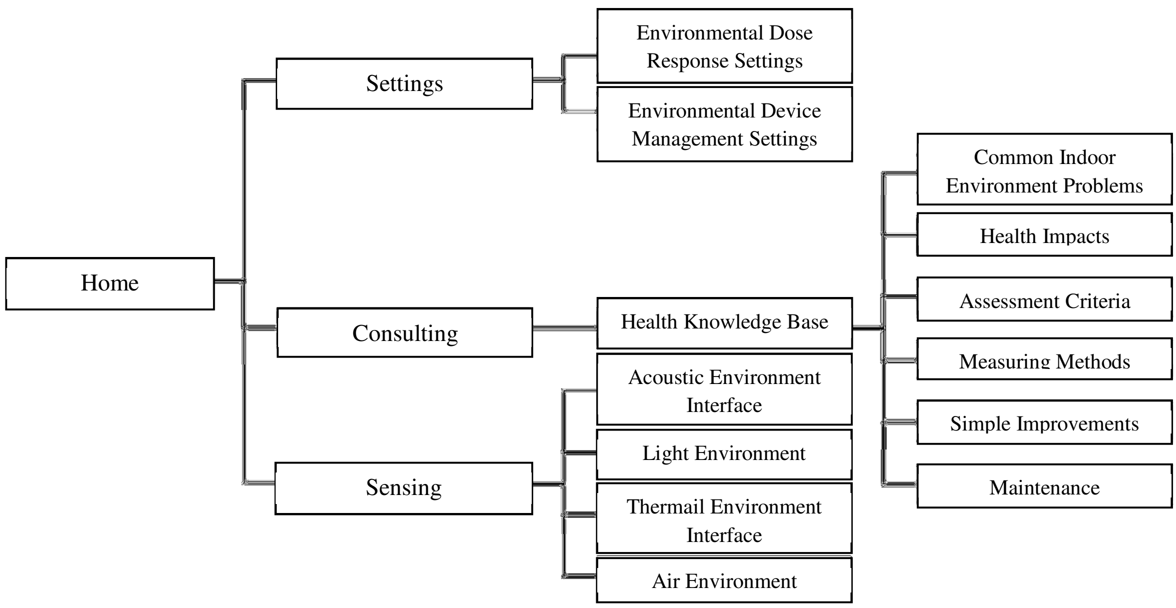

Figure 1 iMOD Sensing & Consulting System Architecture

Results and Discussion

According to the architecture in Figure 1, the App homepage of the iMOD Sensing & Consulting System is shown in Figure 2, where all integrated environmental monitoring information is clearly seen. Three shortcut keys are put on the top in the right to respectively navigate to the Health Knowledge Base (KNOW), HELP and SET. The central environment information can connect to the environmental monitoring situations. For example, if the environmental dose is excessive, the message will display in red, connect to Improvements for a solution. The radar diagram in the lower place can help the user to judge whether the environment is comfortable and healthy.

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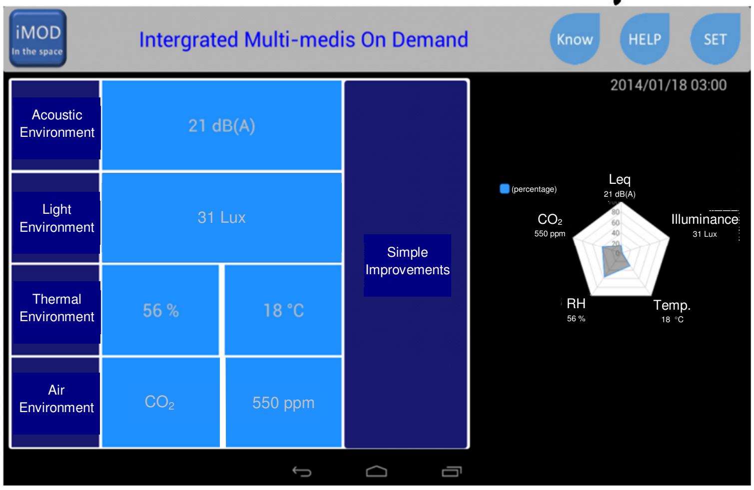

Figure 2 Home of iMOD Visualized Interface

As shown in Figure 3, the environmental factors monitoring can be displayed in visualized simple charts, including mainly environmental noise (Leq), illumination, temperature, relative humidity and CO_2 concentration; the real-time measured values, the past mean values, maximum and minimum values and comprehensive assessment scales etc. are displayed. Health Environment Consulting Knowledge Base gives explanations and suggestions on problems and causes of different environmental factors, and is divided into 6 parts: Common Indoor Environment Problems, Health Impacts, Assessment Criteria, Measuring Methods, Simple Improvements and Maintenance Management. As a result, the user can understand and cognize the changes in ambient environment and feedback and maintain the indoor environment he or she stays in.

Figure 3 iMOD Visualized Sensing Interface

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The iMOD system can be set according to use situations, as shown in Figure 4. It comprises the Environmental Dose Response Settings and the Environmental Device Management Settings. The former can set the environmental dose criteria, warn time, warn type, warm ring, warm picture and notice sound volume to one's own preferences; the latter sets the warning and self-inspection schedule for measuring instruments, lamps and air conditioners, for improving the service life and efficiency of building devices.

Figure 4 SET Interface of iMOD Application

The research designs the above-mentioned visualized interface for the system integrating the handheld device to guide the user to improve environment by hand, set the response alarm and periodical self-inspection according to need. User's simple operation of managing and maintaining environment is the emphasis of the research. Various environmental factors are simplified and integrated to combine the environmental factors impacting human health with life technologies. In addition to displaying environmental changes, it fuses into active and passive guidance design to make itself amicable and popular among people.

Conclusion and Suggestions

This study investigated indoor environmental factors on user's demand, integrated the application with handheld device and simplified the user's learning time and operating of iMOD sensing and consulting system interface, in order to quickly obtain effective and substantively helpful information. Considering the cost, the visualized interface of iMOD sensing and consulting system has the basic functions integrating intelligent, digital and health functions to ensure simple operation, maintain the environment and user's health and implement the health guarantee and management of indoor environment.

References

[1] Fisk, W.J., and Rosenfeld, A.H. (1997). Estimates of Improved Productivity and Health from Better Indoor Environments. *Journal of Indoor Air*, Vol.7, pp. 158-172

[2] Wu, P.C., Li, Y.Y., Lee, C.C., Chiang, C.M., Su, H.J. (2003). Risk assessment of formaldehyde at typical office buildings in Taiwan. *Journal of Indoor Air*, Vol. 13 Issue 4, pp.359-363.

ISBN: 978-84-697-1815-5

[3] Chiang, C.M. (2005). *Research on Constructing Sustainable Environment Integrating Lifecycle and Health Risk Assessment – General Program and Subplan III: Health Risk Assessment in Lifecycle for Physical Environment of Building (III)(2/2)*. National Science Council NSC 93-2621-Z-006-004.

[4] Chen, N.T. (2007). *A Study on Natural Ventilation Efficacy of Wind Deflector*. doctoral dissertation, Graduate Institute of Architecture, National Cheng Kung University.

[5] Chen, N.T., Chiang, C.M. Liu, K.S. Chen, S.Y. and Chiang Y.C. (2012). Designs of Intelligent Environ-Control System Based on Energy Saving and IEH- Study on S House. *Applied Mechanics and Materials*, Vol.121-126, pp.2653-2660.

[6] Ma, Y.P. (2011). *Aesthetics of Interaction Design for Environmental Awareness*. doctoral dissertation, Graduate Institute of Architecture, National Cheng Kung University.

[7] Gustafsson, A. & Gyllenswärd, M. (2005). The Power-Aware Cord: Energy Awareness through Ambient Information Display. CHI 2005, April 2–7, Portland, Oregon, USA.

[8] Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., Landay, J.A. (2009). UbiGreen: Investigating a Mobile Tool for Tracking and Supporting Green Transportation Habits. CHI 2009, April 4–9, Boston, Massachusetts, USA.

[9] Kappel, K. & Grechenig, T. (2009). “show-me”: Water Consumption at a glance to promote Water Conservation in the Shower. Persuasive’09, April 26-29, Claremont, California, USA.

[10] Kim, S. & Paulos, E. (2010). inAir: Sharing Indoor Air Quality Measurements and Visualizations. CHI 2010, April 10–15, Atlanta, Georgia, USA.

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Session 69:

What criteria should be considered to define benchmarks?

Chairperson:

Larsson, Nils
Executive Director. IISBE

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Building sustainability assessment and rating systems in Italy: the definition of benchmark values

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Abstract: *During the last two decades, many methodologies have been developed, showing a considerable utility to assess, certify and rate the energy or, more properly, the sustainability performance of buildings. However, from the analysis of the state of the art, focusing on the Italian context, two main issues emerge: the absence of a complete evaluation tool, totally based on the measurability concept, and the lack of evaluation criteria referred to the whole building life cycle. Firstly, the paper briefly illustrates the steps leading to the development of a new methodology to evaluate the sustainability level of Italian buildings, showing how its structure could be defined. Afterwards, the research emphasizes the importance of 'benchmark values', presenting the application of the new rating system on some exemplary constructions, with a focus on those assessment criteria which have been characterized, until now, by the absence of reference or limit values within the Italian context.*

Sustainable buildings, rating systems, life cycle, benchmarks.

1. Introduction

Over recent years, due to a growing awareness of the constructions'impacts on the Sustainable Development, the building sector has been object of rapid changes. Throughout the world, policies and regulations have promoted the growth of new products and processes to support the reaching of an increasing sustainable built environment. To this aim and, additionally, to face with the complexity that sustainability involves in construction field, the development of specific assessment methods for buildings represents one of the possible effective means. All around the world, many sustainability rating systems have been developed and the most widespread are: BREEAM (Building Research Establishment Environmental Assessment Method) developed in UK; LEED system (Leadership in Energy and Environmental Design) created in USA; CASBEE (Comprehensive Assessment System for Built Environment Efficiency) established in Japan; DGNB (German Sustainable Building Council) made in Germany; HQE (High Environmental Quality) developed in France; SB (Sustainable Building) method, internationally defined, etc. [1].
Therefore, different countries have established their own rating systems, developing new assessment schemes or adapting existing methodologies to their context. In Italy, for instance, the two most diffused protocols are: LEED Italy and ITACA Protocol, derived, respectively from LEED U.S. and SB method.
An analysis of the current Italian state of the art has shown that, for many evaluation criteria within the existing rating systems, the achievement of specific levels is only defined in descriptive terms. Nevertheless, the qualification of a construction work, in order that it could be considered completely reliable, should meet two fundamental requirements, which are: *measurability and objectivity.*

Moreover, within the same context, the lack of evaluation criteria referred to the entire life cycle of buildings has emerged, pointing out the need of a life-cycle-oriented sustainability tool, which, currently, represents one of the main border developments for sustainability evaluation methods.
The research aims to present an innovative approach for the development of a new sustainability rating system for residential buildings, with a special reference to the Italian context. The basic assumption of the research concerns the purpose to reduce, as much as possible, the degree of subjectivity wich could characterize not only the specific contents but also the definition process of a new sustainability assessment tool. Therefore, with the main goal of defining a holistic protocol mostly based on measurability and objectivity, the different and consequential stages leading to its development are breafly shown and discussed. Afterwards, a particular stress is given to the step related to the establishment of benchmark values, which have to be defined for the identified sustainability indicators, in order to get a final comparison rating scale. In the present paper, a possible way to define reference values is proposed, which is the analysis of reference buildings, as typical examples of a certain type of construction work. Therefore, the paper focuses on the definition of possibile reference values, evaluating, specifically, those assessment criteria which, so far, have been characterized by no benchmarks within the Italian context.

2. Method

2.1 Characterization of the protocol structure

To define the structure of the proposed rating system, a critical review of the already existing schemes and of the ongoing standardization work has been performed.
With the main purpose to reach the objectivity, not only of the protocol' s structure but also of the process leading to its definition, two mathematical multi-criteria techniques have been properly applied: the DEMATEL [2] and the AHP [3]. To support the application of these methodologies a panel of experts has been formed, whose members belong to the Italian research world, so that their evaluations mainly reflect this national context.
First of all, the study has focused on the sustainability evaluation areas, which are global categories related to a key-sustainability aspect, e.g., the impact on site; the energy consumption; the use of materials; the occupant wellbeing; etc. Through the application of the above mentioned methods, interrelations and repetitions among evaluation areas, belonging to the existing sustainability systems, have been identified and analyzed [4]. Afterwards, the research has concentrated on the choice of the assessment criteria, representing specific sustainability requirements within the global categories. The main selection principle has been the measurability and objectivity of each criterion. Moreover, by means of DEMATEL and AHP, both assessment areas and criteria have been weighted in order to characterize their relative importance within the final protocol structure. Thereafter, each of the evaluation criterion has been associated to a potential indicator, which is a specific parameters allowing to measure the related sustainability performance. An analysis of potential indicators by the measurability point of view has been done, choosing a final indicator only if objectively quantifiable.

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In conclusion, the structure of the protocol consists of twelve general assessment areas and thirty-five criteria, some of which have been selected among those already developed within the existing protocols, whereas others have been added or completed and improved.

Table 1. *List of sustainability assessment categories and criteria within the suggested protocol*

Categories	Criteria	Categories	Criteria
Impact on site	Land use Ecological impact Preservation of soil permeability Maximization of green spaces Impact on microclimate	Occupant wellbeing	Higrothermal comfort Acoustic comfort Visual comfort Electromagnetic indoor pollution Controllability of comfort conditions
Pollution	Building life cycle impacts Outdoor light pollution Outdoor acoustic pollution	Functional quality	Barrier free accessibility Building adaptability Space efficiency
Waste	Construction and demolition waste Operational waste Wastewater	Process quality	Integrated planning Construction quality assurance Commissioning
Water	Fresh water consumption Reuse of rainwater	Costs	Building lyfe cicle costs
Energy	Non-renewable primary energy Renewable primary energy Overall system efficiency	Technical quality	Fire safety Structural stability Building envelope quality Building maintenance
Materials	Recycled and/or recovered content Non renewable raw materials Hazardous substances materials Embodied energy	Indoor air quality	Ventilation rates/ Air pollutants level Quality of ducted air

2.2 The benchmarks' definition

A benchmark represents a fundamental concept within sustainability assessments, meaning a point of reference by which parameters' values can be measured and compared.
As ISO 21931-1 [5] states: '*Reference levels and/or scale of values can be used in the quantification of indicators within the assessment method'*. Therefore, quantitative information about building sustainability performance need to be referred to predefined baseline scales of values.
Possible sources for the development of benchmarks are, e.g., codes or regulations' prescriptions, experience based and statistical values, political target values, and others. In the present paper it has been proposed another possible way to establish benchmark values, which is the reference to some exemplary constructions, representing typical models of specific type of buildings and uses, as for instance residential buildings.
As already specified, the proposed protocol has been developed including some specific criteria, which integration have been neglected, until now, by the current Italian sustainability rating systems. Since these criteria lack of reference or limit values, their computation, on some exemplary buildings, could usefully support the development of potential benchmarks.

2.3 Case studies

The exemplary buildings, required for the characterization of benchmarks, have been derived from the European project TABULA [6]. Specifically, this project has provided the definition

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of the Italian residential "building-type", with the aim to represent a specific building category (from single family house to apartment block), in a certain construction period and climatic zone, with its average energy performance and potential energy savings.
For the present research, two buildings have been analyzed: a single-family house (SFH) and a multi-family building (MFB), representative of the recent Italian building stock (after 2005). Unlike TABULA project, which consider just an Italian middle climatic zone (E), for this study, the buildings have been located within three different cities, Turin, Florence and Bari, belonging to the main Italian climatic zones: C climatic zone (CCZ), from 900 to 1400 degree-days; D climatic zone (DCZ), from 1400 to 2100 degree-days; E climatic zone (ECZ), from 2100 to 3000 degree-days. The analyzed buildings are characterized by tipical Italian massive structures, whose thermal-physical properties have been defined so as that they correspond to the requirements established, for each climatic zone, by the Italian National energy legislation (D.lgs 311/2006, D.P.R. 59/2009). Particularly, external walls are made by hollow bricks together with external EPS insulation; windows have low-e, air filled double glass, with wood frame; floors and ceilings consist of reinforced brick-concrete slab, with a high level of insulation, through EPS or XPS panels. As regard the HVAC system, the heating system provides for a condensing boiler (efficiency coefficient, $\eta = 0,98$) and underfloor panels, while the domestic hot water (DHW) system consists of a single condensing water heater (efficiency coefficient, $\eta = 0,99$). The cooling and mechanical systems are absent.

Table 2. *Main geometrical features of the analyzed buildings*

GEOMETRICAL DATA	Single-family house	Multi-family building
Heated storeys	2	3 (+ 1 unheated)
Gross heated area	192	915
Reference area	192	1220
Gross heated volume	623	2920
Shape factor	0,72	0,54

3. Analyses and results

Within the developed protocol, three criteria have been chosen for the analyses, namely: “building life cycle impacts” belonging to the category “pollution”, “non-renewable primary energy” and “renewable primary energy”, within the category “energy”.
The environmental impacts and the energy-related outputs, during the whole building life cycle, have been evaluated through the‘Life Cycle Assessment’ (LCA), a methodology that is part of the ISO 14000 environmental management standards (ISO 14040:2006 and 14044:2006). For the LCA analyses, three main life cycle stages have been considered: pre-use phase (raw materials’ supply, production, transport and building construction, refurbishment); use phase (operational energy use: heating, hot water, electricity and operational water use); end-of-life phase (building deconstruction and material transport and disposal). An inventory of the quantities of the main materials used in the building has been realized, including construction waste factors and maintenance amounts. Transportation distances and data on the equipment energy consumption during the building site processes

have been derived from literature [7]. The use phase has been inventoried according to the architectural and thermo-physical features as well as the plants' characteristics, available in TABULA project. The energy consumption related to the use phase, for heating and DHW system, has been evaluated by means of dynamic energy simulations, through EnergyPlus program. Moreover, electric energy and water consumption have been derived, respectively, from statistical data and reference standard values. Finally, for the end of life stage, three main steps have been considered: selective dismantling of re-usable/recyclable components (windows, system alluminium); controlled demolition of the building; operations for the demolition waste recycling, re-use or landfill. Some data refered to this uncertain life phase, such as the energy spent for the equipments, have been taken from similar studies, available in scientific literature.
The life cycle inventory modelling has been performed through the SimaPro 8 software, with reference to Ecoinvent 2.2 database. To define buildings' environmental impacts and the effects of the different substances in the ecosystem, six representative indicators have been computed, through the ReCiPe method, specifically: climate change [CC] (kg CO_2 eq); ozone depletion [OD] (kg CFC-11 eq); terrestrial acidification [TA] (kg SO_2 eq); freshwater eutrophication [FWE] (kg P eq); marine eutrophication [ME] (kg N eq); photochemical oxidant formation [POF] (kg NMVOC). As regard the definition of the amounts of renewable and non-renewable energy, pre-use and end of life phases have been characterized directly within Simapro software; instead, the amount related to the use phase, got through the dynamic energy simulations, has been subsequently associated to the fuel and electricity eco profiles available in Ecoinvent database, with reference to natural gas and Italian electricity mix. The indicators, evaluated by the Cumulative Energy Demand method, have been precisely: fossil non-renewable energy; nuclear non renewable energy; biomass non renewable energy; biomass renewable energy; wind/solar/geothermal renewable energy; water renewable energy.
In order to compare the two different buidings, a functional unit has been defined considering their reference area and life span (m^2/y). The lifetime selected in this paper has been 50 years, which represents a common value for LCA of residential buildings; instead, the reference area has been referred to the total floor area, including that of the unheated storey. Figs. 1, 2 show the final indicators' results, for both SFH and MFB in the three Italian climatic zones (ECZ, DCZ and CCC), including a final grey column showing the average value (AV). As regards the energy-related indicators, it's evident how the total non renewable amount of energy is considerably higher than the renewable one. This is due to the larger use of non renewable energy resources for both building materials and use phase energy. Additionally, the major contribution is from the use phase, around 70%, with the pre-use phase contributing 35% and the end of life phase the remaining 5 %. As regards the environmental indicators, a distinction can be made between those mainly influenced by the pre-use phase and those mostly affected by the use phase. Specifically, CC, TA and POF are mainly related to the production and the use of natural gas and electricity; instead, OD, FEW and ME are mostly influenced by the building construction, particularly by the envelope and bearing structure materials used.

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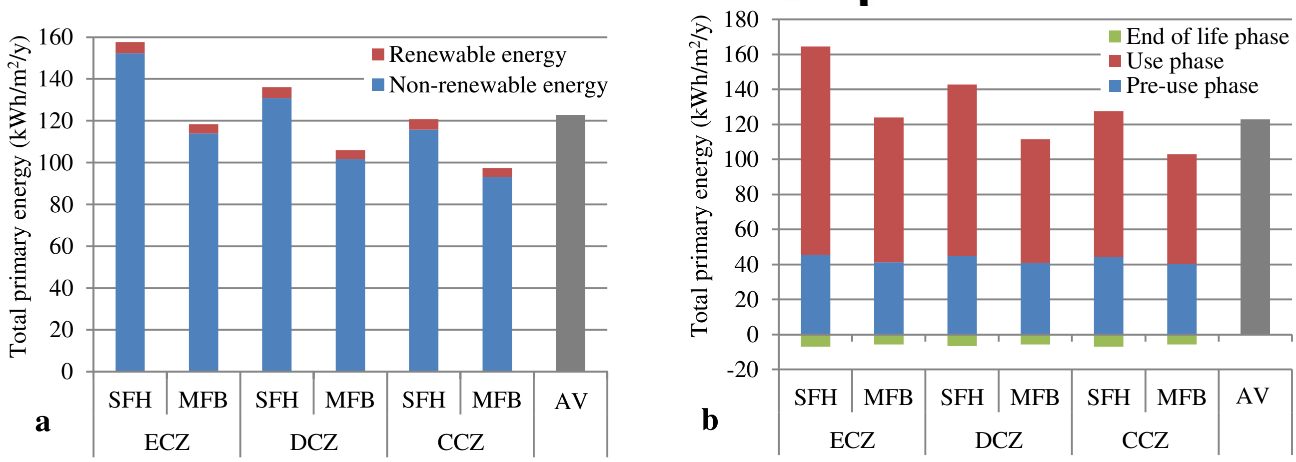

Fig.1. Total primary energy for single- family house (SFH) and multi-familybuilding (MFB) in three Italian climatic zones (ECZ, DCZ, CZC)
[a: Total primary energy split in non-renewable and renewable during the whole life cycle; b: Total primary energy during pre-use, use and end of life phases]

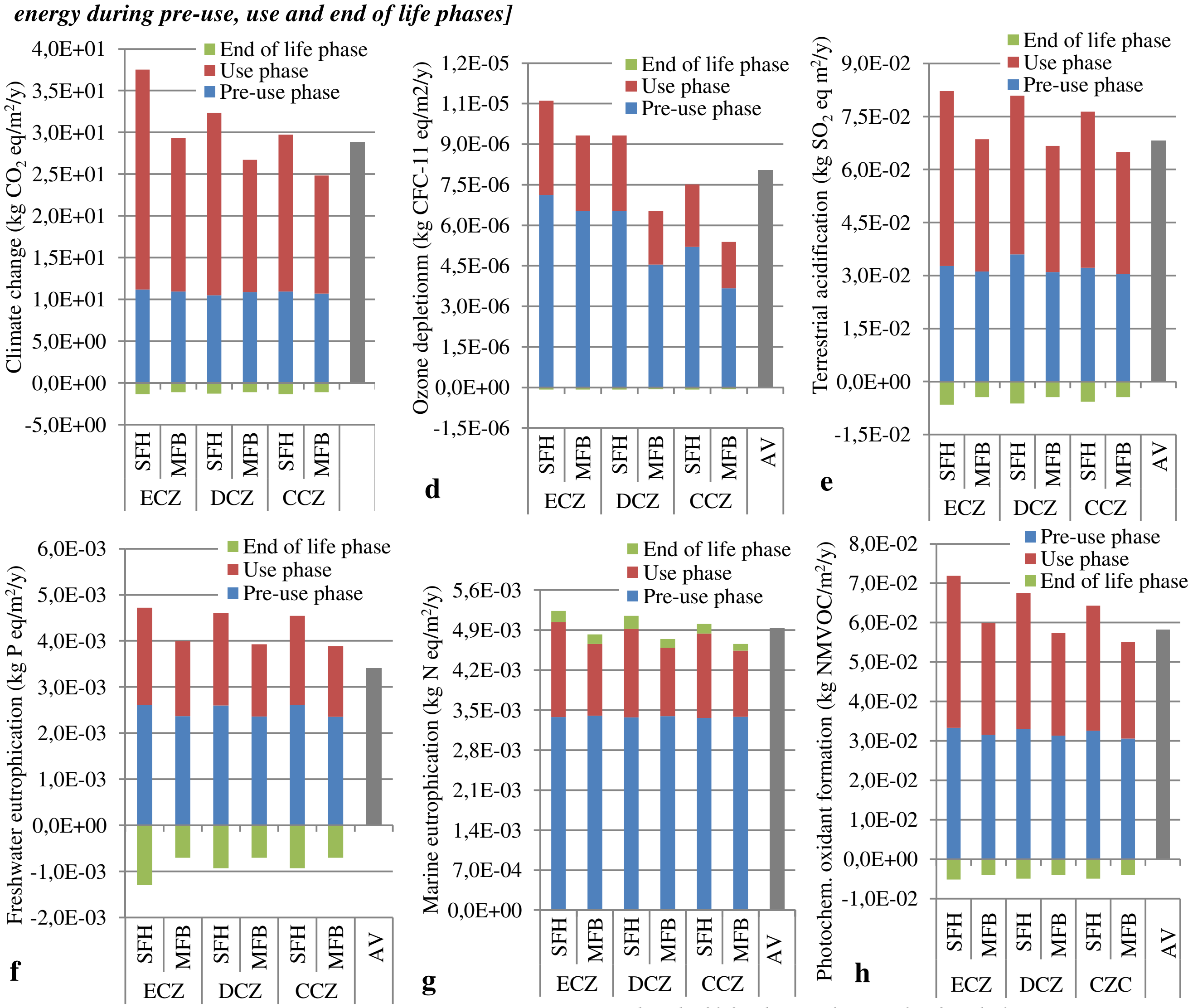

Fig. 2. Life cycle environmental impacts during pre-use, use and end of life phases, for single- family house (SFH) and multi-family building (MFB) in three Italian climatic zones (ECZ, DCZ, CZC)
[c: Climate change; d: Ozone depletion; e: Terrestrial acidification; f: Freshwater eutrophication;g: Marine eutrophication; h: Photochemical oxidant formation]

4. Conclusions and outlook

The paper proposes a possible approach to define a new sustainability rating system, throughout all its main stages, focusing on the Italian context, but with a potential extention to other countries, as well. Given the existence of many sustainability evaluation tools, the research analyzes their best practices and tries to bridge their gaps, providing a holistic framework, with the aim of reaching objectivity both in its contents and in the process towards its definition. Afterward, the need of benchmark values is faced, with a particular reference to those sustainability evaluation criteria that lack of reference or limit values.
The research presents some limitations which could emphasize future research directions.
As regard the first part of the study, for instance, the draft of the new protocol reflects only those existing rating systems applicable in Italy, although the other neglected systems present almost comparable features. Furthermore, the panel of experts is composed of members belonging to the academic world and sharing approximately a similar perspective.
Consequently, the future research might consider other possible mathematical methodologies of analysis and extending the Panel with additional stakeholders of the building sector.
Concerning the second part of the study, the benchmarks' definition process could be extended to the investigation of many different buildings, to accurately improve the reliability of benchmark values. For instance, given the stringent law requirements for energy efficient constructions, the study could enlarge its scope, considering different energy demand requirements, e.g. Passive House or Zero and Positive- energy buildings.

References

[1] T. Saunders, (2008). BRE, *A Discussion Document Comparing International Environmental Assessment Methods for Buildings*.

[2] M. Hiete, A. K., F. Schultman, (2011). *Analysing the interdependencies between the criteria of sustainable building rating systems, Construction Management and Economics*, 29:4: 323-*328, doi: 10.1080/01446193.2011.558105.*

[3] T.L. Saaty (2006), *Fundamentals of Decision making and Priority Theory with the Analytic Hierarchy Process. Pittsburgh. RWS Publishing.*

[4] R. Moschetti (2013), *Sustainability rating systems for buildings: a new methodological proposal,* Proceedings of YRSB13- iiSBE Forum of Young Researchers in Sustainable Building. 25 June, Prague.

[5] ISO/TS 21931-1, *Sustainability in building construction- Framework for methods of assessment of the environmental performance of construction works-Part 1: Buildings*, Geneva, 2011.

[6] V. Corrado, I. Ballarini, S.P. Corgnati, (2012). *National scientific report on the TABULA activities in Italy*. Politecnico di Torino. ISBN: 9788882020392.

[7] VV.AA (2012). *EeB Guide Guidance Document, Part B: BUILDINGS, Operational guidance for life cycle assessment studies of the ENERGY-Efficient Building Initiative.*

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Guidance value of the total environmental impact for buildings

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Abstract: *The building sector accounts for a large share of the environmental impact of a country. The Swiss SIA-efficiency path energy offers target values regarding non-renewable primary energy demand and greenhouse gas emissions. A fully aggregated environmental indicator should complement existing target values and provide a more comprehensive picture about the environmental impacts of buildings.*

33 Swiss buildings are analyzed, 20 thereof being residential houses. On average these residential buildings cause 31'000 eco-points per m^2 energy reference area and year (new) and 24'000 eco-points/m^2/a (refurbished). These values are compared to the budget of tolerable environmental impacts per m^2/a. The budget is defined based on national legal targets regarding environmental impacts. A preliminary coarse approach shows that residential buildings should not exceed between 24'000 and 40'000 eco-points/m^2/a, depending on the reduction target applied. The derivation of target values will be refined and discussed in the project steering group.

Key words: Environmental performance, total environmental impact, eco-points, buildings, target values

Introduction

The building sector accounts for a large share of the environmental impact of a country. Scientific studies of the environmental impacts of the construction sector are carried out worldwide. Their findings should help planners, architects, engineers, construction managers and politicians to further understand the environmental impacts of buildings and take measures to reduce them.

The Swiss SIA-efficiency path energy [1] offers target values regarding non renewable primary energy demand (grey energy) and greenhouse gas emissions, caused by construction and operation of a building as well as the mobility induced by a building. The induced mobility takes into account the environmental impacts caused by mobility based on the building's site, its usage as well as measures taken for affecting mobility. Target values are available for three types of usages, namely residential use, office use and schools. Furthermore, the target values differ for new constructions and refurbished buildings. The target values are in line with the milestone 2050 of the 2000-watt-society [2]. To enlarge the scope of environmental impacts considered in the assessment of the environmental performance buildings, it is now discussed whether a fully aggregated environmental indicator should be included. Using comprehensive information about the total environmental impacts of buildings helps to avoid problem shifting and suboptimisation.

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Meanwhile, reference and target values of non-renewable primary energy demand and greenhouse gas emissions of buildings are well established in the Swiss building planning sector. However there is only little experience with such values in terms of total environmental impacts. To stimulate enhanced sustainable building planning, target values of total environmental impacts are being established in an ongoing project.

Goal and scope

For defining target values for the total environmental impacts of buildings, reference values need to be defined related to construction, operation and induced mobility (the daily mobility determined by the location of the building). The environmental impacts are quantified with the ecological scarcity method 2006 according to Frischknecht et al. [3]. The ecological scarcity method is an end-point impact assessment method taking into account actual emissions and resource use on one hand as well as Swiss political goals and internationally agreed emission targets supported by Switzerland on the other. It is measured in eco-points.

In this process, the environmental impacts of 33 Swiss buildings (refurbished and new buildings), located in Zurich, are analyzed using life cycle assessment (LCA). Based on the LCA results, a procedure for defining reference and target values in terms of total environmental impacts is proposed. Furthermore, the potential of possible reductions in environmental impacts in the future is explored. Correlations between non renewable primary energy demand, greenhouse gas emissions and total environmental impacts of buildings will be analysed at a later stage in the project.

The LCA were calculated with the software Simapro 7.3.3 [4] using ecoinvent data version 2.2 [5].

Environmental impacts of the buildings analyzed

Modelling parameters

33 buildings are analyzed with LCA. All buildings are sampled and modelled equally using one unified data source [6]. They are used as residential buildings (20), retirement homes (3), schools (8) and office buildings (2). The analysis covers three main areas: the materialization (construction phase), the operation and the induced mobility of the building. The construction phase encompasses the construction itself, the maintenance and the deconstruction of the building. The operation phase includes room heating, hot water generation, ventilation and electricity demand for operating the building. The infrastructure used during operation such as boilers is accounted for in the construction phase. The operation phase only covers the environmental impacts related to the energy demand and its supply chain. The induced mobility includes the daily transport services of the inhabitants (or employees and pupils). It is calculated based on location specific parameters such as number of parking places or distance to the next stop of public transports. The induced mobility was calculated according to SIA 2039 [7] and using a fuel consumption of the future average car fleet of 3 liters per 100 km. The existing tool for assessing the non renewable primary energy demand and the

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greenhouse gas emissions of mobility was complemented with the environmental impact indicator.

The life span of the building is 60 years [8] and the life time of its components are defined according to the SIA technical bulletin 2032 [8]. Materials and components that need to be replaced are accounted for in the maintenance phase. At the end of life, the building is deconstructed and the materials are disposed of according to the common disposal routes.

The environmental impacts of the buildings are quantified per square meter of energy reference area per year. The energy reference area covers the floor area which is climatized (heated or ventilated). All elements of the body shell are considered. Internal walls and doors as well as floor and wall covers are included. The electrical and sanitary equipment as well as heating and ventilation equipment are included as well. Neither furniture nor personal equipment is considered.

The refurbished buildings were originally constructed between 1877 and 1983 and are refurbished today. The new buildings were constructed between 2006 and 2016. All buildings analysed comply at least with the Minergy standard and thus are more energy efficient than the average of the entire building stock as well as the average of new buildings erected in Switzerland. For more information on the building characteristics see Züger & Gutri [9], SIA [10] and John [11].

LCA Results

The analyzed buildings vary strongly in terms of materialization and their environmental impacts. The comparison of the average of the different types of buildings (see Fig. 1) shows that the office building causes the highest environmental impacts per m^2 energy reference area and year. This is mainly due to the complex materialization and the induced mobility, which is systematically higher for offices. The level of environmental impacts of the other types of buildings (school, retirement home and residential building) is distinctly lower and similar, lying within a range of 8 %.

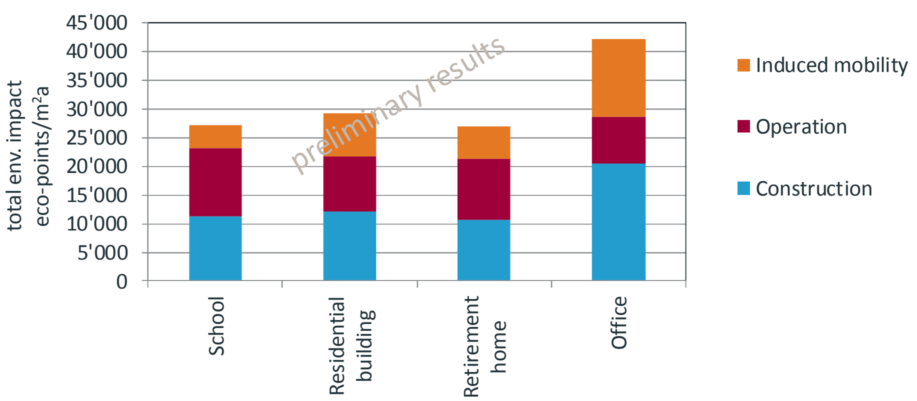

Fig. 1 Total environmental impacts of the average building, grouped according to use type, preliminary results

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At the present stage of the project the main focus lies on the residential buildings. Therefore, only residential buildings are discussed in the following sections. Fig. 2 shows the total environmental impacts of all residential buildings analysed, distinguishing between refurbished and new buildings.

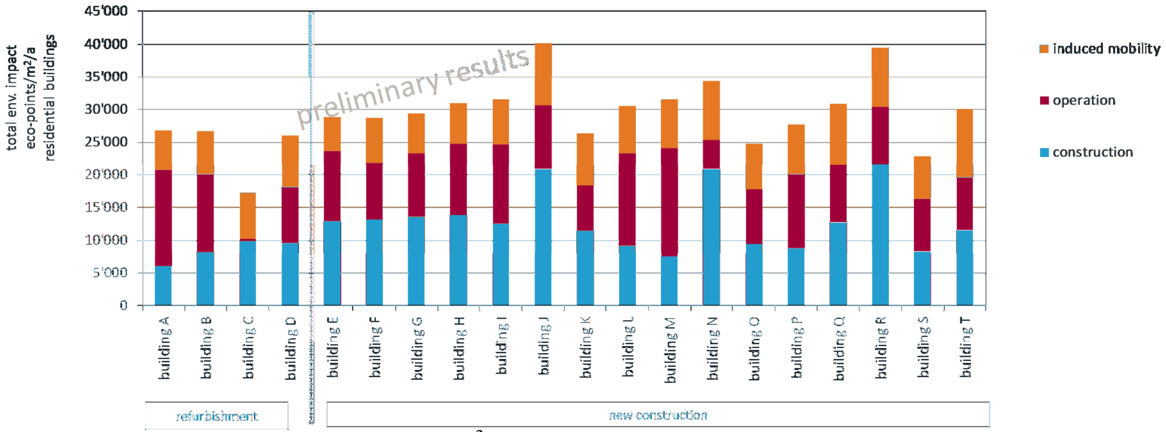

Fig. 2 Total environmental impacts per m² energy reference area and year of 20 Swiss residential buildings differentiated between refurbished and new buildings, preliminary results.

The analysis shows that new residential buildings often have a very complex materialization (glass and steel versus sandstone or bricks, etc.) which leads to higher environmental impacts. Secondly, the energy demand during operation of new buildings is comparatively low. Hence the construction phase often causes the largest share of the total environmental impacts: 43 % of the total environmental impacts for the average of new residential buildings compared to 35 % for the average of refurbished residential buildings. The construction (refurbishment) phase of residential building A causes the smallest environmental impact (about 6’000 eco-points/m^2/a). In contrast, the construction phase of residential building R causes an impact 3.6 times higher (mainly caused by the metallic roof top). Residential buildings J and N cause likewise high impacts in the construction phase due to the high amounts of reinforced concrete and steel used (relatively large share of unheated building surfaces).

On the other hand, the operation phase of an average new residential building causes lower total environmental impacts than a refurbished one (32 % versus 37 % of the total environmental impacts). This shows that a new and energy efficient building infrastructure and insulation helps to reduce the environmental impacts during operation. The lowest environmental impact (245 eco-points/m^2/a) causes the operation phase of residential building C, which fulfills MINERGIE-P standards and covers almost all of its electricity demand by photovoltaics. The highest environmental impacts caused by the operation phase are about 68 times higher and is caused by residential building M.

However, the newly constructed buildings cannot compensate the higher environmental burdens from the construction phase with the savings during operation. Hence, new residential buildings (construction and operation) cause on average 14 % more environmental impacts than the refurbished residential buildings.

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The environmental impacts from induced mobility are higher for the new residential buildings as well. This is mainly because some of the residential buildings are not placed in the city center and hence cause a higher demand on mobility. However the largest as well as the lowest environmental impact from the induced mobility are caused by new buildings. The highest environmental impacts due to mobility (10’500 eco-points/m^2/a) is caused by residential building T, which has a low degree of connectivity to the public transport and a large ratio of parking places per inhabitant. The lowest environmental impacts is caused by mobility induced by residential building E (5’200 eco-points/m^2/a), which is very centrally placed.

Tentative guidance and target values for residential buildings

Top-down approach
A target value for the maximum environmental impacts per m^2 energy reference area and year of building construction, operation and its induced mobility is derived based on the actual building related environmental impacts and a Swiss national reduction target. Hence, the environmental impacts of construction and operation of residential buildings and of the daily mobility related to residential buildings are quantified per person and year. These values are then converted to per m^2 and year values using an average energy reference area of 60 m^2 per person [10].

The construction phase of residential buildings causes about 1 million eco-points/p/a [12, p. 45, Fig. 5.11]. The energy consumption of households (operation phase) causes about 1.9 million eco-points/p/a [12] and the induced mobility contributes about 1.0 million eco-points/p/a (calculation according to SIA 2039 [7]). Overall, the environmental impacts of buildings quantified according to SIA 2040 cause about 3.8 million eco-points/p/a.

To maintain a sustainable level of consumption, Jungbluth et al. [13, p. 101] suggest a reduction of the overall environmental impacts by between 38 % and 63 %. In a first attempt, this range of reduction targets is applied on the building sector, assuming an equally distributed reduction in all sectors and for all areas of consumption.

With this reduction target, a residential building should not exceed a total environmental impact of between 24’000 and 40’000 eco-points/m^2/a. The following Fig. 3 shows the total environmental impacts of all residential buildings (refurbished and new buildings) and the preliminary range of the target value. Only one out of the twenty buildings analyzed slightly exceeds the preliminary upper limit whereas only two buildings are below the preliminary lower limit. All other residential buildings lie within the range of the upper and lower limit of the target value.

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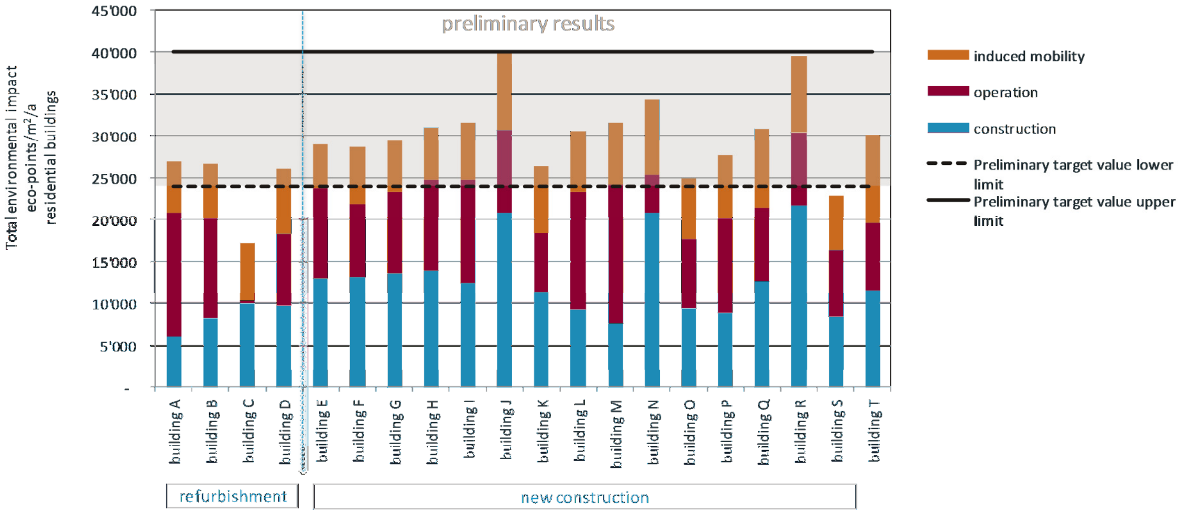

Fig. 3 Total environmental impacts per m² energy reference area and year of residential buildings, differentiated in refurbished buildings (left side) and new residential houses (right side). The preliminary range of the target value of between 24'000 and 40'000 eco-points/m²/a applies for both residential types

While the upper limit seems to be a target easy to reach with current, energy efficient buildings, the lower limit is possibly too ambitious. In a next step, the range of the target value will be narrowed down to one value with the help of further analysing the environmental impacts of the buildings as well as the reduction potentials in construction, operation and mobility.

Residential buildings C and S, both causing environmental impacts lower than the preliminary lower limit of the environmental target value, meet the existing target values of non renewable primary energy demand and greenhouse gas emissions given in [1]. 6 other buildings (B, and D to H) likewise comply with the energy and climate change target values and lie within the range of the lower and the upper limit of the preliminary environmental target value. However 12 of the buildings which are within the range of the environmental target value exceed the target values regarding non renewable primary energy demand and/or greenhouse gas emissions. These preliminary findings will further be analysed and used to fix the environmental target value.

Conclusions

The results of the project show that it is possible to quantify the environmental impacts of buildings going beyond non renewable cumulative energy demand and greenhouse gas emissions.

Newly built and refurbished residential buildings show distinct differences in their environmental performance. On average, new energy efficient residential buildings cause most environmental impacts during construction, whereas the operation phase is most important for newly refurbished buildings. This confirms previous findings regarding cumulative energy demand and greenhouse gas emissions. The induced mobility is of lesser importance for most of the buildings, which is partly due to the fact that environmental impacts caused by private cars are quantified using a future average car fleet.

The level of the target value still needs to be finally fixed. At first sight, it seems that the buildings lying within the preliminary environmental target value do not necessarily comply with the target values energy and greenhouse gas emissions. However those buildings below the lower range of the total environmental target value both do fulfill the target for non renewable primary energy demand and greenhouse gas emissions.

With the experience gained in this project it will be easier to judge whether or not it is appropriate and useful to introduce an encompassing environmental indicator in the building and construction sector to help improving its environmental efficiency.

References

1. SIA, *Merkblatt 2040: SIA-Effizienzpfad Energie*. 2011, Schweizerischer Ingenieur- und Architektenverein (SIA): Zürich. p. 28.
2. EnergieSchweiz für Gemeinden, Stadt Zürich, and Schweizerischer Ingenieur- und Architektenverein SIA, *Bilanzierungskonzept 2000-Watt-Gesellschaft, Entwurf Stand Oktober 2013*. 2013, EnergieSchweiz für Gemeinden: Ettenhausen.
3. Frischknecht, R., R. Steiner, and N. Jungbluth, *The Ecological Scarcity Method - Eco-Factors 2006: A method for impact assessment in LCA*. 2009, Federal Office for the Environment (FOEN): Zürich, Bern, Switzerland.
4. PRé Consultants, *SimaPro 7.3.3*. 2012: Amersfoort, NL.
5. ecoinvent Centre, *ecoinvent data v2.2, ecoinvent reports No. 1-25*. 2010, Swiss Centre for Life Cycle Inventories: Duebendorf, Switzerland.
6. KBOB, eco-bau, and IPB, *Ökobilanzdaten im Baubereich, Stand Juli 2012*. 2012, Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik.
7. SIA, *Merkblatt 2039: Mobilität – Energiebedarf in Abhängigkeit vom Gebäudestandort*. 2011, Schweizerischer Ingenieur- und Architektenverein (SIA): Zürich.
8. SIA, *Merkblatt 2032: Graue Energie von Gebäuden*. 2010, Schweizerischer Ingenieur- und Architektenverein (SIA): Zürich. p. 31.
9. Züger, Y. and C. Gutri, *Ökobilanz Erstellung - Bauprojekte im Vergleich*, A.f.H. Stadt Zürich, Fachstelle nachhaltiges Bauen, Editor. 2012: Zurich. p. 8.
10. SIA, *Dokumentation D 0236: SIA-Effizienzpfad Energie, Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040*. 2011, Schweizerischer Ingenieur- und Architektenverein (SIA): Zürich. p. 49.
11. John, V., *Derivation of reliable simplification strategies for the comparative LCA of individual and "typical" newly built Swiss apartment buildings* 2012, Professur für Nachhaltiges Bauen, ETH Zürich: Zürich.
12. Jungbluth, N., R. Itten, and M. Stucki, *Umweltbelastungen des privaten Konsums und Reduktionspotenziale*. 2012, ESU-services Ltd. im Auftrag des BAFU: Uster, CH.
13. Jungbluth, N., R. Itten, and S. Schori. *Environmental impacts of food consumption and its reduction potentials*. in *8th International Conference on LCA in the Agri-Food Sector*. 2012. Rennes, France.

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Evaluation of sustainability aspects and the use of local materials in the housing construction in Colombia

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Abstract: *Housing deficit in aspects of quality and sustainability is one of the most sensitive items of the developing countries. Colombia has a cumulative deficit of 3.828 million of households, of which 57.9 % are located in urban areas. This deficit is quantitative (homelessness) and qualitative (overcrowding and structural conditions), a situation aggravated because many homes are destroyed and damaged by heavy rains and floods in the recent years. This context defines housing demand of nationwide. In addition, the fast urbanization and the lack of them in some planning process have generate an regional imbalances and high vulnerability to natural phenomena on homes in high risk areas, mainly from lower social stratum, which are magnified by human actions. Based on the defined criteria in this research, the appropriation of technologies and materials in the construction process has demonstrated a significant reduction in the environmental burdens during the lifecycle of housing. It has been found that the use of alternative sources of unconventional water (rainwater, graywater) for domestic use may represent a reduction of 0.28 kg* CO_2 *eq./*m^3 *of replaced tap water. Additionally, the use of local materials, as an example bamboo in low-densityof single-family houses can reduce the potential environmental impacts (31.2 kg* CO_2 *eq./*m^2 *) and boost the local employment.*

LCA, bamboo, rainwater harvesting, housing projects

Introducción

Housing policy in Colombia has been geared to meet the quantitative demand of houses and the issue of housing quality is subordinated to the budget resources available and the

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repayment ability of the applicant families of this good. This policy stance has generated some housing projects aimed at low-income population but they not provide a set of conditions to ensure the welfare of families and they meet to real needs in their homes. On the other hand, the environmental problems resulting from the construction of infrastructure have not been considered an important aspect. As example, pollution of water sources derived from elements such as lead, asbestos, zinc, which are inherent to conventional building materials, among other problems that increase the water and energy footprint.

In Colombia, the government has proposed an economic model of growth (and urban growth) with a projected increase of 5% in 2010 to 6% in 2014 (DNP, 2005). This is affecting the natural resources, including water.

The historical development of urban areas in Colombia posed a predominantly rural country (in 1951, the percentage share of the municipalities of the country was 39.6%) to an urbanized country (in the census of 2005 he obtained a level of concentration of population in urban areas 75.0%) (DANE, 2010). In the last 10 years (2004-2013) the annual growth rate of urban population can be estimated based on projections from the 2005 census in 1.59% (DANE, 2005).

The housing deficit (quality and sustainability) is one of the most sensitive aspects of the developing countries. In Colombia a cumulative deficit is estimated in 3.828 million of households, of which 1,611,588 are located in rural areas (42.1% of the total deficit) (DANE, 2005). According to the 2005 Household Census (DANE, 2005), the deficit is quantitative (12.4%) and qualitative (overcrowding and structural conditions) (23.5%). In addition, many homes were destroyed and damaged by heavy rains and floods in 2010 (2,049 homes were destroyed and 275,569 were damaged in 654 municipalities of Colombia) (Press National Risk Management for president of the Republic of Colombia cited by Ministry of Interior and Justice, 2010).

This context defines the housing demand in nationwide. In addition, a rapid urbanization and the lack of it in urban planning programs generate a regional imbalances and a high vulnerability to natural phenomena on homes in high-risk areas, mainly from lower socioeconomic strata, which are magnified by human actions (Ministry of Environment, Housing and Territorial Development, 2005).

Regarding the supply of housing, the construction sector provides housing solutions to social strata with a high payment capacity (strata defined as 4, 5 and 6 or areas of high urban development) which corresponds to 51% of the population, while for the “strata 1” does not reach 1%; and potential beneficiaries to obtain housing subsidies are skilled at levels 1

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and 2, that meet requirements 5.1 million households in the country (Comptroller General of the Republic, 2010).

The current National Development Plan (NDP 2010-2014) in the component called Environmental Management Sector has a theme related to improving of environmental quality in cities, which aims to develop tools for designing and building of environmentally sustainable buildings and homes (Comptroller General of the Republic, 2013) or "those that prioritize the use of local, renewable, recyclable materials, and the implementation of efficient systems for consumption of water and energy, optimizing the quantity and quality of supply depending on needs and uses" (Pérez et al., 2009). According to the scope of avoid as much production as polluting of waste generated by the production of elements (e.g. water and sewer pipes and building materials) that are used in the development of infrastructure for conventional housing; the consumption of non- renewable natural resources; and the pressure generated on ecosystems because the environmental cost accounting is considered an externality generated in this process (Biblioteca Luis Angel Arango, 2010).

In Colombia, besides the research that has been developed in this field, the traditional domestic architecture cannot be ignored. A clear example is the type of construction as defined in the culture of the Coffee Cultural Landscape (CCL), World Heritage Site by UNESCO (Ministerio de Cultura y Federación Nacional de Cafeteros, 2011), including an approximate of 143,000 hectares and a population of 80,000 inhabitants. Being the typical set of space, materials (rammed earth, adobe and clay tile, bamboo as the carrier material, which was used in both vertical and horizontal and inclined structures, and constitutes one of the plant species more representative of the region), and the traditional construction techniques used by them. The rural properties of CCL are harmoniously integrated into the landscape and it is where people have developed the social life using traditional concepts of building homes of low density (Ministerio de Cultura y Federación Nacional de Cafeteros, 2011). In addition to coffee, the housing is one of the highlights of the coffee landscape. Also, some urban projects can be found in cities of CCL that involve traditional concepts of building in low-density housing.

However, the CCL has the similar housing problems that affect all the country. Besides the qualitative and quantitative deficit, both, the phenomenon of El Niño and La Niña have forced to generate adaptive strategies around of variability and the climate change through the development of environmentally sustainable housings that use appropriate technologies to reduce of consumption, and reuse and recycling water and energy. In addition, the use of alternative materials either from the region or exogenous prioritizing local exogenous materials.

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Based on these needs, the main objective was to define the sustainability criteria of social housing. The purpose of these criteria is to address the housing deficit and to work for a set of conditions that will enable future achieve dignity and the full development of its people, in harmony with their biophysical environment.

Methodology

The methodological framework is holistic and systemic approach with a mixed approach (qualitative and quantitative). The research was conducted in the city of Pereira (Colombia), using as study population the neighborhoods reported in different promoter housing institutions that have shaped the urban landscape in the last 40 years. Pereira is a city of 410,535 inhabitants (National Administrative Department of Statistics, 2010) located in the heart of the Colombian Coffee Region and inside the Coffee Cultural Landscape decreed by UNESCO.

The qualitative approach was used to take a representative sample of the neighborhoods built in the time frame of 40 years in order to study the different criteria to assess sustainability. The quantitative approach was addressed by selecting one of the types of housing that were found using the local materials as the main feature of the building. Finally, a detailed analysis of one of the components of sustainable housing analysis was performed: the use of surplus resources such as rainwater, based on the results of the study by Morales-Pinzón et al. (2012a) referring to new construction of urban housing in Colombia. A model system-family low density housing that represented the average conditions of new housing in Colombia as reported by Morales -Pinzón et al. (2012a) (see Table 1). Thus in terms of the use of rainwater and graywater and the environmental potential impacts when replacing tap water, following the methodology of life cycle assessment impact (LCA).

Table 1. Parameters of the simulated system.

Variable	Value
Domestic water demand (L/day)	503
Domestic rainwater demand (laundry water use) (L/day)	136
Domestic graywater demand (toilet water use) (L/day)	101
Catchment area (m^2)	40

Data were processed using the Plugrisost software (Morales-Pinzón et al., 2012b) in which the uptake, storage and distribution of rainwater and greywater reuse in the system, were modeled. The lifetime of the system was defined in 50 years according to the original

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proposal of Roebuck et al. (2011). The quantities of materials and energy used by the system were estimated using the Plugrisost software (Morales-Pinzón et al., 2012b). Concrete tank, pipes of polypropylene and a stainless steel pump were simulated. Precipitation in the area was obtained from historical records for the years 2008-2013 reported by the Red Hidroclimatológica del Departamento de Risaralda (Universidad Tecnológica de Pereira, 2014).

According to ISO 14040 (2006), the functional unit is defined as the collection, storage and supply 1 m^3 of unconventional water (rainwater or graywater) for use as drinking water for laundry (rainwater) or toilet (graywater) with a constant demand in a period of 50 years. As an analysis method for the potential impacts and according to Guinée et al. (2001) the Baseline v2.04 CML was used, and the impact category Global Warming Potential (GWP, kg CO_2 eq.) was selected.

The mathematical equations that support the technical component of Plugrisost software including a detailed inventory of materials and processes for construction (collection, storage or distribution) are in Morales-Pinzón et al. (2012b).

Results

Assessing the sustainability of housing

The qualitative evaluation showed that the permanence of the neighborhoods is defined as territorial structures and they are affected by the very dynamics of the land market and the sense of belonging and permanence of owners. However, it is interesting to see how social stratifications may not correspond to the perceptions of the people and their demands. Thus, the perception and the needs (housing area, transport system, public services) in the neighborhood for an owner of lower-middle social stratum can be similar to the needs of an owner of high stratum and in vice versa. Contrary to expectations, the average social stratum is the most different from all (see Figure 1).

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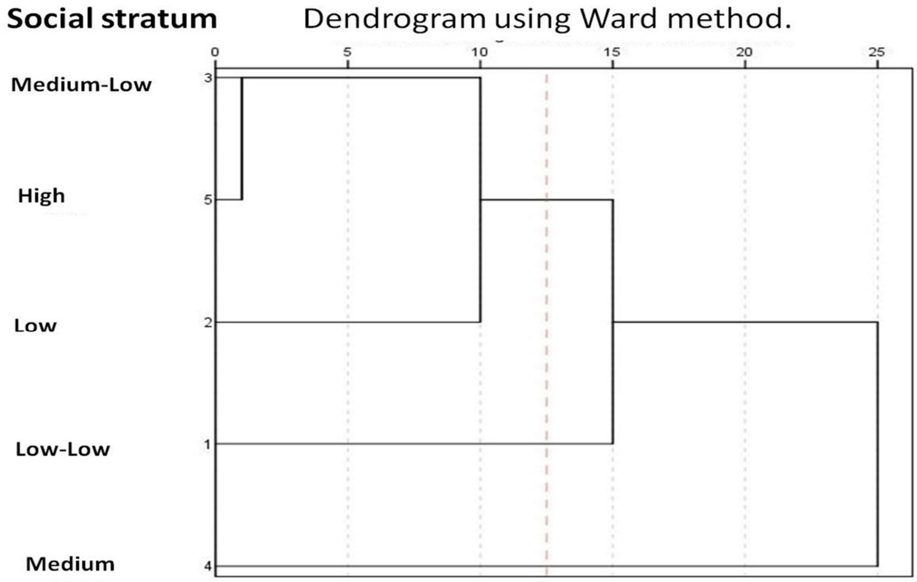

Image 1. Similarity in perception of housing based on sustainability attributes.

However, the knowledge and care of these needs does not constitute a priority for planners of housing projects (for this sector of the population or lower socioeconomic stratum); since investment decisions are being taken by the criterion of minimum cost, and basically are costs direct (building and land) as these investments are concentrated in these criteria. Therefore the price of land is being that determines the decision, since the value of the construction is similar no matter where; and the soil is less expensive in places where there is less amount of urban services (coverage of domiciliary utilities, community facilities, road connectivity and coverage, among other services necessary for the overall development of families).

Consequently, projects are planned according to price of land, when it should have an effective participation of families beneficiaries of homes, where they are permitted to engage in the design, production and processing of your habitat and their homes, and they become in agents of their own development.

This targeting the high cost of developable land left in the background the issue of quality and the housing habitability. The families say they need housing with broad and better finishes, since the lower strata is characterized by numerous homes and housing projects consisting of a bedroom, a multiple space,a kitchen and a bathroom. There are low social housing deals that favor the transformation to suit the changing requirements of families, and this usually happens when homes have a greater ability to pay. This shows how little attention is given to the particularities of the low-income population in their family diversity, and poor urban environmental management.

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Potential Environmental Impact Avoid using local materials and surplus resources

To make the environmental analysis, the type of housing selected is a draft of urban housing reconstruction result of the Earthquake Coffee Belt in 1999 (Arango and Quintero, 2000). This housing type presented as main feature the use of bamboo and clay tile as replacements for conventional materials (brick, tile cement). This housing has been occupied in the last 15 years without detectable improvements or structural renovations.

In the environmental analysis, it was found that the potential for substitution of prefabricated brick material by plump bamboo is 5950 kg for a house of 45 m^2 of built area on one floor. The total potential environmental impact of a kind home in Colombia is 8.62 E +02 kg CO_2 eq • m^{-2} and 28% corresponds to the construction phase impact (Ortiz-Rodriguez et al., 2010), but when it is used the renewable local materials as bamboo, an estimated of 131kg per m^2 of brick masonry is replaced, which is equivalent to a reduction in the global warming potential of 31.2 kg CO_2 eq./m^2. In this case, the contribution of the construction phase to the total potential environmental impact occurred during a life cycle is reduced to 26%.

Using of rainwater and graywater can achieve significant environmental benefits. The results of the simulation carried out for the selected dwelling have estimated that a minimum storage capacity of 0.5 m^3 is enough to meet 100% of demand for greywater. Thus, each cubic meter of harvested graywater can reduce the Global Warming Potential in 0.6 kg CO^2 eq. In addition, for a house of 40m^2 of effective surface for collecting rainwater and the climatic conditions of the city Pereira (annual rainfall of 2258 mm and bimodal regime), using a storage tank of 1m^3, this can reduce the potential emissions between 0.14 and 0.71 kg CO^2 eq./m^3 (an average of 0.28) of harvested rainwater.

Conclusions

The use of local materials such as bamboo, brick and clay tile, and the use of surplus resources as rainwater should be weighted with high values of importance in defining sustainability standards of housing in developing countries. Their inclusion in the public policy of social housing can be a strategy that lasts over time, beyond the limited conception of local materials and the use of surplus stocks is a bet just for the lower income population.

The homes built with local materials and the low economic cost have a lower environmental impact and they can last over time, even in urban areas where is predominantly the use of conventional materials and new materials (no traditional or local materials). This will also generate benefits in environmental terms, and it represents an opportunity to address the shortage of social housing and its priority, to the extent that resources are optimized and can involve families through self-management.

The Coffee Cultural Landscape goes beyond rural areas and it is possible to build typical housing adapted to urban conditions of intermediate cities like Pereira in Colombia.

Acknowledgment

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References

Arango, G., Oscar y Rodríguez, P., Gladys. (2004). Ciudad Región Eje Cafetero. Hacia un desarrollo urbano sostenible. Pereira. Red Alma Mater.

Arango, J. D. Y Quintero, B. E. Dianóstico del Sismo del 25 de enero de 1999. (2000) En: Boletin de la Red Sismológica del Eje Cafetero. Vol.8 Manizales: 46–53.

Biblioteca Luis Ángel Arango. Materiales del Siglo XXl. (2010). Colombia. Disponible en: http://www.lablaa.org/blaavirtual/ayudadetareas/matcon/matcon43.htm.

Colombia. Contraloría General de la República (CGR). (2010). Informe del Estado de los Recursos Naturales y del Ambiente 2008 -2009.

Colombia. Contraloría General de la República (CGR). (2013). Informe del Estado de los Recursos Naturales y del Ambiente 2011 -2012.

Colombia. Ministerio de Ambiente, Vivienda y Desarrollo Territorial (MAVDT). (2005). Serie Ambiente y Ordenamiento Territorial. Guía Metodológica 1. Incorporación de la Prevención y la Reducción de Riesgos en los Procesos de Ordenamiento Territorial.

Colombia. Ministerio de Cultura y Federación Nacional de Cafeteros (MC-FNC). (2011). Paisaje Cultural Cafetero. Un paisaje cultural productivo en permanente desarrollo. Bogotá, Colombia.

Colombia. Ministerio de Interior y de Justicia (MIJ). (2010). Decreto 4579: Decreto de Desastre Nacional.

Departamento Administrativo Nacional de Estadísticas (DANE). (2005). Sistema de consulta, Censo ampliado 2005. Disponible en http://www.dane.gov.co.

Departamento Administrativo Nacional de Estadísticas (DANE). (2010). Proyecciones nacionales y departamentales de población 2005-2020.

Guinée, J. (ed.), Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., y otros. (2001). Life cycle assessment: an operational guide to the ISO standards. Parts 1 and 2.

Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands (Guinée JB, final editor).

ISO 14040. (2006). Environmental management —life cycle assessment— principles and framework. International Standard 14040. International Organisation for Standardisation, Geneva.

Morales-Pinzón, T; Rieradevall, J; M. Gasol, C.M., Gabarrell, X. (2012a). Plugrisost v1.0. Modelo dinámica de flujos de agua para uso doméstico, con énfasis en aprovechamiento de fuentes no convencionales (pluviales, grises). Grupo de Investigación en Sostenibilidad y Prevención Ambiental (Sostenipra), Universidad Autónoma de Barcelona (España) y Grupo de Investigación Gestión Ambiental Territorial (GAT), Universidad Tecnológica de Pereira (Colombia). Available (Spanish version) in http://sostenipra.ecotech.cat/login.php?referrer=plugrisost

Morales-Pinzón, T., Rieradevall, J., Gasol, C. M., Gabarrell, X. (2012b). Potential of rainwater resources based on urban and social aspects in Colombia. Water and Environment Journal, 26(4), 550–559. doi:10.1111/j.1747-6593.2012.00316.x

Ortiz-Rodríguez, O., Castells, F., & Sonnemann, G. (2010). Life cycle assessment of two dwellings: one in Spain, a developed country, and one in Colombia, a country under development. The Science of the total environment, 408(12), 2435–43. doi:10.1016/j.scitotenv.2010.02.021

Pérez R., Margarita y González C., Alexander. (2009). Guía para la Construcción de Viviendas Eco Sostenibles. V encuentro Nacional y III encuentro latinoamericano sobre edificaciones y comunidades sustentables – ELECS. Recife. Pernambuco. Brasil.

Roebuck, R., Oltean-Dumbrava, C., Tait, S. (2011). Whole life cost performance of domestic RWH systems in the United Kingdom. Water and Enviroment Journal, 25, 355-365.

Universidad Tecnológica de Pereira. (2014). Red Hidroclimatológica del Departamento de Risaralda. Accesado en marzo de 2014 de http://www.utp.edu.co/hidroclimatologica/es/inicio.

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Monitoring dwelling stock efficiency through energy performance register: Trends in Dutch social housing

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Abstract: *In 2002 EU adopted the Energy Performance of Buildings directive which was subsequently adopted by the member states. However, more than a decade later, no national registers of certificates have become available publicly or to research institutions in order to give feedback on the introduced regulation. By exploring the 4 million certificates contained in the Dutch energy performance register we demonstrate the trends in energy efficiency of the dwelling stock in years 2008 – 2012 and discuss the usefulness of the register for energy efficiency monitoring and possible improvements.*

Energy label, energy performance register, dwelling stock efficinecy, monitoring

Background

Energy Performance of Buildings Directive is, since its first adoption in 2002, the main driver in reducing energy consumption in buildings in Europe. In May 2010, a recast EPBD was drafted as a response to the more ambitious 2020 targets - 20% for energy and 30% for CO2 set by the commission. To ensure that the directive is paving the way towards achievement of the set goals, registers of performance certificates were established nationally in 11 member states [1] with the share of dwellings it contains ranging up to 24% in The Netherlands and UK. However, no in-depth analysis of these data was found during the literature review. The goal of a 110PJ reduction set for the built environment in the Netherlands can be translated into 18% for the horizon 2008 – 2020. To evaluate the progress of the energy saving policies in the Dutch social housing sector, AgenschapNL has in the years 2008 - 2012 commissioned research on the dynamics of uptake of renovation measures. In the mentioned years together it was established that about 950.000 dwellings were made 20 – 30% more energy efficient [2]. This monitoring was indirect and relied on data of questionable quality. However, using the energy performance register as basis, the quality of the monitoring can be significantly improved. This paper investigates overall changes in the stock in 2008 – 2013. A related paper base don similar data by [3], focusses on annunal improvement pace of the dwelling stock.

Dataset properties and methodology

Background of the SHAERE database

For the use in this paper, Aedes, a Dutch umbrella organisation of housing associations, has provided us with their register of energy performance certificates (called SHAERE). Since 2010, more than three quarters of all Dutch housing associations report their entire stock to Aedes in the beginning of each year for the previous year (e.g. in January 2014 for 2013).

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They report the status of their whole dwelling stock which they manage with Vabi Assets software. The software is used for appreciation, rent estimates, plan maintenance and also to order to obtain an energy label certificate according to the Dutch energy label methodology. However, SHAERE is in fact much richer than only official Dutch energy labels, since it consists of all dwellings of participating housing associations at the end of each calendar year, including the most recent interventions and the corresponding energy label (so called pre-label) and energy consumption. Because these annual records of dwelling descriptions have not yet all been registered with the authorities, we will refer to them as pre-labels. Since certificate registration only obligatory at the time of rent or sale, not all dwellings in SHAERE also have a label registered at the RVO (Table 1). In 2013 72% of the pre-labels had a registered certificate (but this registered certificate may be from before 2011).

Year	Reg. status	Frequency	Percent
2010	Not registered	438205	38,68%
	Registered	694741	61,32%
	Total	1132946	1
2011	Not registered	246034	20,74%
	Registered	940033	79,26%
	Total	1186067	1
2012	Not registered	457542	31,80%
	Registered	981158	68,20%
	Total	1438700	1
2013	Not registered	333553	23,03%
	Registered	1114713	76,97%
	Total	1448266	1
Total	Not registered	1475334	28,34%
	Registered	3730645	71,66%
	Total	5205979	1

Table 1: Status of pre-labels in SHAERE

Unfortunately, SHAERE only contains the dwelling properties at the end of each calendar year (referred to as the reporting year) and not also the properties at the time of energy label registration (if it did occur). It does, however, contain information of the label category (energy index) and precise date of registration of each registered label certificate. Using the registration year and energy index at registration we can compare the quality of the stock according to their energy certificate with the stock according to the data used in the pre-labels. The description above thus reveals two ways of analysing the SHAERE data – using the information of pre-labels on one hand and the registered label certificates on the other. For more in depth research, pre-labels offer more opportunities due to the fact that all dwelling properties are known for that point in time. Quality of the pre-labels is considered as high as of the registered certificates [3] and when changes have been made in a dwelling, housing associations communicate that quite directly to their consultant, who updates the status in Vabi Assets immediately. Besides more detailed data, another clear advantage of pre-labels is the larger sample. The data was obtained from 243 housing corporations (in 2011 there were in total 289) in The Netherlands and contains 2.083.561 individual dwellings which is 89% of the total Dutch social housing stock. It is important to note, that social housing represents 33% of the Dutch dwelling stock. The dwellings geometry, detailed envelope and installation system characteristics are included, as well as metadata on the inspection and label registration process. Such rich datasets are pioneering on European level and as such offer good representatively for social housing sector in The Netherlands.

Analysis setup

There are two possible ways to analyse the changes efficiency of the stock, firstly by specifically tracking the dwellings whose energy label have undergone changes during this period (this can also be done by analysing the pre-labels (A) or by analysing only the registered certificates (B). Secondly, we analyse the changes in total pre-label stock (C) between 2010 and 2012 (or in case of limiting the research to registered label certificates 2008 till 2013)

For point A. we first we removed one of the duplicate records, if pre-labels with exactly the same address and the same energy index and reporting year were found. Then we saw that there were a lot of cases with exactly the same address and the same reporting year, but different energy index. In such an instance both of the cases were removed. After this 5.200.505 cases were left. To generate the results, we removed pre-labels that were only calculated once, there were 546.206 of such pre-labels (therefore also 546.206 unique dwellings with a unique pre-label). Out of the remaining records we then obtained first and last record in time, if there was a pre-label reported in each consecutive year from 2010 until 2013, we discarded the 2011 and 2012 records, leaving 1.537.355 dwellings having two different pre-labels.

For B, the analysis is made on the registered label certificates, (n=3.516.467) some of which again had exactly the same address and the same energy index and registration year. We selected a single case from these duplicates and were left with 1.730.367 cases. After this, cases were still found that had exactly the same address and the same registration dates, but different energy index. In this case, we looked at the reporting date to SHAERE and discarded the case with older reporting year, leaving 1.715.669 cases. The final step was the deletion of a handful of cases, which had the same reporting year, and registration date, but different energy indexes, ending in a dataset of 1.714.496 cases, which correspond to individual dwellings. Some of the certificates out of the 1.714.496 were only registered at the RVO once, and are as such not useful to trace changes. We discarded this way 1.230.571 certificates (unique dwellings). Out of the remaining certificates, we retained only the first and last certificate for each dwelling. This sample finally consisted of 233.670 dwellings with two certificates.

Also in C, we looked at both, pre-labels and registered label certificates. Analysis on the pre-labels was simple, since each dwelling is already represented only once in a given year in SHAERE. With the registered label certificates, it was slightly more complicated, since the

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same certificate could have been reported to Aedes multiple times and the procedure applied in B. was used to isolate 1.714.496 useful records.

Results

Dwellings which have undergone a transformation

1.537.355 out of the total number of dwellings with a pre-label is 2.083.561 have more than two pre-labels. It means that 74% have undergone a change in their pre-label. If we look at the percentages with regard to the total number of dwellings with a pre-label (2.083.561), we can say that 12% had the pre-label improved, 58% had an unchanged label and 4% had a worse pre-label. For the 58% with a constant label it would be interesting to know whether the energy index changes or not (it may be that the label has not changed, but the EI had, indicating a small dwelling improvement). The total number of dwellings with multiple registered certificates in years 2008-2013 is 233.670 which translates into 16 % of the total that has undergone changes. The turnover is much less than in the pre-labelled stock, but of the same magnitude as the improved pre-labels (12%), which tends to show that registration at RVO almost only takes place when the pre-label is improved. 8% of re-registered certificates had the label improved, 6% had an unchanged label in the first analysis and 1% had a worse label. According to the pre-labels analysis, 12% of the dwellings have undergone a renovation that led to a label improvement in the period 2010-2013, that is on average 4 % per year. According to the analysis of the registered certificates, these figures are 8% in the period 2008-2013, that is on average 1,6 % per year. However, the number of label steps per changed dwelling is significantly higher in the category of registered certificates.

Dwellings with a pre-label (2010-2013)			
2083561	100%	total stock	**Average per year**
1537355	74%	turnover	24,7%
258352	12%	improvements	4,0%
1200506	58%	stays the same	19,3%
78497	4%	worsening	1,3%
284204/336849	0,84	label steps per changed dwelling	
Dwellings with registered label certificates (2008-2013)			
1754588	100%	total stock	**Average per year**
233670	16%	turnover	3,2%
116864	8%	improvement	1,6%
99721	7%	no label category change	1,4%
17058	1%	worsening	0,2%
155723/233670	1,16	label steps per changed dwelling	

Table 2: Comparison between the three analysis for the dwellings with multiple pre-labels or certificate

Total stock annually

Looking at the distribution of total stock of pre-labels each year (Figure 1), we can observe a positive trend – the percentage of categories A, B and C is steadily growing, whereas the percentage of poor label categories is decreasing. With the current pace, the proportion of B

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labelled dwellings would reach about 32% by the year 2020, whereas The trend in mean energy index is shown in Figure 4 and would lead to approximately 1,4.

Looking at the annually registered certificates, there are bigger differences between frequencies of each category. It seems that in the recent years, more and more A labelled dwellings get registered (from 2 – 7%) and also dramatic is the rise in registration of B labelled dwellings (8 – 20%). Also the amount of dwellings with a poor label decreased more dramatically than in the analysis of pre-labels. However, given the fact that most certificates were actually issued in the first years (2008 and 2009), no great change can be detected if we observe the label distribution in all certificates available until a given year (green bars in Figure 1). The results are very similar to the distribution of pre-labels.

The comparison with Figures 2 and 3 (for the registered certificates) shows that the trends using registered label are much flatter than using the pre-labels as the basis. If the goals were almost met using the pre-labels as basis, the Dutch dwelling stock has yet a much longer way to go if we look at the registered certificates (the share of B labelled dwellings will be only 22% and not 30% as forecasted by the pre-labels). Similar trends are seen if mean annual energy index is plotted on a graph.

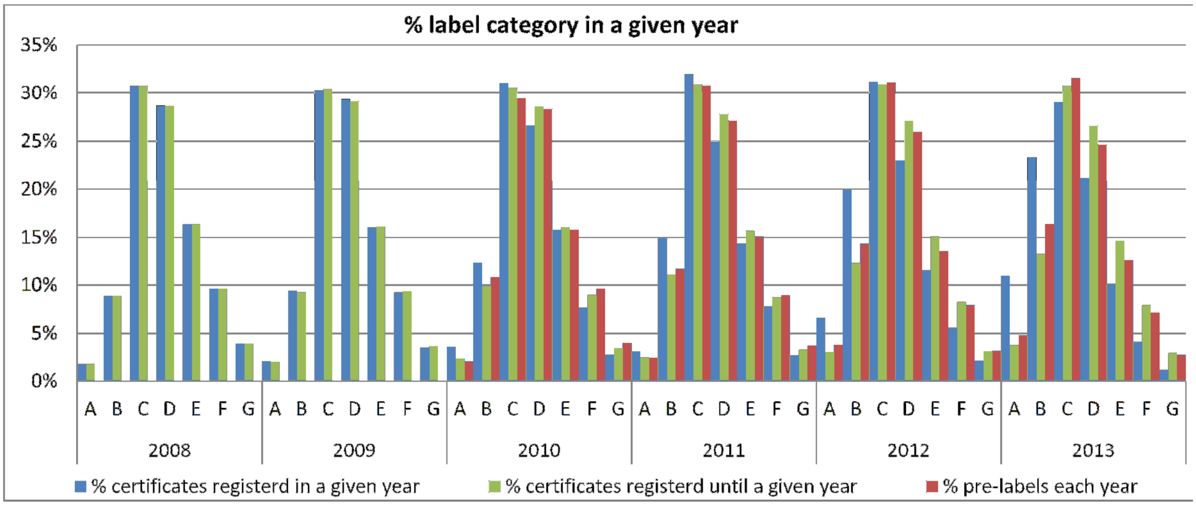

Figure 1: Share of label categories calculated in a given year

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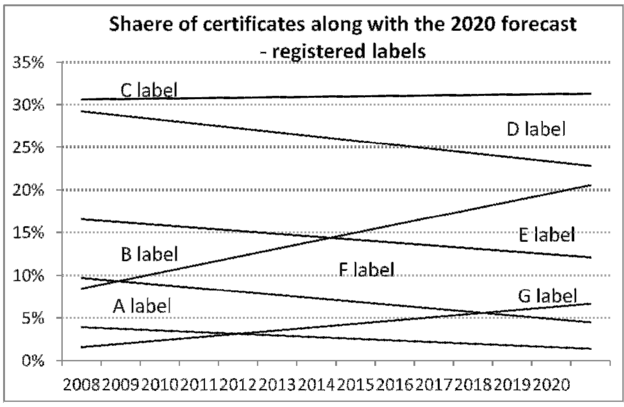

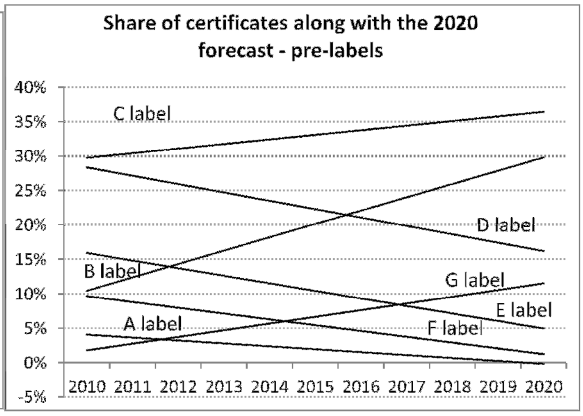

Figure 2 and 3: Trends in proportion of label categories (all re-registered label certificates)

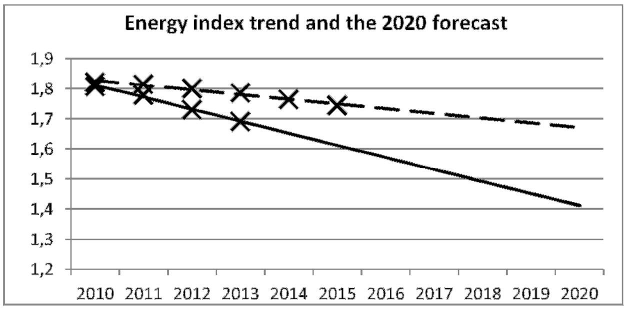

Figure 4: Decreasing trend in energy index (dashed line – registered labels, full line - prelabels)

Discussion

In the results observed in section 3, there are large differences between results obtained with pre-labels or registered labels when looking at dwelling with multiple records. The turnover is much higher in pre-labels, which is logical, since all dwellings get reported every year and many of them probably had no change occurring. Some possibly had a small improvement, but if the label step does not change, the motivation for reregistration is less strong.

However, the improvement rate seems to be relatively comparable – 12% in the pre-labelled stock and 8% in registered labels. If this is extrapolated to the whole Dutch social housing dwelling stock (2.315.963), each year 92.600 dwellings would be improved using the pre-label data and 61.700 using the re-registered certificates. Both these instances are, however, slightly off from the 135.000 dwelling that were improved in 2011 according to the monitoring carried out in the past [2]. However, the 12% is close to the goal adopted by Meer met Minder agreement (goal of 300.000 annually improved dwellings), as it can be translated into 280.000 dwelling improved annually, which is good news. Moreover, the 12% rate is also comparable to the results of the previous monitoring (950.000 improved dwellings in 2008 – 2011). Also looking at the energy index, the target of average index 1,25 by 2020 set in seems almost achievable using the pre-labels, but less so using the registered label. The target of 80% of the stock being label C by 2020 might however be overly ambitious.

Overall, the data from the registered certificates are much more conservative than the data from the pre-label, except the average label step improvement. However, the fact that the frequencies of label categories in registered labels are coming closer to the frequencies of pre-labels as time passes (Figure 2), speaks towards the future focus being on investigation of pre-labels, also because as stated in the 2.1, this data is much richer.

Conclusions and future research

The results show that the Dutch social housing stock is on a good way to improve its energy performance, however, the measures taken should probably be strengthened if the goals are to be achieved. The biggest problem of this study are the uncertainties regarding data quality. From the interviews with Vabi and Aedes, we tend to conclude that the pre-labels are more accurate because they represent the actual state of the dwelling stock at the end of each year. The registered certificates are supposed to be less accurate because the certificate is valid for 10 years and housing associations do not always want to re-register a dwelling, also when they could ask for more rent with a higher label. Further study should show if this hypothesis is right. As described in chapter 2, the composition of the database was complex, which significantly impacted the usability of the data. In the future better documentation of the data is necessary if the database is to be used further for research purposes. Further study is planned into the effectiveness of the measures implemented in the SHAERE, however, the fact that for registered labels, the only information available is the energy index and label category without any dwelling characteristics, limits the analysis to investigation of the pre-labels for which the dwelling properties are available, but the date of the last change is not very accurate. This relates to another goal of the study we plan, which is the coupling of the dwellings with their annual actual gas consumption. Since large discrepancies were found between actual and theoretical energy consumption in the past [4], insight into actual effectiveness of renovation measure implemented should be more than valuable. However, the fact that a precise date of last dwelling transformation is not known hinders the coupling greatly. As was mentioned before, this dataset is the first of its kind on European scale and although it offers great opportunities, it still has many weaknesses which should be upgraded in the future.

References

[1] Europe's buildings under the microscope, Country-by-country Review of the Energy Performance of Europe's Buildings, BPIE, 2011.

[2] Hezemans A., Marquart E., Monné T., Monitor Energiebsparing Gebouwde Omgeving 2012, Agentschap NL, Juni 2012.

[3] Fillipidou F., Niebor N., Visscher H., The pace of energy improvement in the Dutch non-profit housing sector, Submitted on 26 May for WSB14 conference in Barcelona

[4] Majcen D., Itard L., Visscher H., Theoretical vs. actual energy consumption of labelled dwellings in the Netherlands: Discrepancies and policy implications, Energy Policy 54 (2013), pp. 125–136.

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Session 70:

Which are the limits of life-cycle assessment as a rating tool to evaluate sustainability in building? (II)

Chairperson:

Macías, Manuel

Profesor/Responsable del área de Investigación. Universidad Politécnica de Madrid/GBCe

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Building Life Cycle Assessment (LCA): results sensitivity to the choice of LCA data and reference service lives of construction products

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Abstract: *Several LCA databases are available at European and national levels to evaluate the environmental impacts of construction products and buildings (generic LCA or Environmental Product Declaration provided by manufacturers). The aim of this study is to compare the embodied environmental impacts related to the production phase provided by two LCA databases used in France: ecoinvent v2 and the EPD data from the INIES database. In addition, this study compares different service lives data for construction products (use phase). Results of a building case study with concrete, timber and steel frame systems show a non-negligible deviation for some indicators of EN 15978 standard. The differences for the CO2 emissions vary from 10% to 34% between generic and EPD while they vary from 9% to 24% for the service lives datasets. The outcomes of the study highlight both variability's of existing LCA data and the need of detailed guidance for a national context towards reproducible embodied impacts assessment.*

Keywords: Life cycle assessment, buildings, reproducibility, embodied impacts, EPD, generic data

1. Introduction

The environmental impacts of the construction sector are a major concern since the beginning of the industrial revolution. In 2013, buildings still consume 30% of the energy and produce 25% of CO2 emissions. To evaluate the environmental impacts related to buildings, there is a need of environmental assessment tools. To address this issue, quantitative assessment tools have been developed such as the Life cycle Assessment (LCA) method and applied to the construction sector. LCA is a scientifically-based methodology that quantifies the environmental impacts of any product or service for its life cycle. In the construction sector, different standards aim at providing European or national rules for the assessment of the environmental impacts of the production of construction materials sold in each country by the different producers [1][2]. These sector-specific rules are linked to the development of LCA databases adapted to these industrial practices. In the same time, in France, most building LCA studies published so far are based either on generic LCA data (e.g., from European LCA databases such as ecoinvent) or on the national EPD database INIES (being a sector-specific database).

In this paper, we are interested to understand the consequences of the use of either generic data or EPD provided by manufacturers on the embodied impacts results. As no harmonized service lives are currently available in Europe, the comparative analysis will also include a sensitivity test on existing service lives datasets that can be used e.g. for cradle-to-grave generic or EPD data.

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Previous studies have compared the assumptions used in building LCA tools, and EPD data. For example, the PRESCO project compared the results provided by eight European building LCA tools. The authors found that the tools do not differ +/- 10% between each other for the CO2 emissions of a single family house [3]. Another study concludes that an EPD of a product (office chair) calculated using specific or generic raw data (e.g., for the recycling rates, the energy consumption of the manufacturing process etc.) can present substantial differences in LCA results up to 612% for the eutrophication potential indicator [4].
Even if some previous studies exist as shown above, none of them have compared generic and EPDs data for different building's alternatives. The main objective of this paper is thus to analyse LCA results' sensitivity on a building case study due to LCA data and assumptions for the production stage and different service lives datasets (influencing the replacement rates during the use stage).

2. Materials and methods

2.1. Building case studies

As shown in Figure 1, this study is based on three alternatives of the same building: a steel frame building, a timber frame building and a concrete frame building. These three alternatives have been compared during an early design stage and have the same living area and the same energy performance target (low energy requirements according to the French thermal regulation).

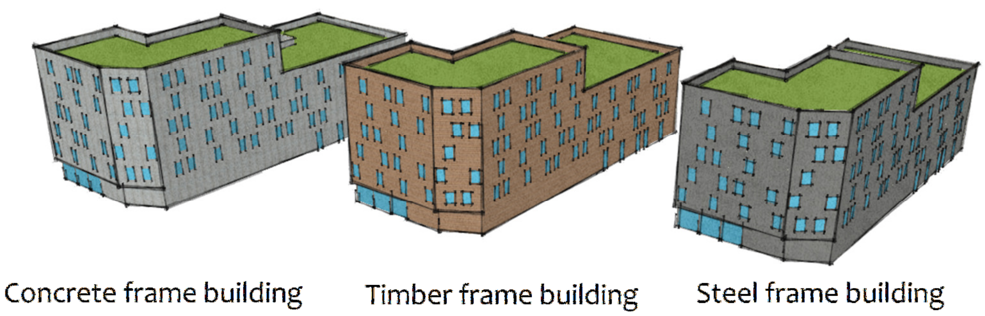

Figure 1: 3D representation of the building's alternatives

2.2. System boundaries

According to the EN 15978 standard [2], modules A, B and C are considered for the impacts related to the building structural products only (technical equipment are not included in the scope of this study). Figure 2 presents the system boundaries.

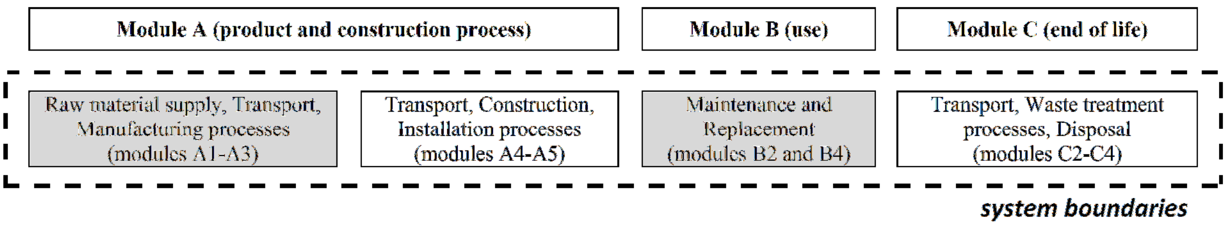

Figure 2: System boundaries for the LCA of the three building designs

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2.3. Data used

2.3.1. LCA data for the production stage

In this study, the sensitivity analysis for the production LCA datasets is conducted only for the key structural elements depending on the building's alternative. For instance, the differences between LCA databases for the wood production (resp. reinforced concrete, steel) will be solely tested on the timber frame building (resp. concrete and steel frame). It means that for the other elements, the same data namely EPDs for the interior and finishings have been used. Table 1 presents the details of the three datasets used in this study. These are based on Ecoinvent data from version 2 (ecoinvent, 2014) as well as average and specific EPDs provided by manufacturers in the national reference database INIES [5].

Table 1: LCA datasets used to assess the impacts related to the production of structural elements for the three alternatives (concrete, steel and timber frames)

Structural building materials	LCA datasets for the production phase		
	Generic Ecoinvent database v2	Average EPD data (France)	Specific EPD data (France)
concrete	concrete, normal, at plant (ready mix concrete based on Portland cement CEM I 300 kg)	EPD manufacturer's data: average ready mix concrete based on Portland cement CEM II 280 kg	EPD manufacturer's data: ready mix concrete based on project specific formulation of concrete (cement CEM I, III, V)
reinforcing steel	reinforcing steel, at plant	French average data representing the impacts of the reinforcing steel sold in the French market (DIOGEN database)	-
steel beam (I, H)	steel low alloyed, at plant	EPD for steel beam and EPD for steel cladding (based on WorldSteel data)	-
timber (structure, cladding, OSB)	sawn timber, hardwood, planed, kiln dried, u=10%, at plant oriented strand board, at plant	EPD for structural timber EPD for wood cladding EPD for OSB	-

2.3.2. Service lives data for the use stage

Only non-structural elements are subjected to the replacement rates as structural elements are assumed to be in place until the reference study period (RSP) of a building is reached. In this study, three service lives datasets are considered for the non-structural elements (interior and finishing) as shown in Table 2. The first two datasets are based on manufacturers' declarations in EPD data [5] and default service lives values proposed in a building LCA tool [6]. A third service lives' dataset comes from an international study on existing values for building products conducted by CSTB [7].

Table 2: Datasets of reference service lives used for the interior and finishing elements

Interior and finishing building materials	Service lives datasets used in France		Service lives from an international study on existing SL		
	Data based on manufacturer's declaration	Default values based on EQUER LCA tool	Statistical data (1st quartile)	Statistical data (median value)	Statistical data (3rd quartile)
Cover coat	50	= RSP*	10	15	25
Seal membrane	50	= RSP*	20	25	30
Windows	30	30	25	30	40
Interior doors	50	30	25	30	40
Partition wall	50	100	20	30	50
Gypsum plaster board	50	100	20	30	50
Screed	50	= RSP*	= RSP*	= RSP*	= RSP*
Insulation for screed	50	= RSP*	= RSP*	= RSP*	= RSP*
Insulation for thermal bridges	50	= RSP*	= RSP*	= RSP*	= RSP*
Polystyrene (EPS) insulation	50	= RSP*	30	50	50
Fibrastyrene slab insulation	50	= RSP*	= RSP*	= RSP*	= RSP*
Ceramic tiles	50	10	10	40	60
Parquet floor	100	10	10	40	60
Paint	30	10	10	15	25

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2.3.3. Scenarios for the transport, on-site implementation and end of life

The transport, construction and installation processes stages will be modelled using the same assumptions based on EPDs for all case studies i.e. the differences in the results will only come from the production stage impacts. Table 3 presents the assumptions used for the EOL modelling for each building material based on EPD assumptions (for timber) and applied to all the datasets.

Table 3: LCA scenarios used to model the EOL impacts of structural elements for the three alternatives (concrete, steel and timber frames)

Structural building materials	Scenarios used for the end of life (EOL) phase for the different case studies		
	Landfill	Recycling	Incineration
concrete	25%	75%	0%
reinforcing steel	13%	87%	0%
steel beam (I, H)	13%	87%	0%
timber	100%	0%	0%

2.4. Environmental indicators

Eight indicators are used in this study based on the French NF P01-010 and European EN 15804 standards for LCA in the construction sector [1][2]. Table 4 presents the names, units and abbreviations of these indicators.

Table 4: List of environmental indicators considered in this study

Indicators	Abbreviations	Units
Total primary energy	PE	kWh
Non renewable primary energy	PE-nr	kWh
Water consumption	WC	L
Waste	WA	kg
Radioactive waste	RW	kg
Global Warming potential	GWP	kg eq-CO2
Acidification potential	AP	kg eq-SO2
Photochemical ozone creation potential	POCP	kg eq-C2H4

3. Results

The results of the sensitivity analyses are expressed per m² of net floor area per year. The baseline RSP is 50 years for the sensitivity analyses of LCA data for the production stage while for the sensitivity analysis of service lives datasets, one more is tested: 100 years. The sensitivity analyses on LCA data presented below are decomposed for the main structural materials (reinforced concrete, structural steel and timber frame). We assess the embodied impacts to analyse differences due to production stage. Then, sensitivity analysis on embodied impacts due to service lives datasets are lead for two different RSPs. The study was conducted using the ELODIE LCA software for buildings [8].

3.1. Sensitivity analyses for LCA production data of concrete and reinforcing steel

Figure 2 presents the results for the concrete frame building. For the concrete data, the main difference appears on the water consumption (WC) indicator. It reaches at least 52% between Ecoinvent and any of the EPDs. In the meantime, differences are opposite and range from 15% to 48% on the primary non-renewable energy (PE-nr) indicator. The variation is similar for the PE indicator though slightly reduced. Differences on non-hazardous waste production (WA) and radioactive waste (RW) are only from 1% to 10%.

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For the reinforcing steel, the main difference appears on the PE-nr indicator with 25% of differences between the average EPD and the Ecoinvent data. For the other indicators, the Ecoinvent values are higher with around a 10% difference.

The reasons of these deviations can be linked to the assumptions used in each datasets. First, the deviations between EPDs from INIES and Ecoinvent can be related to the different production processes between Switzerland and France. For instance, the differences in the water consumption come from a difference in the types of gravels (crushed at mine in Switzerland and coming from rivers in France). As a result, more water consumption is needed in the first case. This mainly explains the difference on the WC indicator. On the PE-nr indicator, even if specific EPDs and Ecoinvent are close, the average EPD with the same formulation as Ecoinvent shows that it is a coincidence. Indeed, these two data with equivalent formulations are distant from 48%. The Ecoinvent PE-nr indicator does not take into account the energy recovery that frequently occurs in cement plants while EPD indicator takes into account recovered energies. This reason mainly explains the difference on this indicator. Regarding the reinforcing steel data, the shares between blast furnace and electric arc furnace routes in the two LCA data are different. The Ecoinvent data assumes that 63% of the steel originates from raw material (iron and coke) while the French data considers that 98% of the steel is recycled steel according to a study conducted in partnership with the Association of certification of reinforcing steel in France [9].

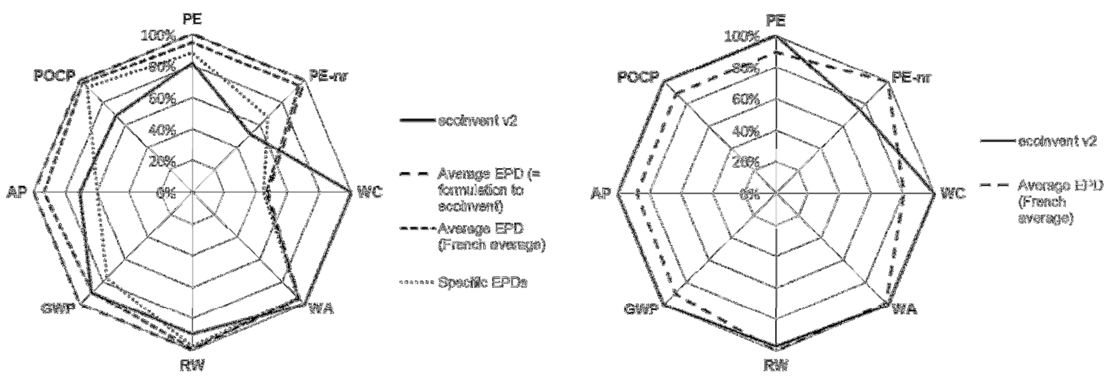

Figure 3: Differences of concrete frame building LCA results due to the use of different datasets for ready mix concrete (left spider diagram) and reinforcing steel (right spider diagram)

3.2. Results of the sensitivity analysis for LCA datasets of the production of structural steel

Figure 3 presents the results of the sensitivity analysis of the structural steel data on the steel frame building. Unlike for the reinforced concrete LCA, we assess differences between EPDs, ecoinvent and WorldSteel data. The EPD being based on the primary WorldSteel data.
The results are found to be closed for all the indicators between the two datasets based on specific data: the EPD and the WorldSteel data. They showed the link between the EPD and the WorldSteel data. As EPD used WorldSteel data as background data, the results are similar, the only differences being the production process to set up the beam in a French factory for the EPD.
When comparing ecoinvent vs. these two data, we notice that the CO2 impacts are higher in the ecoinvent data but due to the fact that the structural steel does not have a major contribution in the building LCA results, the difference is not significant in the final results.

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The same is noticed for the POCP, the AP and the RW indicator. The waste production is however much more important in ecoinvent (generic data) than in the EPD or worldsteel due to a lower amount of recycled steel in ecoinvent data than in EPD and a high contribution of steel to the waste indicator in the steel frame building.

3.3. Sensitivity analysis for LCA datasets of the production of structural wood

Figure 4 presents the results for the timber frame building. First of all, we notice that taking into account biogenic carbon contained in wood products is hugely impacting the GWP indicator (86% difference between the two Ecoinvent datasets). When carbon content of a wood product is considered as biogenic, it means the wood is originate from sustainable managed forests. As a consequence, the production stage of wood has a negative impact on GWP which reduces the embodied impacts of the building. This happens for ecoinvent data and for the EPDs that are also representatives of woods harvested from sustainable forests.
Then, we notice that the EPDs' building alternative has higher CO2 emissions (34%) than Ecoinvent alternative. The difference is even more significant on the POCP indicator, it reaches 54%. The PE indicator gets the same value but there is a 23 % difference on PE-nr. Eventually, WC and waste indicators are equivalent whatever the datasets (less than 5%).

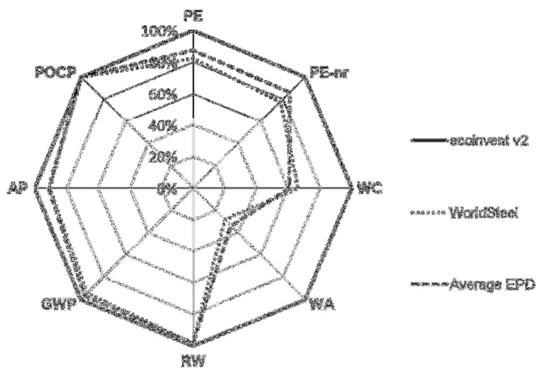

Figure 4: Differences of steel frame building LCA results due to the use of different datasets for structural steel

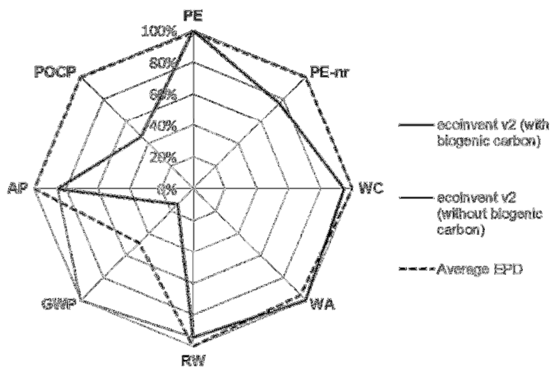

Figure 5: Differences of timber frame building LCA results due to the use of different datasets for structural wood

The differences on the GWP indicator between ecoinvent with biogenic carbon and EPDs mainly originate from production process efficiency and transportation of woods during the production stage. Indeed, the ecoinvent data reflects a Swiss situation with lower

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transportation distances due to the local availability of resources and the size of the country than in France (bigger country with the EPDs reflecting woods imported from Scandinavia's forests). This would explain the higher GWP, POCP and PE-nr found for the timber frame building modelled using EPDs from INIES.

3.4. Sensitivity analyses for the service lives datasets (replacement rates)

Figure 5 now presents the results differences due to the different RSL datasets. We can notice that, assuming a 100 year RSP, the service lives dataset based on manufacturers' declarations leads to lower impacts than service lives dataset based on novaEQUER LCA tool (except for the POCP indicator). Differences range from only 5% on the POCP indicator to 47% on PE. If the RSP is only 50 years, the service lives dataset from manufacturers is inferior on all considered indicators. Differences vary from 8% on POCP to 40% on PE.

Two differences exist between these two datasets: the number of products subjected to replacement (less products are declared equal to the RSP on the manufacturers' dataset) and the service lives themselves. If the first difference was driving the results, the rank of these two datasets should have been opposite. It means the service lives values of building products are the significant parameter to focus on especially for interior and finishing products.

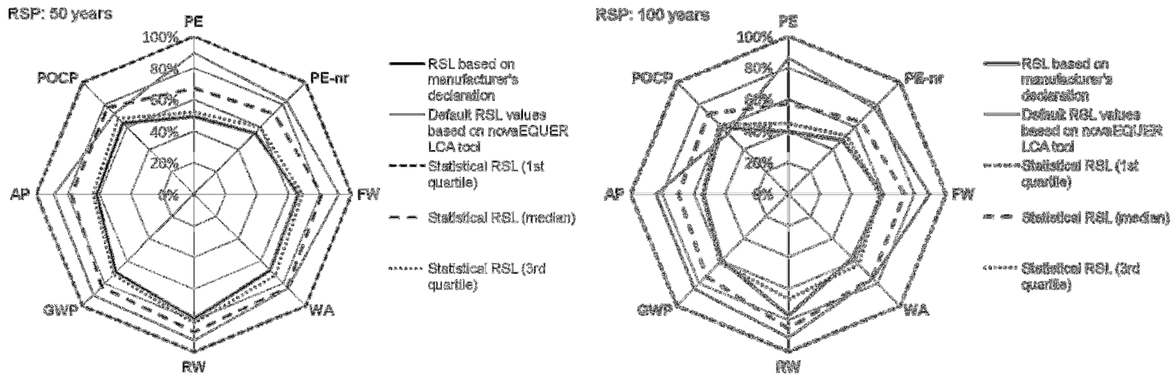

Figure 6: Differences of concrete frame building LCA results due to the use of different datasets for RSL data for two reference study period: 50 years (left) and 100 years (right)

The statistical datasets from literature (3rd quartile) are found very close to the service lives reported by manufacturers: data declared by manufacturers are in the optimistic part of the sample. They declare the longest service lives by using optimistic use phase scenario. On the other hand, the default service lives dataset from novaEQUER is located between the median values and the first quartile: this dataset is less optimistic regarding the products' durability.

4. Discussion and conclusions

According to the assumptions used in this study, it was found that the most important differences on building embodied impacts are linked to the service lives datasets. On the other hand, for specific indicators like WC or GWP, differences due to the LCA results of the production stage can be important depending on the assumptions between EPDs and generic data. In a further study, it would be useful to combine the different LCA and service lives datasets in comparative LCA of building's alternatives to see if ranking inversions occur due to diverging assumptions. Similarly, it would also be interesting to expand the study to the EOL stage which is not explored in details in this study. In particular, the influence to different EOL scenarios for wood products can be even more significant on embodied impacts than difference on production stage data.

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Based on these results, practitioners should be aware that differences can occur in the final results of different constructive systems for the set of 8 indicators presented in this study due to different production processes, LCA assumptions, recycling rates and also assumptions on replacements rates between a generic and a specific LCA study.
In order to move towards reproducible results of embodied impacts in a national context, we recommend harmonizing the service lives' datasets and some critical LCA data e.g., for structural elements. Generally speaking, we also recommend using EPD instead of generic data as they describe more accurately the impacts of a building material sold in a national context. Generic data may be used but only as proxy. However, in France and in Europe, some building LCA tools developers may still prefer relying on generic LCA data (such as ecoinvent) as these data can display a broader set of LCA indicators e.g., for biodiversity, human health impacts etc. i.e. beyond the indicators proposed in building LCA standards e.g., in EN 15804 and used in this study cf. Table 4. The choice should thus be motivated by the goal of the study.

References

[1] AFNOR, 2004. Norme NF P01-010, Qualité environnementale des produits de construction. Agence française de Normalisation. 48 p.

[2] CEN, 2012. EN 15804: Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products. European Committee for standardization.

[3] PRESCO, 2014. Practical Recommendations for Sustainable Construction, European project (FP7), 2011, deliverables available online: www.etn-presco.net/, accessed 25/04/2014

[4] Modahl I. S., Askham C, Lyng K-A, Skjerve-Nielssen C, Nereng G. 2013. Comparison of two versions of an EPD, using generic and specific data for the foreground system, and some methodological implications. International Journal of Life Cycle Assessment 18(1):241-251

[5] INIES, 2014. French EPD database for building products, available online : www.inies.fr

[6] novaEQUER, building LCA tool, available online: http://www.izuba.fr/logiciel/novaequer, accessed 30/04/2014.

[7] CSTB, 2012. Internal report on statistical analyse of existing service lives datasets available at the international level (confidential).

[8] ELODIE, 2014. Building LCA tool, available online : www.elodie-cstb.fr, accessed 25/04/2014

[9] Gomès F, Brière R, Habert G, Feraille A, Lasvaux S, Tessier C. 2013. Adaptation of environmental data to national and sectorial context: application for reinforcing steel sold on the French market, International Journal of Life Cycle Assessment, June 2013, Volume 18, Issue 5, pp 926-938

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Study on Life Cycle Carbon Minus House Part 1: Summary of Project

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Abstract: *The LCCM (life cycle carbon minus) house is a detached house that consumes low energy. It also generates energy and its amount is same as or more than its energy consumption by using on-site renewable energy systems (ex. photovoltaic). To realize the concept of LCCM house, this project has started from 2009 and was processed for 3 years by focusing on four WG. In part 1, Summary of LCCM housing project will be introduced.*

The LCCM house is considered as the Japanese top runner house. We aim to spread the ideas widely by constructing the demonstration house and displaying its efficiency. LCCM house is aimed to reduce the CO2 emissions in a lifetime which includes the production, construction, operation and discard phase. In this manner, it is important to note that during operation as well and take into account up to the reduction of CO2 emissions during construction.

Keywords, LCCM (Life Cycle Carbon Minus), LCA (Life Cycle Assessment), Detached house, CO2 emissions during Operation, CO2 Emissions during Construction, LCCO2 assessment tool

1. Introduction
Recently, the necessity of energy saving has much importance in residence part of Japan. Not only the movement to higher the minimum standard of entire houses, but also new concept is required as a top runner. In this situation, the concept of life cycle carbon minus(LCCM) house, which surpasses energy-saving or zero-energy houses, and changes CO2 emission to minus level through a life cycle of house, is considered. To realize the concept of LCCM house, this project has started from 2009 and was processed for 3 years by focusing on four WG. In part 1, Summary of LCCM housing project will be introduced.

2. Concept of LCCM house
LCCM house means a house that thoroughly reduces amount of CO2 emission from entire procedures of production, construction, operation and discard, and generates energy by using renewable solar energy, solar heat, biomass and others, and could decrease amount of CO2 emission to minus level. (Fig.1)

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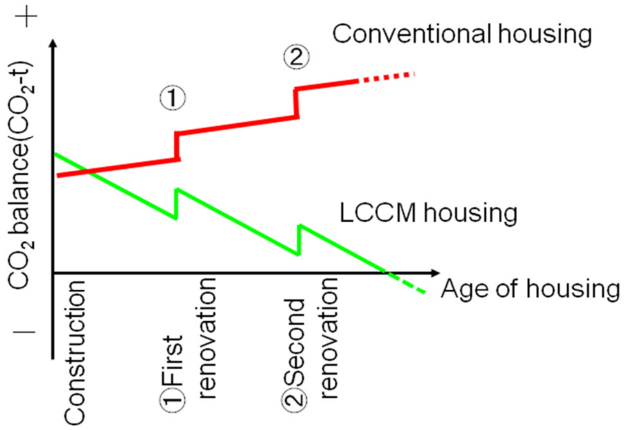

Fig.1 CO2 balance throughout life cycle (image)

The features are divided into three. First is to thoroughly adapting advanced energy saving technology, second is to generate energy that exceeds CO2 emission during operation, and lastly, third is reducing CO2 emission during construction or improvement to achieve LCCM. Although certain technology developments of these three are on the process, it is very difficult to be entirely realized in one house. Development of various technologies to apply on the house by this new concept is purpose of the LCCM house research development project.

A variety of developments on the concepts of zero-energy house, plus-energy house, zero-carbon house and others has been carried out overseas, such as BedZED of UK that aims for zero-carbon and “Plus-Energie Haus” of Germany which allows selling electricity generated from solar power. The concept of Japan is different from other nations which attempts to decrease the amount of CO2 emission to minus level during a building lifecycle.

To make the amount of CO2 emission become minus, the reduction of CO2 amount during construction is also the focus to be experimented. The two approaches for reducing the amount of CO2 emission during construction are: One is to select members of framework and materials that are produce low CO2 emission on manufacture and transportation. The other is to choose the members and materials which are longevous. To reduce the CO2 amount by the first approach is to reduce the carbon footprint from each stage of manufacture, collection and transportation of materials. To reduce the CO2 amount by the second approach is to extend the period of material lifecycle. For example, the CO2 emission amount will become half through extending the lifecycle years from 15 years to 30 years. Therefore, not only choose the low CO2 emitted material, but also consider using the materials for longer period. A LCCM house is required to be energy-conserved and long life cycled. The requirements are the same as the goal of Japanese housing development.

3. Study of the research systems and plans of development

As mentioned above, various technology developments are on certain level of process. However, for accomplishing and popularizing the idea of LCCM, it is necessary to realize carbon-minus as gathering all technologies together but it is very difficult. Therefore, the

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construction of demonstration house is in order to identify the various issues for accomplishment of LCCM house and to verify its effectiveness. (Fig.2) The purpose of this house is to prove each technology and produce data for popularization trough this residential construction.

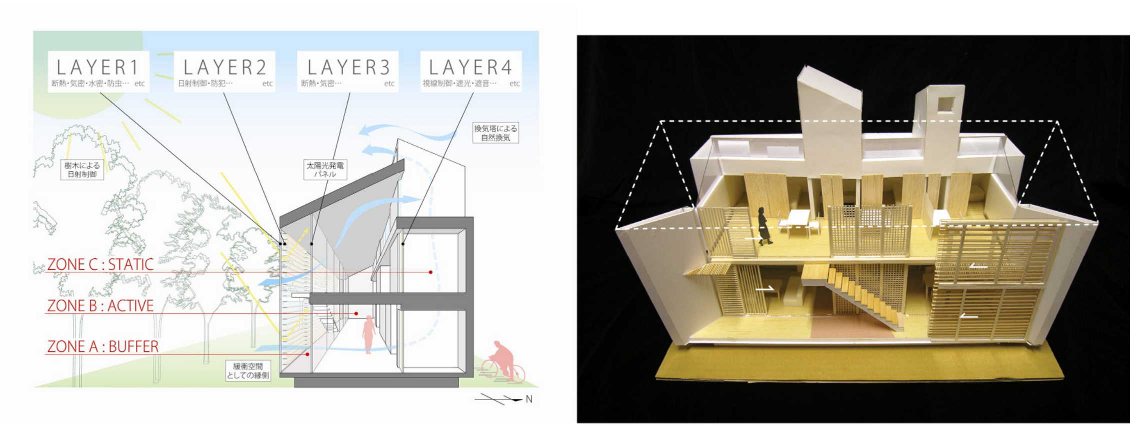

Fig.2 Image of LCCM housing

To realize LCCM house, the basic concept on early stage is as follows:

1) Clearly separate the modes in summer, winter and the season between with an awareness of seasonal differences (Type of housing and lifestyle are variable corresponding season)
2) Develop and disseminate the constructer techniques including various hardware or software to achieve the technologies of energy conservation and energy generation.
3) Integrate software technologies and the hardware technologies for multi-objective optimization and integrated design
4) Examine various demonstrated houses.
5) Develop the production technology and social systems for promoting and popularization

As research and development projects of the Ministry of Land, Infrastructure and Transport, and Building Research Institute and Development Committee has been continued "research and development life cycle cabon minus house" (Chairman Shuzo Murakami) which is provided in the Japan Sustainable Building Consortium general. In the end, we consider about the verification of operation, construction method study of technology, the development of LCCO2 assessment tools, the design and construction of the demonstration house.

And, to achieve the above concepts, the research development was processed for 3 years since 2009 by focusing on following four Working groups. In 2010, the residential model was constructed in Tsukuba City. From 2011, experiments for verification is proceed in the demonstrated house.

1) LCCO2 WG (chair : Toshiharu Ikaya, Keio University)
 : Concept design and establishment of a calculation system of LCCO2 in housing
2) Energy and building equipment WG (chair :Yasuo Kuwasawa, Building Research Institute)

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: Development of various environmental technologies and equipment to reduce CO2 emissions
3) Construction technology WG (chair : Tsuyoshi Seike, the University of Tokyo)
: Development of construction methods to reduce CO2 emissions
4) LCCM housing design WG (chair : Masao Koizumi, Tokyo Metropolitan University)
: Design of LCCM demonstration house and creation of building design manual

4. Study of the research systems and plans of development

During a lifecycle of residential building more than 30 years, the period that emits the most CO2 is during the operation, and the amount is about 70% of total emission. The issue becomes the first step to be considered for a LCCM house. To save energy completely, use not only high-efficiency air conditioning and water heating equipment, but also natural energy. Therefore, it is necessary to well combine equipment with ventilation in summer and solar radiation in winter. (Fig.3)

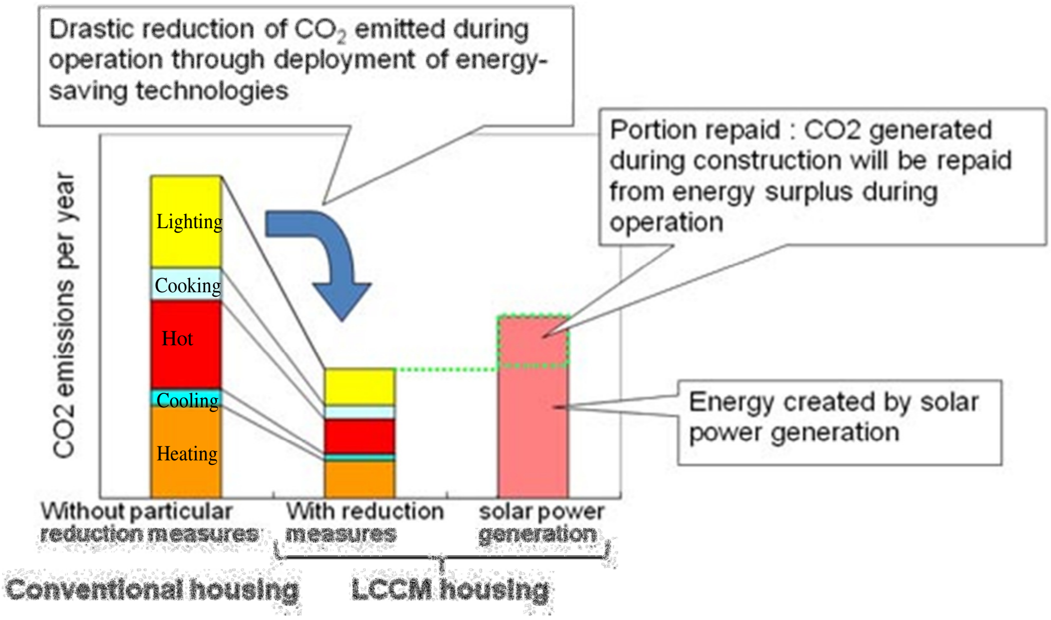

Fig.3 Achievement of carbon minus through energy saving and energy creation (Image with a focus only on the operation stage)

LCCM house is a complex which is properly operated as important as well designed. Therefore, we simulated a variety of equipment related to the environment; the result of the simulation became the reference for designing the demonstration house.

Especially, the way of HVAC system usage will relate to an architectural design. To implement the passive design and utilize natural resource, the composition of building opening and the interior space have to be well considered. It takes time to find the best design combination by simulating. However, it might be difficult to do such comprehensive discussions and simulation studies for most housing design projects. If design tools could be developed, the idea of LCCM would become possible to apply on all housing design.

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We assume the equipment such as performance of the water heating and the lighting dominants the result of the energy conservation; the optimum operating condition of high-efficiency equipment has been studied. The method for energy generating we chose is solar power system and fuel cell. The electricity is generated efficiently by installing solar panels on the south roof of the demonstration building. The point we are focusing is not only the simulation result of the equipment operation, but also the appropriate equipment selection.

5. Study of CO2 emissions during construction

In order to achieve the goal of LCCM, energy conservation and CO2 emission reduction during operation are basic requirements. However, the situation might happen that the amount of CO2 can't become minus during building lifecycle by only meet the requirement. In such case, to reduce the CO2 emissions during construction is also important. Hence, we examined the amount of CO2 emissions during both design and construction phases for the LCCM demonstration house. Furthermore, wooden structure is chosen to build LCCM house because of its small amount of CO2 emission.

The CO2 emission amount of LCCM house is larger than the amount of conventional house during construction, because that the higher performance element are used. After reducing the quantity of concrete by changing the shape of the foundation, the CO2 amount is decreased.(Fig.4) The elements which can control the amount of CO2 emission during construction are the choice of materials, the distance of transportation…etc. However, the goal to achieve high performance is more important than to reduce CO2 emissions only during construction.

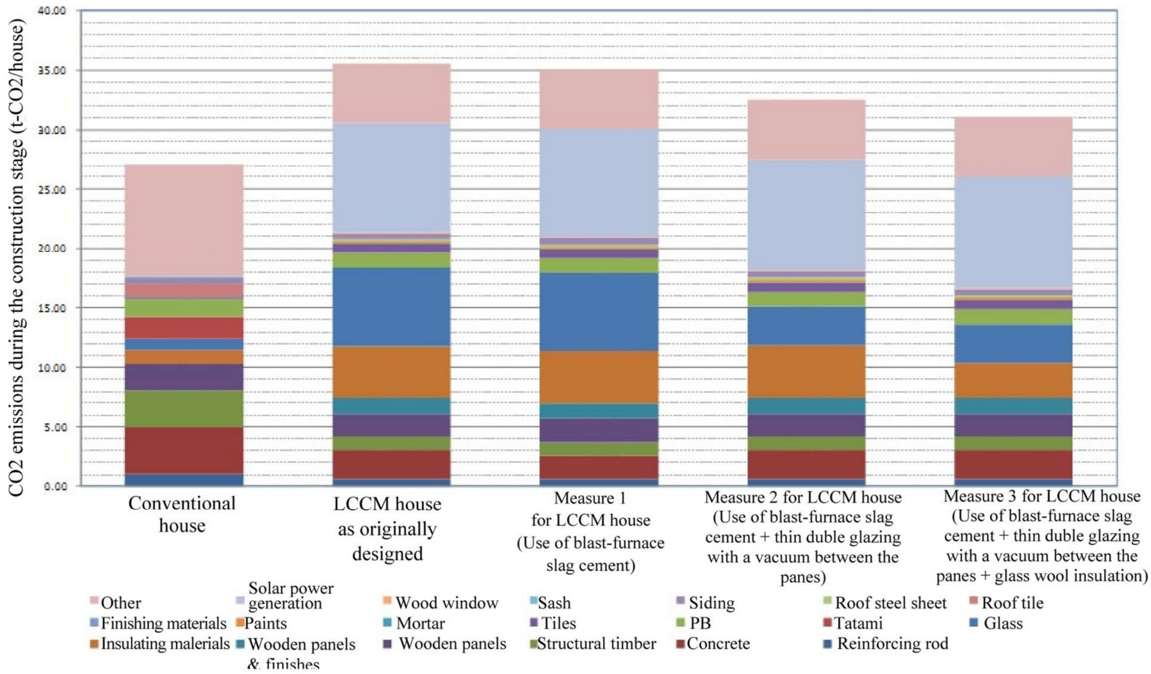

Fig.4 Proposed measures to reduce CO2 emissions during the construction stage

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By current design technique is still not able to complete the process of LCCM design, because of the lack of data for assessment. Therefore, the development of database for simulation and assessment tool are important.

Furthermore, to accomplish the goal of LCCM, it is important to develop a tool of calculating the CO2 emissions during construction and also the database. However, there is not enough information to make the data. To popularize the concept of LCCM house on entire social environment, the database should be developed and completed.

6. Development of LCCO2 assessment tool
To realize a LCCM house, we have to ascertain that the house design meets the requirement of LCCM; an evaluation tool is needed. The evaluation tool of LCCM house is able to calculate the amount of CO2 emissions in lifecycle of the house. The developed tooI can evaluate each stage of LCCM housing lifecycle such as material production, construction, operation, renovation and reconstruction; especially it can evaluate the wood materials locally, transportation and circulation process detailly.

On the other hand, to evaluate LCA in detail needs lots of works. The evaluate approaches are difficult to be follow for constructing a detached house. Therefore, a simple version of the tool should also be develped; local builders and designers can easily use the tool for assessing the construction and design of detached houses. The tool is planed to be inculded in 'CASBEE for Detached Houses(for New Construction)'.

The most construction evaluation will become easy to be calculated for detached houses through "CASBEE(Comprehensive Assessment System for Built Environment Efficiency)". In present "CASBEE for Detached Houses(for New Construction)", we can easily evaluate LCCO2 and the result is certificated by the number of green star. The highest score is five stars. (Fig.5)

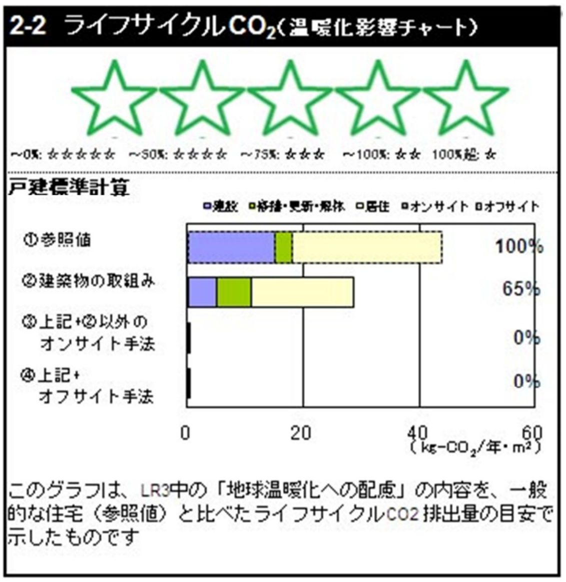

Fig.5 LCCM housing of five star

7. References

[1] LCCM House Research and Development Comittee (2012), Design Method for LCCM House, Kenchiku Gijyutsu, Inc., ISBN 978-4767701332 (in Japanese)

[2] Tsuyoshi SEIKE et al., (2013), Study on Life Cycle Carbon Minus House Part1: Summary of LCCM Housing Project, International conference SB13 Oulu Finland, Proceedings of international conference SB13 Oulu Finland

[3] Ryo Murata et al., (2013), Study on Life Cycle Carbon Minus House Part2: Design of demonstration house, International conference SB13 Oulu Finland, Proceedings of international conference SB13 Oulu Finland

[4] Kozo TAKASE et al. (2013), The Result of Experimental Residence in LCCM Demonstration House, AIJ J. Technol. Des. Vol.19, No.42, 661-664 (in Japanese)

[5] Manabu KANEMATSU et al. (2011), Life Cycle Assessment of Carbon Dioxide of LCCM Demonstration Housing. Part.1, Summaries of technical papers of Annual Meeting AIJ. A-1, 1005-1006 (in Japanese)

[6] Ken YOSHIMORI et al. (2011), Life Cycle Assessment of Carbon Dioxide of LCCM Demonstration Housing. Part.2, Summaries of technical papers of Annual Meeting AIJ. A-1, 1007-1008 (in Japanese)

[7] Yuki SENO et al. (2011), Life Cycle Assessment of Carbon Dioxide of LCCM Demonstration Housing. Part.3, Summaries of technical papers of Annual Meeting AIJ. A-1, 1009-1010 (in Japanese)

[8] Kozo Kadowaki et al. (2011), Design Process of the Demonstration House for the “Life Cycle Carbon Minus” Concept, Summaries of technical papers of Annual Meeting AIJ. E-1, 997-998 (in Japanese)

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Study on Life Cycle Carbon Minus House Part 2: Design concept of the LCCM demonstration house (Best Papers SB13 Oulu)

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Abstract: *The LCCM (life cycle carbon minus) house is a detached house that consumes low energy. It also generates energy and the amount is same as or more than its energy consumption by using on-site renewable energy systems (ex. photovoltaic). This project has started in 2009 and a demonstration house was constructed in Tsukuba, Japan in 2011. Part 2 shows the design concept of the LCCM demonstration house.*

Design of the demonstration house was proceeded with detailed predictions of building's properties, such as the estimation of embodied CO2 that are emitted from various building materials during construction, the calculation of energy consumption and generation during operation. To achieve appropriate balance of CO2, the demonstration house is designed on the concept of " the house changing to different set of clothing for seasons." It means this house has the mode change system for its environmental control.

Keywords, LCCM (Life Cycle Carbon Minus), LCA (Life Cycle Assessment), CO2 emission, Embodied CO2, Renewable energy, Detached house, Mode change System, Passive design, MultiLayered Composition, Human Activity

1. Introduction

The LCCM (life cycle carbon minus) house is aiming to ultimately reduce CO2 emission impact through a life cycle of house. Its goal is to achieve that the balance between CO2 emission and CO2 offset by using renewable energy systems shows surplus for the amount of CO2 offset through its life cycle. It means that the LCCM house is quite different to other usual ecological houses on its concept. Because many ecological houses in the past mainly focused on reduction of environmental impact which these houses emit during operation, whereas the LCCM house aims to reduce both CO2 emission during construction and operation. The aim of the LCCM demonstration house is verification of possibilities and problems of the LCCM house and spread its concept through its actual construction.

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2. Design concept of mode changeable house
Realization of the concept of LCCM needs conditions such as 1) the construction methods and building materials are low CO2 emission, 2) the building performance and equipment allow low energy consumption for hot-water supply, heating, cooling, ventilation and lighting, 3) the house has the equipment which can generates energy or use renewable energy, and moreover, 4) people who live in it know how they should behave to utilize its building environmental performance.

These conditions sometimes conflict each other, such as day lighting and sun shading. The LCCM demostration house solves this kind of problems by its design methodology of "the house changing to different set of clothing for seasons". For environmental control, the house has the mode change system which can response to various requests from seasons and human activities. It suggests a flexible way to control building environment, just like wearing the cloth. This shows a big difference comparing with the way which defeats nature by force. (Fig.1, Photo.1, 2)


Fig.1 Design concept of the LCCM demonstration house (left)
Photo.1 Exterior (right above), Photo.2* Interior of 1st floor * Photograph by Koichi TORIMURA*

3. Principal design strategies

3.1 Stripe planning

The LCCM demonstration house is a two-story detached house (Fig.2). Entrance, living room, dining room, kitchen, lavatory and guest room are on the first floor. Three small bed spaces and two workspaces are on the second floor. The shape of floor plan is long from east to west. This form allows to maximize solar gain from the south and to reduce negative effect of sunlight in summer.

The floor plan is composed of three zones arranged in stripe pattern (Fig.3). Southern zone is "BUFFER ZONE". This zone has engawa or veranda that are open to the south for facing sun.

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Northern zone is "STATIC ZONE". This zone is closed for protection against a north wind. Central zone between them is "ACTIVE ZONE". This zone is spacious with high ceiling, to stimulate lively human activities (Photo.3).

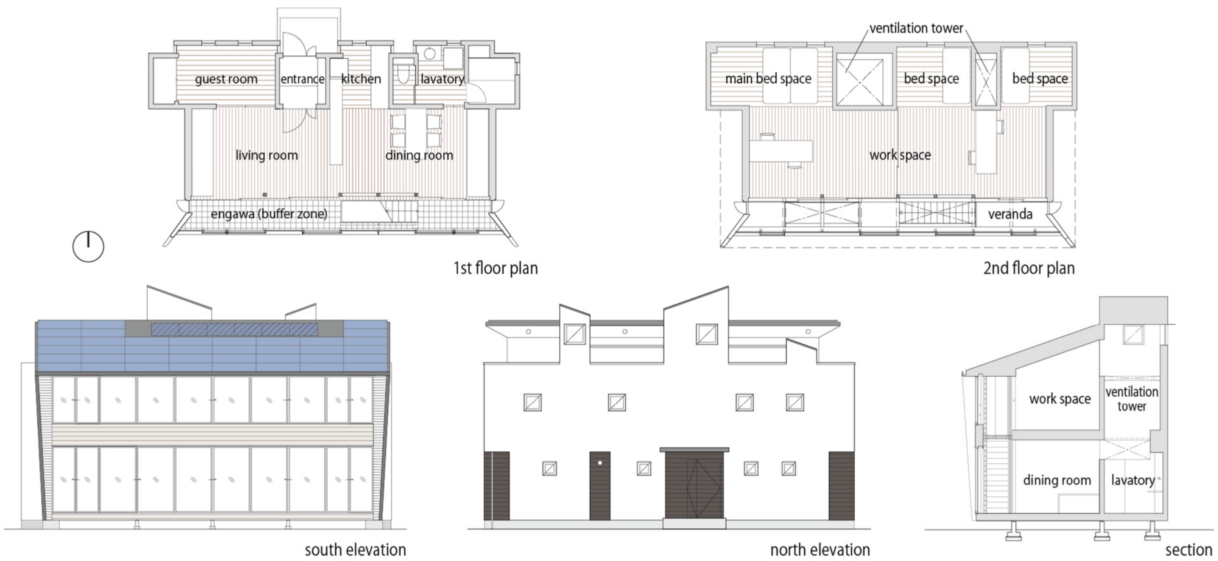

Fig.2 Drawings of the LCCM demonstration house

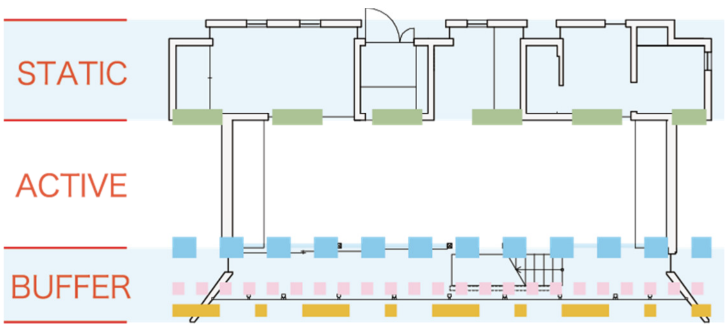

Fig.3 Stipe planning (left), Photo.3 View from ACTIVE ZONE to BUFFER ZONE*

3.2 Multi layered sectioning

The structure of this house is timber framework method that is ordinary in Japan. But in this case, its normal two-story height is differentiated spaces for human activities from spaces for environmental elements, such as light and wind. These different eight spaces are stacked alternately, therefore the section shows multi layered composition (Fig.4, Photo.4).

This sectioning made possible integration of design methods to reduce CO2 emission during both construction and operation. For example, the foundation is the lowest layer. Its form is continuous footing and raised-floor style. The edge of floor is cantilevered. This shape aims to reduce the volume of concrete, so that it can reduce CO2 emission during construction. Furthermore, it allows natural ventilation by using floor inlets of engawa (Photo.4).

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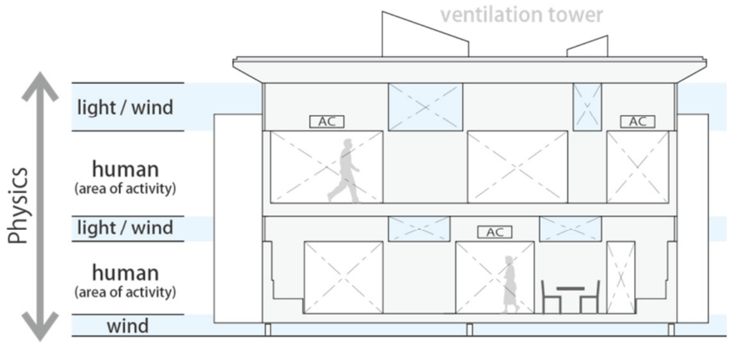

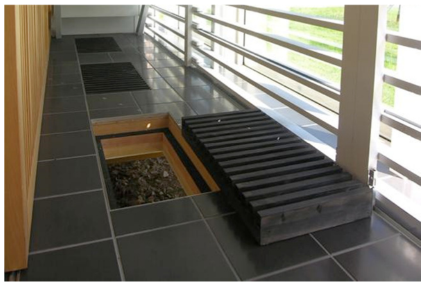

Fig.4 Multi layered sectioning (left), Photo.4 Floor inlets of engawa

3.3Multilayered windows

This house is equipped with many windows that have various different functions. These windows are arranged in multi layered way for passive and active environmental control in daily life. According to different requests from seasons and human activities, they can be used in various combinations (Fig.5, Photo.5, 6).

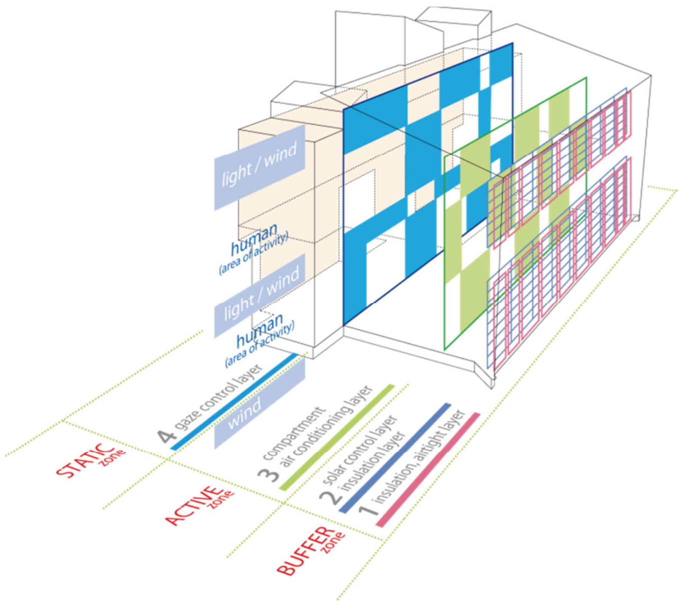

Fig.5 Multi layered composition diagram (left)

Photo.5* View from engawa, Photo.6* View from main bed space

The functions of each layers are as follows: 1) insulation and airtight layer of wooden window, 2) solar control layer of wooden louver, 3) insulation layer of honeycomb screen, 4) compartment air conditioning layer of wooden door and honeycomb screen, 5) gaze control layer of roll screen. Furthermore, deciduous trees and grasses planted around the house act as the natural layer to control sunlight and radiant heat from the ground.

Residents can customize the indoor environment by combinations of ON/OFF of these layers according to climate and their life style.

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3.4 Mode change system responding to various seasons and human activities

These characters of this house keep in close cooperation, so that this house has the mode change system responding to various environmental differences, such as seasonal, day and night, human activities and their lifestyles. Fig. 6 shows basic six modes that are based on the methodology of use of passive and active ways according to its needs.

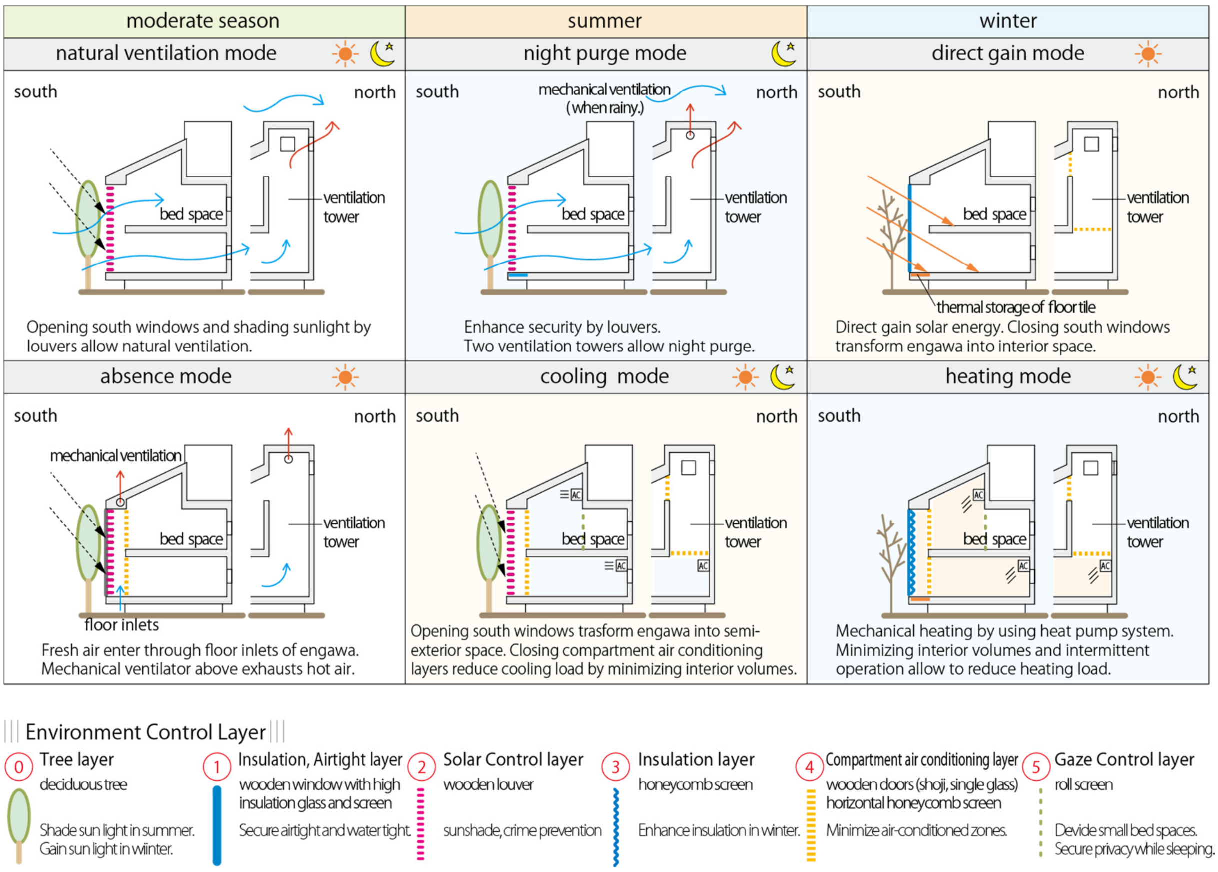

Fig.6 Basic six modes of environment control

In a calm season, "natural ventilation mode" creates comfortable breezed and shaded spaces. In summer night, "night purge mode" is ready for taking in the cool air. While the mode is in these cases, the ventilation towers in northern zone are open to encourage smooth airflow. Furthermore the southern windows as the insulation and airtight layer are also open, so that it creates big semi-outdoor spaces under the eaves by transforming engawa and veranda. In winter sunny day, "direct gain mode" gives maximum use of solar energy. Southern windows are closed, engawa changes into an interior space just like a sunroom.

These modes mentioned above are mainly in passive way, whereas "cooling mode" in summer daytime and "heating mode" in winter are based on active control. In these active modes, multi layered windows are closed to achieve low energy consumption by minimization of interior spaces that are air-conditioned.

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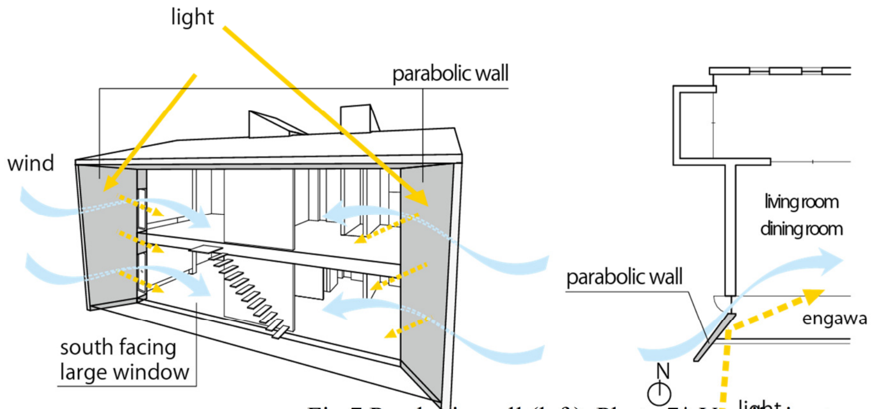
"Absence mode" is ready for cases when residents are out. This mode allows to avoid situations which high-insulated and air-tight houses sometimes overheat caused by shutting all windows while resident's absence. The idea of this mode is like "the standby mode" of home electronics or "the sleep mode" of personal computers. It gives quick and effective air conditioning after resident's return.

3.5 Parabolic wall and ventilation tower

The south façade of this house was intended to be open to gain solar energy, therefore the shape of walls of east and west has become parabolic (Fig.7). This form allows to increase both the amount of solar gain and the area of photovoltaic panels on the roof. In addition, these walls serve as the wind-catcher because they create gaps of air pressure around them that are useful for natural ventilation.



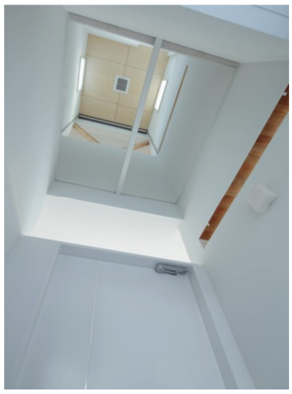


Fig.7 Parabolic wall (left), Photo.7* Ventilation tower

In northern zone, two towers are located in the position sandwiched between small bedrooms (Photo.7). They also create gaps of air pressure above roof, create the airflow from bottom area to towers. To avoid the backward flow that causes intake of negative hot air, the angle of roof and the position of windows of towers are decided with CFD simulations. In addition, these towers act as the day-lighting device. Therefore they serve natural brightness to the northern zone where it tends to be darker in general.

3.6 Wooden sunshade louver

In general, the sunshade on the outside of window is more effective than inside. But this type of sunshade needs to resist weathering. In this case, aluminum blinds are employed, whereas they emit high CO_2 during their manufacture. And the season when the sunshade plays an active roll is the period when the natural ventilation is also prominent. It means that the strength against wind is also necessary for the sunshade.

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For reasons mentioned above, this house has wooden sunshade louvers on the inside of southern windows. Wooden louver is weaker than aluminum against weathering. But it has a big advantage of embodied CO2. In this house, wooden louvers are protected on the inside of windows and under the roof. Their dimension (depth, thickness and interval) is decided according to the prevention of unnecessary sun light during summer and the strength against wind while natural ventilation mode. Moreover, they are movable to allow that solar gain and sunshade are compatible (Fig.8).

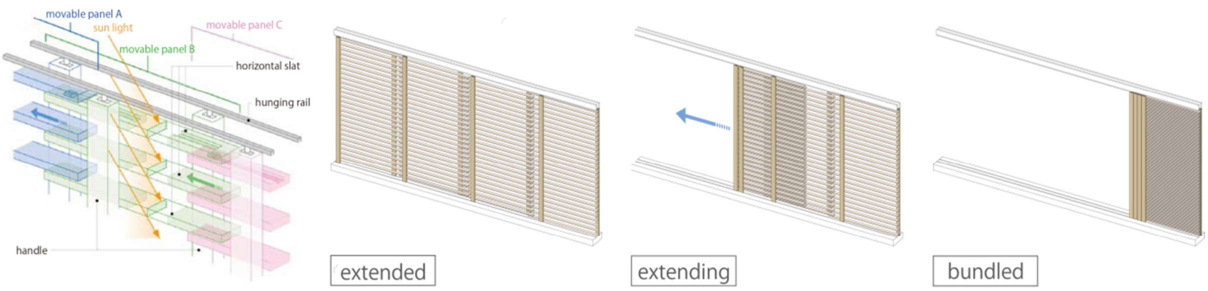

Fig.8 Structure and mechanism of wooden sunshade louver

4. **Conclusion**

The LCCM demonstration house is for realization of the latest concept of ecological house as LCCM that targets on ultimate reduction of CO2 impact. Through the design and construction of the demonstration house, many kinds of subjects are discussed. Therefore, various verifications including experimentations of inhabitants have been conducted. In the experimentations, many environmental factors were validated. For example, they are the amount of CO2 emissions by each use, the amount of solar power generation in various weather conditions, the fluctuations of indoor and outdoor temperatures and the effectiveness of mode change system. The details of these results are shown in the references [1] [2].

This is a demonstration house, not a model house. In other words, it means diverse possibilities of design on the LCCM concept are left.

5. References

[1] Kozo TAKASE et al., THE RESULT OF EXPERIMENTAL RESIDENCE IN LCCM DEMONSTRATION HOUSE, AIJ J. Technol. Des. Vol.19, No.42,661-664, Jun., 2013

[2] LCCM House Research and Development Comittee, DESIGN METHOD FOR LCCM HOUSE, Kenchiku Gijyutsu, Inc, ISBN 978-4767701332, Mar., 2012 (in Japanese)

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Survey on LCA results analysis, interpretation and reporting in the construction sector

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Abstract: *Life Cycle Assessment (LCA) is widely recognized as the most relevant tool to evaluate building environmental impacts. Previous works have proposed different building LCA tools to spread LCA in the building sector practices. However, as initial questions are different depending on the user profiles, answers should be different from a building LCA tool developer's perspective. Indeed, one single LCA tool embedding a single methodology and a single way to analyse and express the results will not fulfil the needs of all stakeholders. In this study, a national survey was conducted in order to better understand the needs of these building stakeholders to feed back LCA tool developers. Focus was put on the interpretation and reporting steps of the LCA method as defined in ISO 14040. Results showed different practices, expertises, and scope of studies. Stakeholders not familiar with LCA prefer easy-to-go interpretation while experts still prefers keeping detailed results. Outcomes of this survey can now be used by building LCA tool developers to better ajust the analysis and interpretation tools in their software to match the user needs.*

Key words: Life cycle assessment, energy efficient building, building environmental assessment, renewable energy, allocation, dynamic

1. Introduction

The building sector is a major contributor to the environmental impacts including climate change, energy consumption, waste generation and air pollution [1]. In that context, the Life Cycle Assessment (LCA) method can serve as an instrument to assess the environmental performance of buildings and building products [2] providing a holistic overview of their life cycle. LCA is standardized through the ISO 14040-14044 standards and, for the construction sector, the European standards EN 15804 and EN 15978 provide general calculation rules for LCA of building products, technical equipment and buildings [3]. In the construction industry, LCA is increasingly used in research projects and in daily practice. Building certification schemes (e.g. BREEAM, HQE or DGNB) have started relying on LCA to assess the environmental performance of buildings. To ease the operational practice, guidance documents have proposed study types to adapt the levels of details of the LCA calculation rules to the project stages and objectives (e.g. screening, simplified and complete LCA) e.g., in the EeBGuide Infohub for building LCA [4].

Reviews of LCA tools for buildings are available in Ortiz et al. [5], Bribian et al. [6] and more recently in Lasvaux et al. [7]. These state-of-the-art of building LCA tools in Europe revealed

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different levels of maturity between the tools and different choices for the databases, the methodological rules and the environmental indicators. Indeed, no existing tools match all the user needs because they have been developed with different starting points e.g. as decision making tools for architects or thermal anlyisis engineers or in opposite for certification purposes. Despite the high number of available tools, using LCA in practice is still not a common practice [8]. While a complete harmonization of the different philosophies, there is a need to better link users' expectations and the interpretation and reporting aspects within building LCA tools. Very few research works have been conducted in the field of LCA results interpretation for the specific case of the building sector. Saunders et al. [8] analyzed the practice of LCA in the US building sector. The authors concluded that even though stakeholders are aware that LCA provides information about environmental impacts, the lack of building related metrics was highlighted as a prominent barrier.

In this study, a survey is conducted to better understand the link between the different user profiles of LCA in the building sector and the types of interpretation and reporting methods. The next section presents the assumptions used to build the survey and section 3 presents the results.

2. Methodology

2.1. Online survey

A web-based survey using Google Drive ™ was set up and diffused using differen tools to increase the visibility (e.g. mailing lists, social networks, expert forums, etc). No particular restriction was adopted since the study objective was to reach various user profiles and stakeholders interested in LCA. The survey went live from the 07/15/2013 to the 02/10/2014 and collected a total of 121 responses. Except questions on LCA result display, the survey contains parts to characterize the sample at both levels: general profile information (professional duty and organization size) and LCA knowledge.

2.2. Sampling methods

The results of the survey were grouped according to two criteria:

- Type of stakeholders (see Table 1)
- Level of LCA expertise (see Table 2)

The first grouping criterion is based on work typology. Table 1 presents the stakeholders' groups and the number of answers collected per group. The respondents come from a wide range of professions in the building.

Table 1: Number of answers based on professions

Stakeholders groups based on their professions	Sample
Architects	3
Consulting engineers for contracting authority	13
Design office	36
Trade unions	8
Building certification engineer	4
Construction engineer	14
Building manufacturers	11

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Prime contractor	7
Contracting authority	6
Public policies experts	6
Researchers	12
Economist	1
Total	***121***

A second grouping criterion was proposed according to the level of LCA expertise of the survey's participants. Considering:

$$C_{th\_n}: theoritical\ knowledge\ level\ of\ participant\ n$$
$$XP_{pr_n}: pratical\ experience\ level\ of\ participant\ n$$
$$N_{mod\_n}: number\ of\ LCA\ study\ performed\ by\ participant\ n$$
$$N_{lect\_n}: number\ of\ LCA\ report\ red\ by\ participant\ n$$

Thereafter, calculating both indicators:

$$SE_n = C_{th\_n} + XP_{pr\_n}: self-estimation\ of\ participant\ n$$
$$PQ_n = 3 \times N_{mod\_n} + N_{lect\_n}: practical\ quantification\ of\ participat\ n$$

The factor "3" applied on the number of performed LCA study allows increasing the weighting of LCA practitioners. Then, these two conditions are considered:

$$If\ SE_n \geq 7\ then\ t_{1\_n} = 1\ else\ t_{1\_n} = 0$$
$$If\ PQ_n \geq 10\ then\ t_{2\_n} = 1\ else\ t_{2\_n} = 0$$

Wherein: $t_{1_n}: condition\ 1\ results\ for\ participant\ n$

$t_{2\_n}: condition\ 2\ result\ for\ participant\ n$

Finally, the sum of both test results gives the expertise level:

$$If\ t_{1\_n} + t_{2\_n} = 0 \rightarrow low\ expertise\ level$$
$$If\ t_{1\_n} + t_{2\_n} = 1 \rightarrow middle\ expertise\ level$$
$$If\ t_{1\_n} + t_{2\_n} = 2 \rightarrow high\ expertise\ level$$

The global sample can be splited up in three groups as shown in Table 2 and helpful to study:

- The possible modification of interpretations from a group to another,
- The posible modification of interpretations from a group to the whole simple.

Table 2: Number of answers based on LCA expertise

Stakeholders groups based on LCA experience	Sample
Low expertise level	64
Middle expertise level	21
High expertise level	41

2.3. Topics included in the survey

Next to the general information asked to better characterize the panel, a complete set of LCA indicators was included in the survey. The stakeholders are asked to give priority to each environmental aspect (e.g., climate change, raw material extraction and depletion, water consumption).

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Similarly, they are asked to give their opinion in the normalisation and aggregation steps of a LCA. These two steps enable to summarize the LCA results into single score and into equivalent units to be able to identify the most relevant actiosn to take. For instance, such tools can help focusing on energy consumption rather than eutrophication in the building sector due to the high share of this sector in the global energy consumption.

3. Results

3.1. LCA understanding, knowledge, practice and goals

Figure 1 presents the relationship between the theoretical knowledge and the operational practice of the different respondents. Average values are represented for each group. Despite an important proportion of low-practical level respondents (43 % responding 1 or 2 whathever the group, not shown in Figure 1), a majority of people states having a pretty good theoretical level as shown by the averages values in Figure 1 (from 2,5 to 4,5).We notice a linear relation of the results in X (theoretical knowledge) and in Y (operational practice). The least knowledge is reported for the group "economist" (only 1 respondent) while the highest knowledge and operational practices correspond to the building manufacturers. About 25% of the answers came from design office engineers both energy and environmental experts. It is important to mention that in every group a substantial variability of the knowledge and practice exists though the average value should be taken as indicative. The next section presents the results of the survey.

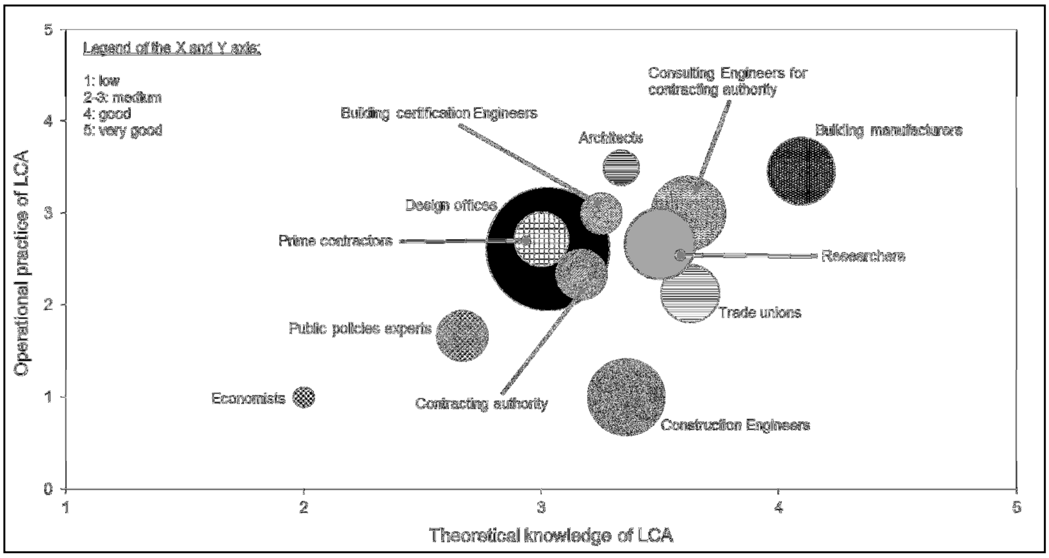

Figure 1: Stakeholders' group respondents' knowledge and practice in LCA. The size of the bubbles indicates the number of respondents in each group. The centre of the bubble represents the average score for the theoretical knowledge and operational practice.

Figure 2 presents the shares of the type and number of LCA studies either conducted or red by the diferent stakeholders. First, a large part concerns building LCA and product LCA, only minor parts (less than 20%) go for process or neigboorhood LCA. Second, most of the people have conducted less than 10 LCA studies (resp. read less than 10 LCA studies).

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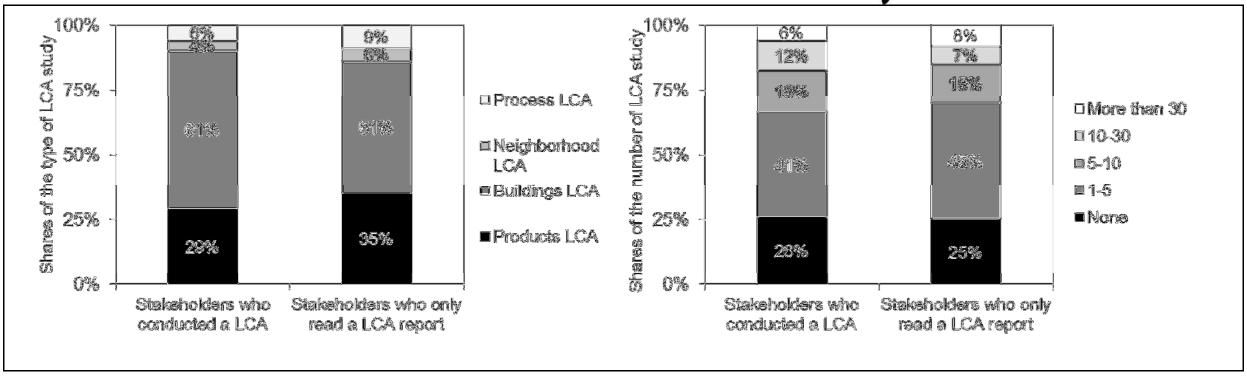

Figure 2: Shares of the type of LCA study conducted or red by the stakeholders.

To the question *"would you estimate yourself relevant to understand and use building LCA results?"* 48 % of the respondents answer *"yes"*. That highlights two notable points:

- Half of the respondents would give relevant trails thanks to their knowledge and understandings of the difficulty.
- Half of the respondents would give relevant trails by clearly underline the lack and hotspot without any background.

The last question concerns the goal and scope of the LCA. Most LCA practitioners mentioned *eco-designing*, *decision support* and *certification/labeling* as primary goals.

3.2. LCA interpretation: environmental indicators' ranking

In the survey, a list of environmental indicators has been proposed among the most commonly indicators found in LCA tools for buildings in France. People were asked to qualify their priorities on a four-grade scale (1: not useful, 2: not very important, 3: moderately important, 4: highly important). Based on the percentage got for the four ranking grades of each indicator among the sample of construction stakeholders', two types of weighting factors are calculated. The first one is only based on the 1st and 2nd rankings while the second one is based on all rankings. These factors are calculated with the formula below:

$$W_i = \frac{\sum_j R_j \times P_j}{4}$$

With: *W_i : weighting factors for indicator i*

$j \in [1;4]$

R_j: grade of ranking j

P_j: percentage of ranking j

Even if the weighting factors are only indicative, they describe stakeholder's priorities. As an illustration, Figure 3 presents the scatterplots of the two types of weighting factors for the LCA indicators used in French building LCA tools according to stakeholders' choices.

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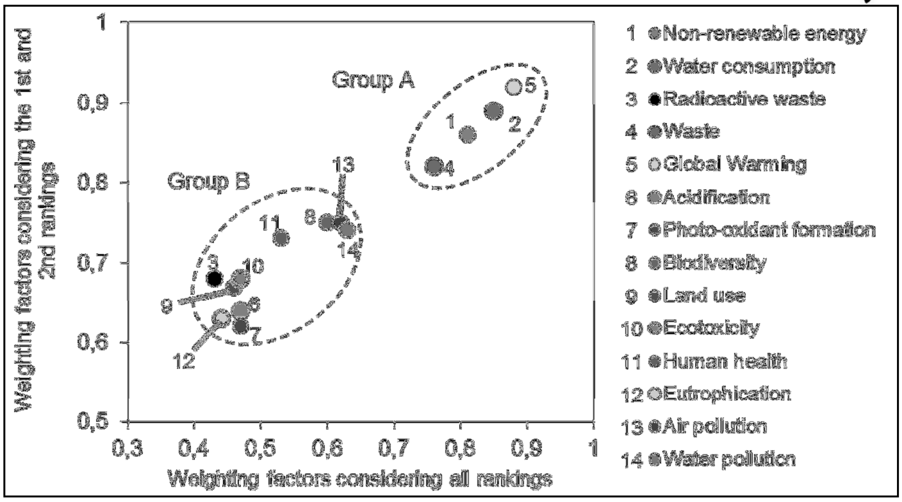

Figure 3: Representation of the weighting factors for each LCA indicators based on stakeholder's priorities

Two groups of indicators can be separated based on the results of Figure 3. The first one gathers four indicators: the primary energy, the global warming, the water consumption and the waste generation. The weighting factors vary from 0,75 to 0,92. The other group has all the other indicators with weighting factors around 0,5 (from 0,4 to 0,63). Interestingly, the top four indicators match with the public policies priorities in France following the "Grenelle de l'Environnement". The results are relatively stable whatever the level of expertise of the respondents.

3.3. Other results for the LCA interpretation: normalisation and weighting

Normalization is the prior step to weighting and aggregation. In this survey, people were asked to give their opinion on two types of normalization factor systems. Two choices were proposed: the first one is a customized factor system (i.e., each practitioner could set his own factors) and the second one is a default factor e.g., based on LCA tool developers assumptions or other national or European statistics (energy consumption, CO2 emissions in the building sector etc.). We found that t presents the answers of both questions about the needs of customizable normalization factor system and default normalization factors in the tools.

Table 3: Stakeholders' needs for normalisation factors

	Stakeholders answers	
Questions	YES	NO
Customized normalisation factor system	57%	43%
Default normalisation factor in LCA tools for buildings	62%	38%

We found that the two solutions are approved by the majority of respondents. Similarly, Table 4 presents the results of the stakeholders' needs in single score's indicators.

Table 4: Stakeholders' needs for an aggregation system and single score display

	Stakeholders answers	
Questions	YES	NO
Get a unique score for LCA result display	56%	44%
Customized aggregation factor system	51%	49%
Default aggregation factors in tools	55%	45%

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Table 4 shows the interest in aggregated score to express building LCA results (percentages of "yes" between 51 to 56%). It seems that people are slightly more interested in getting default aggregation factors than having the possibility to create their own factor set.

3.4. LCA reporting

The last point of the survey consists in exposing users to LCA reporting document examples. The aim is to test several display formats and get an appraisal about each. Four different documents were proposed.

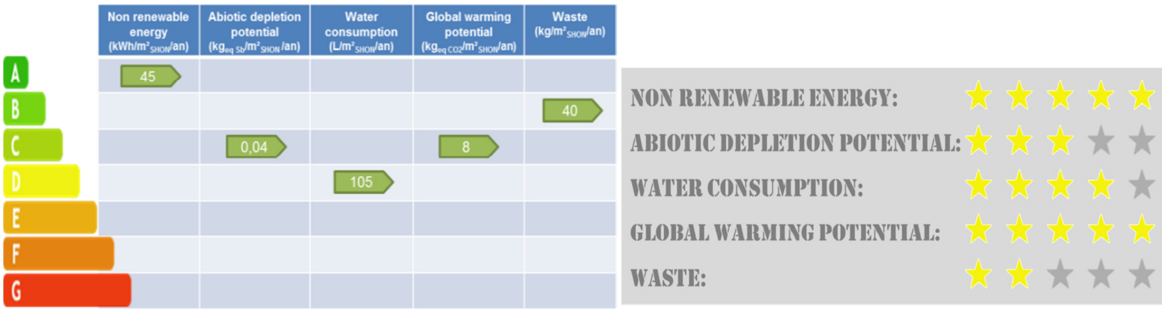

Figure 4: Two examples of impact indicators display submitted in the survey one with both classified and raw values (left) and a very synthetic one with only classified values (right)

Figure 4 shows two examples of display solutions exposed in the survey. The top one is predominantly preferred as it gives on the same succinct insert an easily understandable classified system for non experts and the raw values for higher expertise level.

A third document gives a well-appreciated solution with a radar chart for comparison to a reference building. This helps people to evaluate and put into perspective a project to the common practice. A solution to match all needs with a synthetic format could be to provide on the same LCA report the classified/raw values table (as in Figure 4 top) and a radar chart.

4. Discussions and conclusions

Since the questionnaire was sent exclusively in France, the findings of this study are particularly relevant for this national context though some general conclusions are valid whathever the context. According to the survey's results, stakeholders judge important to focus on primary energy, greenhouse gases emissions, water consumption and waste generation. The inclusion of normalization factors is preferred by a majority of respondents of this survey. Indeed, such a system enables to identify the most relevant indicator to work on in terms of impacts' shares for the building sector (e.g., expressed in equivalent inhabitants per year). Another way to normalize is to compare the LCA results to the actual construction practice mean impacts. Generally speaking, they prefer the use of aggregation system but with the possibility to modify the weighting. Similarly, they agree on sets of weighting e.g., based on default values (or based on public policies).

Last but not least, the findings of this survey reinforce the need to have public consultation and practitioners' meeting during the development (or the update) of a LCA tool of building to be sure that the user needs will be taken into account.

ISBN: 978-84-697-1815-5

5. References

[1] KELLENBERGER D, ALTHAUS HJ. *Relevance of simplifications in LCA of building components*. Building and Environment 44 (2009) 818–825.

[2] PEUPORTIER B., HERFRAY G., MALMQVIST T., ZABALZA I., STALLER H., TRITTHART W., WETZEL C. and SZALAY Z. *Life cycle assessment methodologies in the construction sector: the contribution of the European LORE-LCA project*, Sustainable Building Conference, Helsinki, October 2011

[3] EN 15978: Sustainability of construction works – Sustainability assessment of buildings – calculation method. CEN – European Committee for Standardization. Brussels: CEN – CENELEC 2010.

[4] EeBGuide Info Hub. Guidance documents, available online : http://www.eebguide.eu/

[5] ORTIZ O, CASTELLS F, SONNEMANN G. *Sustainability in the construction industry: A review of recent developments based on LCA*. Construction and Building Materials 23 (2009) 28–39.

[6] BRIBIAN IZ, USON AA, SCARPELLINI S. *Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification*. Building and Environment 44 (2009) 2510–2520.

[7] LASVAUX S, GANTNER J, SAUNDERS T. *Requirements for building LCA tool developers, Deliverable 4.3*. European Project EeBGuide, 2012, 46 p. available online: www.eebguide.eu/eebblog/wp-content/uploads/2012/12/D-4.3.-Requirements-for-Building-LCA-tool-designer.pdf

[8] SAUNDERS, C., LANDIS, A., MECCA, L.,JONES, L., SCHAEFER L., BILEC, M. *Analyzing the Practice of Life Cycle Assessment: Focus on the Building Sector*, Journal of Industrial Ecology, Volume 17, Issue 5, pages 777–788, October 2013