Net-Zero Energy Building: the two major drawbacks

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ABSTRACT

The concept of net-zero energy buildings has by definition two major drawbacks. While the individual house may use an average of net zero energy over a year, it may demand energy at the time when peak demand for the grid occurs. In such a case, the capacity of the grid must still provide electricity to all loads. Therefore, a ZEB may not reduce the required power plant capacity or may suffer from the poor efficiency within the electrical grid. In buildings with strongly reduced energy demands the influence of the occupants becomes more and more of importance. Therefore the energy need resulting from the comfort demands of users as well as the actual user behavior becomes more important for ZEB's. It is necessary to come up with new solutions to tackle the above mentioned problems. The paper presents paths to solution.

INTRODUCTION

As the results of the energy use of the built environment, which is arout 40% of the toatal energy consumption, become more clearly (depletion of fossil fuel and global warming), there is a demand for energy reduction and even an zero energy target. Energy 0 – projects are already developed from the late fourties, e.g. the 1939 MIT Solar House 1 [Hernandez & Kenny 2010], and during nearly more than two decades in the Netherlands. An overview and evaluation of the early Dutch projects was given in 2001 [Hoiting et al 2001]. One of the first projects was the Zero-energy house of Kroon in Woudbrugge 1993. A overview of possibilities in the context of the Dutch built environment is given by Gilijamse {1999]. However at that time the necessary technology had to be developed further. At the moment the technology is there { Charron 2005], however a recent literature review has indicated that there is wide diversity among ZEB definitions [Torcellini et al 2006, Marszal and Heiselberg 2009, Kilkis 2010]. In current practice ZEB use the electricity grid both as a source and a sink of electricity to avoid expensive on-site electric storage systems [Hernandez & Kenny 2010]. The European Parliament recently defined net-zero energy building 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 source on site*". This leaves however still many questions open and their aim is to release a more detailed definition by 2011 [Hernandez and Kenny 2010]. Agreeing to a common definition of ZEB boundaries and metrics is essential to developing design goals and strategies [Crawley et al 2009]. This makes it difficult to develop an optimal strategy for designing ZEB. Furthermore ZEB by definition do not mandate a minimum heating and cooling performance level thus allowing oversized renewable energy systems to fill the energy gap. Without an optimized thermal envelope the embodied energy, heating and cooling energy and resource usage is than higher than needed. The ultimate goal is to create zero energy buildings there fore there are many different international NZEB targets, see Fig. 1.

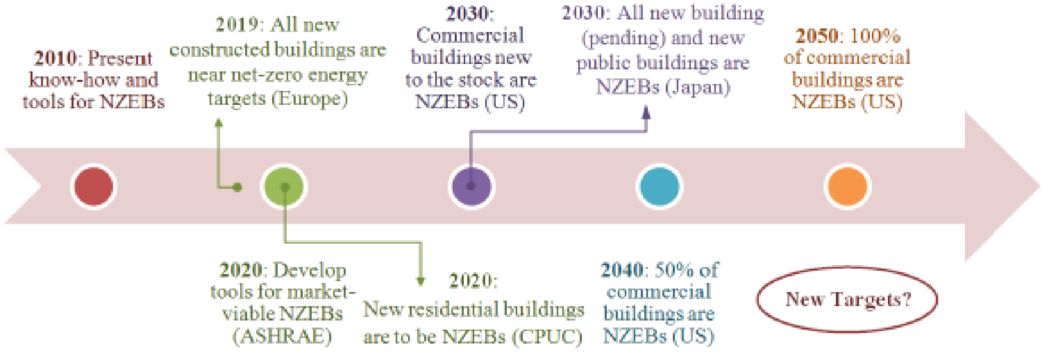

Figure 1: Summary of some of the major targets for NZEBs around the world [Kilkis 2010]

However at the moment energy use in the built environment accounts for nearly 40% of the total energy use in the Netherlands. Most of this energy (nearly 87% for non-residential and 72% for residential buildings) is used for building systems or room heating with the goal of providing comfort of the occupants of the buildings, see Fig.2.

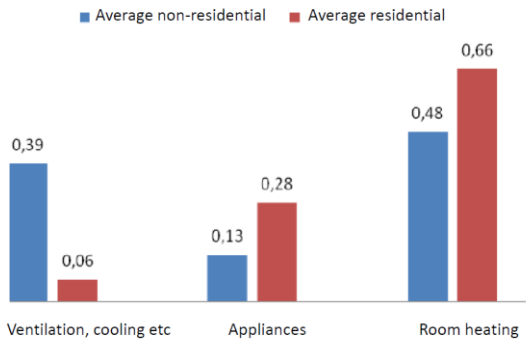

Figure 2; Energy consumption profile for the Dutch built environment in 2000 in % of the toal energy consumption [Opstelten et al. 2007]

ZEB and the Grid

Domestic electricity is traditionally supplied through generation in large central power stations, with subsequent transmission and distribution through networks. The current generation efficiency of the power stations varies between around 32% for older coal stations to over 54% for modern combined cycle stations, averaging to about 39%. In the Dutch situation When transmission and distribution losses are considered, the average overall efficiency of the system sinks to 35%. However in high peak demand situations the average overall efficiency is less and near to 30%. Zero-energy buildings often need their energy from the grid during these poor conditions and deliver their surplus on moments that there is little need.
A building could be a site ZEB but not realize comparable energy cost savings. If peak demands and utility bills are not managed, the energy costs may or may not be similarly reduced. This was the case at Oberlin, which realized a 79% energy saving, but did not reduce peak demand charges. Uncontrolled demand charges resulted in a disproportionate energy cost saving of only 35% [Torcellini 2006]. If demand charges account for a significant portion of the utility bills, a net cost ZEB becomes difficult. For example, Oberlin’s rate structure is not weighted toward energy rates combined with minimal demand savings. A 430-kW PV system would be required for a cost ZEB at Oberlin at current levels of performance. This is 3.6 times the size of the PV system Oberlin would need to be a site or source ZEB. For this 13,600 ft2 building to be a net cost ZEB, a PV system approaching 40,000 ft2 would be required—much larger than the building footprint[Torcellini 2006]..

In the long run, we will rely on renewable energies. Renewable energies are generally based on a large number of even smaller sources of power, producing power much closer to the location in which it is used. Some installations, such as those producing heat, can only supply users in their immediate area, while equipment which produces electricity, such as wind turbine, biomass systems, or photovoltaic roof panels, can be used to supply to electricity networks. The introduction of renewable energy will be more efficient once the development of new ICT systems for obtaining energy efficiency and meeting grid requirements takes off, while maintaining high standards of comfort, quality and reliability of services as well as connectivity. In addition, the future availability of storage devices (such as batteries in electric cars) opens up new perspectives and constraints, both from the sides of storage and supply (to the grid), as well as demand (from the grid).

The demand for electricity in a large network varies dynamically as millions of users continuously switch on and off independently their equipment. ICT is necessary to provide the means to manage the operation of millions of small-scale electricity generation appliances like photo-voltaic panels, both on behalf of their owners and for the networks into which they feed. ICT tools have to monitor a range of variables and ensure that both individuals and the network as a whole gain maximum efficiency from the energy generation capacity available. Development of such ICT systems will therefore be necessary to apply efficiently renewable-energy-based generation capacity.

The electricity grid has to cope with the variable output of future generators and variable uptake of consumer devices, many of which are still unknown. In principle, the smart grid is an upgrade of 20th century power grids which generally "broadcast" power from a few central power generators to a large number of users, to instead be capable of routing power in more optimal ways to respond to a very wide range of conditions. The conditions to which a smart grid must respond, may occur anywhere in the power generation, distribution and demand chain. Events may occur generally in the environment (clouds blocking the sun and reducing the amount of solar power, a very hot day), commercially in the power supply market (prices to meet a high peak demand exceeding one dollar per kilowatt-hour), locally on the distribution grid (MV transformer failures requiring a temporary shutdown of one distribution line) or in the home (someone leaving for work, putting various devices into hibernation), which motivate a change to its power flow.

One of the problems smart grids are facing is that not all decentralized micro-generation systems have forecastable electricity generation patterns. For example solar cell's power output is dependent on the cloud coverage, the time of the day and the amount of indirect and direct sunlight. Wind energy is only available if there is wind and micro-CHP systems only produce electricity in case of a heat demand. As a consequence, decentralized systems sometimes produce electricity when there is no need for it locally.
The combination of decentralized generation of electricity, smart grids and ICT techniques must lead to a dependable electricity network. Due to the scale of smart grids and the needed dependability, fundamental research in dependable and large decentralized ICT systems is required.

The occupant and ZEB

Normally only simple approaches are applied to incorporate the comfort demand of occupants or their behaviour and use of appliances. Often only on the level of house or building and only sometimes on room level, see Fig.3.

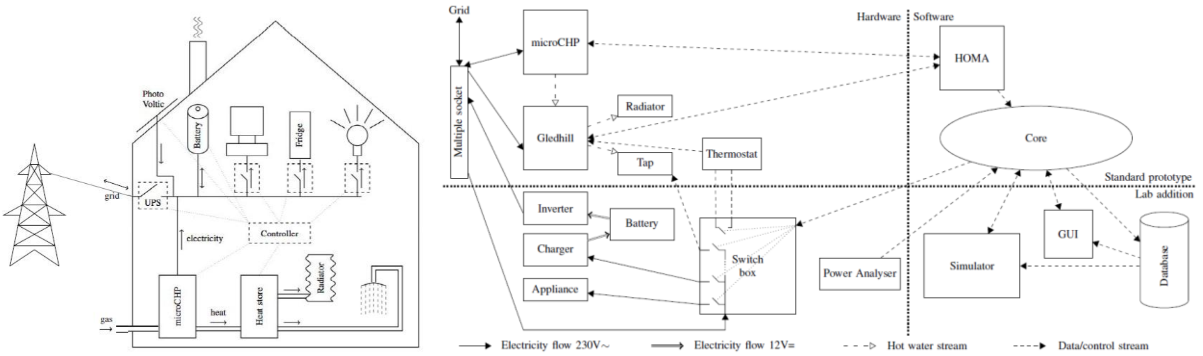

Figure 3: Model of domestic energy streams and chematic overview of the hard- and software [Molderink et al 2010].

We now want to look more closely to the individuals on working space and personal level. So we do not look only to room temperatures and thermostat settings of hot water taps but really look into the dynamic parameters related to the individual thermal comfort, the actual occupancy, the actual parameters of the building services installations and use of appliances.
The energy supply to a building must be related to actual dynamic changing comfort needs, behaviour of the occupants of the building and the behaviour of the building itself due the weather conditions. Therefore, more actual information is needed. The application of low cost wireless sensors offers new practical applicable possibilities [Neudecker 2010, Gameiro Da Silva et al 2010]. If so, then energy demand and energy supply could become more balanced and less energy wasted. A promising technology to achieve the necessary dynamic process control is by using Multi Agent System technology [Davidsson and Boman 1998, Akkermans 2002, Qiao et al. 2006, Dounis and Caraiscos 2009, Lee 2010]. Agent technology in combination with low cost sensor networks can be implemented at different levels of building automation. Individual agents for individual climate control for each user of the building in combination with feedback on the energy consumption (costs/ sustainability) leads to better acceptance of the individual comfort and a reduction of the energy consumption [Jelsma et al 2003, Kamphuis et al 2005].

Research method

The goal and intended result is to design, build and test an intelligent energy grid within buildings with the actual individual human need as leading principle. Therefore, the first step is to apply an appropriate design approach. A hierarchical functional decomposition approach is used to structure the energy infrastructure of a building [Zeiler & Quanjel 2007]. This method approach makes it possible to study the energy flows connected to heating, cooling, ventilation, lighting, and power demand, within a building on the different levels of hierarchical functional abstraction, see Fig.4. Compared the common approaches our approach offers the possibility to focus on the level of workplace and the level of the individual. This enables us to look more closely on the comfort and energy demands of individuals and to built a more detailed process representation. The individual user has become leading in the whole process to optimize the necessary use of energy to supply the occupants with their own preferred comfort environment and energy for their activated appliances.

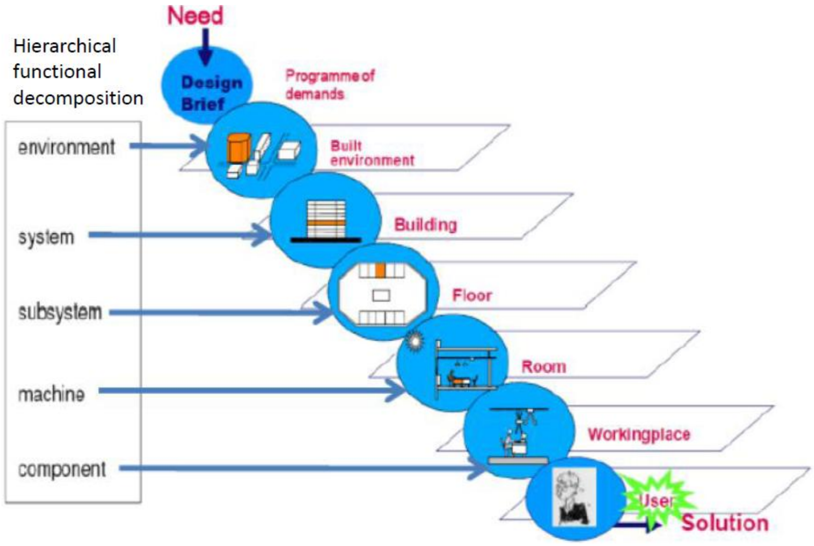

Figure 4: Hierarchical functional decomposition of the built environment.

On different levels abstraction a functional representation of the building and its occupants will be made. By making a coupling with the Building Management system of the building all the necessary data will be made available to fit and to investigate the behavior of the model compared to real historical data of before the intervention. In analogy with this approach and that of Yeh et al [2009], we will design a protocol stack, which consists of the following layers:

- User layer: defines how a user can access the system through the user interface
- Service layer: defines the rules by which the system provides and manages ies services
- Profiel layer: maintains all profiles for users, sensor nodes, power-line control devices, and rules
- Sensor layer: controls the actions of sensor nodes
- Actuator layer: provides an abstraction of electrical appliances to upper layers

The insights gained from the modeling of the local personal comfort on personal level, workspace level and room level, leads to a concept for monitoring and management of the comfort and the energy flows in a real building in a more detailed and accurate way.

The potential of exploiting ICT to save energy is well documented [Røpke et al 2010], however, much of the literature that focuses on ICT often overlooks the role of user behaviour in energy conservation. Optimised process control is vital for the energy performance of buildings [Yu et al. 2007]. Overall the role of the occupant and user related energy use is found to be important [Papakostas and Sotiropoulos 1997, Haas et al 1998, De Groot et al 2008]. The need to address these user energy consumption behaviour issue becomes more significant in the development of ambitious, smart energy efficient building concepts [Pauw et al 2009]. It is known, for example, that the benefits of technology are often minimised by what are termed human rebound effects, and that there is a strong need to develop control strategies that can mitigate such user behaviour. Therefore, it is necessary to focus on applying ICT in ways that optimize energy efficiency and conservation as the outcome of multiple interactions between technological systems and human users [Midden et al. 2008]. The research challenge is to minimize energy consumption in offices by using the possibilities of (wireless) sensor networks for comfort management, energy monitoring and control. Using multi agent it will be possible to dynamically interact with all changing circumstances and led the individual comfort preference of the occupants become leading. The interaction between user and comfort energy management systems will be provided by a GUI which give the user the opportunity to adjust the personal settings. Instead of applying new cooling, heating or ventilation devices our approach is focussed on the optimal process control of comfort demand and the necessary energy for that. This means that the developed process control strategy could be applied in new as well as in existing buildings. It could become the leading technology for realising the technical savings potential of advanced control systems in the Dutch built environment which is no less than 19% of the total energy usage of the Dutch built environment [Kester and Zondag 2006].In energy management systems the control strategy is based on a simplified approach to comfort, leading to dissatisfaction and unnecessary energy consumption. To be really smart with energy and to reach the optimal combination of efficient supply and necessary demand, it is therefore important to look at the comfort demand more precisely. The human behaviour can influence the energy consumption by more than 100% [Brohus et al 2010, Parys et al 2010], so therefore it is necessary to incorporate the human needs. Sensing, monitoring and actuating systems in relation to the user perception and preferences play the key role in reducing overall energy consumptions in buildings. Therefore we start with looking more closely to the perceived comfort.

Traditionally, calculations of human comfort have been based on the theory of Fanger [1970]. Basically, this theory makes it possible to calculate the thermal sensation indicator representing the perceived comfort with

6 parameters: Temperature, Relative Humidity, Air Velocity and Radiant Temperature. However, activity level and clothing insulation of occupants have a strong effect on thermal comfort, but they are variable and usually not measurable. As a result, in practice the comfort control is simply done on the room level by controlling the room temperature. The variations of the other parameters of influence on the individual comfort demand are not taken into account. This omission results in differences depending on for example the place of the workspace in the room, e.g. close to a window or more in the back of a room. As a result the comfort is only controlled within a broad range, resulting in more complaints and more energy use than necessary. In theory, 95% of the users should be satisfied if all conditions stay within the specific ranges, however in field studies there is a much smaller satisfaction range of between 80% to 50% (Zimmerman 2008). By optimizing the responses to the individual human comfort differences energy conservations of up to 25% are possible [Buitenhuis and Drissen 2007, van Oeffelen et al 2010]. Measuring the radiating temperatures by a low cost Infra Red camera should make it possible by image post-processing to estimate energy fluxes and temperature distributions with comfort prediction. Correct temperature distribution measurements could be calculated by remote camera control and thermographic parameter correction [Revel and Sabbatini 2010]. Thermal comfort for all can only be achieved when occupants have effective control over their own thermal environment [van Hoof 2008]. This led to the development of Individually Controlled Systems (ICS) with different local heating/cooling options [Filippini 2009, Wanatabe et al. 2010].

As until now in practice user behavior has not been part of the building comfort system control strategy in offices, the energy consequences of the user behavior are not accounted for. However, occupant presence and behaviour has a large impact on space heating, cooling and ventilation demand, energy consumption of lighting and room appliances [Page et al 2007] and thus on the energy performance of a building [Hoes et al 2009]. User behaviour may be defined as the presence of people in the building, but also as the actions users take to influence the indoor environment, the opening or closing of windows or blinds. Human behaviour can be explained to result from physical needs and psychological needs [Tabak and de Vries 2010]. Physical needs are highly individual and concern space, light, climate conditions and sound [Zimmerman 2008]. The psychological needs are the result of interaction, privacy and personalization, so obviously highly individual too. Human behaviour related to the physical conditions can be described in terms of user control of the installation systems and building facilities like windows. In this context user behaviour may be defined as the presence of people in a workplace location in the building and the action users take (or does not take) to influence their indoor environment [Hoes et al 2009]. Recently models have been developed to describe human behavior and include it in building performance analyses [Degelman 1999, Nicol 2001, Reinhart 2004, Bourgeois et al 2006, Mahdavi 2006, Rijal et al 2007, Page et al. 2007, Hoes et al 2009, Tabak and de Vries 2010]. However, only a few studies successfully demonstrate energy reduction from occupancy behavioral patterns that have been determined because there was no formal connection to the building energy management systems of these buildings [Dong and Andrews 2009].
An analysis of occupant behaviour on the energy consumption [Brahme et al 2009],shows that conservation oriented behaviour can reduce energy consumption by one-third (Fig. 5), while in more efficient buildings, by nearly half (Fig. 6).

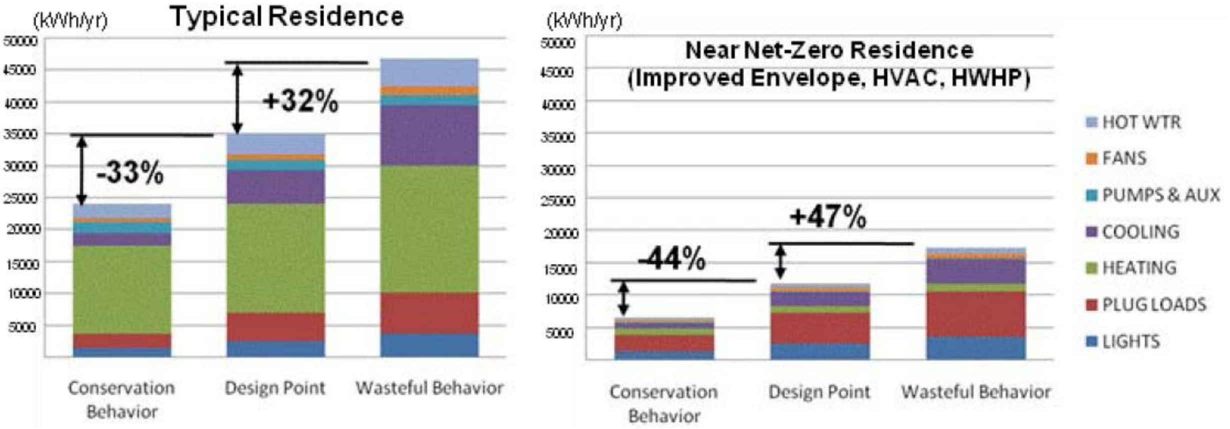

Figure 5: Behaviour impact on typical residence { Brahme et al 2009] & Figure 6: Behaviour impact on high efficiency residence {Brahme et al 2009]

Feedback to the user is therefore very important and will be incorporated with in a multi agent comfort energy management system. Reduction of or optimizing of energy use is often done without really taking in to account the goal of the energy consumption, human comfort . However energy reduction can only be achieved if user comfort is individually addressed [De Groot et al 2008].Trying to optimize energy efficiency without addressing occupant comfort is not going to work [Nicol 2007]. Human behaviour is an important factor to consider in the thermal exchanges between a building and its surroundings and the resulting energy consumption [Palme et al. 2006]. The ability for occupants to make their own choices and control the environment is critical to the satisfaction of users [Isalque et al.2006]. This leads to the need to optimize and control the comfort demand and the energy needed to provide it. This research will focus on the application of a smart grid, existing of wireless low cost sensors and actuators for energy management in office buildings. Especially the application of such a smart grid combined with multi agent technology in a real setting of a office building with its own building management system for process control, will show the relevance of the anticipated applications for comfort and energy management.

There is ongoing cooperation between Eindhoven University of Technology with Kropman and ECN, unit Intelligent Energy Grids, group Energy Management and Distributed Control. Within the Flexergy project the University of Technology Eindhoven, Kropman, ECN and Installect Building Services Consultants worked on a design methodology for structuring and combining different energy flows within a building. The project focuses on the integral optimization of energy flows within the built environment when fitting in decentralized sustainable energy concepts. The research outcomes are tested in an existing office of Kropman [Zeiler et al 2008, Zeiler et al 2009, Pruissen and Kamphuis 2010]. This design methodology should lead to solutions that offer more flexibility to the energy infrastructure; Flex(ible)en)ergy. However in the Flexergy project the user was still represented by a comfort level day profile based on the room temperature setting. Field tests were held at Kropman Utrecht [Pruissen et al 2009, Zeiler et al 2009, Pruisen and Kamphuis 2010, Zeiler et al 2010]. Based on the experiences with multi-agent system projects and a literature review on the latest developments concerning human comfort we will derive a concept for the optimization of individual comfort and energy consumption by the use of an intelligent building energy grid with a combination of low cost wireless sensors, infra red cameras and long term as well as short term weather forecast predictions. Kropman has in cooperation with Octalix and Nijeboer-Hage won a grant in the tender UKP NESK for a demonstration project of building an energy-0 office building for CBW-MITEX. Building Energy Management System in combination with wireless technology is one of the key technological elements of the innovative project. Kropman wants to develop their approach further and presented to a broad audience [van Zoelen 2010]. The expected use of instrumentation is based on a concept for the placing and use of different wireless sensors and infra red camera is shown in Fig. 6. Such a grid of low cost sensors would make it possible to control and manage the individual comfort and the necessary energy for it. Fig. 6 shows how the actual experimental setting of the Smart Energy Building grid could look, based on a recent design by Kropman.

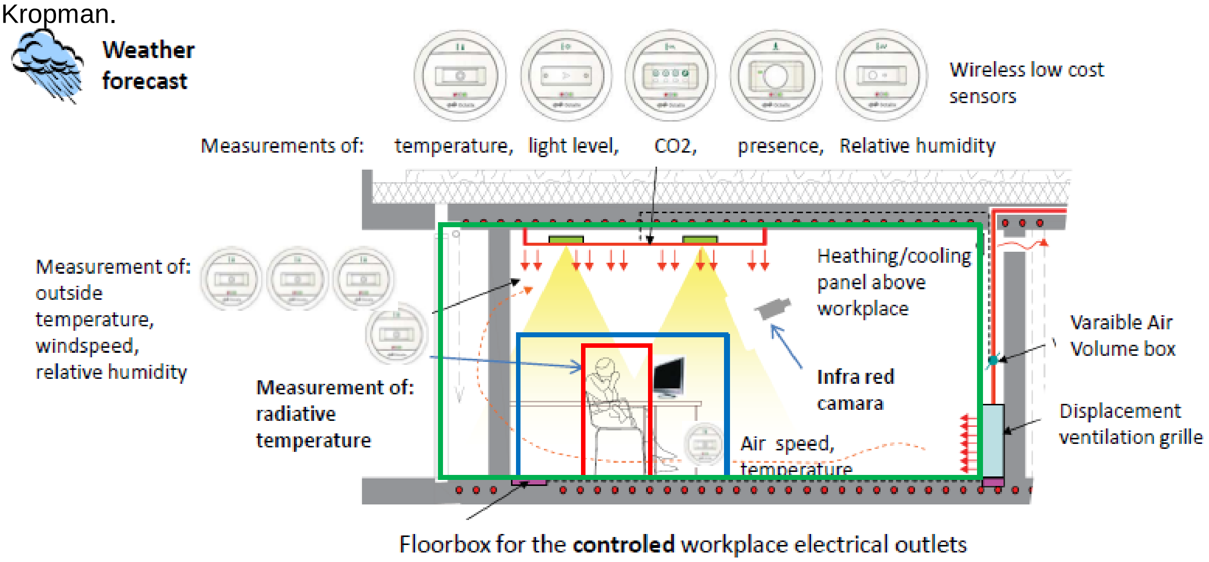

Figure 6: The ZEB Smart grid concept: individual-workspace-room level

Conclusion and discussion

Are ZEB achieveable, maintainable and practical? Probably more important than answers at the moment is the search, which is yielding new applications and strategies [Turner 2009]. The discussion about ZEB lead to a list of key questions, which should be taken into consideration when developing ZEB [Marszal and Heiselberg 2009];

- What type of energy use should be included be the balance?
- What requirements could be included in the new definition?
- Can one general definition include all cases?
- Should there be any requirements for building-grid interaction?

Clearly the effect of ZEB and its interchange with the grid is of great importance for its overall performance. Another very important factor is the user with its comfort need, user behavior and interaction with the building. Without these aspects the design of ZEB is incomplete. So these are the two major drawbacks at the moment concerning to ZEB development.

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