Improved service life predictions for better life cycle assessments

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Summary

The importance of assessments of the environmental performance of materials in buildings based on life cycle assessment is growing. The applied life span for the building and service lives of its construction products have big influence on the outcome of these assessments. This paper shows on basis of conducted research, the influence of the applied life span and services lives on these environmental calculations. Based on the results it is concluded that with the current tools and assumptions the actual environmental impact of less durable building elements will be higher and that of durable elements lower than calculated. Important parameters influencing the service life and solutions for improving service life predictions for buildings and building elements are presented in order to optimize the reliability of the environmental assessments.

Keywords: service life, life span lca, assessment, sustainability, improved service life predictions, Factor method, ESL, RSL

1. Introduction

Usually one can only judge afterwards whether a used service or product really has been environmentally sustainable. This applies also to the sustainable performance of buildings. These performances are nowadays frequently assessed by ‘calculations’ with one of the specialised instruments on the market like e.g. LEED, BREEAM, GPR and Greencalc. It is expected that the applied life span of the building and the applied service life of the building elements have large impact on the outcome of the assessment of the environmental performance of the building related to materials. With the current various assumptions for life spans and service lives it is the question whether the assessed environmental performance of a building comes close to the actual performance. On the one hand it is common practice to use the reference service life (RSL) of a building element that gives an indication for the period it will last. The RSL only represents one value which is an average. On the other hand, mostly a standard ‘Reference Study Period’ (RSP) is used for the life span of the building that can differ from practice. The influence of the applied life span and service lives on the results of environmental calculations was studied and to improve the reliability of the results the possibility to use more realistic life spans for buildings and more realistic service lives for building elements was investigated.

2. The effect of service life on calculations

2.1 Sustainability and building components

Sustainability is a broad concept, and it is easy to relate a lot of subjects to it. In accordance with the European Standards made by CEN TC 350 – ‘Sustainability of construction works’ [1] it is accepted that the environmental, economic and social performances all are important dimensions to make a good sustainability assessment at the building level. A building with a high quality, comfort and a good economic value for the future is the basis for a long service life. After that it is important to minimize the environmental impact. In this paper the following definition (derived from N.A. Hendriks [2] and expanded by Van Nunen [3]) is used for the environmental performance related to building components: ‘the sustainability of a building component is the ability in its function, despite occurring degradation factors, to fulfil certain performance requirements, if needed by necessary maintenance with the lowest negative impact of that component on the environment’. The first part of the definition reflects the part that is associated with durability. The last part relates to the environmental impact of a component. This definition can also be used for the entire building. The second part ‘with the lowest negative impact of that component on the environment’ leaves a choice for different solutions and materials. For example, the choice can be made to use several products with a low environmental burden, or one product with a higher environmental burden, but a longer service life. The choice can be made on component level or at the level of the entire building.

2.2 LCA as basis for environmental calculations

The Environmental Life-Cycle Assessment (LCA) is the basis for determining the ‘environmental impact’ of building components used in construction. The origins of LCA lie in the research of the energy sector. Over the years, more and more data was gathered to arrive at a description of the environmental profile of a product. The entire field of LCA now is described in the ISO 14000 series. But a full LCA of a building is complex. Therefore new programs were developed with the building sector in mind. Three examples of tools that originated in the Netherlands are GPR, Dubocalc and Greencalc. All three tools use some of the data from a full LCA, but with simplified input and output. In LCA, the environmental interventions of the entire lifecycle of a product is scrutinized and 'translated' into the environment. From extraction through production, transport and (re) use, to disposal. Or: from cradle to grave. LCA in the construction sector is a relatively new field of expertise, and a lot of research still has to be done. One of the items that is not applied correctly, is time. For example usually a fixed life span of 75 years is used for dwellings in the Netherlands. LCA was originally not developed for buildings, and for buildings the time factor is of special importance [4]. Many buildings will last for a long time, for example 75, 100 and even 125 years and longer. A big part of the building components last a part of this period. Deterioration will cause loss of performance, but maintenance and replacement can improve that performance. These actions have an influence on the environmental burden themselves.

2.3 Calculations based on a single family house

The actual life span of a building and the nature and frequency of maintenance and replacement of building components have a major impact on the actual environmental impact of materials. For if a material last ten times longer than other materials, then the environmental impacts of such material in principle counts, only for one tenth. To get more information on the degree of influence, calculations were done with the Dutch calculation tool GPR-building (www.gprgebouw.nl) on basis of a standard Dutch single family house. This tool uses one number for the average service life of the building elements and in the calculations the total environmental impact of the building element (product stage + use stage + end-of-life stage) is divided by the life span of the building. The result is an (average) environmental burden per year.

Figure 1 shows the deviation in results from calculations with the often for dwellings used Reference Study Period (RSP) of 75 years, from actual life spans. The blue line in this figure shows that when the actual life span turns out to be 125 years the total environmental impact by all the building elements is 19,5% less than calculated with a life span of 75 years. The red line shows that the total influence on building elements that don’t need replacement or maintenance during the buildings life span is even more: the actual environmental impact is 40% less than calculated.

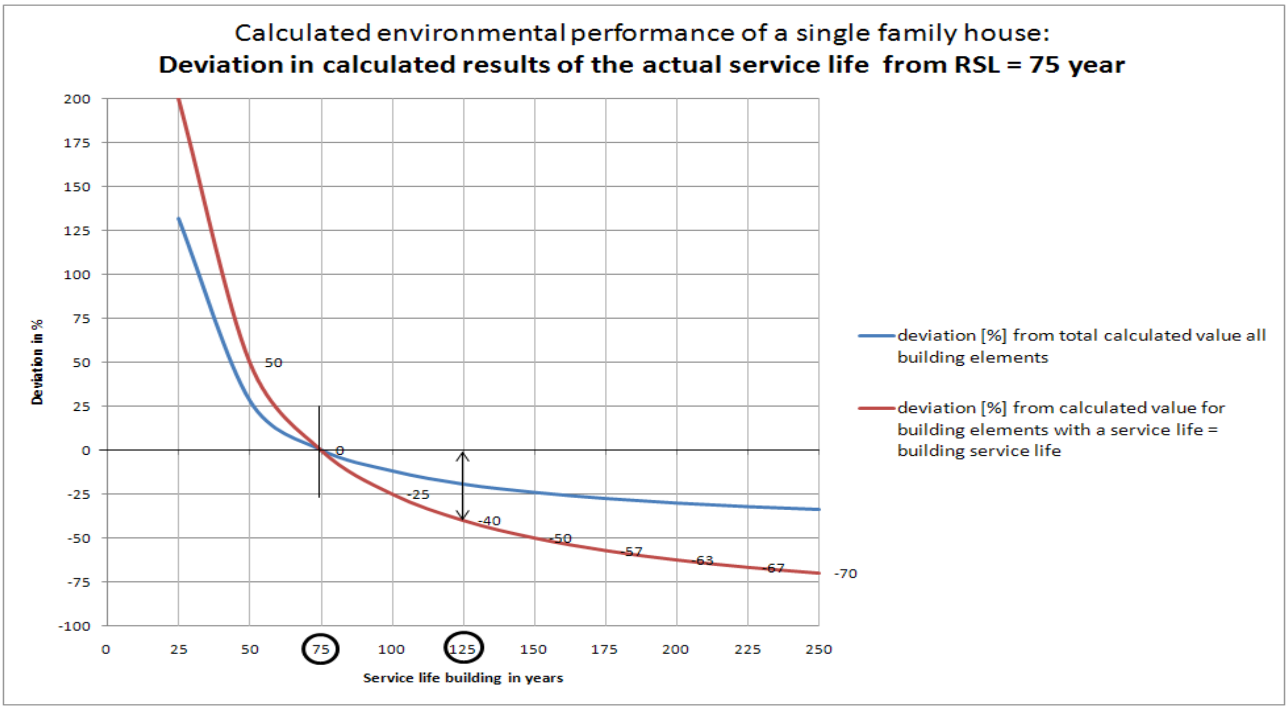


Fig. 1 Deviation in calculated results of the actual service life from RSP = 75 years

A division was made between building elements that need replacement during the life span of the single family house and building elements that don't need replacement, because of their long service life. Then the total environmental impact by this two groups was summarized. The share of building elements that don't need replacement during the service life of the used reference single family house causes 67% from the initial environmental impact by all building elements. In here the foundation and structural elements take a share of about 40%. The outer leave and the inner leave of the cavity wall are important elements of the other 27%. It is clear that these figures shall vary per building.

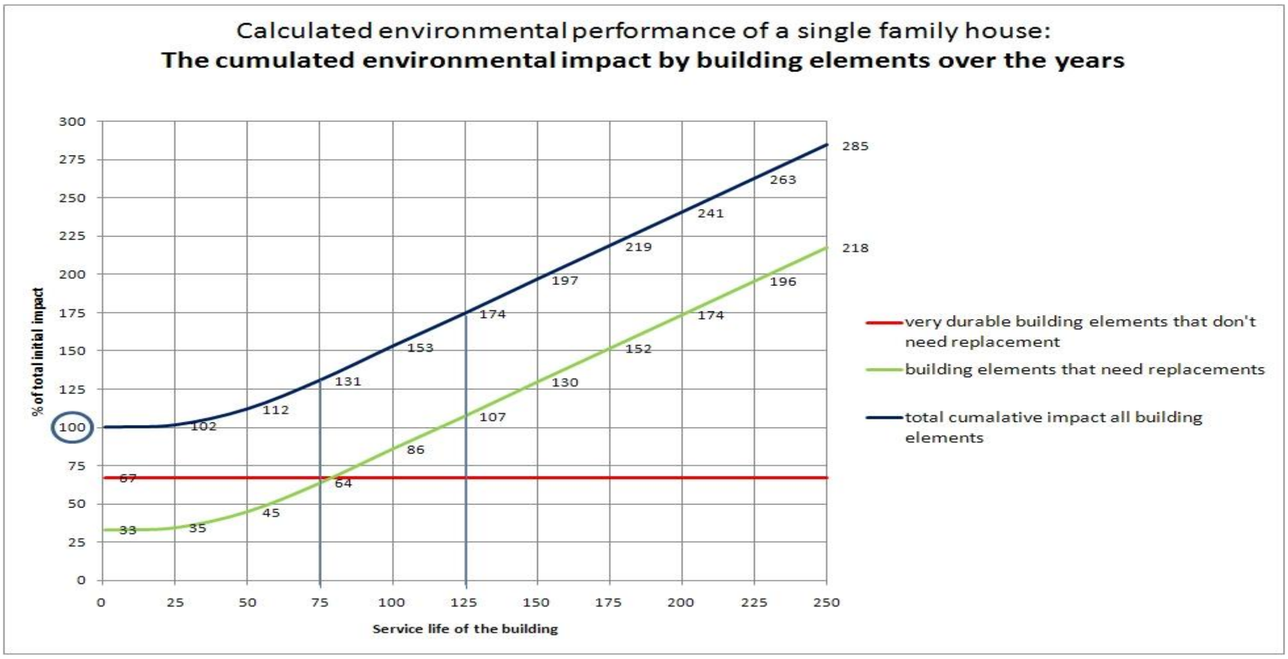


Fig. 2 The cumulated environmental impact by building elements over the years

Figure 2 shows the cumulated environmental impact by building elements over the lifetime of the building. It is clear that maintenance and replacements of building elements are important within the assessment of the environmental impact. Building elements that can have a great impact on the results caused by replacements are windows, glass and doors, technical systems, building related furniture and interior walls.

Figures 3 and 4 show the growing contribution to the cumulative environmental impact caused by replacements of windows, glass and doors and the declining contribution by the brickwork facade. The upper figure shows the contribution at the initial stage (t=0) and the lower figure 3 after 125 years (t=125)

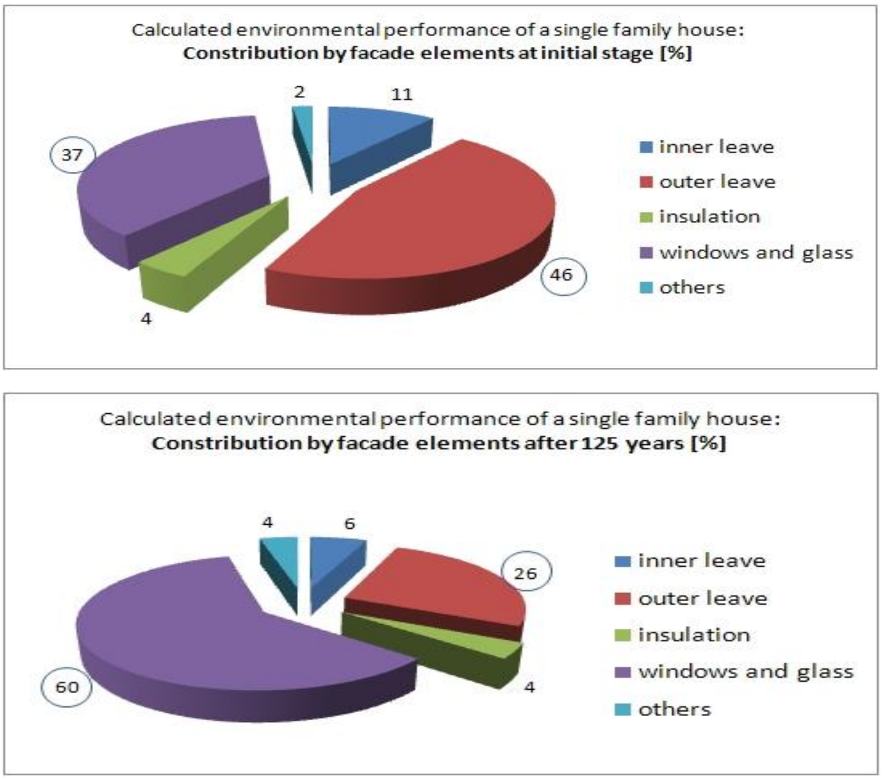


Figure 3 Change in contribution by different façade elements over the years

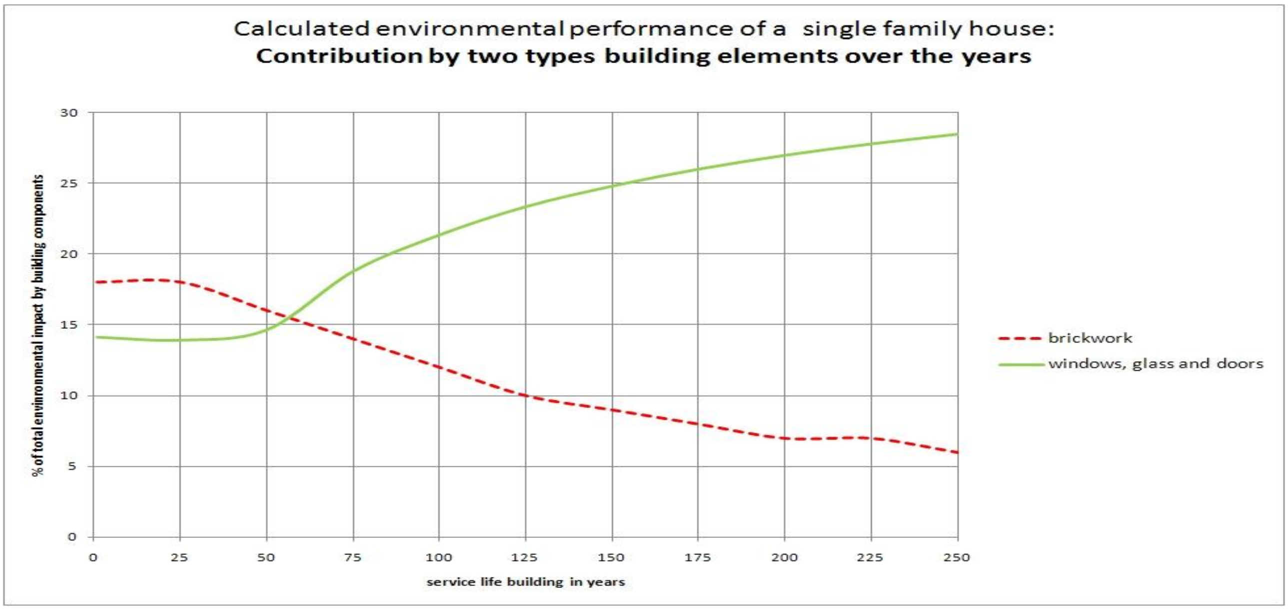


Figure 4 Contribution to the total cumulative impact of the building by two types of building elements used in the façade

It is concluded that reliable life span for buildings and service lives for building elements are essential for making correct Life Cycle Assessments or other calculations. A right life span of the building is most important in relation with very durable building elements, while for less durable building elements this is the actual service life of the product itself.

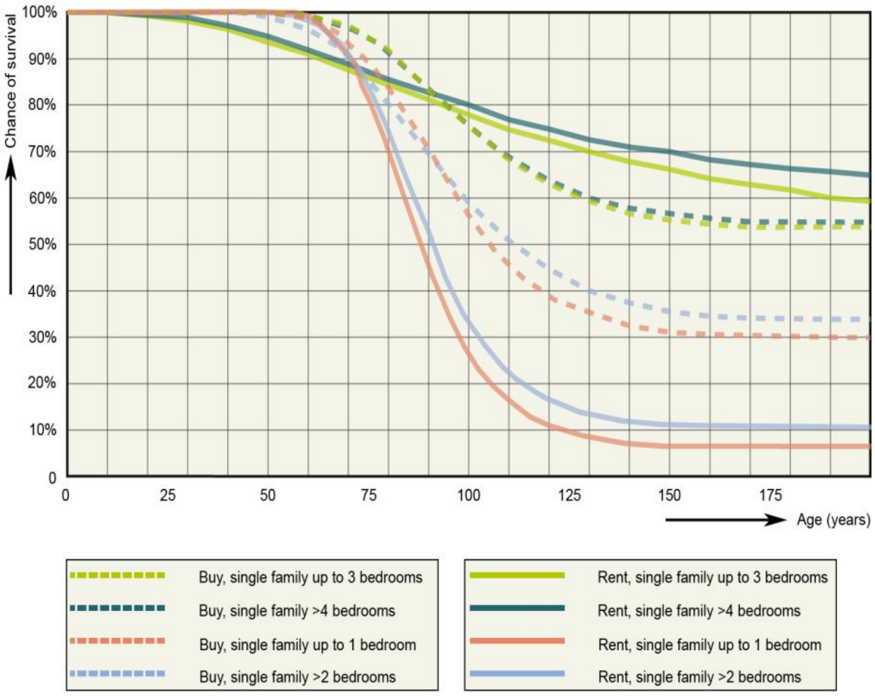
3. Life span of the building

3.1 General

In practice most buildings are built without any clear idea of how long they have to last. Only in the case of temporary or deconstructable buildings an expected life span is mentioned. As a result decisions regarding the materials to be used, construction principles or replacements cannot be based on logic. If the quality of a building elements is an issue, this often has only to do with guarantees for a (short) period after the building was constructed. To get a better idea of the actual life span of dwellings in the Netherlands existing studies were analysed on the actual service life and the reasons for demolition. Next to that figures on building production and demolition give relevant information and opinions of experts were inventoried.

3.2 Research into the actual life span of dwellings in the Netherlands

The Technical University of Delft / OTB has investigated the life span of existing dwellings in the Netherlands and what characteristics play a role [5]. This history is examined from the 16th century to the present. It is stated that a regular ‘filtering process’ will take place. Dwellings with the lowest quality are demolished and the remaining dwellings are always adjusted to the changing needs and remain there for ages. Depending on the type of dwelling there are very big differences. Figure 5 shows that the ‘filter process’ is concentrated in the age range of 75 to 125 years. The rental single family homes are an exception. With this type of dwelling the ‘filter process’ starts earlier while ultimately they have the greatest chance of survival. For ‘multiple family houses’ the ‘filter process’ was more radical, especially in the rental sector. The bigger the dwelling the greater the chance of survival.



The Technical University of Delft also examined the reasons for demolition based on data from ‘social rent dwellings’ owned by housing corporations [6]. It is good to state that these corporations are the owners of dwellings with a relatively short service life. It is concluded that especially rental multifamily houses are more demolished. Very few single family houses are demolished, only a limited number of early post-war homes. After the Second World War a lot of relatively small scale homes were built with tight dimensions and low quality.

Fig. 5 The chances of survival of single family houses according to ownership and amount of bedrooms

Key reasons for the demolition of rented multifamily houses were limited spatial qualities, combined with poor technical qualities such as poor foundations, wooden floors, inadequate thermal or acoustic insulation, moisture problems and poor accessibility. It is noted that the main reasons for demolition will be much less applicable to the current new build dwellings in the Netherlands. It can therefore be expected that the actual service life of the modern dwelling will further increase.

3.3 Expert opinions

To get a better view on the life span of a new dwelling, experts were asked about their opinion as part of a recent PhD thesis [3]. The answers varied widely between 55 and 500 years. A trimmed average was used for this question, so that the extreme values (upper and lower 12.5%) were flattened out. This resulted in an average life span for a dwelling of 120.8 years. Further analysis of the answers showed that the background of the experts has influence on the responses. According to the opinion of experts of building associations the average life span of a dwelling would be 79.4 years (minimum 55, maximum 100 years). Building consultants come to an average life span of 145.8 years (minimum 75, maximum 200 years). The answers of the research institutes varied between 60 and 350 years, with an average of 162 years. Project developers come to an average of 288 years, but there were few results from this group.

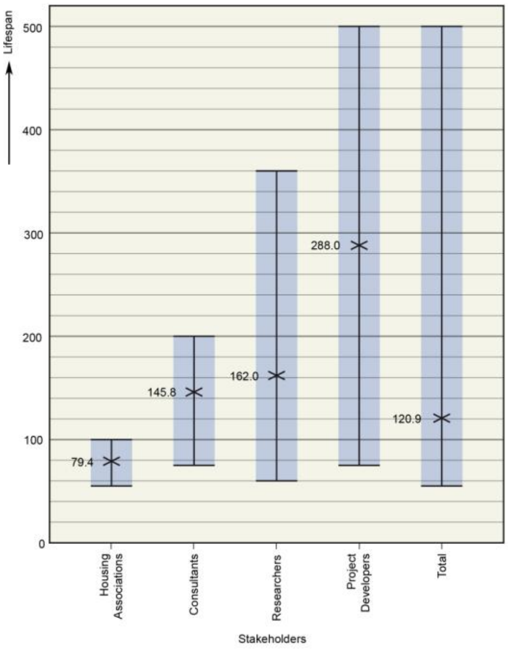


Fig. 6 Average life span of dwellings, according to different stakeholders

The context is important with regard to the life span. Housing associations tend to use 50 years as a service life, because their financial system is based on this period. Building consultants and Research Institutes take a broader view, but are not restricted by the circumstances of the everyday practice.

3.4 Market information

The current (2011) housing stock in the Netherlands is 44 years old on average. That indicates that for a RSP of 75 years 7 million dwellings have to be replaced in the coming 31 years. That means 226.000 new dwellings a year while the total production of dwellings in the Netherlands never became above 82.000. The number of demolished dwellings over the last 20 years was between 8000 – 19000 dwellings per year. That is always less than 0,3% of the total housing stock. This indicates as well that a life span of 75 years is not accurate but also not possible giving the current demand of dwellings.

3.5 Recommendations

Based on the information in chapter 3 it can be stated that the life span of a dwelling in the Netherlands needs to exceed 75 years. 120 years is a good alternative. It was pointed out by the experts. Moreover earlier research studies in this field came to 100 or more (up to 350) years (Thomsen) [6] and 110 years (Priemus) [7]. On basis of the research mentioned in 3.2 it is recommended to come to a further differentiation of advised life span for use as RSP based on the type of dwelling and its associated features. Table 1 gives as an example of a proposal for the Netherlands. For long life spans (> 120 years) it is recommended to make some preconditions e.g. related to spatial comfort and the level of insulation of the building.

Table 1: Example proposal for RSP for dwellings in the Netherlands

Type of dwelling	Number of rooms	Life span [years]
Buy or rent	≥ 3	175
Buy	< 3	120
Rent	< 3	85

4. Service life of building components

4.1 Differences in service life

Service life, design life or working life; they all refer to the period of time a product can be used, with some minor differences. Although these differences may look insignificant, they have influence on the amount of materials in a building that have to be used over a certain period of time. Because the end of service life is an indication for replacement, it should be possible to calculate the amount of materials that are necessary to achieve the complete life span of the building. When this amount of materials is known, the costs can be calculated, as well as the environmental burden and other material-related information. To give a well-founded assessment of building related aspects, such as the environmental burden or (maintenance) costs, the service life of components needs to be known in as much detail as possible. This is indicated by the point at which a material can no longer function.

Several studies discuss the end of life. Rudbeck [8] for example differentiates between the life spans of a building and the way the end of life will occur. He indicates that there are two reasons for obsolescence: due to deterioration and due to social decisions. The three types of obsolescence mentioned in ISO 15686 [9] have the same form. Obsolescence due to deterioration is called the technological service life. Obsolescence due to social decisions is represented by functional as well as economic obsolescence. The distinction made between deterioration-based and decision-based obsolescence is important when one tries to look at service life of a product.

Technological obsolescence was of main importance in the past. Products were used until they were broken and no longer functioned (technically). Over time this changed to other indicators as a reason for replacement. Functional obsolescence did occur previously, but it was not a common reason for replacement. Economic obsolescence came into view in the last decades. Prosperity increased and so did technical developments. A good example of technological developments can be found in the building services. The technical service life of a heating system was overtaken by technical advances. The coal oven was replaced by gas ovens before the coal ovens were technically obsolete.

It can therefore be said that in more and more cases, it is not longer the product that indicates the end of the (technical) service life of a product, but the occupant who decides that the (functional) service life of the product is over.

4.2 Factor Method

In prior research the Factor Method came to the fore. This method, defined in the ISO 15686 series, presents a way of using a reference service life of components (RSL) combined with seven known factors ((A) quality of components, (B) design level, (C) level of work execution, (D) indoor environment, (E) outdoor environment, (F) in-use conditions, and (G) the maintenance level). The RSL can be transformed into an estimated service life of components (ESL) using the effects of the factors. The ESL can be adjusted for specific circumstances, by giving a higher (better), or lower (lesser) value to the factor. The default value of the factors is 1.0, therefore the RSL and ESL are equal if no other effects occur. The value of the factors can be derived from several criteria, indicating the performance of the individual factors. In the Netherlands a research by SBR is ongoing to provide these criteria. In France a platform was started [10] to provide criteria to score the factors. The Factor Method provides a method that is relatively simple, but offers more detailed information about service life compared to the average RSL. The Factor Method is described by the formula ESL = RSL * A * B * C * D * E * F * G

The Factor Method is quite new. In 2000 the first ISO standard (15686-1) was published and the last one dates from 2009 (15686-9). Up to now, there is not much expertise in the field, and research is still ongoing to improve the application of this method. The method leaves room for improvement. As part of the recent PhD study [3] three major improvements are added to the existing method.

4.3 The Improved Factor Method

The lack of social aspects in the service life was part of the study [3]. The first improvement is the addition of two factors. It is stated that technical requirements are no longer the only reason for replacement, but that economic and functional requirements need to be incorporated as well. Looking at the indicators for replacement, two factors were added. The first one is called ‘Related components’ (R), and is used to take replacements into account that are not necessarily based on technical deterioration, but because other materials connected to the one under review are replaced, (i.e. when a window needs replacement the window-pane will also be replaced). The second added factor is called ‘Trends’ (T). This factor is used to adjust the reference service life according to the choices people make, based on how a product looks (image), or how a space is used (usage). This factor is especially important when flexibility is an issue.

The second improvement is the addition of probability to the factors. Each factor is awarded a suitable statistical probability. That way the outcome is based on more accurate figures than just a single fixed value. The third improvement is the application of weighing to the factors. Weighing is a possibility that is not used at present. However, it is possible that some factors have a larger influence than others do. A set of weighing factors is therefore added to the method. During the data collection for the weighing factors, the possibility of excluding one or more factors was also examined. In the end, all nine factors (seven from ISO 15686 and two new factors) were provided with a weighing factor. The Improved Factor Method provides in a more accurate estimation for the service life of a component.

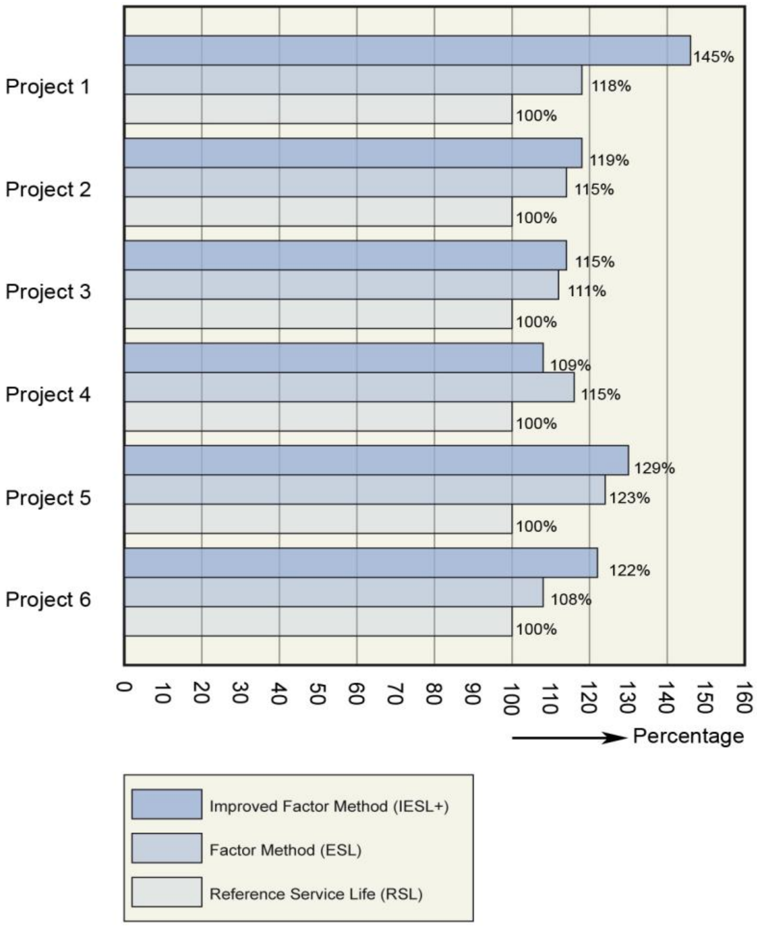


Fig. 7 Calculation environmental impact of six sample projects using different models for service life prediction

4.4 Example

During the research [3] six building projects were used as a sample project. These projects were a selection from the government programme Industrial Flexible and Demountable (IFD) building. The programme was initiated to stimulate these three fields of building. The aim of the research was to look into the possible relationship between flexibility and the environmental burden. As a consequence all the projects from the IFD-programme have a certain degree of flexibility.
The six projects were used to calculate the environmental burden. All the projects were set at an expected life span of 120 years, and during this time the necessary maintenance and replacement was conducted. Even alterations (refurbishments) were taken into account, based on predetermined scenarios. These scenarios are based on the growing demand of floor space of the individual rooms and the total building as well. Figure 7 shows the result of the LCA calculations. The outcome of the LCA is currently displayed in Ecopoints based on Eco Indicator 99, but every other method could be used. Every project is calculated using the reference service life (RSL). The outcome of the total environmental burden is set at 100%. Then the existing Factor Method is used, generating an Estimated Service Life (ESL). The outcome of this calculation is set in perspective to the outcome with the RSL. Finally the Improved Factor Method is used. This gives the IESL+, which is also put in perspective to the RSL.

It becomes clear that when the ESL or IESL is used the calculated environmental burden becomes higher. Differences up to 45 % can occur when compared to RSL. The average outcome of IESL+ lies 23% higher than using the RSL. More detailed information leads to more detailed calculations. Some replacements occur early because of refurbishment. The main reason is that the RSL is often negatively influenced by the factors.

4.5 Division over different life cycle stages

Based on the six sample projects an overview of the environmental burden is generated where the average environmental burden is divided into the building phase, use phase, and disposal phase. The disposal phase can be calculated as a single value. If maintenance and replacement are not calculated the outcome will give the results for building and disposal. Now all the different phases can be distinguished. Calculation leads to a division of 30% building phase, 50 % use phase and 20 % disposing, taking the sample projects as a reference (Figure 8). In this figure the environmental burden over 120 years is displayed by the thick line. Left the environmental burden is displayed as a straight line. In this illustration it shows 100% in 120 years. Prolonging the service life to 150 years leads to an increase to 123%. Shortening the service life gives 66% at 75 years and 41% at 50 years. The fact is ignored that the building and disposal phase always occur and that the use phase is the variable. The illustration on the right side shows a more accurate picture. Prolonging to 150 years leads to an increase to 113%. Shortening to 75 years gives 81% and to 50 years leads to 71%. The figure on the right side is a more accurate representation, because the structural elements are left out of the life span discussion. When figure 8 is compared to figure 2 some similar outcomes can be found. Prolonging from 120 to 150 years has in both approaches an increase of 13% (and not 23% as in the current calculations) as a consequence. Shortening form 120 to 75 years leads to a reduction of 24% in figure 2 and 19% in figure 8. Compared to the current approaches that come to 34% it is a huge difference. This underlines the need for better service life prediction.

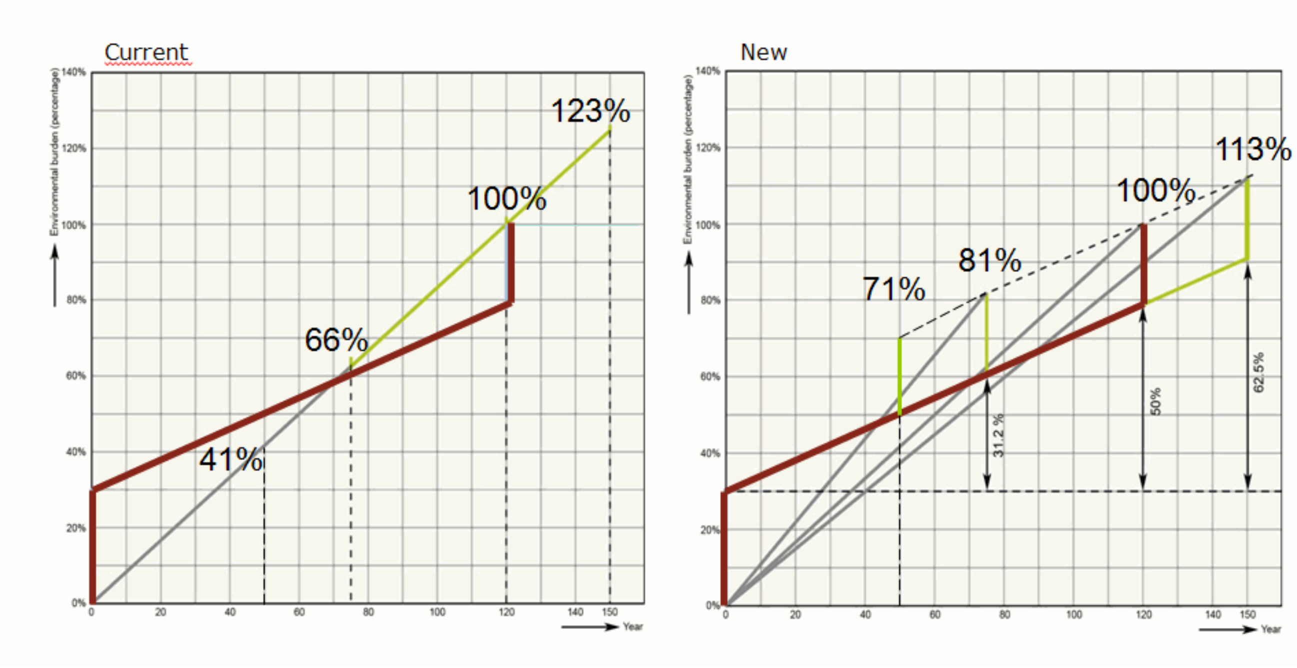


Figure 8 Environmental burden illustrated. Current method using average per year (left) or dividing in phases (right).

5 Conclusions

The applied life span of the building and the applied service lives of building elements have a very large impact on the outcome of the assessment of the environmental performance of the building related to materials. With the current tools and assumptions the actual environmental impact of less durable building elements will mostly be higher and that of very durable building elements lower than calculated. More accurate life spans of buildings and service lives of building elements are essential to improve the reliability of the environmental assessments. An accurate life span of the building is most important in relation with very durable building elements. For less durable building elements the actual service life of the product itself is very important because maintenance and replacements of buildings elements have a big influence on the environmental impact of the building. In that case the different life cycle stages become important.

It is recommended to come to a further differentiation of advised life spans for buildings for use as the Reference Study Period (RSP). This can be done by a greater distinction between the type of building and its associated features. National studies on the actual life span of buildings, opinions of experts and figures on the building production and rate of demolition can be used to come a list with advised life spans for use as RSP.

Not only the life span of buildings needs to be harmonized. The individual service life of a product needs attention as well. Current RSL's are too much an average to do justice to the actual situation. Differences averaging 23% with peaks of double that amount can occur in the calculations of the environmental impact. This leads to huge differences in LCA. The Factor Method is a good way to estimate a service life (ESL) that is more close to the actual time. With the improved service life (IESL) as presented by Van Nunen this is even more elaborate.

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