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SUSTAINABILITY, FINANCIAL AND QUALITY EVALUATION OF DWELLING TYPES "SUFIQUAD"

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INTEGRATED SUSTAINABILITY ASSESSMENT OF DWELLINGS IN THE BELGIAN CONTEXT

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Keywords: *housing, life cycle assessment, life cycle costing, monetary valuation, Pareto, quality, willingness to pay*

Abstract

In 2007 a four-year project began towards optimising the sustainability of Belgian dwellings, focusing on environmental impact, financial cost and quality based on an integrated approach. The aim of this work is to evaluate the whole life cycle of representative existing and new dwelling types and formulate a preparatory policy document to evolve towards more sustainable housing.

This paper elaborates on a methodology developed and its implementation using three dwelling types. These dwellings are assessed during the first phase of the project; and the methodology is under further revision with a vision to apply it to representative dwelling types based on the results of our assessment.

The environmental impact is estimated based on life cycle assessment and translated into financial terms. In combination with the evaluation of the financial cost, this enables an investigation of the consequences if societal damages are considered. Moreover, a quality evaluation using a multi-criteria analysis is added to the assessment to support requirements for sustainability and enable comparison of non-identical functional units. The selected optimisation procedure is based on analysis of marginal improvements.

1. Introduction

Sustainabiltiy, Financial and Quality evaluation of Dwelling types (SuFiQuaD) is an ongoing project executed for the Belgian government in order to investigate and improve the sustainability of Belgian dwellings. Various factors are analysed within this sustainability evaluation including environmental impacts, financial costs and quality. The final aim of the project is to elaborate a preparatory policy document based on a developed methodology with results of extensive analysis.

The analysis is executed at the dwelling level, including the whole life cycle by a 'life cycle assessment' (LCA) and 'life cycle costing' analysis (LCC). Moreover, the research focuses on different dwelling types in order to formulate recommendations that are recognisable by inhabitants and are therefore assumed to improve action taking in terms of executing measures to improve sustainability of their dwellings.

The research consists of different steps, starting with the development of an assessment method (integrated approach), which is transformed into a tool for use in analysis. The method is applied to several dwelling types (*e.g.*, freestanding house, apartment, terraced house) in order to evaluate and improve the methodology and tool. The final stage involves method and instrument revision and implementation to a set of representative dwelling types. This paper reports on the earliest phase of the project by elaborating and looking critically at the methodology and first implementation.

Within the overall project, long term and short term policy recommendations will be formulated. Preliminary insights indicate that for the long term the environmental costs need to be internalised within the financial costs. As a consequence, alternatives (*e.g.*, dwelling layout, technical solutions for building elements like walls, roofs, windows) with a higher environmental load will be avoided or replaced. Short term recommendations are checked against this long term perspective. The idea is to follow the same approach taken by the *energy performance regulations (EPB)* established in Belgium in 2006. This means that minimum requirements—becoming more severe over the years—are obligatory while better performance is stimulated. A tool, provided by the government, enables to calculate the life cycle environmental and financial cost of the buildings following a standardised method, and includes a database with the necessary information. As with EPB, an architect (or responsible person) is able to extend this database with specific

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LCA/LCC data when available and checked by an independent third party. To stimulate environmental measures that are not financially interesting, government incentives such as subsidies or tax reductions are encouraged. This proposed policy will be critically evaluated based on the analysis of the selected Belgian dwellings and adapted when necessary. Moreover, clarity will be gained about which measures are most efficient upon review of the completed project.

This paper does not elaborate on the proposed policy measures, but focuses rather, on the developed methodology and discusses the results of the first implementation. The implementation to three dwelling types is included to illustrate the method and formulate initial feedback on the proposed method.

2. Methodology

The integrated approach proposed in this paper is based on a combination of existing methods and is described thematically. These themes are identified and include LCA, LCC, multi-criteria analysis and optimisation by searching for the Pareto front.

2.1 Assessment at the building level

When evaluating the sustainability of a dwelling the whole life cycle needs to be considered. A dwelling typically consists of different life phases involving pre-build, construction, use, and end-of-life (EOL). These life phases include extraction of resources, production of building materials, transportation to the construction site, construction of the dwelling, use of the dwelling, demolition, transport of materials for EOL-treatment and EOL-processing. For each life phase, the materials, products and processes are inventoried in order to determine financial costs and environmental impacts.

A building is characterised by a heterogeneous composition that has resulted in a separate research domain within life cycle studies. This requires thorough and detailed data collection in order to avoid double counting and/or missing parts. Within this research the '*element method for cost control*' (De Troyer (2007), a.a. (1968), a.a. (1991a)) is used which enables a hierarchical decomposition of the dwelling and therefore guarantees the completeness of the data collection. The '*element method*' is originally developed for the analysis of financial investment costs of buildings. The method is applied in this research and extended with life cycle financial and environmental costs.

Inventory analysis reveals that data are lacking concerning transport of building materials (distances, means and load percentage) and EOL treatment (% landfill, % incineration, % recycling and % re-use) for the Belgian context. Therefore, surveys are executed by the *Belgian Building Research Institute* to fulfil this shortcoming. The environmental costs of these phases are determined based on the surveys. The financial cost for transport to the construction site and the construction are searched for in the available cost database and is thus not based on the surveys. Moreover, the financial cost of the EOL treatment is not assessed within this research since data are not available for the costs of the occurring EOL processes.

The relatively long lifespan of dwellings makes the use-phase an important part of the life cycle. It is, however, hard to predict the actual dwelling lifespan and therefore a sensitivity analysis is made by considering a lifespan of 60 and 120 years. During the use-phase different processes occur such as heating, cleaning, maintenance and replacements. These are assessed using energy calculation software (EPB) and through literature reviews (cleaning, maintenance and replacement processes and frequencies).

A comparative analysis requires identical functional units; however, due to the multi-functional character of dwellings, this virtually impossible. Therefore 'one square metre of floor area, per year' is chosen as functional unit to compare dwellings with different size, layout and lifespan. Since the performance of this square metre is not identical for all dwellings, a quality evaluation is added. In this way the cost for a certain quality can be compared. Larger buildings often lead to a lower cost per square metre floor area (financial and environmental). This results in a preference for larger buildings that are not necessarily more sustainable if these accommodate the same number of inhabitants. Therefore, the cost is also calculated 'per inhabitant, per year' to compare dwellings with difference in size or number of inhabitants.

2.2 Financial Cost

Financial cost evaluations in the construction sector are commonly limited to the 'investment cost' (IF), while costs during the whole life cycle (LF) are of importance to make informed decisions. In this research, financial cost analysis involves the evaluation of the IF and the LF.

IF includes both the material cost and the labour cost for the construction. The data are mainly taken from the 'ASPEN database' (2006). For the missing data, the database of the 'Bouwunie' (2004a, 2004b, 2004c) or product specific data are consulted. LF includes all costs—including the IF—during the lifespan of the dwelling and is calculated based on the classic LCC methodology. Literature consulted includes, for example, ISO (2007), De Troyer (2007) and Verbeeck (2007).

For LF the sum of the present values (SPV) of the costs is calculated. The formulae are not elaborated here, but are described in a previous publication (Allacker et al. 2008). Economical parameters as discount and growth rate need to be estimated. For the three analysed dwelling types the following assumptions are made based on an extended literature study: real discount rate of 2%, real growth rate of labour cost of 1% and of material cost of 0%; and real growth rate of energy cost of 2%. For energy cost, national statistics are consulted and the average for 2006 is used (0,0131 euro/MJ gas).

2.3 Environmental Impact

For the evaluation of the environmental impact, again the whole life cycle of the dwelling is considered in order to make correct decisions. The evaluation is therefore based on an LCA. Literature such as ISO 14040 (2006), ISO 14044 (2006), Guinée et al. (2002), a.a. Regener (1997), SETAC (1991) and SETAC (2003) are consulted.

For the inventory of the environmental data of the building related products and processes, the Ecoinvent database is used (www.ecoinvent.ch). For the translation of the inventoried in- and outputs to environmental effects, all categories as defined within *Eco-indicator 99* (Goedkoop et al. 2001), are considered. However, since the aim of this research is to integrate the environmental impact and financial cost, the monetary value of the environmental impacts is determined instead of expressing these in *Ecopoints* as in the original eco-indicator method.

For monetary valuation, a damage function approach is followed based on market prices and willingness to pay (WTP) in order to prevent or respond to negative impacts. Different sources are consulted and the proposed method combines a number of these in order to make the assessment as complete as possible. As a result, the chosen method consists of monetary values of emissions and environmental impacts.

The monetary value of greenhouse gas emissions is based on information from Tol (2005), Stern (2006) and Watkiss et al. (2005a, 2005b). The monetary value of other airborne emissions (PM2.5, NH_3, SO_2, NO_x, VOCs) is based on the *ExternE* studies. More specifically, the values of the *Clean Air For Europe* (CAFE) project are used (Holland et al. 2005). These emissions all contribute to the effects on human health as defined within Eco-indicator 99. Furthermore, a monetary value is determined for impacts to human health caused by other emissions. Based on different sources, the monetary value of 60.000 euro/disability adjusted life years (DALY) is estimated (De Nocker et al. 2008). Finally, the impact on the quality of ecosystems (acidification, eutrophication, ecotoxic emissions and land use) and the depletion of resources (minerals and fossil fuels), as assessed within Eco-indicator 99, are considered. The value of 0,49 euro/'potentially disappeared fraction (PDF) x m2 x year' and 0,0065 euro/MJ surplus energy are retained (De Nocker et al. 2008).

For the assessment of future processes occurring during the lifespan of the dwelling, the same approach is applied as for the financial cost by calculating the SPV of all environmental costs (LE). However, a lower value (1%) is chosen for the discount rate of the environmental costs since a social discount rate is assumed to be lower than a private discount rate.

2.4 Quality Assessment

For the reasons formulated before, a quality assessment is added and is based on an existing method, consisting of a multi-criteria analysis (a.a. 1991b).

Table 1 Main Quality Aspects and Sub-aspects and the Corresponding Weighting Factors (adapted)

Global distribution of points	Maximum points sub-aspects	Maximum points main aspects	Percentages % (max)
Dimensional characteristics		*2690*	*37,62%*
Size of rooms	1090		
Room width	690		
Windows size + orientation	610		
Efficient use of floor area	300		
Functional characteristics		*1620*	*22,66%*
Available length for furniture	500		
Relation between the different rooms	780		
Flexibility/adaptability	340		
Technical characteristics		1260	17,62%
Ventilation and safety	100		
Hygro-thermal characteristics	0		
Acoustical performance	350		
Technical installations	690		
Surface of materials: maintenance	120		
Surroundings of the dwelling		1580	22,10%
Direct surroundings	880		
Broader surroundings	700		
Financial cost		0	0,00%
Financial cost	0		
Total		7150	100,00%

Within the existing method different quality aspects are considered and hierarchically structured whereof the qualities at the highest level are: dimensional, functional and technical characteristics, surroundings of the dwelling and financial cost. The dimensional characteristics are for example sub-divided into room size, room width, window size and orientation, and efficient use of floor area. These are again subdivided in different qualities, such as size of living room, size of bedrooms, size of bathroom and so on.

For each quality at the lowest level, a score between zero and ten can be obtained. The obtained score is defined by a score function that was developed by an expert panel in the original method. If some quality aspects are not relevant for a certain dwelling, such as acoustical performance of shared walls in the case of a freestanding house, these aspects are not considered in the evaluation and thus the maximum obtainable score can differ for each dwelling. A single score is determined by calculating the sum of the weighted scores. Within the original method the weighting factors (importance of each quality) were defined by a panel of experts.

For the application of the methodology within this research, some adaptations to the original method are made to avoid double counting and to be in line with current Belgian and European building regulations. The financial cost and hygro-thermal characteristics, for example, are excluded from the original method since these are already assessed within the LCA and LCC. In table 1 an overview is given of the qualities considered and the weighting factors assigned within the adapted method.

2.5 Optimisation

Within the optimisation procedure, both the optimisation of costs and costs/quality are determined to investigate if decisions based on costs only differ from the ones considering quality. For cost optimisation a reference dwelling is the starting point, whereby the highest life cycle cost reductions for the additional investment cost are examined. The obtained subset of options is called the Pareto front. For cost/quality optimisation, a similar approach is used, but the search consists of the highest quality improvement for the additional cost. The cost/quality optimisation has the potential to be limited to initial costs or to consider the life cycle cost. Different optimisation criteria are moreover possible: one can limit the analysis to financial or environmental cost or investigate the sum of both (total cost). These different criteria generally lead to a different selection and ranking of the Pareto options.

The chosen optimization procedure thus enables a selection of the most optimal solution within a certain budget out of a range of possible solutions by determining the best spending of money. This is important for this study since it is assumed that most people have a budget restriction and are interested in how to spend optimally. The most optimal solution only equals the minimum cost if there are no budget restrictions.

3. Dwelling Types

The developed methodology is translated into excel and applied. In the next section, a freestanding house, an apartment and a terraced house are described, followed by the analysis and preliminary results.

3.1 Description of the Dwelling Types

3.1.1 Freestanding House

The freestanding house is L-shaped, consists of a ground floor level of 159 m^2 and has a compactness of 0,80 m. The house consists of a living room, kitchen and bathroom, storage room and three bedrooms. There is an entrance and night hall, but no garage. The garden is surrounding the house and there is a terrace adjacent to the living room. The dwelling is designed to accommodate four inhabitants.

3.1.2 Apartment

The apartment building consists of 11 identical floors, a ground floor and a technical top floor. Each of the 11 floors has eight apartments of different sizes. The ground floor mainly consists of gathering and storage rooms and has two more apartments. Within this analysis, one apartment has been considered with a total floor area of 69 m^2. The apartment consists of one bedroom, an entrance hall, living room, kitchen, bathroom, storage and separate toilet; and has a small balcony. The compactness of the apartment equals 5,12 m. The apartment is designed to accommodate two inhabitants, is located at the front side (street) in the middle of the building. Part of the apartment building consists of shared space and elements (exterior walls, roof, ground floor, intermediate floors, foundation and shared interior walls). These are included in the analysis by assigning a proportion of these to each apartment in accordance to its floor ratio.

3.1.3 Terraced House

The terraced house consists of two floors with a total floor area of 157 m^2 and a compactness of 1,35 m. The ground floor consists of a living room, kitchen, storage room, garage and toilet. The upper floor consists of three bedrooms, a bathroom and second separate toilet. The dwelling is designed to accommodate four inhabitants. There is a garden at the back of the house, adjacent to the living room.

3.1.4 Building Elements

Building elements are defined according to the 'element method' and concern independent constituting parts of a building, such as, exterior walls, floors, roofs, and windows. Various technical solutions for these elements are present, yet extremes are selected for the purpose of exploration. That is, for the exterior walls, cavity walls consisting of bricks (both inner and outer layer) are compared with other facade finishes (wood claddings, cement fibre board) and with another structural inner layer (wood skeleton). For the flat roof and intermediate floors both a concrete slab and wood beams are considered. For the inner walls, concrete blocks, sand-lime brick, clay bricks and wood skeleton are compared. For the building envelope (exterior wall, roof and ground floor) non-insulated and well-insulated alternatives are selected. For the windows normal double glazing and thermally improved glazing are considered, while the window frame is kept unmodified (aluminium). However, the exterior and load-bearing inner walls of wood structure are omitted for the apartment since these are prohibited in Belgium for safety reasons (fire). The same accounts for the intermediate floor and the flat roof alternatives consisting of a wood structure.

3.1.5 Limitations of and Differences in Assessment

For the analysis of all three dwellings, the environmental costs due to the construction activities are omitted due to lack of data; however, the production and transport of the materials are included. The financial cost for the demolition and EOL treatment are also excluded for the same reason.

Since the methodology and tool have been revised and further developed through the implementation process, there are some differences between analyses of the dwellings. For the freestanding house, cleaning and maintenance costs are not yet assessed, while these are included in the analysis of the other dwellings. Moreover, the EOL estimations for the freestanding house and newly built terraced house are based on first approximations that proved to be unrealistic and are adapted for the apartment.

3.2 Analysis of the Dwelling Types

For each dwelling the environmental and financial costs during the different life phases and the quality score are calculated for all possible combinations of technical solutions of elements. For the freestanding house, the total number of simulations equals 1152, for the terraced house 6912, and for the apartment 3072. Moreover the Pareto fronts are searched for within the optimisation procedure. A comparison of the analysed dwellings is included to point out some interesting aspects.

3.2.1 Cost Optimisation

In this section some of the cost optimisation results are elaborated to illustrate the methodology and discuss the results of the case studies. The results are graphically presented in order to give insight into the extensive amount of data. Figure 1 shows the results for the cost optimization for the terraced house. A similar graph is derived for the apartment and freestanding house. All costs are expressed per m^2 floor area, per year. The initial costs are plotted horizontally while the life cycle costs are shown on the vertical axis. The options in the left and right grouping of a same symbol represent respectively a lifespan of 120 and 60 years. Moreover the environmental, financial and total costs are shown together with the derived Pareto fronts.

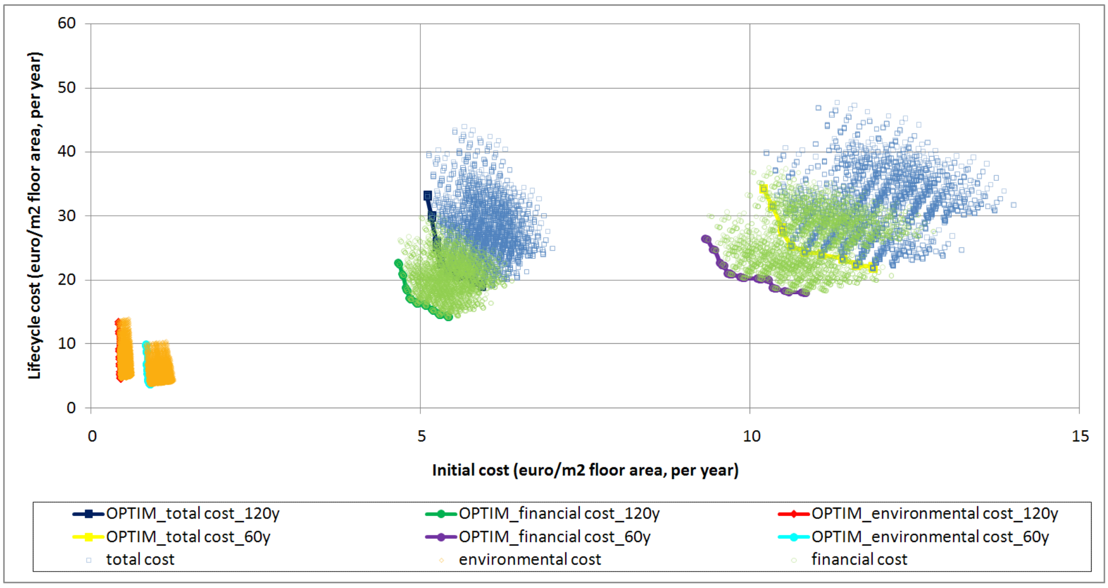

Figure 1 Results for the cost optimisation of the terraced house (60 and 120 y).

The graph in figure 1 shows that dwellings with a longer lifespan clearly lead to a lower investment cost per m^2 floor area per year. The life cycle cost of these per m^2 floor area per year, however, is not necessarily lower than the life cycle cost of dwellings with a shorter lifespan.

A detailed analysis of the Pareto solutions clarifies that these are different depending on the costs considered and depending on the lifespan assumed. For example, opting for thermally improved glazing instead of normal double glazing leads to the highest reduction of the environmental life cycle cost for the lowest increase of environmental investment cost. If the financial cost is the only consideration, an investment in floor and roof insulation leads to largest reduction of the life cycle cost for the lowest extra investment costs. It may be concluded, therefore, that decisions based on environmental cost and financial cost can differ.

For a lifespan of 120 years, the maximum life cycle environmental cost for the Pareto front solutions equals 1609 euro/m^2, while the minimum equals 550 euro/m^2. This means a reduction of 66%. The extra environmental investment for this improvement equals 4,72 euro/m^2 (8%), while an extra financial investment of 45,71 euro/m^2 is required (9%). From this analysis, it is clear that large reductions of life cycle environmental cost are possible for a small extra environmental and financial investment.

Figure 2 illustrates a comparison between the life cycle costs of the different dwellings for the solutions situated on the Pareto front. The minimum, maximum and average total life cycle cost per square metre floor area per year (left axis, dotted line) and per inhabitant per year (right axis, continuous line) are shown.

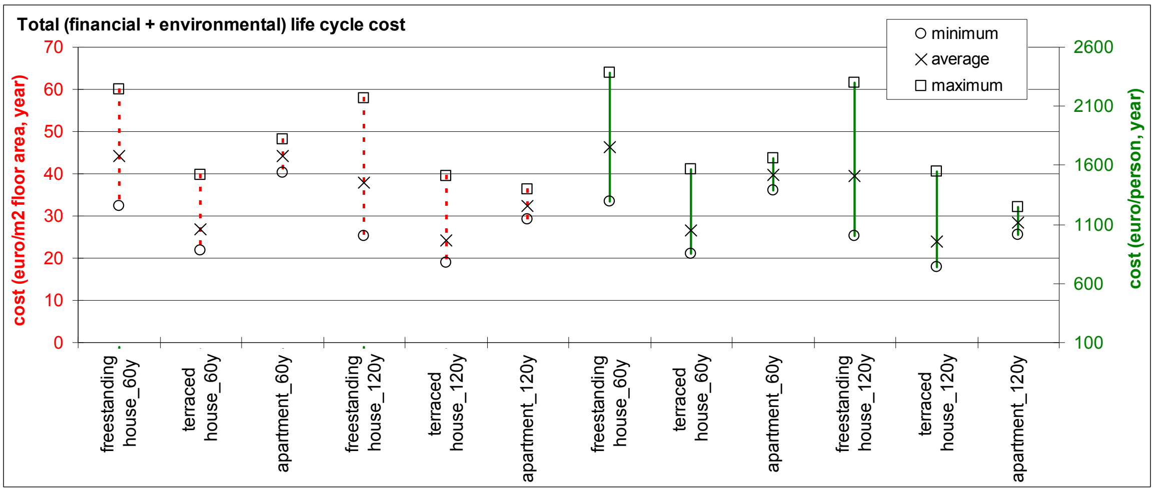

Figure 2 Comparison of the total life cycle cost of the different dwellings for the subset of Pareto solutions, per metre floor area, per year and per inhabitant, per year.

Figure 2 shows that the lowest average life cycle cost per square metre floor area, per year is obtained for the terraced house. The average cost per square metre floor area per year of the freestanding house is virtually identical to the apartment. However, some of our results for the freestanding house show a lower life cycle cost than the terraced house due to the choice of building materials and insulation level.

Figure 2 also shows that if a dwelling is occupied longer, the yearly total cost generally reduces, which can be explained by the fact that the investment and EOL costs are spread over a longer period. However, this is not necessarily always true, since a longer occupation can lead to higher maintenance and replacement costs. The highest reduction is achieved for the apartment that can be explained by the high investment cost and low heating cost (despite the high cleaning and maintenance cost).

The comparison 'per inhabitant, per year' shows that the difference between the apartment and the terraced house is reduced compared to the cost 'per m2, per year' due to the fact that the floor area per inhabitant is smaller for the apartment. Moreover the difference between the freestanding house and the other dwellings has increased, which can be explained by the larger floor area per person in the freestanding house.

3.2.2 Importance of the Different Life Phases and Contribution of Environmental and Financial Costs

Analysing the importance of the different life phases reveals a large difference between the Pareto options of one dwelling. For the freestanding house with a lifespan of 60 years, for example, the minimum contribution of the initial phase to the total life cycle cost equals 23%, while the maximum contribution equals 47%, the average being 35%. However, the environmental cost for demolition and transport to the EOL treatment are always negligible. Moreover, the initial environmental cost is responsible for a small part of the total life cycle cost: the maximum contribution for the Pareto subsets is 5%. However, this cost is suspected to contribute more for better insulated dwellings.

The analysis moreover indicates that for the initial phase the environmental cost is responsible for nearly 9% and the financial cost for 91%. For cleaning, maintenance and replacements, a difference is noticed between the dwellings: the contribution is highest for the terraced house: 14%, followed by the freestanding house (6%) and the apartment (3%). For heating, the contribution of the environmental cost ranges from 37% (freestanding house and terraced house) to 40% (apartment) for a lifespan of 60 years. For a lifespan of 120 years, the contribution ranges from 46% (freestanding house and terraced house) to 48% (apartment).

Figure 3 represents the average contribution of the life phases, differentiating between initial phase (pre-build, construction), use phase, demolition and EOL phase. It illustrates that the importance of the life phases is differing for each dwelling type and that this depends on the lifespan.

Finally the average contribution of the environmental cost to the total life cycle cost is analysed. For a lifespan of 60 years this ranges from 10% (apartment) to 21% (freestanding house); while for the terraced house it equals 18%. For a lifespan of 120 years the average contribution ranges from 17% (apartment) to 31% (freestanding house), while for the terraced house it equals 26%.

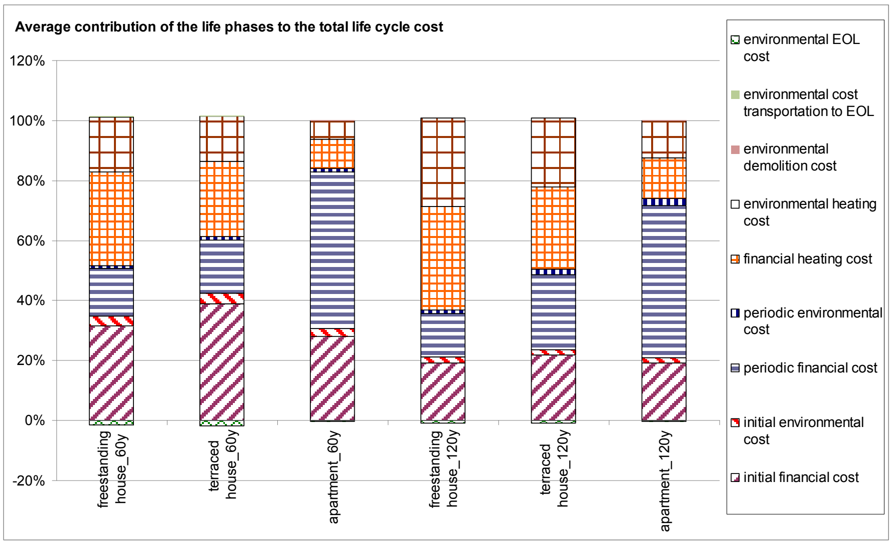

Figure 3 Average contributions of the different life phases of the Pareto subset to the total life cycle cost.

The analysis indicates that adding the environmental cost to the financial cost leads only to an increase of 9% of the investment cost. However, a high augmentation (ca. 40%) of the heating cost is noted. Therefore, the internalisation of environmental costs primary leads to better insulated dwellings, and not necessarily to the use of more environmentally-friendly materials. A recommendation here is that the use of more environmentally-friendly materials could be stimulated by government. This is even more valid for future-built dwellings because these will be insulated better and thus the initial phase will gain importance.

The above described analysis does not include transportation of inhabitants during use-phase. A transportation scenario is defined for an average Belgian family. It reveals that the financial cost due to transportation is by average responsible for 46% (freestanding house) to 65% (apartment) of the life cycle financial cost and the environmental cost for 42% (freestanding house) to 78% (apartment) of the life cycle environmental cost. Based on this result it is deemed important to investigate transportation in more detail for the use-phase in the representative dwelling types during the second phase of the project.

3.2.3 Cost/Quality Optimisation

As previously described, optimal solutions based on cost/quality analysis are investigated to check if these differ from the ones considering cost only. This is confirmed by the analysis: tiles, for example, are preferred as floor finishing when including the quality in the assessment, while carpet gains the preference when considering costs only.

The analysis furthermore indicates that the quality score only slightly differs between the options of a same building. The reason is that the analysed alternatives only differ in technical solutions of the elements that all fulfil the European and Belgian performance standards. This implies good quality and thus little distinction. However, a differentiation in layout of dwelling is suspected to influence the quality score to a greater extent. Moreover, the quality score does differ for the different dwelling types, ranging from 4319 to 5309 points. The highest quality score is obtained by the freestanding house, the lowest by the apartment.

From the cost/quality analysis we can conclude that quality is one criterion that will determine the choice of the end-user besides environmental impact and financial cost. However, it is a subjective parameter and therefore implies that it is hard to predict final choices.

4. Conclusion and further research

This paper summarises a methodology developed within the *SuFiQuaD* project to optimise the sustainability of Belgian dwellings. Financial and environmental costs are evaluated, including a quality assessment and considering the whole dwelling life cycle. Moreover, the implementation to three dwellings is elaborated. The analysis reveals that decisions based on environmental cost and financial cost can differ. Moreover, recommended measures differ depending on the dwelling type and considered lifespan. It is also clear that high reductions of the life cycle environmental cost are possible for a small extra environmental and financial investment. The analysis further shows that internalisation of environmental costs influences the decisions for one dwelling type more than for another. Moreover, the inclusion of the environmental cost did not influence the initial cost to a large extent (maximum of 9%). Internalising environmental costs will therefore not immediately lead to the use of more environmental friendly materials. The environmental cost does, however, constitute an important part of the total heating cost. Internalising environmental costs thus in the first instance results in better insulated dwellings. Finally, the use of environmental friendly materials is necessary since the initial phase will gain importance if heating costs are reduced, which can be stimulated by the government.

During the coming years, the updated method and tool will be applied to representative Belgian dwelling types and policy recommendations will be re-formulated.

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Dossier duurzame woningbouw: de aftrap! - 31/01/2011

Iedereen heeft de mond vol over duurzaam bouwen, maar hoe kan je eigenlijk weten of een woning duurzaam is of niet? Dat was – in zeer eenvoudige bewoordingen - het uitgangspunt van de doctoraatsstudie van Karen Allacker (KU Leuven). De belangrijkste resultaten ontdek je de komende weken op Livios. In dit eerste deel stellen we het onderzoek in grote lijnen aan je voor.

De bouwsector is verantwoordelijk voor een belangrijk aandeel van de totale milieuvervuiling in België. In 2007 werd een onderzoek gestart om efficiënte, betaalbare maatregelen te bepalen om daar verandering in te brengen. In opdracht van de federale overheid (BELSPO) werd door het departement ASRO (Architectuur, Stedenbouw en Ruimtelijke Ordening) van de KU Leuven een studie (SuFiQuaD) opgezet, in samenwerking met VITO (Vlaams Instituut voor Technologisch Onderzoek) en WTCB (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf). Het doctoraatsonderzoek van Karen Allacker, waarvan Livios de belangrijkste resultaten zal publiceren, werd uitgevoerd binnen deze studie.

Behalve het bepalen van acties om te komen tot een duurzamer woningbestand in België, was het onderzoek gericht op het ontwikkelen van een instrument om de duurzaamheid van gebouwen tijdens hun hele levensduur te evalueren. Dit moet architecten toelaten de milieu-impact van gebouwen mee als ontwerpparameter op te nemen, net zoals dit nu gebeurt met de financiële investeringskost. Het onderzoek is gebeurd in verschillende stappen.

Methodologie


[Foto: Terca]

Eerst werd een methodologie ontwikkeld voor het evalueren van de milieuprestatie en financiële kost van gebouwen waarbij de volledige levenscyclus beschouwd wordt. De milieubelasting is uitgedrukt in milieukosten, ook wel externe kosten genoemd.

Evaluatietool

De ontwikkelde methodologie is vertaald naar een evaluatietool: via een beperkte input worden zowel de milieuprestatie - aan de hand van milieukosten - als de financiële kosten berekend. De analyse gebeurt op gebouwniveau en beschouwt de volledige levensduur. Bovendien wordt de energieprestatie van de woningen volgens de Vlaamse EPB-normering berekend. Een eenmalige input geeft dus een zicht op het K- en E-peil, de investeringskosten, de levenscycluskosten en op de initiële en en levenscyclus milieu-impact.

Zestien woningen


[Foto: RENSON Sunprotection]

Zestien woningen zijn milieutechnisch en financieel beoordeeld aan de hand van het ontwikkelde instrument. De milieuprestatie, investeringskost en levenscyclus financiële kost zijn in kaart gebracht van bestaande woningen daterend uit vier periodes: voor 1945, 1945 – 1970, 1971 – 1990 en 1991 – 2001. Deze zijn vergeleken met de huidige bouwpraktijk. Ten slotte is via een optimalisatie onderzocht welke verbeteringen mogelijk zijn met huidige technologie.

De tool laat naast een optimalisatie op gebouwniveau een meer beperkte optimalisatie op elementniveau toe. Voor de meest voorkomende elementen, zoals vloer op volle grond, buitenwanden, binnenwanden en daken, is op een analoge manier een optimalisatie uitgevoerd, die focust op materiaalkeuze en op isolatiegraad.

In de artikels die volgen wordt in eerste instantie gefocust op elk van de geanalyseerde elementen en worden de belangrijkste resultaten samengevat. Vervolgens bekijken we in de daaropvolgende artikels de resultaten van de woningen. Aangezien deze een brede waaier van de bestaande en nieuwbouwwoningen binnen de Belgische bouwcontext vertegenwoordigen, zijn ze exemplarisch voor heel wat gelijkaardige woningen.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.

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Dossier duurzaam bouwen: zoektocht naar de ideale vloer - 07/02/2011

In dit tweede artikel van de reeks duurzaam bouwen, vertelt onderzoekster Karen Allacker hoe je de milieu-impact en levenscycluskost van een vloer op volle grond op een betaalbare manier kan verminderen.

Aanpak

De verschillende vloertypes zijn gedurende hun volledige levensduur geanalyseerd. Niet alleen de initiële milieu-impact en kostprijs zijn bekeken, maar ook de kosten voor schoonmaak, onderhoud, vervangingen, afbraak en eindelevensduurbehandeling (storten, verbranden, recyclage en hergebruik). Bovendien zijn de warmteverliezen via de vloer meegerekend op basis van de verwarmingskost die hiermee gepaard gaat. Enkel de op dit moment beschikbare materialen en technieken zijn geanalyseerd (zie **FIGUUR**).

De analyse is per laag van de vloer (grondaanvulling, isolatie, dekvloer, afwerking) uitgevoerd waarbij telkens een levensduur van 60 jaar werd beschouwd. De milieu-impact is uitgedrukt in milieukost, ook wel schaduwkost genoemd. Dit is de kost ten gevolge van gezondheidsproblemen en andere milieu-effecten (inclusief uitputting van grondstoffen) die we als individu momenteel niet betalen, maar die naar de maatschappij doorgeschoven worden.

Linoleum is volgens het onderzoek één van de vloerafwerkingen met de kleinste impact op het milieu.

Belangrijkste conclusies

Uit de analyse blijkt dat de gebruiksfase het belangrijkst is voor de kosten. Voor de financiële kost is dit vooral te wijten aan schoonmaakkosten, terwijl vanuit milieuoogpunt vooral de warmteverliezen nadelig zijn. **In vergelijking met de huidige bouwpraktijk is een levenscycluskostvermindering van 20 % mogelijk en een levenscyclusmilieukostvermindering van 60 %.**

De isolatiewaarde en de vloerbekleding bleken de belangrijkste parameters om de levenscyclus financiële- en milieukost te beperken, waarbij de dikte van de isolatie belangrijker is dan de keuze van het isolatiemateriaal. Naargelang het type isolatie is een andere optimale dikte bepaald (zie **TABEL**).

[Foto: Quick-Step/ Unilin bvba division Flooring]
Ook laminaat levert een kleine 'levenscyclusmilieukost' op.

Vanuit milieuoogpunt is meer isoleren nog belangrijker dan wanneer we enkel naar het financieel rendement kijken. De grotere isolatiedikte volgens het financieel optimum in vergelijking met de diktes die in de huidige woningbouw courant toegepast worden, vergt een meerinvestering van gemiddeld 5 % en resulteert in een beperkte levenscycluskostvermindering van gemiddeld 1 %. Hiertegenover staat een reductie van de levenscyclusmilieukost van gemiddeld 14 %. De optimale diktes vanuit milieuoogpunt vragen een extra investeringskost van gemiddeld 16 %, resulteren in een toename van de financiële levenscycluskost van gemiddeld 2 %, maar in een reductie van de levenscyclusmilieukost van gemiddeld 18 %.

De vloerafwerkingen die leiden tot de kleinste levenscyclusmilieukost zijn linoleum, kurk, laminaat en tapijt. Hygiëne en stootbestendigheid kunnen uiteraard steenachtige materialen vereisen. Blauwe hardsteen uit Azië is goedkoper dan deze uit België, maar zorgt voor een grotere milieukost door de ontginningsprocessen en transport.

[Foto: Carrières du Hainaut]
Ecologisch gezien is Belgische Blauwe hardsteen het interessantst. Blauwe hardsteen uit Azië is goedkoper, maar zorgt voor een grotere milieukost omwille van ontginnngspocessen en transport.

Aanbevelingen

Omdat het bijzonder moeilijk is om het isolatieniveau van een vloer op volle grond te verhogen bij een latere renovatie, is het bij het bouwen van de woning **absolute noodzaak om te streven naar een degelijke vloerisolatie.** De vloerbekleding kan je later gemakkelijk vervangen en is in die zin van secundair belang.

Bovenstaande analyse maakt deel uit van het onderzoeksproject SuFiQuaD (Sustainability, Financial and Quality evaluation of Dwelling types), uitgevoerd in opdracht van de federale overheid (BELSPO) door KULeuven, departement ASRO (Architectuur, Stedenbouw en Ruimtelijke Ordening) in samenwerking met VITO (Vlaams Instituut voor Technologisch Onderzoek) en WTCB (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf). Meer specifiek is de beschreven analyse onderdeel van een doctoraatsonderzoek uitgevoerd binnen het SuFiQuaD project.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.

Lees meer over 'Heet van de naald'
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	3 cm	4 cm	5 cm	6 cm	8 cm	10 cm	12 cm	15 cm	18 cm	20 cm	21 cm	24 cm
PUR op	0.37		0.28		0.20	0.17		0.13		0.10		
PUR onder		0.33			0.21	0.18	0.15		0.10			0.08
PUR schuim	0.38	0.33	0.29	0.26	0.21	0.18	0.15	0.13	0.11		0.10	
resol op		0.32			0.20	0.17	0.15	0.11				0.08
resol onder		0.33			0.21	0.18	0.15		0.11			0.08
EPS op		0.39			0.27	0.23	0.21		0.15			0.12
EPS onder		0.40			0.28	0.24	0.21		0.15			0.12
XPS op		0.39			0.27	0.23			0.15	0.14		
XPS onder		0.40			0.28	0.24	0.21		0.15			0.12
rotswol op	0.46		0.37		0.29	0.25	0.23		0.17			0.13

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Milieukost optima

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Duurzame woningbouw: kies de geschikte binnenwand - 14/02/2011

In dit derde artikel van de reeks duurzaam bouwen focust onderzoekster Karen Allacker op niet-dragende binnenwanden. Hiervoor neemt ze diverse mogelijke oplossingen onder de loep.

[Foto: Kalisto]

Van verschillende massieve en skeletbinnenmuren (bijvoorbeeld houtskelet) berekende Karen de levenscycluskost en milieu-impact. Daarnaast bepaalde ze de investeringskost om na te gaan wat de onmiddellijke kosten zijn als je bouwt.

Aanpak

Er zijn 16 muurvarianten geanalyseerd op basis van hun volledige levensduur. Niet alleen de initiële impact en kost zijn bekeken, maar ook die ten gevolge van schoonmaken, onderhoud, vervangingen, afbraak en eindelevensduurbehandeling (storten, verbranden, recyclage en hergebruik). Enkel de op dit moment beschikbare alternatieven zijn geanalyseerd (**FIGUUR 1**). De wandafwerking werd niet gewijzigd en bestaat uit een gipspleister voor de massieve wanden en uit gipskarton voor de skeletvarianten, beide geschilderd met een acrylverf. Voor de levensduur van de wanden werd uitgegaan van 60 jaar.

[Foto: Ytong]

Het verschil in onder andere thermische capaciteit en akoestische eigenschappen tussen de alternatieven is niet in rekening gebracht, aangezien het belang van deze eigenschappen afhangt van de toepassing en dus enkel bekeken kan worden binnen de context van het volledige gebouw. De impact op het milieu is uitgedrukt in milieu- of schaduwkosten. Dit zijn kosten ten gevolge van gezondheidproblemen en andere milieu-effecten (inclusief uitputting van grondstoffen), die we als individu (momenteel) niet betalen, maar die naar de maatschappij doorgeschoven worden.

Belangrijkste conclusies

Uit de analyse blijkt dat **vervangingen tijdens de gebruiksfase** (herschilderen en herpleisteren of vervangen van gipskartonplaten) de belangrijkste bijdrage in de levenscyclusfinanciëlekost zijn, terwijl vanuit milieuoogpunt bekeken, de initiële fase (productie en constructie) het meest doorweegt (geïllustreerd voor wandtype 1 in **FIGUUR 2**).

De **skeletwanden zijn iets goedkoper dan de massieve wanden**, gemiddeld 6 % wat de investeringskost betreft en gemiddeld 10 % op vlak van levenscycluskost. Het verschil in investeringskost tussen de verschillende alternatieve massieve wanden is maximum 5 %. Het verschil in levenscycluskost is met 2 % verwaarloosbaar klein.

De **verschillende isolatiematerialen voor de skeletwanden leiden niet tot grote verschillen in investerings- of levenscycluskost** (respectievelijk maximum verschil van 13 % en 4 %). Glaswol is het goedkoopst, gevolgd door houtvezel isolatieplaten, cellulose vlokken, rotswol en hennep-katoen.

Vanuit milieuoogpunt is het verschil tussen de massieve en skeletwanden niet zo duidelijk en eerder tegengesteld: massieve wanden leiden in de meeste gevallen tot een lagere levenscyclusmilieukost dan skeletwanden. **De milieukost van hennep-katoen isolatie is opvallend hoog** en is te wijten aan de nodige landoppervlakte voor de productie van katoen.

Analoog aan de financiële analyse, blijkt de metal stud te verkiezen boven het houtskelet. **De hogere milieukost van de houtskeletvarianten is te wijten aan extra landgebruik**. Als we landgebruik buiten beschouwing laten, zou het houtskelet te verkiezen zijn boven metal stud (vanuit milieuoogpunt). De cellenbeton en kalkzandsteen alternatieven zijn te verkiezen vanuit milieuoogpunt (ongeveer gelijke levenscycluskost). De metal stud met cellulose leidt tot een ongeveer gelijke levenscycluskost, maar vergt een hogere milieu-investeringskost (+ 43 %).

De wand in gewapend beton heeft de hoogste levenscyclusmilieukost (36 % hoger dan cellenbeton). In tegenstelling tot de financiële kost maakt de isolatiekeuze van de skeletwanden wel een groot verschil in milieukost met een verschil tussen minimum en maximum levenscycluskost van bijna 30 % (hennep-katoen niet meegerekend). De voorkeursvolgorde is cellulose, glaswol, rotswol en houtvezel.

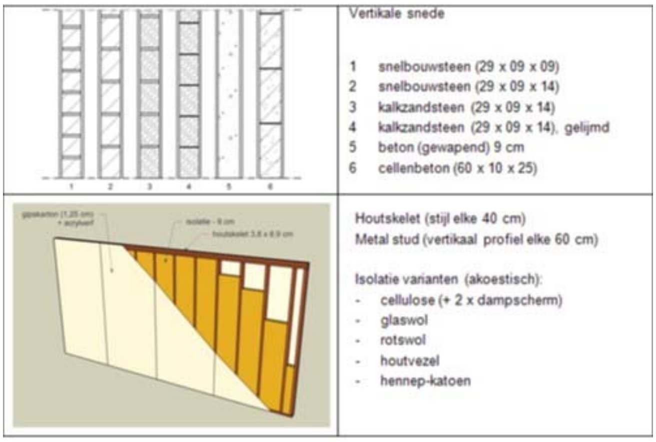
Aanbevelingen

Het verschil in levenscycluskost (zowel financieel als vanuit milieuoogpunt) tussen massiefbouw en skeletbouw voor niet-dragende binnenwanden is gemiddeld gezien klein. Om een doordachte keuze te maken, moeten we dus kijken naar eisen zoals aanpasbaarheid, akoestische prestaties en thermische massa.

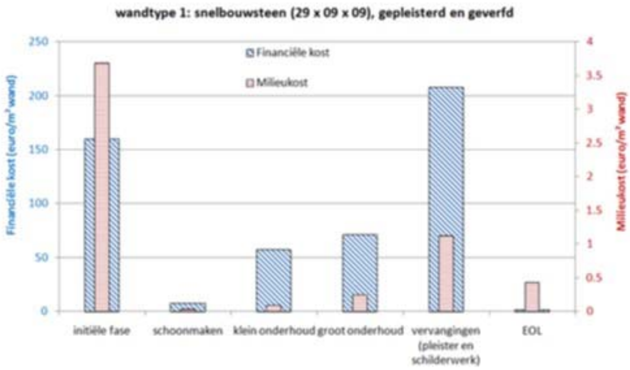
Als je kiest voor massiefbouw gaat de voorkeur naar cellenbeton en kalkzandsteen vanuit milieuoogpunt. Kies je voor een skeletbouw, dan is vooral het type van akoestische isolatie van belang voor de levenscyclusmilieukost. Cellulose geniet de voorkeur, terwijl je hennep-katoen beter niet kiest omwille van de benodigde landoppervlakte voor de katoenproductie.

Bovenstaande analyse maakt deel uit van het onderzoeksproject SuFiQuaD (Sustainability, Financial and Quality evaluation of Dwelling types), uitgevoerd in opdracht van de federale overheid (BELSPO) door KU Leuven, departement ASRO (Architectuur, Stedenbouw en Ruimtelijke Ordening) in samenwerking met VITO (Vlaams Instituut voor Technologisch Onderzoek) en WTCB (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf). Meer specifiek is de beschreven analyse onderdeel van een doctoraatsonderzoek uitgevoerd binnen het SuFiQuaD project.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.



FIGUUR 1. Opbouw van de geanalyseerde binnenwandvarianten (niet-dragend): massiefbouw (boven) en skeletbouw (onder).



FIGUUR 2. Snelbouwsteen (wandtype 1): bijdrage in de kosten (financieel en milieu) voor de verschillende levensfasen en –processen.

Lees meer over '[Heet van de naald]'
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Passiefhuis
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Dossier duurzaam bouwen: buitenwand kiezen - 21/02/2011

Op betaalbare manier milieu-impact verminderen

In dit vierde artikel van onze reeks over duurzaam bouwen focust onderzoekster Karen Allacker op de opbouw van buitenwanden. Behalve de levenscycluskost en de milieu-impact, berekende ze ook de investeringskost voor verschillende buitenwanden.

Karen analyseerde verschillende buitenwanden tijdens hun volledige levensduur. Niet alleen de initiële milieu-impact en kost zijn bekeken, maar ook die ten gevolge van schoonmaken, onderhoud, vervangingen, afbraak en eindelevensduurbehandeling. Karen onderzocht enkel de alternatieven die momenteel beschikbaar zijn (zie FIGUUR 1). Ze analyseerde hiervoor de verschillende lagen van de buitenwanden en ging uit van een levensduur van de wanden van 60 jaar. Voor de milieu-impact hield zij ook rekening met de kosten die we als maatschappij dragen, zoals gezondheidsproblemen of bijvoorbeeld de uitputting van grondstoffen.

Belangrijke conclusies:

- Vanuit financieel oogpunt zijn de initiële kosten de belangrijkste.
- Vanuit milieuoogpunt heeft naast de initiële kost, ook het energieverbruik een grote impact.
- Dankzij een goede keuze van de buitenwand is een levencycluskostvermindering van 20 % en levenscyclusmilieukostvermindering van 40 % mogelijk. De keuze van isolatiemateriaal is hierin minder belangrijk dan de dikte van isolatie. De optimale dikte is afhankelijk van het type isolatie, en is voor spouwisolatiesamengevat in TABEL.
- De dikst mogelijke isolatielaag is het best voor het milieu. Maar natuurlijk kost een dikkere isolatielaag ook meer. Als bouwer probeer je hierin dus best een evenwicht te vinden.
- Cellulosevlokken als spouwisolatie zijn af te raden vanwege de noodzakelijke extra houten structuur, die leidt tot hoge financiële en milieukosten.
- Vanuit financieel oogpunt is cellenbeton te verkiezen als draagstructuur. Dit enkel echter in combinatie met isolatie. Vanuit milieuoogpunt, kies je best voor een kalkzandsteen of isolerende snelbouwsteen.
- Bij een skeletvariant kies je vanuit financieel oogpunt best voor houtskelet bij kleine diktes en voor FJI-profielen bij grote diktes. Vanuit milieuoogpunt kies je steeds best voor FJI-profielen. FJI-profielen gevuld met cellulosevlokken blijken de beste keuze: een dikte van 41 cm leidt tot de laagste milieukost; 24 cm tot de laagste financiële kost.
- Naast de isolatiewaarde, blijkt ook de buitenafwerking een belangrijke factof voor de milieu-impact van de wand. Buitenafwerkingen zoals buitenpleister op isolatie, gevelsteen en kunstofplaten leiden tot de kleinste milieukost. Een afwerking in zink, aluminium, keramische leien en graniet leiden tot de hoogste milieukost.
- De keuze van binnenafwerking beïnvloedt de levenscycluskosten maar weinig.

	3 cm	4 cm	5 cm	6 cm	7 cm	7,5 cm	8 cm	9 cm	10 cm	12 cm	14 cm	16 cm	16,5 cm	18 cm	20 cm	22 cm
rotswol		0.53	0.46	0.41	0.35				0.28	0.24	0.21	0.19		0.17	0.16	
glaswol			0.46	0.41		0.35		0.30	0.28	0.24	0.21		0.19	0.17	0.16	
EPS			0.46	0.41	0.37		0.33	0.28	0.24	0.21		0.19		0.17	0.16	
PUR	0.48		0.34		0.26		0.23		0.19		0.15	0.13		0.11	0.11	
XPS		0.52	0.45	0.40			0.32		0.27	0.24		0.19			0.15	
cellenglas			0.47	0.42	0.38		0.35	0.32	0.29	0.26	0.22	0.20		0.18	0.17	
cellulose		0.55		0.44			0.37		0.32	0.28	0.25	0.22		0.20	0.19	0.17
PUR schuim		0.57	0.49	0.43	0.38		0.35	0.31	0.29	0.25	0.22	0.19		0.17	0.16	

Financiële kost optima

TABEL: Optimale spouwisolatiediktes vanuit financieel oogpunt met aanduidig van de U-waarde van de totale wand (W/m2K).

Advies

Bij het bouwen van een woning is de isolatiewaarde van de buitenwanden een erg belangrijke factor. Want het is erg moeilijk om het isolatieniveau van buitenwanden te verhogen bij een latere renovatie zonder grote extra kosten. Ook de keuze van buitenafwerking is niet onbelangrijk, maar kan gemakkelijker aangepast worden in een latere fase. De binnenafwerking is dus van minder belang.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.

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Duurzame woningbouw: milieu-impact en kost van een halfopen woning - 05/04/2011
Duurzame woningbouw: milieu-impact en kost van een rijwoning - 28/03/2011
Duurzame woningbouw: impact van de technische installatie - 21/03/2011

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Duurzame woningbouw: hellend dak kiezen - 28/02/2011

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Duurzame woningbouw: hellend dak kiezen - 28/02/2011

Milieu-impact betaalbaar verminderen


[Foto: Monier Dakpannen]

In dit vijfde artikel van onze reeks over duurzaam bouwen focust onderzoekster Karen Allacker op de opbouw van het hellend dak. Behalve de levenscycluskost en de milieu-impact, berekende ze ook de investeringskost voor verschillende daktypes.

Karen analyseerde verschillende dakvarianten over hun volledige levensduur, waarbij niet alleen de initiële impact en kost werden bekeken, maar ook deze ten gevolge van schoonmaken, onderhoud, vervangingen, afbraak en eindelevensduurbehandeling. Ook de warmteverliezen doorheen het dak werden in rekening gebracht op basis van de verwarmingskost die hiermee gepaard gaat. Enkel materialen en technieken die nu beschikbaar zijn, werden geanalyseerd (zie **FIGUUR 1**). Dit gebeurde laag per laag (structuur, isolatie, onderdak en dakbedekking), waarbij Karen telkens uitging van een levensduur van 60 jaar.

	8 cm	8 + 6 cm	8 + 10 cm	8 + 14 cm	8 + 16 cm	8 + 18 cm	8 + 20 cm	8 + 22 cm	8 + 26 cm	8 + 30 cm
rotswol (houten latten onder isolatie)	0.39		0.20	0.17		0.15		0.13	0.12	0.11
rotswol (houten latten tussen isolatie)	0.39		0.22	0.18		0.16		0.14	0.13	0.12
geëxpandeerde kurk	0.40	0.26	0.21		0.17		0.15	0.14	0.12	0.11
houtvezel isolatieplaat	0.39	0.19	0.15		0.11		0.09			
cellulose vlokken	0.40		0.21	0.18		0.15		0.14	0.13	0.12
PUR schuim	0.35		0.17	0.14		0.12		0.11	0.09	0.08

Milieukost optima

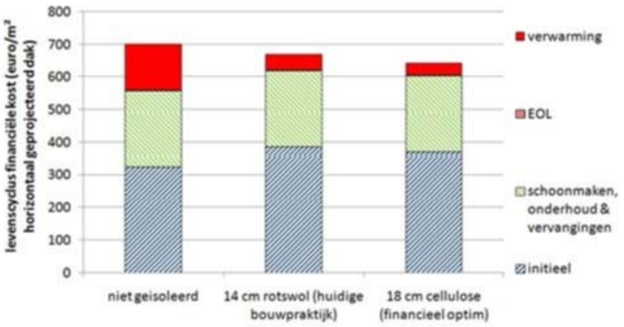
TABEL Optimale isolatiediktes vanuit milieuoogpunt met aanduidig van de U-waarde van de totale dakopbouw (W/m^2K).

FIGUUR 1: Optimale isolatiediktes vanuit milieuoogpunt met aanduidig van de U-waarde van de totale dakopbouw (W/m2K).

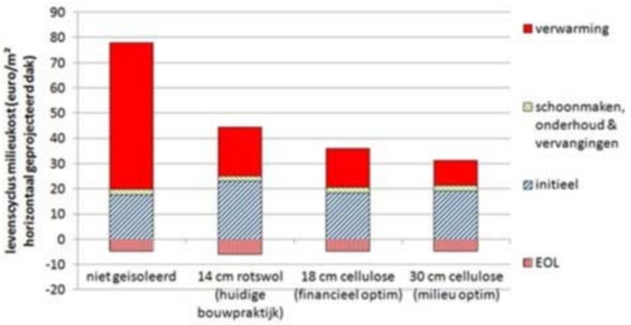
De binnenafwerking is niet gewijzigd aangezien de meeste afwerkingen identiek zijn aan deze voor skeletwanden (zie artikel buitenwanden). De milieu-impact werd ingerekend via de kosten die we als maatschappij dragen ten gevolge van milieu-effecten, zoals gezondheidsproblemen of bijvoorbeeld de uitputting van grondstoffen.

Belangrijkste conclusies

- Voor huidige, courant gebruikte (nieuwbouw) dakopbouwen, is de investeringskost goed voor ca. 60 % van de levenscyclusfinanciëlekost (**FIGUUR 2.1**).
- De verwarmingskost is met ca. 50 % de belangrijkste factor in de levenscyclusmilieukost (**FIGUUR 2.2**).
- In vergelijking met de huidige bouwpraktijk blijkt een levenscycluskostvermindering van ca. 10 % mogelijk en een levenscyclusmilieukostvermindering van ca. 40 % met huidige beschikbare materialen en technieken.
- Het dak beter isoleren blijkt de belangrijkste parameter om zowel de levenscyclusmilieukost als financiële kost efficiënt te verminderen, gevolgd door de keuze van de dakbedekking.
- De eerste centimeters isolatie zorgen bovendien voor een grote vermindering van de milieukost. Een minimale dakisolatie is dus duidelijk onontbeerlijk.
- De optimale isolatiedikte vanuit financiële overwegingen is voor alle materialen gelijk aan 8 cm, waarbij enkel isolatie geplaatst wordt tussen de kepers. Alleen cellulose-isolatie heeft een optimale dikte van 18 cm.
- Vanuit milieuoogpunt is dikkere isolatie nodig (zie **TABEL**). Dit vraagt een extra investeringskost van gemiddeld 10 % ten opzichte van de huidige vereiste diktes, wat de financiële levenscyclus doet stijgen met zo'n 4 %, terwijl de levenscyclusmilieukost hiermee gemiddeld 11 % daalt.
- De milieukost kunnen we verder terugdringen door de keuze van het isolatiemateriaal. Hierbij gaat de voorkeur naar cellulose, gevolgd door rotswol. Ook de manier waarop de isolatie geplaatst wordt, is van belang (bijvoorbeeld houten latten tussen de isolatie of onder de isolatie).
- De te verkiezen dakbedekkingen zijn beton en keramische pannen en dit zowel vanuit financieel als milieuoogpunt. Alle andere beschouwde alternatieven leiden tot een hogere levenscycluskost.
- De levenscyclusmilieukost is opvallend hoog voor leien in zink (te wijten aan een hoge initiële impact) en bitumen shingles (te wijten aan een kortere levensduur en dus meer vervangingskosten). Ook de houten shingles leiden tot een onverwachte hoge milieukost, vanwege het nodige landgebruik voor hout. Nemen we landgebruik niet mee in onze berekening (vrij grote onzekerheid van de milieu-impact), dan hebben de houten shingles een gelijkaardige levenscyclusmilieukost als betonnen dakbedekking en keramische pannen.



FIGUUR 2.1: Bijdrage van de verschillende processen tot de levenscyclusfinanciëlekost.



FIGUUR 2.2: Bijdrage van de verschillende processen tot de levenscyclusmilieukost.

Aanbevelingen

Voor bestaande woningen met ongeïsoleerde daken is het aanbrengen van een minimale dikte aan isolatie een belangrijke maatregel om de milieu-impact te verminderen. Dit is zeker het geval voor daken waar al een onderdak aanwezig is, aangezien de financiële investering dan beperkt is en de maatregel hierdoor ook vanuit financieel oogpunt interessant is.

Voor nieuwbouwwoningen leveren de huidige bouwvoorschriften al een belangrijke bijdrage aan het beperken van de levenscyclusmilieukost. Maar dikkere isolatie en de keuze van het soort isolatiemateriaal kunnen deze nog verder verminderen.

Aangezien een aantal dakbedekkingen (zoals leien in zink en bitumen shingles) resulteren in een hoge levenscyclusmilieukost, kan je deze beter vermijden om de levenscyclusmilieukost te beperken.

Bovenstaande analyse maakt deel uit van het onderzoeksproject SuFiQuaD (Sustainability, Financial and Quality evaluation of Dwelling types), uitgevoerd in opdracht van de federale overheid (BELSPO) door KU Leuven, departement ASRO (Architectuur, Stedenbouw en Ruimtelijke Ordening) in samenwerking met VITO (Vlaams Instituut voor Technologisch Onderzoek) en WTCB (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf). Meer specifiek is de beschreven analyse onderdeel van een doctoraatsonderzoek uitgevoerd binnen het SuFiQuaD project.

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Duurzame woningbouw: plat dak kiezen - 07/03/2011

Milieu-impact betaalbaar verminderen


[Foto: Zelfbouwmarkt]


[Foto: Livios]

In dit zesde artikel van onze reeks over duurzaam bouwen focust onderzoekster Karen Allacker op de opbouw van het plat dak van een woning. Behalve de levenscycluskost en de milieu-impact, berekende ze ook de investeringskost voor verschillende daktypes.

Karen analyseerde verschillende dakvarianten over hun volledige levensduur, waarbij niet alleen de initiële impact en kost werden bekeken, maar ook deze ten gevolge van schoonmaken, onderhoud, vervangingen, afbraak en eindelevensduurbehandeling. Ook de warmteverliezen doorheen het dak werden in rekening gebracht op basis van de verwarmingskost die hiermee gepaard gaat. Enkel materialen en technieken die nu beschikbaar zijn, werden geanalyseerd (zie **FIGUUR 1**). Dit gebeurde laag per laag (structuur, isolatie, dakafdichting en dakrand), waarbij Karen telkens uitging van een levensduur van 60 jaar.

De binnenafwerking is niet gewijzigd aangezien de meeste afwerkingen identiek zijn aan deze voor wanden (zie artikel buitenwanden). De milieu-impact werd ingerekend via de kosten die we als maatschappij dragen ten gevolge van milieu-effecten, zoals gezondheidsproblemen of bijvoorbeeld de uitputting van grondstoffen.

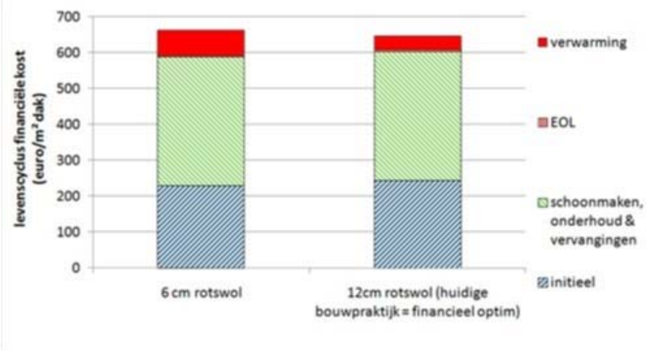
Belangrijkste conclusies

- Voor huidige courant gebruikte (nieuwbouw) dakopbouwen bedraagt de investeringskost ca. 40 % en de onderhoudskost ca. 55 % van de levenscyclusfinanciëlekost.
- De initiële en verwarmingskost vertegenwoordigen elk ca. 45 % van de levenscyclusmilieukost (**FIGUUR 2**).
- In vergelijking met de huidige bouwpraktijk blijkt een levenscycluskostvermindering van ca. 10 % mogelijk en een levenscyclusmilieukostvermindering van ca. 50 % met de beschikbare materialen en technieken.
- Vanuit financieel oogpunt is de keuze van dakstructuur de belangrijkste factor, terwijl vanuit milieuoogpunt isolatie de belangrijkste parameter is, gevolgd door het type dakstructuur.
- Van de geanalyseerde massieve structuren blijkt de cellenbetonplaat de beste keuze, zowel vanuit financieel als milieuoogpunt.
- Financieel gezien zijn voorgespannen vloerelementen (welfsels) en keramische potten en balken te verkiezen, na de cellenbetonplaat. Vanuit milieuoogpunt gaat de voorkeur naar betonpotten en balken (na de cellenbetonplaat). Uit de geanalyseerde balkenstructuren blijken de FJI-balken te verkiezen op basis van milieubeschouwingen en de houten balken vanuit financieel oogpunt.
- Naargelang het type isolatie is een andere optimale dikte bepaald vanuit financieel oogpunt (zie **TABEL**). Deze diktes komen overeen met de huidige bouwvoorschriften (epb-regelgeving). Vanuit milieuoogpunt is dikkere isolatie vereist, waarbij voor alle materialen de grootst beschouwde dikte de beste is.
- Bovendien blijkt dat de dikte van de isolatie belangrijker is dan de keuze van het isolatiemateriaal. Voor isolatie op structuren geniet resol de voorkeur, voor isolatie tussen balken gaat de voorkeur naar cellulose.
- De grotere optimale diktes vanuit milieuoogpunt, ten opzichte van huidig geplaatste diktes, vragen een extra investeringskost van gemiddeld 16 %. Ze doen de financiële levenscycluskost toenemen met gemiddeld 4 %, maar zorgen voor een vermindering van de levenscyclusmilieukost van gemiddeld 10 %.
- Voor platte daken opgebouwd uit een balkenstructuur, wordt de isolatie bij voorkeur geplaatst op de structuur om vochtproblemen te vermijden. Bij grote isolatiediktes krijg je zo een extreem dikke dakopbouw. Daarom wordt bij lage energiewoningen en passiefhuizen vaak isolatie tussen de balken geplaatst, in combinatie met isolatie op de structuur. Om het risico op vochtproblemen bij een dergelijke opbouw te vermijden, is het belangrijk dat het dampscherm zorgvuldig geplaatst wordt en dat de onderdakplaat droog is (RV<80 %).
- Uit de analyse van beide opties blijkt dat bij gebruik van dezelfde isolatiematerialen, de milieukost voor de meer risicovolle plaatsing tussen de balken verwaarloosbaar kleiner is.
- FJI-balken, gecombineerd met isolatiematerialen bedoeld om ingeblazen/ingespoten te worden tussen de balken (bv. cellulose), leveren een aanzienlijke vermindering van de milieukost op. Isolatie tussen een balkenstructuur moet je wel altijd combineren met een isolatielaag op de structuur om inwendige condensatie te vermijden.

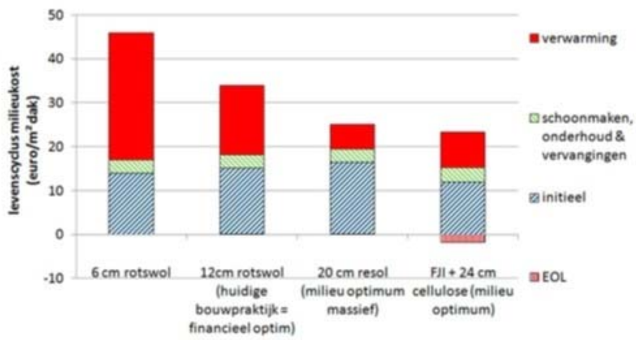
	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm	17 cm	18 cm	20 cm	24 cm
rotswol	0.55		0.36	0.30		0.23			0.19	0.16
EPS		0.40	0.32	0.27		0.21			0.17	
PUR	0.41		0.25	0.21			0.15		0.13	0.11
houtvezel isolatieplaat	0.63			0.35				0.24		0.18
resol	0.32		0.21		0.15				0.11	

Financiële kost optima

TABEL: Optimale isolatiediktes (voor isolatie op dakstructuur) vanuit financieel oogpunt met aanduidig van de U-waarde van de totale dakopbouw (W/m2K)



FIGUUR 2.1: Bijdrage van de verschillende processen tot de levenscyclus financiële kost.



FIGUUR 2.2: Bijdrage van de verschillende processen tot de milieukost.

Aanbevelingen

Voor nieuwbouwwoningen blijken de huidige bouwvoorschriften te voldoen om het economisch optimum te bereiken. Maar vanuit milieuoogpunt zijn grotere isolatiediktes aan te raden.

Voor de massieve dakstructuren geniet vanuit financieel oogpunt een cellenbetonplaat de voorkeur, gevolgd door voorgespannen welfsels en keramische potten en balken. Vanuit milieuoogpunt is dit opnieuw de cellenbetonplaat, gevolgd door betonpotten en balken. FJI-balken, gecombineerd met cellulose resulteren in de laagste milieukost.

Bovenstaande analyse maakt deel uit van het onderzoeksproject SuFiQuaD (Sustainability, Financial and Quality evaluation of Dwelling types), uitgevoerd in opdracht van de federale overheid (BELSPO) door KU Leuven, departement ASRO (Architectuur, Stedenbouw en Ruimtelijke Ordening) in samenwerking met VITO (Vlaams Instituut voor Technologisch Onderzoek) en WTCB (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf). Meer specifiek is de beschreven analyse onderdeel van een doctoraatsonderzoek uitgevoerd binnen het SuFiQuaD project.

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Duurzame woningbouw: impact van de technische installatie - 21/03/2011
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Duurzame woningbouw: impact van de technische installatie - 21/03/2011

In dit zevende artikel van onze reeks over duurzaam bouwen analyseert onderzoekster Karen Allacker technische installaties voor verwarming, productie van sanitair warm water en ventilatie. Daarnaast bepaalde ze ook de investeringskost om na te gaan wat de onmiddellijke uitgaven zijn als je bouwt.

[Foto: Zehnder Group Belgium Acova-Zehnder]

Karen analyseerde verschillende types installaties over hun volledige levensduur, voor zowel een niet-geïsoleerde (K100) en goed geïsoleerde (K20) woning. Zowel de initiële impact en kost werden bekeken, maar ook deze ten gevolge van het energieverbruik, onderhoud, vervangingen, afbraak en eindelevensduurbehandeling. Enkel de nu beschikbare technieken zijn geanalyseerd, waarbij de analyse is gebeurd voor de verschillende onderdelen van de installatie (zie **TABEL 1 en 2**).

TABEL 1: Geanalyseerde alternatieven voor de ruimteverwarming (CV), per component.

PRODUCTIE	DISTRIBUTIE	EMISSIE	CONTROLE
niet-condenserende olieketel	tweepijps octopus systeem in PE buizen	kolomradiatoren	manuele radiatorkranen
condenserende olieketel		- gietijzer	thermostatische radiatorkranen
atmosperische gasketel		- staalplaat	klok (aan/uit)
condenserende gasketel		paneelradiatoren	kamerthermostaat
warmtepomp:		- staalplaat	buitenvoeler
- grond/water (vertikaal)		wandconvectoren	
- grond/water (horizontaal)		- aluminium	
- lucht/water		vloerconvectoren	
- lucht/lucht		- polyester	
zonneboiler		- staal	
niet-condenserende pelletketel		vloerverwarming	
condenserende pelletketel			

* De in grijs aangegeven productiealternatieven zijn enkel geanalyseerd voor de goed geïsoleerde woning.

TABEL 2: Geanalyseerde boilers voor sanitair warm water

PRODUCTIE
onafhankelijk van CV: doorstroomboiler (14 l/min voor ?T = 25K)
onafhankelijk van CV: elektrische verwarmd voorraadvat (120 liter)
gekoppeld aan CV: doorstroomboiler
gekoppeld aan CV: voorraadvat (120 liter voor olie- en gasketels, 300 liter voor warmtepompen)
zonneboiler

Er werden ook vier ventilatiesystemen bestudeerd: A, C, C+ en D+ (**TABEL 3**). De levensduur van de woning is verondersteld op 60 jaar en er is aangenomen dat de installatie vervangen wordt na 30 jaar. De milieu-impact werd ingerekend via de kosten die we als maatschappij dragen ten gevolge van milieu-effecten, zoals gezondheidsproblemen of bijvoorbeeld de uitputting van grondstoffen.

TABEL 3: Geanalyseerde ventilatiesystemen

type	opbouw
Systeem A	Natuurlijke toevoer en afvoer
Systeem C	Natuurlijke toevoer en mechanische afvoer
Systeem C+	Natuurlijke toevoer en gecontrolleerde mechanische afvoer (CO2 en RV)
Systeem D+	Mechanische toevoer en afvoer met warmteterugwinning

Belangrijkste conclusies

Voor de **niet-geïsoleerde woning** zijn de belangrijkste besluiten:

- Op basis van de levenscyclusfinanciëlekost gaat voor centrale verwarming de voorkeur naar een laagtemperatuursysteem bestaande uit een modulerende condenserende gasboiler, gecombineerd met paneelradiatoren en sturing via een buitenvoeler in combinatie met thermostatische kranen en een klok (in de woonkamer). Voor de productie van sanitair warm water krijgt een doorstroomboiler gekoppeld aan de cv-installatie de voorkeur.
- Op basis van levenscyclusmilieukost voor centrale verwarming is een gelijkaardige opbouw het interessantst, maar met een lichte voorkeur voor vloerverwarming in plaats van paneelradiatoren. Het verschil tussen radiatoren en vloerverwarmig is echter klein. Voor de productie van sanitair warm water zorgen twee afzonderlijke doorstroomboilers voor badkamer en keuken (niet gekoppeld aan cv-installatie) voor de laagste levenscyclusmilieukost.
- Zonneboilers voor de productie van sanitair warm water blijken niet interessant vanuit financieel oogpunt, wel vanuit milieuoogpunt. Aangezien doorstroomboilers vanuit milieuoogpunt te verkiezen zijn boven een voorraadvat, kwamen deze niet als voorkeursoplossing uit het onderzoek.
- Het variëren van de warmteafgiftelichamen (radiatoren, convectoren of vloerverwarming) leidt tot weinig verschil, noch in de financiële noch in de milieukosten.

Voor de **goed geïsoleerde woning** zijn de belangrijkste besluiten:

- Voor de goed geïsoleerde woning is een cv-ketel van slechts 8-10kW nodig (als deze niet gebruikt wordt voor de productie van sanitair warm water). Alleen blijken deze kleine vermogens voor veel ketels niet beschikbaar te zijn op de huidige markt.
- Vanuit financieel oogpunt gelden dezelfde conclusies als voor de niet-geïsoleerde woning, behalve dat een extra afzonderlijke geiser in de keuken aan te bevelen is.

- In tegenstelling tot de resultaten op basis van financiële kost, blijken de warmtepompen en pelletketels wel te concurreren met de condenserende gasketel wat betreft de levenscyclusmilieukost. Voor een zo laag mogelijke levenscyclusmilieukost gaat de voorkeur naar een lucht/water-warmtepomp of een grond/water-warmtepomp met horizontale captatie, gekoppeld aan een voorraadvat voor de productie van sanitair warm water.
- Kijkend naar milieu- én financiële overwegingen gaat de voorkeur naar een condenserende gasketel voor centrale verwarming en twee aparte doorstroomboilers voor keuken en badkamer.

[Foto: Kingspan Insulation B.V.]

Uit de analyse van de **verschillende ventilatiesystemen** blijkt:

- De levenscyclusfinanciëlekost van systeem A, C en C+ is telkens nagenoeg hetzelfde, terwijl systeem D+ een 8 % hogere levenscycluskost heeft dan systeem C. De extra investering en onderhoudskosten van ventilatiesysteem D+ worden dus niet gecompenseerd door het verminderd energieverbruik.
- De levenscyclusmilieukost van de systemen A en C zijn gelijkaardig, terwijl systeem C+ en D+ respectievelijk leiden tot een 15 % en 24 % lagere levenscycluskost t.o.v. systeem C.

Invloed keuze installatie op de **levenscycluskost** van het gebouw:

- Voor de niet-geïsoleerde woning kan een andere keuze in installatie leiden tot een reductie van ca. 40 % van de levenscyclusmilieukost, terwijl dit voor de goed geïsoleerde woning ca. 45 % is. Financieel gezien is dit respectievelijk 10 % en 8 %.

Aanbevelingen

De technische installatie heeft een belangrijke invloed op de levenscyclusmilieukost van een woning. Maar een goede keuze van de installatie hangt af van de isolatiegraad en is dus voor elke woning anders. Vooral de keuze van de verwarmingsketel in combinatie met een juist sturingsmechanisme is van doorslaggevend belang. De gebruikte warmteafgiftelichamen (radiatoren, convectoren, vloerverwarming) zijn van minder van belang. De vier ventilatiesystemen (A, C, C+ en D+) leiden tot nagenoeg dezelfde totale levenscycluskost. Maar vanuit milieuoogpunt krijgen de systemen C+ en D+ de voorkeur.

Bovenstaande analyse maakt deel uit van het onderzoeksproject SuFiQuaD (Sustainability, Financial and Quality evaluation of Dwelling types), uitgevoerd in opdracht van de federale overheid (BELSPO) door KU Leuven, departement ASRO (Architectuur, Stedenbouw en Ruimtelijke Ordening) in samenwerking met VITO (Vlaams Instituut voor Technologisch Onderzoek) en WTCB (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf). Meer specifiek is de beschreven analyse onderdeel van een doctoraatsonderzoek uitgevoerd binnen het SuFiQuaD project.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.

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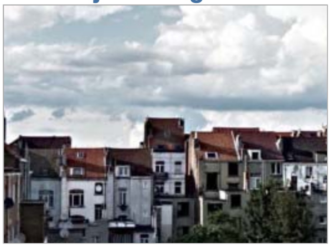
Kopen en huren
Klussen

Duurzame woningbouw: milieu-impact en kost van een rijwoning - 28/03/2011

Vandaag focust Karen Allacker in onze reeks rond duurzaam bouwen op de milieu-impact en financiële kost van rijwoningen. Behalve de meer voor de hand liggende factoren zoals het isolatieniveau en de grootte, heeft ook de locatie een grote invloed op de duurzaamheid.



Karen analyseerde vier rijwoningen, die allemaal verschilde qua grootte, ontwerp en ouderdom. Ondanks die verschillende ouderdom werd voor het onderzoek verondersteld dat elke woning een nieuwbouw was. Per woning werden er liefst 3.000 tot 30.000 varianten geanalyseerd om na te gaan welke de meest duurzame rijwoning is. De verschillen uiten zich in isolatiegraad, materiaalkeuze en technische installaties.

Kenmerken onderzochte woningen

	Rijwoning 1	Rijwoning 2	Rijwoning 3	Rijwoning 4
Vloeroppervlakte (m²)	99	426	344	200
Volume (m³)	288	1.756	910	549
Aantal bewoners	3	6	6	4
Compactheid (m)	2	3,43	2,56	1,96

Belangrijkste conclusies:

[Foto: Woningbouw Huyzentruyt]

[Foto: SuperHuis]

- De milieu-impact van een standaardwoning kan je aanzienlijk verminderen (30 % tot 45 %) en dit tegen een betaalbare meerinvestering (6 % tot 10 %).
- Voor de vier woningen, gebouwd volgens de huidige bouwpraktijk, wordt het grootste aandeel van de milieubelasting veroorzaakt door het energieverbruik voor verwarming tijdens de gebruiksfase.
- In functie van het beschikbaar budget, zijn er ingrepen die de voorrang krijgen om een rijwoning duurzamer te maken. Deze verschillen voor de vier woningen. Bovendien varieert de efficiëntie van eenzelfde ingreep per woning. Vanuit milieuoogpunt zijn volgende prioritaire stappen vastgesteld:
  - **Rijwoning 1 (hellend dak):** energiezuiniger ventilatiesysteem (C+ i.p.v. C), dakisolatie (8 cm rotswol), thermisch verbeterde beglazing (U = 1.1 W/m²K), vloerisolatie (10 cm PUR of indien budget dit toelaat 21 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), verhoogde buitenmuurisolatie (14 => 20 cm EPS) + dakisolatie (30 cm rotswol), zonneboiler.
  - **Rijwoning 2 (hellend dak):** analoog aan rijwoning 1, maar een verhoogde buitenmuurisolatie (14 => 20 cm EPS) geniet de voorkeur boven de verhoogde vloerisolatie (21 cm PUR).
  - **Rijwoning 3 (plat dak):** vloerisolatie (3 cm PUR), energiezuiniger ventilatiesysteem (C+ i.p.v. C), driedubbele beglazing i.p.v. thermisch verbeterd glas (U = 0.6 W/m²K), verhoogde vloerisolatie (10 cm PUR), verhoogde buitenmuurisolatie (14 => 20 cm EPS), extra dakisolatie (14 => 20 cm resol), extra vloerisolatie (21 cm PUR), zonneboiler.
  - **Rijwoning 4 (hellend dak + plat dak):** thermisch verbeterd glas (U = 1.1 W/m²K), vloerisolatie (3 cm PUR), energiezuiniger ventilatiesysteem (C+ i.p.v. C), hellend dakisolatie (8 cm RW), verhoogde vloerisolatie (10 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), extra hellend dakisolatie (30 cm RW), extra wandisolatie (14 => 20 cm EPS), extra vloerisolatie (21 cm PUR), zonneboiler.
- Vanuit puur financieel oogpunt zijn driedubbele beglazing en een zonneboiler uitgesloten.
- Omdat de vervoerskosten van de bewoners naar het werk, de school, ... (volgens het patroon van een gemiddelde Belg) een grotere milieukost veroorzaakt dan de verwarming van de woning, is de ligging van de woning uiterst bepalend voor de duurzaamheid.
- De kosten (financieel + milieu) van water en elektriciteit van een doorsnee Belg zijn vergeleken met de andere levenscycluskosten. Hieruit blijkt dat voor standaardwoningen water- en elektriciteitsverbruik milieugezien minder belangrijk zijn dan verwarming. Maar bij de geoptimaliseerde woningen zijn dit nagenoeg de belangrijkste milieukosten. Financieel gezien blijven water en elektriciteit de minst belangrijke factoren.
- Uit een vergelijking van de vier woningen blijkt bovendien dat de grootte van de woning een bepalende factor is voor de milieu-impact en financiële kost. Het aantal m² per bewoner is dus een belangrijk aspect bij het streven naar een duurzame woning.

Drie aanbevelingen

1. Als je een duurzame nieuwe rijwoning wil bouwen, is de locatie van de woning een eerste vereiste. Ligt ze dicht bij het werk, school, winkels of ontspanningsmogelijkheden? Zo niet, is ze dan goed bereikbaar met het openbaar vervoer?

2. In tweede instantie zijn de grootte en de compactheid van de woning erg belangrijk. Een goed geïsoleerde maar erg grote woning kan een hogere milieukost hebben dan een slechter geïsoleerde, kleinere woning.

3. Ten slotte moet je het beschikbare budget om de woning te verbeteren zo efficiënt mogelijk besteden. Hierbij zijn de isolatiegraad, de luchtdichtheid, het ventilatiesysteem en het verwarmingssysteem belangrijk. Ook de materiaalkeuze heeft een grote invloed op de milieu-impact van een woning.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.

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Kopen en huren
Klussen

Duurzame woningbouw: milieu-impact en kost van een halfopen woning - 05/04/2

Vandaag focust onderzoekster Karen Allacker in onze reeks rond duurzaam bouwen op de milieu-impact en financiële kost van halfopen woningen. Daarbij bl isolatie, compactheid en ook de locatie belangrijke factoren.

Karen analyseerde vier halfopen woningen, die allemaal verschillen qua grootte, ontwerp en ouderdom. Ondanks die verschillende ouderdom werd voor het onderzoek verondersteld dat elke woning een nieuwbouw was. Per woning werden er liefst 3.000 tot 30.000 varianten geanalyseerd om na te gaan welke de meest duurzame halfopen woning is. De verschillen uiten zich in isolatiegraad, materiaalkeuze en technische installaties.

Belangrijkste conclusies:


[Foto: Woningbouw Huyzent

- De milieu-impact van een standaard halfopen woning kan je aanzienlijk verbeteren (30 tot 45 %) tegen een betaalbare meerinvestering (4 tot 7 %). Enkel voor de eerste woning resulteerde dit in een meerinvestering van 37 %.
- Voor de vier woningen, gebouwd volgens de huidige bouwpraktijk, wordt het grootste aandeel van de milieubelasting veroorzaakt door het energieverbruik voor verwarming tijdens de gebruiksfase.
- Voor de laatste drie geoptimaliseerde woningen blijkt de verwarming nog altijd het zwaarst door te wegen op de milieu-impact van de woning. Voor de geoptimaliseerde eerste woning draagt de intiële fase (vanaf de ontginning van de grondstoffen tot en met het bouwen van de woning) het meest bij tot de milieu-impact van de woning.
- In functie van het beschikbaar budget, zijn er ingrepen die voorrang krijgen om een halfopen woning duurzamer te maken. Deze verschillen voor de vier woningen. Bovendien varieert de efficiëntie van eenzelfde ingreep per woning. Vanuit milieuoogpunt zijn volgende prioritaire stappen vastgesteld:
  - **Halfopen woning 1 (hellend dak)**: buitenmuurisolatie (14 cm EPS), energiezuiniger ventilatiesysteem (C+ i.p.v. C) + dakisolatie (8 cm rotswol), thermisch verbeterde beglazing (U = 1.1 W/m²K) + vloerisolatie (10 cm pur), driedubbele beglazing (U = 0.6 W/m²K), verhoogde buitenmuurisolatie (20 cm eps), meer dakisolatie (30 cm rotswol), extra vloer isolatie (21 cm pur)
  - **Halfopen woning 2 (hellend dak + plat dak)**: buitenmuurisolatie (14 cm eps), energiezuiniger ventilatiesysteem (C+ i.p.v. C) + hellend dakisolatie (8 cm rotswol), thermisch verbeterde beglazing (U = 1.1 W/m²K) + vloerisolatie (3 cm pur) + plat dakisolatie (cellenbetonplaat + 14 cm resol), extra vloerisolatie (10 cm pur), driedubbele beglazing (U = 0.6 W/m²K), verhoogde buitenmuurisolatie (20 cm eps), extra dakisolatie (30 cm rotswol), extra vloerisolatie (21 cm pur)
  - **Halfopen woning 3 (hellend dak + plat dak)**: buitenmuurisolatie (14 cm eps), energiezuiniger ventilatiesysteem (C+ i.p.v. C) + vloerisolatie (3 cm pur) + plat daksolatie (cellenbetonplaat + 14 cm resol), thermisch verbeterde beglazing (U = 1.1 W/m²K) + hellend dakisolatie (8 cm rotswol), verhoogde vloerisolatie (10 cm pur), driedubbele beglazing (U = 0.6 W/m²K), verhoogd hellend dakisolatie (30 cm rotswol), verhoogde buitenmuurisolatie (20 cm eps), verhoogde vloerisolatie (21 cm pur)
  - **Halfopen woning 4 (hellend dak + plat dak)**: buitenmuurisolatie (14 cm eps), energiezuiniger ventilatiesysteem (C+ i.p.v. C) + thermisch verbeterd glas (U = 1.1 W/m²K) + vloerisolatie (3 cm pur) + plat dakisolatie (cellenbetonplaat + 14 cm resol), verhoogde vloerisolatie (10 cm pur), driedubbele beglazing (U = 0.6 W/m²K), verhoogde buitenmuurisolatie (20 cm eps) + verhoogd hellend dakisolatie (30 cm RW), verhoogde vloerisolatie (21 cm pur), verhoogde plat dakisolatie (20 cm resol)
- Louter financieel bekeken, liggen de prioriteiten anders. Driedubbele beglazing is bijvoorbeeld niet meer aan de orde.
- Omdat de vervoerskosten van de bewoners naar het werk, de school, ... (volgens het patroon van een gemiddelde Belg) een grotere milieukost veroorzaakt dan de verwarming van de woning, is de ligging van de woning uiterst bepalend voor de duurzaamheid.
- De kosten (financieel + milieu) van water en elektriciteit van een doorsnee Belg zijn vergeleken met de andere levenscycluskosten. Hieruit blijkt dat voor standaardwoningen water- en elektriciteitsverbruik milieugezien minder belangrijk zijn dan verwarming. Echter, voor de geoptimaliseerde varianten bleek het belang te verschillen per woning. Zo bijvoorbeeld was verwarming het belangrijkst bij woning 3 en 4 en elektriciteit bij woning 1; en voor woning 2 bleken verwarming en elektriciteit een even grote bijdrage te leveren tot de levenscyclus milieu-impact. Financieel gezien blijven water en elektriciteit de minst belangrijke factoren.
- Uit een vergelijking van de vier woningen blijkt bovendien dat de grootte een bepalende factor is voor de milieu-impact en financiële kost. Het aantal m² per bewoner is dus een belangrijk aspect bij het streven naar een duurzame woning.


[Foto: Super


[Foto: Passiefhuis - Platform


[Foto: AVL Woningb

Tabel 1: Samenvattende tabel woningkenmerken

	Halfopen woning 1	Halfopen woning 2	Halfopen woning 3	Halfopen woning 4
Vloeroppervlakte (m²)	81	150	162	144
Volume (m³)	235	445	470	525
Aantal bewoners	3	3	5	5
Compactheid (m)	1.38	1.70	1.4	1.60

Aanbevelingen


[Foto: Nuyts Woningb

1. Als je een duurzame halfopen woning wil bouwen of kopen, is een eerste vereiste goed te letten op de locatie van de woning. Ligt ze dicht bij het werk, school, winkels of ontspanningsmogelijkheden? Zo niet, is ze dan goed bereikbaar met het openbaar vervoer?
2. In tweede instantie zijn de grootte en de compactheid van de woning erg belangrijk. Een goed geïsoleerde, maar erg grote woning kan een hogere milieukost hebben dan een slechter geïsoleerde, kleinere woning.
3. Ten slotte moet je het budget zo efficiënt mogelijk besteden. Hierbij zijn de isolatiegraad, luchtdichtheid en technische installaties belangrijk.
4. Voor erg energiezuinige woningen qua verwarming, zijn het zuinig omspringen met elektriciteit en het kiezen voor hernieuwbare energie de volgende aandachtspunten, gevolgd door het kiezen voor milieuvriendelijke materialen en het zuinig omspringen met drinkbaar water.

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Duurzame woningbouw: impact van de technische installatie - 21/03/2011
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Duurzame woningbouw: milieu-impact en kost van een vrijstaande woning - 11/

Vandaag focust Karen Allacker in onze reeks rond duurzaam bouwen op de milieu-impact en financiële kost van vrijstaande woningen. Daarbij blijken isolatie, compactheid, maar ook de locatie belangrijke factoren.


[Fo

Karen analyseerde vier types vrijstaande woningen, verschillend qua grootte, ontwerp en ouderdom **(tabel 1)**. Ondanks die verschillende ouderdom werd voor het onderzoek verondersteld dat elke woning een nieuwbouw was. Per woning werden er liefst 3.000 tot 30.000 varianten geanalyseerd om na te gaan welke de meest duurzame vrijstaande woning is. Er gebeurde een analyse op basis van de standaardwoningen, maar anderzijds ook voor mogelijk betere alternatieven (opgebouwd met duurzamere elementen). De verschillen uiten zich in isolatiegraad, materiaalkeuze en technische installaties.

Kenmerken onderzochte woningen

	Vrijstaande woning 1	Vrijstaande woning 2	Vrijstaande woning 3	Vrijstaande woning 4
Vloeroppervlakte (m²)	127	98	149	123
Volume (m³)	502	293	371	382
Aantal bewoners	3	4	5	4
Compactheid (m)	1,23	1,1	0,87	1,18

Belangrijkste conclusies:


[Foto: Monier D

- De levenscyclusmilieukost van een standaard vrijstaande woning kan je aanzienlijk verbeteren (30 tot 55 %).
- Bij de vier standaard vrijstaande woningen wordt het grootste aandeel van de milieubelasting veroorzaakt door het energieverbruik voor verwarming tijdens de gebruiksfase.
- In functie van het beschikbaar budget, zijn er ingrepen die de voorrang krijgen om een vrijstaande woning duurzamer te maken. Deze verschillen voor de vier woningen. Bovendien varieert de efficiëntie van eenzelfde ingreep per woning. Vanuit milieuoogpunt zijn volgende prioritaire stappen vastgesteld:
  - **Vrijstaande woning 1 (hellend dak + plat dak):** hellenddakisolatie (8 cm rotswol) + thermisch verbeterde beglazing (U = 1.1 W/m²K) + vloerisolatie (10 cm PUR) + platdakisolatie (cellenbetonplaat met 14 cm resol) + buitenmuurisolatie (14 cm EPS), extra vloerisolatie (21 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), verhoogde buitenmuurisolatie (20 cm EPS) + meer hellend dakisolatie (30 cm rotswol), zonneboiler.
  - **Vrijstaande woning 2 (hellend dak):** buitenmuurisolatie (14 cm EPS), dakisolatie (8 cm rotswol), thermisch verbeterde beglazing (U = 1.1 W/m²K) + vloerisolatie (10 cm PUR of 21 cm PUR indien het budget dit toelaat), driedubbele beglazing (U = 0.6 W/m²K) + extra dakisolatie (30 cm rotswol), meer buitenmuurisolatie (20 cm EPS), zonneb
  - **Vrijstaande woning 3 (plat dak):** thermisch verbeterde beglazing (U = 1.1 W/m²K) + plat dakisolatie (cellenbetonplaat en 14 cm resol) + buitenmuurisolatie (14 cm EPS), vloerisolatie (10 cm PUR), verhoogde vloerisolatie (21 cm PUR), verhoogde buitenmuurisolatie (20 cm EPS), driedubbele beglazing (U = 0.6 W/m²K), zonneboiler, meer dakisolatie (20 cm resol).
  - **Vrijstaande woning 4 (hellend dak):** buitenmuurisolatie (14 cm EPS), hellenddakisolatie (8 cm rotswol), thermisch verbeterd glas (U = 1.1 + vloerisolatie (10 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), meer hellenddakisolatie (30 cm rotswol), meer buitenmuurisolatie (20 cn zonneboiler, verhoogde vloerisolatie (21 cm PUR).
- Louter financieel bekeken liggen de prioriteiten anders. Driedubbele beglazing en een zonneboiler zijn dan zelfs niet meer aan de orde.
- Omdat voor een gemiddelde Belg het vervoer naar het werk, de school, … een grotere milieukost veroorzaakt dan de verwarming van de woning, is de uiterst bepalend voor de duurzaamheid.
- De kosten (financieel + milieu) van het water en elektriciteitsverbruik van een doorsnee Belg werden vergeleken met de andere levenscycluskosten. V standaard vrijstaande woningen, blijkt verwarming een grotere impact te hebben dan elektriciteits- en waterverbruik. Voor de geoptimaliseerde wonin verschilt het belang per woning. Financieel bekeken blijven water en elektriciteit de minst belangrijke factoren.
- Uit een vergelijking van de vier woningen blijkt bovendien dat de grootte van de woning een bepalende factor is voor de milieu-impact en financiële k aantal m² per bewoner is dus een belangrijk aspect bij het streven naar een duurzame woning.

Drie aanbevelingen

1. Als je een duurzame nieuwe vrijstaande woning wil bouwen of kopen, is een eerste vereiste goed te kijken naar de locatie van de woning. Ligt ze dich werk, school, winkels of ontspanningsmogelijkheden? Zo niet, is ze dan goed bereikbaar met het openbaar vervoer?
2. In tweede instantie zijn de grootte en de compactheid van de woning erg belangrijk. Een goed geïsoleerde, maar erg grote woning kan een hogere mi hebben dan een slechter geïsoleerde, kleinere woning.
3. Ten slotte moet het budget zo efficiënt mogelijk besteed worden. Hierbij zijn de isolatiegraad, de luchtdichtheid en de technische installaties bepalend milieubelasting van de woning, samen met de materiaalkeuze.
4. Bij energiezuinige woningen (qua verwarming), gebouwd met milieuvriendelijke bouwmaterialen, zijn het zuinig omspringen met elektriciteit en het ki hernieuwbare energie de volgende aandachtspunten, gevolgd door het zuinig omspringen met drinkbaar water.

Het volledige onderzoek van Karen Allacker kan je downloaden via deze link, of bestellen via karen.allacker@asro.kuleuven.be.

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Duurzame woningbouw: milieu-impact en kost van een appartement - 19/04/2011

Vandaag focust Karen Allacker in onze reeks rond duurzaam bouwen op de milieu-impact en financiële kost van appartementen. Daarbij blijken isolatie, compactheid, maar ook de locatie belangrijke factoren.

Karen analyseerde vier appartemententypes, verschillend qua grootte, ontwerp en ouderdom (**tabel 1**). Ondanks die verschillende ouderdom werd voor het onderzoek verondersteld dat elk appartement een nieuwbouw was. Per appartement werden er maar liefst 3.000 tot 30.000 varianten geanalyseerd om na te gaan wat het meest duurzame appartement is. Er gebeurde een analyse op basis van de standaardappartementen, maar anderzijds ook voor mogelijk betere alternatieven (opgebouwd met duurzamere elementen). De verschillen uiten zich in isolatiegraad, materiaalkeuze en technische installaties.

Belangrijkste conclusies:

[Foto: SuperHuis]

[Foto: Durabrik]

- De levenscyclusmilieukost van een standaard appartement kan je aanzienlijk verminderen (30 tot 40 %) tegen een betaalbare meerinvestering (0 tot 9 %)
- Bij de eerste drie appartementen wordt het grootste aandeel van de milieubelasting veroorzaakt door het energieverbruik voor verwarming tijdens de gebruiksfase en dit zowel voor de standaard uitvoering als voor de geoptimaliseerde variant. Voor het laatste appartement wordt het grootste aandeel van de milieubelasting veroorzaakt voor de constructie van het gebouw (ontginning van de grondstoffen tot en met het bouwen van het appartement) en dit opnieuw voor zowel de standaard uitvoering als voor de geoptimaliseerde variant.
- In functie van het beschikbaar budget, zijn er ingrepen die voorrang krijgen om een appartement duurzamer te maken. Deze verschillen voor de vier appartementen. Bovendien varieert de efficiëntie van eenzelfde ingreep per appartement. Vanuit milieuoogpunt zijn volgende prioritaire stappen vastgesteld:
  - **Appartement 1**: dakisolatie (cellenbetonplaat + 14 cm resol) + thermisch verbeterde beglazing (U = 1.1 W/m²K) + buitenmuurisolatie (14 cm EPS), vloer isolatie (3 cm PUR, of indien het budget dit toelaat 10 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), verhoogde vloerisolatie (21 cm PUR)
  - **Appartement 2**: dakisolatie (cellenbetonplaat + 14 cm resol), thermisch verbeterde beglazing (U = 1.1 W/m²K), buitenmuurisolatie (14 cm EPS), vloerisolatie (3 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), verhoogde vloerisolatie (10 cm PUR)
  - **Appartement 3**: dakisolatie (cellenbetonplaat + 14 cm resol) + buitenmuurisolatie (14 cm EPS), thermisch verbeterde beglazing (U = 1.1 W/m²K), vloerisolatie (3 cm PUR), driedubbele beglazing (U = 0.6 W/m²K), verhoogde buitenmuurisolatie (20 cm EPS)
  - **Appartement 4**: analoog aan appartement 3, maar zonder de laatste stap.
- De prioriteiten verschillen bovendien vanuit financieel oogpunt, waarbij driedubbele beglazing zelfs niet als prioriteit voorkomt.
- Omdat het transport van de bewoners een grotere milieukost veroorzaakt dan de verwarming van het appartement, is de ligging van het appartementsgebouw een uiterst belangrijke parameter voor de duurzaamheid.
- Voor de standaardappartementen blijkt verwarming een grotere impact te hebben dan elektriciteits- en waterverbruik. Bij de verbeterde appartementen levert het elektriciteitsverbruik de grootste impact op het milieu.
- Uit een vergelijking van de vier appartementen blijkt bovendien dat de grootte is een bepalende factor is voor de milieu-impact en financiële kost. Het aantal m² per bewoner is dus een belangrijk aspect bij het streven naar een duurzaam appartement.

Tabel 1: Samenvattende tabel kenmerken appartementen

	Appartement 1	Appartement 2	Appartement 3	Appartement 4
Vloeroppervlakte (m²)	92	99	84	143
Volume (m³)	304	321	308	298
Aantal bewoners	3	4	3	3
Compactheid (m)	2.66	2.49	3.51	1.58

Aanbevelingen:

[Foto: Livios]

1. Als je een duurzaam nieuw appartement wil bouwen of kopen, is een eerste vereiste goed te letten op de locatie. Ligt het dicht bij het werk, school, winkels of ontspanningsmogelijkheden? Zo niet, is het dan goed bereikbaar met het openbaar vervoer?
2. In tweede instantie zijn de grootte en de compactheid van het appartement erg belangrijk. Een goed geïsoleerd, maar erg groot appartement kan een hogere milieukost hebben dan een slechter geïsoleerd, kleiner appartement.
3. Ten slotte moet het budget zo efficiënt mogelijk besteed worden. Hierbij zijn de isolatiegraad, de luchtdichtheid en de technische installaties bepalend voor de milieubelasting van het appartement, samen met de materiaalkeuze.
4. Bij erg energiezuinige appartementen, gebouwd met milieuvriendelijke bouwmaterialen, zijn het zuinig omspringen met elektriciteit en het kiezen voor hernieuwbare energie de volgende aandachtspunten, gevolgd door het zuinig omspringen met drinkbaar water.

Selecteer een provincie

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Financiële kosten en milieu-impact

De aandacht voor duurzame ontwikkeling steeg de voorbije jaren gestaag in de bouwsector. Tot op heden is er niettemin slechts weinig objectieve informatie beschikbaar over de milieuvriendelijkheid van de verschillende bouwconcepten. Het WTCB voert daarom al gedurende een aantal jaren onderzoeksprojecten uit om de kennis over het milieuvraagstuk in de bouw te verhogen.

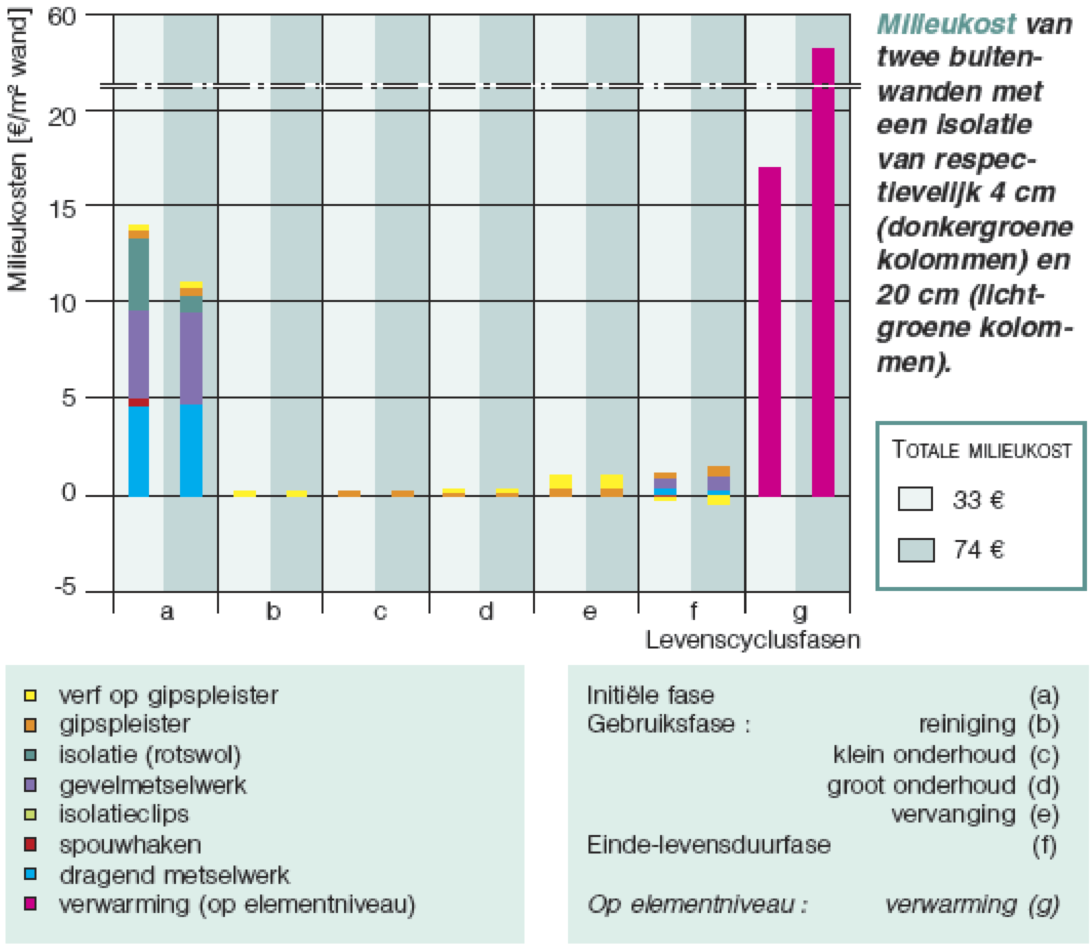
Analyse op gebouwniveau

Gelet op de erg lange levensduur van gebouwen, is het opportuun om reeds van bij het ontwerp stil te staan bij de milieu-impact ervan. Binnen het federale onderzoeksproject SuFiQuaD (1) ontwikkelde het WTCB, in samenwerking met de K.U.Leuven en VITO, daarom een methodologie voor de bepaling van de financiële kosten en de milieu-impact van residentiële gebouwen tijdens hun volledige levensduur.

Binnen deze methodologie wordt gebruik gemaakt van een levenscyclusanalyse (LCA) waarbij de levensduur van een gebouw onderverdeeld wordt in drie fasen :

- **initiële fase** : deze fase vindt plaats vóór de ingebruikname van het gebouw. Ze omvat de productie van de nodige bouwproducten, het transport van de materialen naar de bouwplaats en de bouwfase zelf
- **gebruiksfase** : deze fase omvat zowel de schoonmaak, het onderhoud en de eventuele vervangingen, als het energieverbruik
- **einde-levensduurfase** : deze fase vangt aan bij de afbraak van het gebouw en omvat ook het transport van het sloopafval en de verwerking van de verschillende afvalfracties.

Om tot eenduidige conclusies te komen, kan men de milieu-impact van een gebouw uitdrukken met een eengetalsscore. Eén van de manieren om tot een dergelijke score te komen, bestaat uit de toekenning van een geldwaarde (milieukost) aan de milieu-impacten (bv. 0,05 €/kg CO_2-uitstoot). Vervolgens kan men de totale milieukost berekenen voor de volledige levenscyclus van het gebouw. De financiële kosten van een gebouw tijdens zijn levensduur kunnen op gelijkaardige wijze berekend worden aan de hand van een levenscycluskostenanalyse (LCC). Ten slotte kan men de meest geschikte bouwoplossing selecteren op basis van de totale kosten (financiële kosten + milieukosten).



***Milieukost* van twee buitenwanden met een isolatie van respectievelijk 4 cm (donkergroene kolommen) en 20 cm (lichtgroene kolommen).**

Analyse op elementniveau

Bij de uitvoering van een LCA of LCC op het niveau van het bouwelement dient men steeds het energieverbruik (2) in aanmerking te nemen om te vermijden dat een isolatieverhoging enkel bijkomende materiaalkosten zou opleveren (en er geen rekening gehouden wordt met het verminderde energieverbruik). Men kan dit benodigde energieverbruik berekenen aan de hand van een vastgelegde warmtebehoefte (aantal equivalente graaddagen) en de U-waarde van het bouwelement.

Er zijn per gebouwelement diverse bouwtechnische oplossingen mogelijk die hoofdzakelijk verschillen qua draagstructuur, isolatie, binnen- of buitenafwerking. Dankzij een gedetailleerde analyse van de financiële kosten en de milieu-impact kan men de juiste oplossing selecteren. Doordat een analyse van alle mogelijke oplossingencombinaties ons te ver zou leiden, voerden we deelanalyses uit waarbij we telkens één component van het bouwelement wijzigden.

In het onderstaande staafdiagram worden de milieukosten van twee buitenwanden vergeleken. Beide wanden bestaan uit een dragend metselwerk waarvan de spouw gedeeltelijk opgevuld is met isolatie (respectievelijk 4 en 20 cm rotswol). Het gevelmetselwerk is opgebouwd uit bakstenen en de binnenzijde van de wanden bestaat uit een bepleistering met een verflaag. Uit de afbeelding blijkt dat het energieverbruik in beide gevallen de grootste milieukosten oplevert, maar dat het relatieve aandeel ervan in de totale milieukost sterk afhankelijk is van de isolatiegraad. De initiële milieukosten vormen voor beide varianten de tweede duurste post die gedomineerd wordt door de kosten voor de dragende structuur en de gevelafwerking. Het is ten slotte van secundair belang om de milieukost van verschillende isolatiematerialen te vergelijken.

In een volgende publicatie zullen we dieper ingaan op de variaties in de structuur en de isolatie van buitenwanden.

K. Putzeys, ir.-arch., adjunct labohoofd, laboratorium 'Duurzame ontwikkeling', WTCB

([1]) SuFiQuaD : Sustainability, Financial and Quality evaluation of Dwelling types, gesubsidieerd door de POD Wetenschapsbeleid.
([2]) Het energieverbruik wordt in principe enkel op gebouwniveau berekend, maar is ook van belang op elementniveau om de invloed van de isolatie na te gaan.

Methodology for financial and environmental optimisation of buildings

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Abstract

The four-year project SuFiQuaD that started in 2007 has developed a methodology that can be applied to optimise dwellings, taking into account their environmental impact, financial cost and their quality considering the entire life cycle.

The methodology has been translated into a work instrument, which performs a simultaneous assessment of a large number of technological alternatives for a given dwelling type, resulting in an optimisation of both environmental and economic performance, using LCA and LCC methodology. To be able to combine environmental impacts and financial costs in an integrated assessment, a monetary valuation of environmental impacts is used. For the optimisation, initial costs (environmental and financial) are compared to life cycle costs. This allows to identify the optimal technical solution for a given initial cost limitation.

In the following step, the LCA-LCC results are combined with a quality evaluation based on a multi-criteria analysis (including issues such as floor areas, access to daylight, acoustic performance, flexibility, …). A second optimisation process is then performed, aiming to realise the highest marginal quality improvement for the lowest possible additional financial and environmental cost.

This paper describes the main principles of the developed methodology for LCA-LCC analysis that can be carried out on both building and element level. As an example of analysis on the element level, the results are presented for a variation of the structural part and insulation (materials and thickness) of exterior walls.

1. Introduction

As in other sectors, sustainable development has become an important topic in the construction sector. However, most of the current approaches aiming at a sustainable development of the building sector are focusing on only one or a combination of a few aspects (e.g. materials, energy use). Therefore, the four-year research project SuFiQuaD (**Su**stainability, **Fi**nancial and **Qua**lity evaluation of **D**welling types) [1] has developed a methodology for the integrated assessment and optimisation of life cycle environmental impact, economic performance and quality of residential buildings. The developed methodology (which has been translated into an evaluation tool) combines an LCA and LCC approach with a multi-criteria quality evaluation on dwelling level (including issues such as floor areas, access to daylight, acoustic performance, flexibility, …). This paper will mainly focus on the LCA-LCC methodology.

2. Methodology for LCA-LCC

2.1 Life cycle of the building

The approach for the environmental (LCA) and financial assessment (LCC) of buildings is very similar. In both cases, the entire life cycle of the building is taken into account, subdivided into the initial phase (before use of the building), the use phase and the end of life phase. This principle is illustrated in Fig. 1.

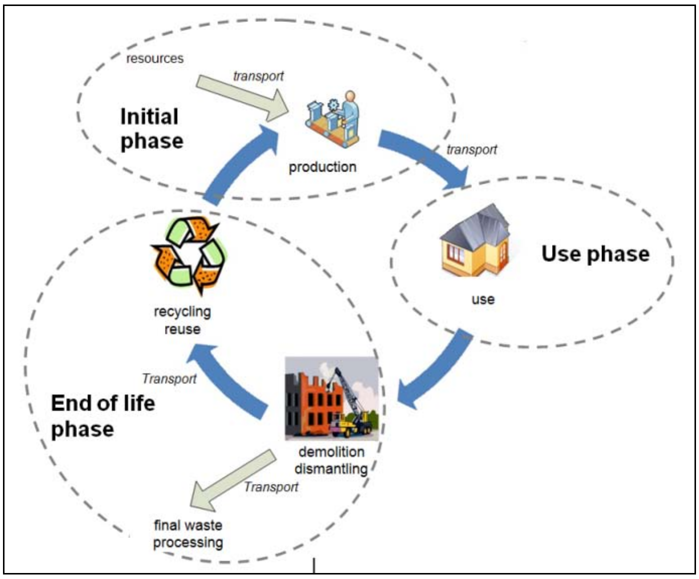

Fig. 1 Life cycle of a building

For the LCA analysis, the initial phase is further subdivided into the production of construction products, including extraction of resources and transport of these resources to the production plant, transport of construction products to the construction site (using default scenarios for a series of product groups) and the on-site construction processes (mainly limited here to taking into account a fixed % of construction waste). For the LCC analysis, the initial phase comprises both the material costs and the labour cost for installing the products in the building.

The use phase is included in a similar way in the LCA and LCC calculations. On the one hand, there are material's related burdens (environmental and financial) for cleaning, maintenance and replacements. For the financial costs, it is assumed that all actions are being paid for, in order to ensure fair comparisons. On the other hand, there are burdens related to the energy use of the building (only heating, sanitary hot water and ventilation).

With regard to the environmental assessment of the end of life (EOL) phase, following elements are considered: demolition/dismantling activities, transport of the waste materials, impact of the sorting plant, and final waste treatment. For waste going to recycling, both the impacts related to the recycling process and the avoided impact from the production of the primary resources it replaces are taken into account. Financial EOL costs include demolition costs and costs for waste removal (global cost per container and additional cost per ton waste of a specific fraction, e.g. inert waste or metals).

2.2 Monetary valuation

The interpretation of the results of an LCA is rarely unambiguous. Indeed, generally LCA results are expressed as a set of various environmental indicators. So, when comparing different alternatives, it is often difficult to draw a straightforward conclusion of which alternative is preferred. For, one alternative might have the best score for some of the impact categories while the other alternative scores best for other impact categories. To overcome this ambiguity, the different indicators are often weighted and aggregated in a single score.

Different methods exist to calculate such an aggregated single score. Within SuFiQuad, monetary valuation is used. This means that LCA results are translated into environmental costs, allowing for the summation of all impacts into an overall environmental cost. The principle of monetary valuation is illustrated in Fig. 2. A hybrid monetary valuation method was developed in the SuFiQuaD project, by combining impact assessment as used within the series of the European ExternE projects [2] and the Ecoindicator 99 [3] approach. The valuation is based on the willingness-to-pay approach and for the assessment of human health aspects mainly applies the monetary values of the CAFE project for the Belgian context. The monetary values for the quality of ecosystems and depletion of resources is based on several other sources.

The reason for chosing monetary valuation above other aggregation methods is that this method makes it possible to combine LCC and LCA results in an optimisation step (as now both results are expressed in the same unit, i.e. cost in euros). A separate analysis of environmental effects and financial costs can still be made, but also the total costs can be determined.

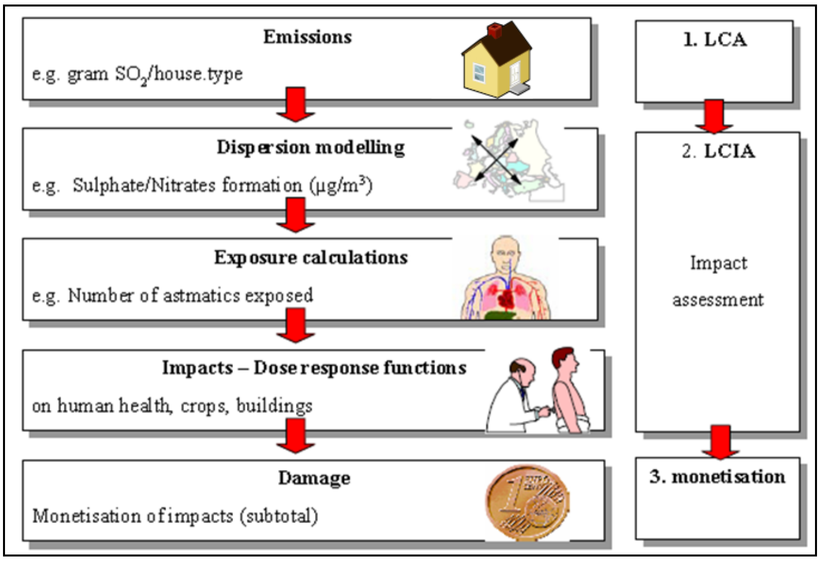

Fig. 2: Monetary valuation of environmental impacts [7]

2.3 Evaluation tool

The LCA-LCC methodology has been translated into an evaluation tool, which contains an extended database of construction materials/products and technical installations (e.g. heating systems based on various energy sources) occuring in dwellings. The financial data are mostly taken from the Belgian database for construction costs ASPEN [5]. In case of lacking data, price offers from contractors are used as a data source. The environmental inventory data are mainly based on the Swiss Ecoinvent database [6]. However, some modifications were made to the original data records to reflect the Belgian situation (e.g. change of electricity mix) better.

Moreover, within the SuFiQuad database each cradle to gate dataset of a product is linked with the appropriate cleaning, maintenance, replacement, transport and EOL scenarios. These scenarios were developed within the project and reflect the Belgian situation. The LCC and LCA data for these different life cycle phases are recorded in a non-aggregated way in the database, so the analysis can also be used to evaluate the importance of the various life cycle phases.

For the LCA-LCC analysis of a building, the building is decomposed into the main building elements (exterior walls, interior walls, floors, roofs, ...). Each element is then further subdivided into components or so-called "work sections" (e.g. brick masonry, screwed gypsum boards, etc.) from the database. At the lowest level, each work section is composed of a number of construction products/materials. A brick masonry wall for example consists of bricks and mortar, in a specific ratio. By determining the amount of each of the building elements and by linking environmental and financial data to each of the materials composing those elements, the LCA and LCC analysis can be done at building level. In this case, the energy demand for heating during the use phase is then calculated based on the Belgian Energy Performance of Buildings Regulation.

In order to compare buildings with different floor area and life expectancy, LCA and LCC results on the building level are calculated per square meter of floor area per year of service life. However, as this functional unit may lead to the conclusion that larger buildings are more sustainable than smaller dwellings, the results are also calculated per inhabitant per year.

The evaluation can also be done at element level, by simply varying the subcompents of that element (e.g. structure, insulation, finishing of an exterior wall). The identification of the optimal element solutions then allows selecting a limited number of element combinations for further analysis at the building level.

An important point of attention for the analysis at the element level is energy use, which is normally assessed at the building level. If energy use is not included in the analysis at the element level, an increased insulation level only leads to an increased environmental and financial burden. The energy use is, therefore, included in the LCA-LCC analysis at the element level by using the equivalent degree days method. The principle of this method is that the heating demand of a building is seen as proportional to the number of "equivalent degree days". The number of "degree days" is defined as the sum of the product of the days where heating is required with the temperature difference between indoor and outdoor. After accounting for the positive effect of solar and internal gains, the "equivalent degree days" can be used as a starting point to calculate the heating demand caused by the transmission losses (Q_T) through the building element. The energy consumption caused by the transmission losses is then equal to the heating demand, divided by the global installation efficiency (Q_T / η_{global}).

2.4 Optimisation

Different criteria can be considered for optimisation: initial or life cycle financial cost, initial or life cycle environmental costs, total initial or life cycle cost (sum of financial and environmental costs). It is possible that these different criteria will lead to different ranking of the optimal solution. In order to select the most profitable option out of a multitude of options, we look for the solution for which the initial investments lead to the biggest reduction in life cycle cost (Pareto Front). When also taking the quality of building into account (not discussed here) one can look for the biggest increase in quality for the smallest increase in (financial and/or environmental) cost.

3. Analysis on element level: exterior wall

3.1 Introduction

Exterior walls are composed of different materials, which can be grouped into a number of sub-components, i.e. interior finishing, structural part, insulation and external finishing. The following paragraphs give a summary of the analysis of a variation of the structural part (4 alternatives: wood skeleton, masonry wall, TJI-beams and steel skeleton) and insulation (alternative materials and thicknesses) of the exterior wall.

The results of the LCA and LCC analysis are presented in a similar way. First, an overview is given of the financial costs of the analysed exterior wall alternatives. Fig. 3 shows the initial costs (IF) versus the life cycle costs (LF). The same is done for the environmental costs (Fig. 4 - IE versus LE). The results presented hereafter are based on a service life of 120 years and a heat demand of 1200 equivalent degree days (heat production with a condensing gas boiler).

3.2 Financial costs

In Fig. 3, each symbol represents a combination of one type of structural part with one type of insulation material (different points marked by the same symbol represent variations in insulation thickness). The four alternatives of the structural part are identified by different types of outlining (see grouping legend). The results show that for each combination of one insulation type and structural part (e.g. bricks EPS), the life cycle financial cost first decreases as the initial cost increases. This can be explained by the increasing initial cost with increasing insulation thickness, which leads to a reduction of the heating demand (and associated costs). However, for some combinations (e.g. bricks PUR foam) an optimum thickness of insulation has been reached within the analysed options. For these, an increased insulation thickness no longer results in a further decrease of life cycle financial costs. The optimal thickness varies depending on choice of structure and type of insulation.

The results also indicate that for a given structural part, there are no large differences in life cycle financial costs for different insulation materials applied in the same thickness. The most optimal solutions (solutions on the Pareto, for which the initial investment leads to the biggest reduction in life cycle cost) within the considered options are all within the brick alternatives. However, the optimal type of insulation depends on the initial budget available.

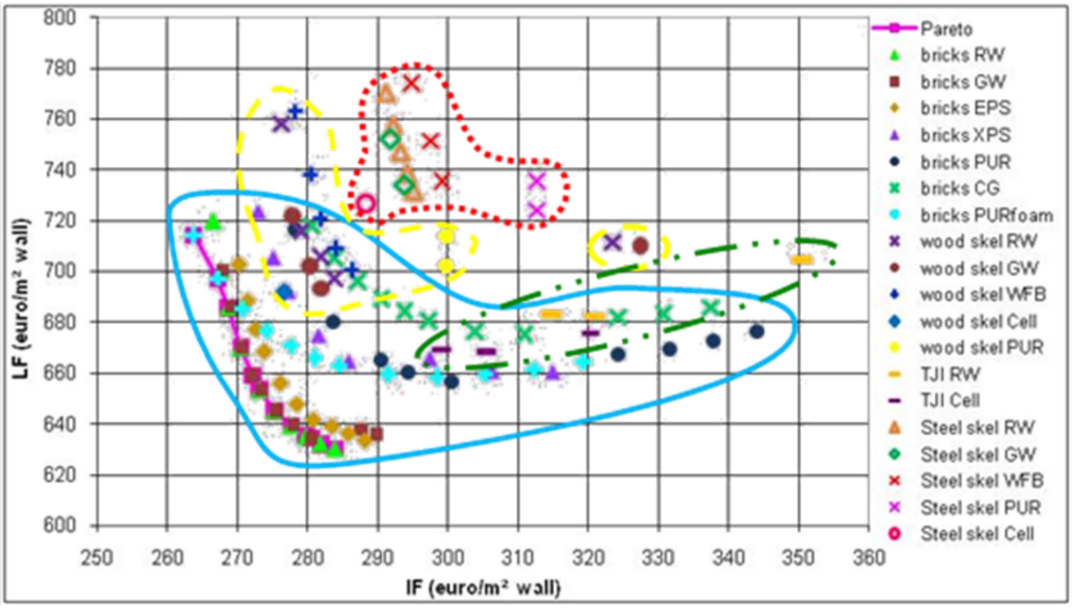

Fig. 3: Initial Financial cost (IF) versus Life cycle Financial cost (LF) for a variation of structural part and insulation of exterior walls

Grouping legend:

(solid blue line)	Structural part = brick masonry
(dashed yellow line)	Structural part = wood skeleton
(dash-dot green line)	Structural part = TJI beams
(dotted red line)	Structural part = steel skeleton

3.3 Environmental costs

Similarly to the financial cost analysis, the initial environmental impacts (costs) are compared to the life cycle environmental costs (see Fig. 4). Again, the four groups of structural types are identified. Important to notice is that there are only small differences in initial environmental cost (the vertical and horizontal axes have different scales). There is, however, a large spread in the life cycle environmental costs. The results show that the life cycle environmental cost largely decreases with increasing initial investment, so additional insulation proves to be a very efficient environmental investment. Moreover, unlike the financial analysis where at some point higher insulation levels resulted in higher life cycle costs , from an environmental point of view the optimum insulation thickness is not reached yet within the considered alternatives.

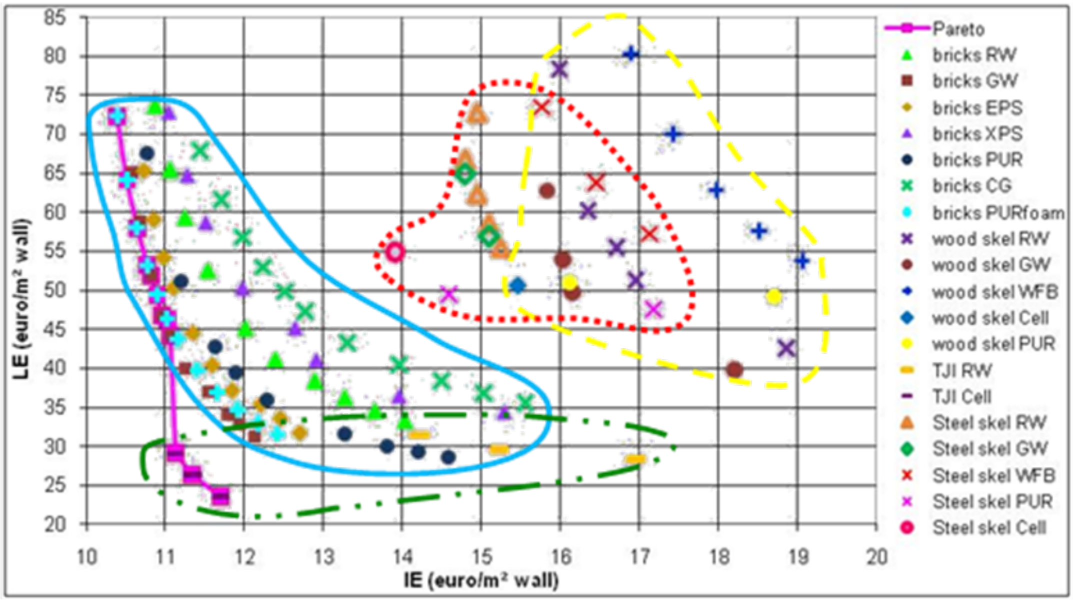

Fig. 4: Initial Environmental cost (IE) versus Life cycle Environmental cost (LE) for a variation of structural part and insulation of exterior walls

4. Conclusions

The research project SuFiQuaD (**Su**stainability, **Fi**nancial and **Qua**lity evaluation of **D**welling types) has developed a methodology for an integrated assessment of the environmental impact, financial costs and quality aspects of dwellings. This paper focused mainly on the approach methodology developed for the environmental (LCA) and financial assessment (LCC), which can be carried out both on building or element level. As an example of analysis on element level, the results were presented for a variation of the structural part and insulation (materials and thickness) of exterior walls.

5. Contributions

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Funding agency: BELSPO – SDD (Belgian Science Policy – Science for a Sustainable Development)

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Striving for a more sustainable Belgian dwelling stock

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Abstract

A four-year project (SuFiQuaD) started in 2007 to optimize the Belgian dwelling stock. The optimization focuses on environmental impacts, financial cost and quality aspects. The aim is to evaluate the whole life cycle of representative housing types and formulate recommendations for improvement. In a first phase the methodology has been developed and is now being applied to a limited selection of extreme dwelling types. Based on this application, the methodology will be revised and applied to representative dwelling types. This paper elaborates on the developed methodology and the first results of the implementation. The basic approach for the optimisation is to search for the highest marginal quality improvement for the additional cost. The cost consists of different aspects: initial financial cost, initial environmental cost, life cycle financial cost and life cycle environmental cost. The environmental cost is calculated by translating the environmental impact – estimated based on life cycle assessment – into financial terms. Finally, a quality evaluation is included. This is considered as an essential part of the analysis since a good quality is a requirement for sustainability, but moreover, the inclusion of the evaluation of the performance of a building enables comparative analysis.

Keywords: life cycle assessment, life cycle costing, multi-criteria analysis, optimisation, Pareto, dwelling, monetary valuation, marginal valuation, Belgium, element method, quality assessment.

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1 Introduction

The Belgian dwelling stock is far from sustainable at the moment. Not only are the houses poorly insulated, but hardly any attention is paid to the environmental impact of the applied building materials. Furthermore a lot of transportation is generated and the amount of building waste is enormous. Although people are more conscious than a decade ago and the government has undertaken some important measures, no overall change is noticeable. This can partly be explained by the relatively long lifespan of buildings leading to a slow renewal/improvement of the existing dwelling stock. However more action is needed and a more integrated approach is required. The research described in this paper is an attempt to search for priority actions.

2 Integrated approach

The approach within this research is an integrated approach since the different stakeholders are addressed, the whole life cycle of the dwelling is included and both costs (financial and environmental) and qualities are analysed. In the following paragraphs the different aspects of this integrated approach are briefly described. In a second part of the paper the first results from the implementation to one of the extreme dwelling types are discussed.

2.1 Environmental impact

The evaluation of the environmental impact of the dwellings is based on a life cycle assessment (LCA [1–6]). For the inventory of the environmental data of the building related products and processes we rely mainly on the Ecoinvent database [7]. For the assessment of the inventoried in- and outputs; the effects as defined within eco-indicator 99 are considered [8]. However a method has been developed to express the impacts into financial terms instead of ecopoints. This method is based on a combination of existing methods and can therefore be called a hybrid method. For the environmental effects of the greenhouse gas emissions, the monetary value is based on the combined information from Tol [9], Stern [10] and Watkiss et al. [11–12]. The monetary value of other airborne emissions is based on the ExternE studies, more specific the values of the CAFE (Clean Air For Europe) project are used [13]. However a comparison of these emissions with the ones assessed within Eco-indicator 99 revealed that for the building related products and processes ExternE was excluding too many important emissions. Therefore a monetary value was determined for the 'disability adjusted life years' (DALYs) caused by the emissions not included within ExternE. These values were based on different sources and led to the value of 60.000 euro/DALY [14]. Moreover the impact on the quality of ecosystems and the depletion of resources, as assessed by Eco-indicator 99, still needed to be included since these again proved not to be negligible for the building related products and processes analysed. Acidification, eutrophication, ecotoxic emissions and land use are therefore included by translating the (PDF x m2 x year), as assessed within Eco-indicator 99, into monetary values based on the studies mentioned before. The value of 0,49 euro/(PDF x m2 x year) was retained. For the depletion of minerals and fossil fuels, the monetary value of 0,0065 euro/MJ surplus energy was determined.

For the analysis of the extreme dwelling type described in this paper, some environmental costs were still lacking: the construction and demolition cost, maintenance costs and the transportation during use phase are omitted.

2.2 Financial cost

In this research, we analyse the investment cost, the periodical costs and the costs at the end of the lifespan of the dwelling by calculating the sum of the present values. We refer to the literature for a more detailed description of Life Cycle Costing [15]. Since it is difficult to predict how material, labour and energy costs will evolve in future, a sensitivity analysis is required.

The required data for the material and labour costs are taken from the ASPEN database, valid for the Belgian context [16]. If data were missing, product specific data were used.

For the description of the analysis of the extreme dwelling type in this paper, the financial cost for the demolition and end-of-life treatment are not included yet. As for the environmental cost, the financial cost for maintenance and transportation during use phase are omitted too. Moreover the financial cost of the heating installation is not yet included.

2.3 Quality evaluation

Finally, a quality evaluation is included in order to enable comparative analysis of the different dwelling and technical performances. The applied method is based on an existing method, consisting of a multi-criteria analysis [17]. The different quality aspects obtain a score on ten, defined by a score function. The single end-score is calculated by the sum of the weighted scores. Within the original method, the weighting factors were defined by an expert panel.

Some adaptations have been made to the original method. First of all, some aspects have been eliminated to avoid double counting (e.g. the score for financial cost and energy use for thermal insulation are excluded since these are already considered in our cost evaluation). Secondly, some score functions have been redefined according to the new European and Belgian norms (e.g. acoustical standards). Thirdly the weighting factors have been revised based on pair-wise comparison of the aspects. From these results, weighting factors have been determined through an Analytic Hierarchic Process (AHP).

2.4 Functional unit

The functional unit is chosen as one square meter of net floor area, per year to enable comparative analysis of dwellings with different size, layout and lifespan. However, to avoid conclusions as "the larger the house, the more sustainable", the results are also calculated per inhabitant, per year. For the analysis of the extreme dwelling type presented in this paper, the size of the dwelling is fixed and therefore the results will only be shown per square meter floor area, per year.

The relatively long lifespan of dwellings makes the use phase an important part of the life cycle and is therefore investigated in detail. The lifespan however is hard to predict, and therefore again, a sensitivity analysis is made. The dwellings are assumed to have a lifespan of 60, 90 and 120 years. However the results in this paper are only elaborated for the two extremes (60 and 120 years).

2.5 Optimisation

For the determination of the most preferable measures for one type of dwelling, or for the determination of the most preferable dwelling type, the basic approach is to search for the highest marginal quality improvement for the additional cost. This means that one starts from a reference building and compares the alternatives with this reference. The subset of options that is more preferable than the other options is graphically represented by the Pareto front.

Different optimisation criteria are considered: initial financial cost, initial environmental cost, life cycle financial cost and life cycle environmental cost, initial total cost and life cycle total cost, with and without the inclusion of the quality evaluation. It is possible that these different criteria will lead to a different ranking of the optimal options.

3 Simulation tool

The above summarized method has been translated into a simulation tool. This tool relies on an extended database containing all required data of the work sections occurring in the dwellings. These are structured per element of the dwelling according to the element method for cost control [15, 18, 19]. The database is structured according to the BB/SfB code [20].

Each element is constituted of work sections selected from the database, which are multiplied with an appropriate ratio (= quantity of work section per unit of element). The elements are defined in such a way that these are as independent as possible. Replacing one element solution by an alternative (other size, other materials) should not influence the other elements. However, for some elements this was impossible. For example, increasing the thickness of the exterior walls (by adding insulation for example) influences the roof edge, the foundation and the fixing and finishing of windows and doors. Elimination of unrealistic combinations requires additional computation time and should further be optimized.

For each element occurring in the dwelling, a unit ratio (= quantity of element per m^2 floor) is calculated. Finally the elements are combined at the building level by multiplying the cost per unit element with the respective ratio. The element table for the extreme dwelling type analyzed in this paper is summarized in figure 1.

The calculation of the energy demand for heating during the use phase is based on Belgian Energy Performance Regulations. Electricity use for the use of electrical appliances and lighting is not included in the analysis.

Element	amount	unit	ratio	IF/m2fl net	IE/m2fl net	PF/m2fl net	PE/m2fl net	EOL F/m2fl net	EOL transport E/m2fl net	EOL E/m2fl net
(13.+) ground floor_T1	159,00	m2	1,000	201,29	28,90	108,06	28,98	0,00	4,61	-19,54
(16.4) foundation	79,24	m	0,498	27,27	10,19	0,00	0,00	0,00	2,02	-20,22
(21.+) external wall T1	174,87	m2	1,100	220,78	14,96	132,10	9,76	0,00	0,49	-4,00
(22.1+) loadbearing internal wall	0,00	m2	0,000	0,00	0,00	0,00	0,00	0,00	0,00	0,00
(22.3+) not-loadbearing internal wall	105,33	m2	0,662	65,99	2,26	252,69	8,58	0,00	0,15	1,18
(27.1+) flat roof	159,00	m2	1,000	219,17	13,43	179,76	7,32	0,00	0,90	-3,76
(31.) door external wall	2,33	m2	0,015	0,00	0,00	0,00	0,00	0,00	0,00	0,00
(31.) windows	35,06	m2	0,221	86,00	15,01	0,00	0,00	0,00	0,00	-0,61
(31.+) window finishes	35,06	m2	0,221	4,71	0,00	0,01	0,00	0,00	0,00	0,01
(32.) door internal wall T1	7,46	m2	0,047	0,00	0,00	0,00	0,00	0,00	0,00	0,00
(37.6) roof edge	79,24	m	0,498	74,01	9,04	43,87	11,27	0,00	0,15	-1,47
				899,21	93,79	716,49	65,91	0,00	8,32	-48,40

Figure 1: Simulation tool: element table derived for the freestanding house.

4 Extreme dwelling types

As explained before, the method is being implemented at the moment to selected extreme dwelling types in order to validate both the approach and the simulation tool. In the following paragraphs, the results will be discussed for a freestanding newly built dwelling. However the approach is also valid for renovation.

4.1 Freestanding house: description

The analysed extreme freestanding house is L-shaped, consists of only a ground floor level and is therefore not compact at all (C = 0,75m). The house consists of a living room, kitchen and bathroom, storage room and three bedrooms. There is an entrance and night hall. There is no garage in the house. The garden is surrounding the house and there is a terrace adjacent to the living room.

For the technical solutions of the different elements, again some extremes were selected. For the exterior walls, cavity walls consisting of bricks (both inner and outer layer) are compared with other facade finishes (wood claddings, cement fibre board) and with another structural solution, wood skeleton (inner layer). For the flat roof both a concrete slab and wood construction are considered. For the inner walls, "heavy alternatives" of concrete blocks, sand-lime brick and clay bricks are compared with the "light" alternative of wood skeleton. For the elements occurring in the building envelope (exterior wall, roof, ground floor and windows) both non-insulated as well insulated alternatives were selected.

4.2 Freestanding house: cost optimisation

In the figures below, the results are shown for the freestanding house. The results for the cost optimisation are shown in figure 2. Horizontally the initial cost is plotted, while vertically the total life cycle cost is shown. Both are expressed per square meter floor area, per year.

The options in the left and right grouping of a same symbol represent respectively a lifespan of 120 and 60 years. The former ones obviously lead to lower investment costs per m2 floor area per year. The life cycle cost of these per m2 floor area per year, however, is not for all options lower than for the options with a shorter lifespan. In the following paragraphs only the results for the dwelling with a lifespan of 120 years are presented more in detail. It is important to report that the subsets of Pareto-optimal solutions for a lifespan of 60 years and 120 years do not necessarily contain the same technical solutions and the identical solutions do not necessarily have the same priority.

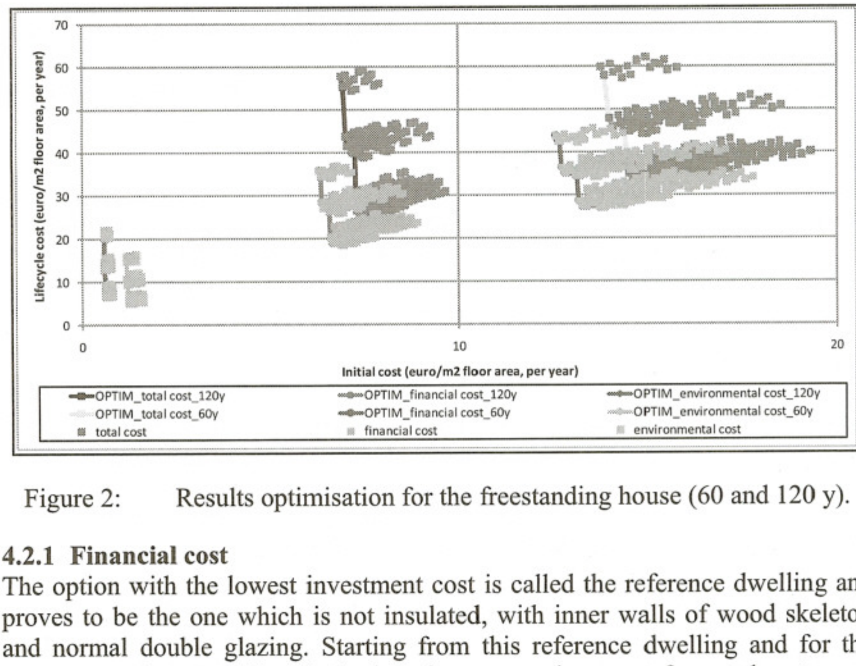

Figure 2: Results optimisation for the freestanding house (60 and 120 y).

4.2.1 Financial cost

The option with the lowest investment cost is called the reference dwelling and proves to be the one which is not insulated, with inner walls of wood skeleton and normal double glazing. Starting from this reference dwelling and for the different options considered, the best investment is to opt for another type of inner walls, namely building bricks. This leads to the highest reduction of financial life cycle cost for the lowest increase of financial investment cost. We must mention that the insulation options considered in this analysis are either no insulation, either a thick insulation layer (two extremes), which can explain the priority of changing an inner wall type above the larger investment of insulating the house.

If a higher investment is possible however, one should preferably invest in ground floor insulation. This requires a higher investment than choosing inner walls of building bricks, but leads to a higher reduction of the life cycle financial cost.

The next investments in order of importance are the following: combination of floor insulation and inner walls of building bricks, roof insulation (wood structure instead of concrete structure), roof and floor insulation, insulated outer walls of wood skeleton instead of building bricks (facing bricks have remained), former one combined with roof insulation, former one combined with floor insulation, and in the final steps changing again to the insulated brick outer wall, combined with an insulated roof and floor, inner walls of sand-lime brick with normal double glazing, which is replaced in a final step by thermally improved glazing.

4.2.2 Environmental cost

The dwelling with the lowest initial environmental cost is again the not insulated dwelling, but with another type of inner wall, namely the sand-lime brick wall instead of the wood skeleton wall. The measure leading to the highest reduction of life cycle environmental cost for the lowest extra initial environmental cost is achieved by opting for thermally improved glazing instead of normal double glazing. The next measure is insulating the floor but keeping normal double glazing; followed by replacing the glazing again. The fourth step is insulating the exterior walls by choosing for an outer wall of wood skeleton with an outer finishing of wood claddings, combined with normal double glazing, followed by improvement of the glazing. This latter combined with floor insulation, again leads to a lower total environmental cost. A next improvement is insulating the roof, in a first step with normal double glazing, in a next step with improved glazing, followed by insulating the floor, again with normal and improved glazing. In the final step the flat roof is changed from a concrete to a wood structure. The option with the lowest life cycle environmental cost, for the options considered, differs from the one with the lowest life cycle financial cost.

4.2.3 Total cost

Finally we can repeat the analysis considering the total cost (sum of financial and environmental cost). The analysis results in an identical reference dwelling and identical final optimal dwelling as for the financial cost analysis. However the steps to evolve from the reference to the final dwelling are more extended now. This indicates that, within a limited budget, the choice based on financial cost considerations will not be identical as the choice based on total cost.

4.2.4 Detailed analysis of the Pareto optimal solutions

Figure 3 shows a more detailed analysis of the solutions on the Pareto front as resulted from the optimisation for a dwelling lifespan of 120 years. For each option the importance of the different life phases is shown. This graph clarifies the earlier reported contradiction between financial and environmental optimisation. For, the figure shows that the initial cost is mainly determined by the financial part, while heating the dwelling induces a financial and environmental cost that are more evenly distributed.

4.3 Freestanding house: cost/quality optimisation

The graph below shows the results of the optimisation procedure considering the life cycle cost and the quality of the dwelling (figure 4). Again the financial, environmental and total costs are investigated separately. The results in the graph represent the freestanding house with a lifespan of 120 years. The same procedure is used as for the cost optimisation, although now the highest quality increase is searched for the lowest additional cost. As can be seen from the figure, the quality is identical for many options. The reason is that the analysed alternatives for technical solutions do not influence the quality to a great extent. For, the chosen technical solutions all fulfil the European and Belgian performance norms and standards. However, the quality evaluation will be more important when optimising the layout of the dwelling and when comparing the different dwelling types.

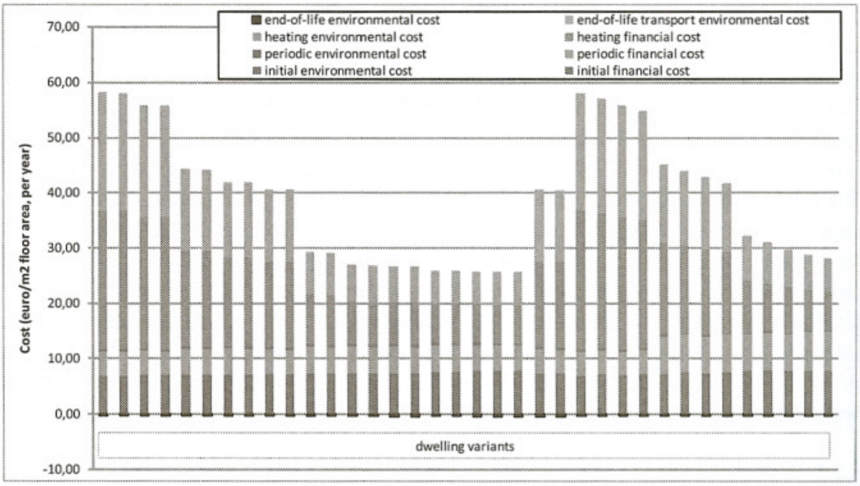

Figure 3: Freestanding house: detailed analysis of the Pareto optimal subset, indicating the importance of the different life phases (120 y).

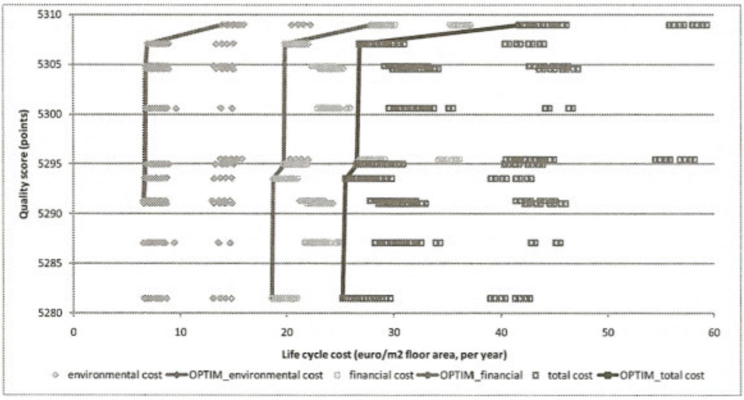

Figure 4: Freestanding house: quality/total cost optimisation, considering life cycle financial, environmental and total cost (120 y).

For the above reason, we will not discuss the above graph in detail. However, it is important to remark that these subsets of Pareto optimal solutions are not identical to the subsets based on the life cycle cost / initial cost Pareto fronts.

5 Conclusion and further research

This paper summarizes the methodology developed within the SuFiQuaD project to optimise the sustainability of the Belgian dwelling stock. Financial and environmental costs are evaluated, including a quality analysis and considering the whole life cycle. Moreover, the translation into a simulation tool and first implementation to an extreme dwelling type have been elaborated. This proved that both the methodology and simulation tool seem valid, although some refinements are still needed. The tool will be implemented to other extreme dwelling types to check compatibility with renovation and multi-family housing (apartments). After refinement, a tool will be available to select priority actions for improvements of different dwelling types and to compare these mutually. Finally it will be used to analyse representative Belgian dwelling types.

Acknowledgement

Finally, we extend our sincere thanks to BELSPO – SSD (Belgian Science Policy – Science for a Sustainable Development) who funded this research.

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SUSTAINABLE BUILDING: THE SEARCH FOR AN INTEGRATED METHOD TO EVALUATE THE SUSTAINABILITY OF DIFFERENT DWELLING TYPES

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ABSTRACT

The four-year project SuFiQuaD has started in 2007 to develop a methodology that can be applied to optimize the Belgian dwelling stock. The aim of the project is to optimize buildings considering their environmental impact, their financial cost and the quality they offer over the whole life cycle, from the production of primary raw materials to the final demolition and end-of-life treatment. In the first phase of the project the optimization methodology is developed: environmental impacts are analyzed by means of a life cycle assessment (LCA). The environmental impacts are then translated into environmental costs using a monetary valuation of the environmental impacts; financial costs are calculated based on life cycle cost (LCC) analyses; and the quality evaluation is based on multi-criteria analyses. The optimization of the three aspects (environmental costs, financial costs and qualities) is based on a Cost Benefit Analysis (CBA). By means of the CBA it is possible to identify the highest marginal quality improvement for the lowest additional financial and environmental costs. The developed methodology is translated into a work instrument and applied in this first phase of the project to a limited selection of dwelling types. In the second phase of the project, the methodology and work instrument will be applied to a series of representative dwelling types for the Belgian dwelling stock. This paper elaborates on the developed methodology and the results of the first implementation with some selected dwelling types.

Keywords: life cycle assessment, life cycle costing, quality assessment, multi-criteria analysis, integrated approach, optimisation, dwelling types, Belgium

1. INTRODUCTION

In Belgium, as in other countries, the construction sector is responsible for an important part of the total environmental impact, of which housing represents a significant fraction. Most of the current approaches aiming at a sustainable development of the (building and) housing sector, are focusing on one or sometimes a combination of a few aspects (materials, energy use of end users, etc.), but do not consider the complex interrelations between housing typology, lifestyle, spatial characteristics, technical solutions for elements and financial and environmental consequences. The SuFiQuaD project therefore takes an integrated approach as the starting point, with the aim to identify the optimal solutions from environmental, financial and dwelling quality viewpoint.

2. THE INTEGRATED APPROACH

The research departs from the need for an integrated approach aiming at a typology-specific analysis concerning the reduction of the environmental impact of the building and housing sector, taking into account the building performance and financial consequences. The approach starts from the insight that the analysis should be carried out at the level of the building and should cover the entire life cycle of the building, from raw material extraction until waste treatment at the end of life of the building. The following paragraphs describe the different parts of the integrated assessment approach, i.e. environmental impact assessment using Life Cycle Assessment (LCA), financial cost evaluation using Life Cycle Costing (LCC) and the quality evaluation using a multi-criteria analysis.

2.1 Environmental Impact Assessment by using LCA

The environmental impact assessment is performed by using a Life Cycle Assessment (LCA) [1-6] of the dwelling. The total life cycle of the dwelling is analyzed: from the extraction of primary raw materials to the final demolition and end-of-life treatment. The following phases are considered in the SuFiQuaD project:

- Product stage: production of the building materials, including transport and all processes upstream of the manufacturing stage, e.g. raw material supply or energy provision;
- Construction process stage: transport to the building site, construction of the dwelling and installation of other services and appliances into the building (e.g. heating equipments);
- Use stage: use of the building (operation e.g. installed services and appliances), maintenance, repair and replacement, refurbishment, including all transport steps;
- End of life stage: de-construction, reuse, demolition, recycling, incineration, … and final disposal of the building materials and equipment, including all transport steps.

In order to be able to optimise the three aspects (environmental impacts, financial costs and qualities of the dwelling over the total life cycle) the environmental impacts are translated into monetary terms (euros) by using a monetary valuation. The environmental impact assessment and the monetary valuation of environmental aspects follow three steps:

- identification and quantification of environmental burdens and emissions;
- assessment of impacts associated with these burdens and emissions;
- monetary valuation of the environmental impacts and emissions.

Derived from the function of the dwellings, the functional unit is defined. The functional unit should measure the performance of the different dwelling types and should provide a reference to which all the environmental inputs (use of raw materials and energy) and outputs (emissions to air, water, soil, other) can be normalised. Since dwellings fulfil more than one function, the choice of the functional unit is not simple. Different functional units occurred in studies reviewed within the literature. In the REGENER project [7], for example, the whole building, located at a certain point in a given region, is considered as the basic functional unit. For this SuFiQuaD project we will use one square meter of the total gross floor area. To be able to compare dwellings with a different life expectancies the environmental impact per square meter of the total gross floor area per year will also be calculated. In addition, the SuFiQuaD method also calculates the results per inhabitant to correct any appearance that larger buildings are more sustainable than smaller ones.

For the analysis of the dwelling that is presented in this paper, the size of the dwelling is fixed and therefore the results will only be shown per square meter floor area, per year. For all dwellings that will be assessed within the SuFiQuaD project we assume an average service life of 60 years, which is an accepted average for the Belgian context [8]. Sensitivity analyses will be performed to assess the impact of other service years (60, 90 and 120 years) on the final results. The relevance of the lifetime is therefore investigated by comparing the dwellings using a service life of 60, 90 and 120 years.

During the collection the of the environmental data (life cycle inventory - LCI-data) related to the entire life cycle of the building we rely mainly on the Ecoinvent database [9]. For the life cycle impact assessment of the inventoried inputs and outputs; we used the eco-indictor 99 method [10]. In addition we developed a method to translate the environmental burdens and impacts into monetary values (euros). In order to cover as many environmental aspects as possible we combine different existing methods for the translation of environmental aspects into monetary terms. Therefore we call it a "hybrid" method. [13]. The method is based on a combination of the impact assessment as used within the series of the European ExternE projects [11], the Eco-indicator 99 approach [10] and other research projects on monetarisation [12].

2.2 Financial Cost evaluation

The aim of the financial cost evaluation is to evaluate the financial costs over the whole life cycle of the dwelling, from the primary extraction of raw materials to build the dwelling to the final end-of-life treatment after demolition of the dwelling. This should be seen as an analysis at the micro-economic level. The whole life cycle is included, meaning that not only the investment costs will be evaluated, but also the costs during use phase (periodic costs) and at the end of the life cycle of the dwelling. For a more detailed description of Life Cycle Costing, we refer to literature [14-16].
Additional to the financial cost evaluation, the aim of the SuFiQuaD project is also to search for the most efficient additional spending, starting from the cheapest acceptable solution, to reduce the total financial costs. Moreover, the importance of the contribution of the different life phases of the dwelling to the total financial cost is also reported and visualised.

Prices for building elements are based on a publicly available database with prices for work sections for Belgium [17-18]. Where data were lacking, specific contractor prices have been used.

2.3 Quality evaluation

The functional unit of the dwellings that will be analysed within the SuFiQuaD project has been defined as one square meter of total floor area per year. Since dwellings are multi-functional and the performance of a single square meter of total floor area is thus not identical for different analysed dwellings, it has been decided to also include a so-called quality evaluation of the dwellings. The quality evaluation is based on an existing method for housing in Belgium [19] and is based on a multi-criteria analysis. In the original method, the qualities are divided in five main aspects: dimensional, functional and technical characteristics, the surroundings of the dwelling and the financial cost. Each aspect is subdivided in different sub-aspects. The aspect 'dimensional characteristics' for example is subdivided in the sub-aspects: size of rooms, room width, window size and orientation and efficient use of floor area. Each sub-aspect is again subdivided in sub-aspects (sub-sub-aspects) for which scores need to be determined. Within the aspect 'size of rooms' for example, there is a score assigned to the floor surface area of each room. The importance of the different qualities has been defined by assigning weighting factors. The weighting factors in the existing method were defined by consulting expert commissions (panel of experts). Each criterion within each sub-aspect is evaluated using a score function and graded on a scale from zero to ten. The different scores are then weighted and aggregated into a final single score for the quality performance of the dwelling. Some adaptations have been made to the original method. Firstly, to avoid double counting, the cost related aspects (both financial as well as environmental costs) like for example the energy use during the use phase of the dwelling, are excluded from the method. Secondly, some of the score functions have been updated, taking into account new European and/or Belgian standards (e.g. acoustic standards). Finally, the weighting factors were adjusted for the elimination of qualities included via the costs.

2.4 Optimisation approach

The three aspects to be optimised are:

- the environmental impacts – expressed as environmental costs in EURO;
- the financial costs - expressed in EURO;
- the qualities - expressed in quality-points.

This optimisation starts from a defined reference dwelling (for each of the different dwelling types considered) and is based on comparative analysis of different technical solutions. For each dwelling analyzed preference will go to the solutions with the lowest environmental impacts and financial costs and with the highest qualities. To do so a cost-benefit analysis (CBA) is used as optimisation method within the SuFiQuaD project.

In the CBA-analysis the benefits are considered as the qualities and the costs are considered as the total life cycle costs (both financial and environmental costs). During CBA-analysis we will determine those dwelling options which offer the highest marginal quality improvement for the lowest additional cost. The other dwelling options on the Pareto front are inferior to those optimal solutions and can only be interesting if there are no budget restrictions.

During CBA different ranking criteria can be considered:

- reduction of the life cycle financial cost per additional initial financial cost
- reduction of the life cycle total cost (= financial + environmental) per additional initial total cost;
- reduction of the life cycle environmental cost per additional environmental cost;
- maximisation of the quality per additional total life cycle cost (= financial + environmental);
- maximisation of the quality per additional financial life cycle cost;
- maximisation of the quality per additional environmental life cycle cost.

These different criteria will lead to a different ranking solutions [13].

3. TRANSLATION OF THE APPROACH INTO A SIMULATION TOOL

The integrated approach, described in the previous paragraphs, has been translated into a work instrument or simulation tool. In a first step, the initial LCA/LCC calculations are carried out. The simulation tool for the LCA and LCC assessment relies on an extended database that contains the required LCA and LCC data. The dwellings are first structured per building elements according to the element method that was originally used for cost control only [16, 20, 21]. This element method is grateful since this method enables to structure all data rigorously. The simulation tool that we developed in the SuFiQuaD project has been structured according to this element method and can be used for both new buildings and renovations. In case of renovation only additional data (e.g. for other technical solutions) need to be gathered in the underlying databases.

For the assessment, the building is divided into (independent) building elements in order to enable one element to be changed without consequences for the other elements. Full independence can, never really be reached. For example increasing the thickness of the exterior walls (by adding insulation for example) influences the roof edge, the foundation and the fixing and finishing of windows and doors. .Elements must be defined “without gaps and overlaps” in order to avoid omissions and double counting.

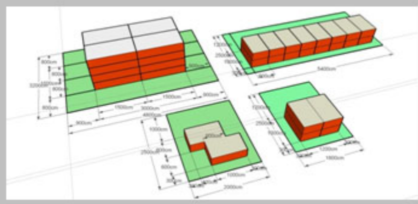
In a similar way, the building elements are divided into different work sections. And the work sections are divided into different building materials and processes. At the level of the work sections, the amount of material and processes per unit of work section is determined. At the level of the elements, the amount (ratio) of each work section per unit of building element has been determined. At the building level, the ratio (proportion) of each building element per m² of total floor area is calculated. The design of the building plays an important role for the latter. Figure 1 presents a print screen of the simulation tool just to illustrate the way the cost are calculated at the building level.

INPUT PARAMETERS

Brief description of project

Dwelling name	TH_ren	TH_ren	TH_new
Dwelling type	renovated terraced house	renovated te	
Floor area analysed dwelling/appartment (m2)	213,00	213,00	157,23
Total floor area apartment building (m2)			2
Total floor area apartments (m2)			94
Total floor area common spaces (m2)			63
	0,00	0,00	0
	0,00	0,00	0
	0,00	0,00	0
	0,00	0,00	0

Combine



<u>**Cost analysis for one building**</u>

Element	amount	unit	ratio	type	IF(material)/ unit element	IF(labour)/unit element	IF/unit element	IE(product)/ unit elemententent	IE(transport)/unit element
(0.+) demolition	1	building	0,005	Demo	1382,06	11398,97	12969,65	0,00	0,00
(13.+) ground floor T1	39,23	m2	0,184	FL_T1	105,07	103,69	208,76	28,31	2,17
(13.+) ground floor T2	33,23	m2	0,156	FL_T1	80,71	96,01	176,72	24,37	2,11
(13.+) ground floor T3	40,25	m2	0,189	FL_T1	36,42	62,09	98,51	18,88	0,33
(16.4) foundation T1	16,48	m	0,077	T1	0,00	4,28	62,10	17,30	1,84
(17.) pile foundtion T1	0	m	0,000	PF_T1	0,00	0,00	0,00	0,00	0,00
(21.+) external wall T1	53,24	m2	0,250	ExW_T1	68,22	150,21	245,51	10,52	1,50
(21.+) external wall T2	30,45	m2	0,143	ExW_T2	96,70	112,01	208,71	8,12	0,18
(21.+) external wall T3	0	m2	0,000	ExW_T1_ng	55,44	145,60	228,12	8,11	1,47
(22.1+) loadbearing internal wall T1	0	m2	0,000	Lwi_T1	0,00	0,00	0,00	0,00	0,00
(22.3+) not-loadbearing internal wall T1	33,67	m2	0,158	NLWi_T1	29,21	103,24	132,46	2,87	0,57
(22.8+) shared wall	0	m2	0,000	SW_T1	0,00	0,00	0,00	0,00	0,00
(23+) floor	45,69	m2	0,215	FLstor_T1	115,32	124,46	239,78	25,28	1,47
(23a+) attic floor	0,00	m2	0,000	0	0,00	0,00	0,00	0,00	0,00
(27.1+) flat roof T1	75,58	m2	0,355	FR_T1	138,89	78,84	217,72	12,74	1,50
(27.2+) inclined roof	40,7	m2	0,191	IR_T1	96,15	266,82	362,98	14,96	0,86
(31.) window external wall part 1	53,34	m2	0,250		0,00	0,00	384,40	30,70	0,1637
(31.+) window finishes - part 1	28,27	m2	0,133	-	38,64	17,81	56,45	1,42	0,13
(31.+) window finishes - part 2	15,25	m2	0,072	-	65,77	20,05	85,82	2,20	0,13
(31.+) window finishes - part 3	18,28	m2	0,086	-	35,92	11,56	47,48	1,42	0,10
(32.) door internal wall - part 1	2,84	m2	0,013	-	229,95	66,51	305,49	0,85	0,03
(32.) door interal wall - part 2	6,49	m2	0,030	-	213,82	60,90	278,59	0,88	0,03
(37.6) roof edge T1 - part 1	32,19	m	0,151	FR_e_T1	47,14	69,73	138,49	17,73	0,69
(5) services	1	building	0,005	Heating1	1584,49	704,78	7401,34	1614,32	6,98
					4419,93	13597,56	23849,08	1840,97	22,24

Legend:

IF (material): initial financial costs related to the materials
IF (labour): initial financial costs related to labour (e.g. construction works)
IF: total initial financial costs
IE (product): initial environmental costs related to the materials and products used in the building
IE (transport): initial environmental costs related to the transport of the materials and products to the construction site

Fig. 1 Print screen of the simulation tool illustrating the cost calculation for a number of building elements at building level

In a second step, the quality evaluation has been translated into the simulation tool. This enables us to calculate for each dwelling type the quality score at the building level. In addition a macro has been developed to enable easily to compare different alternative solutions for the same dwelling.

Finally the optimisation is executed in Excel based on the results from the LCA/LCC simulation (costs) and the results of the quality analysis simulation (benefits).

4. THE RESULTS OF THE FIRST ANALYSIS OF ONE SPECIFIC DWELLING TYPE

The methodological approach and the simulation tools that we developed with SuFiQuaD have been applied to a number of dwelling types in order to test their applicability and viability. The conclusions from this first application exercises led to further improvement and refinement of both the methodology as well as the simulation tools.

In sections 4.1 to 4.4 below the results from one of the dwelling types, i.e. a newly built terraced house, are discussed.

4.1 Description of the dwelling type

The new terraced house is a two-storey house, with an unused attic. The dwelling consists of a living room, kitchen, storage room, entrance hall with staircase, night hall, bathroom, three bedrooms and a garage. A terrace is adjacent to the living room and kitchen. The habitable surface of the dwelling is 144 m². Different options (technical solutions) for most of the building elements are considered and compared in the CBA-analysis. For the facades for example (front and back) cavity walls consisting of bricks (both inner and outer layer) are compared with other facade finishes like wood claddings and cement fibre board) and with other structural solutions, like for example a wood skeleton for the inner layer. For the inclined roof for example two types of finishing are considered (clay roof tiles and concrete roof tiles. For the building elements occurring in the building envelope (exterior wall, roof, ground floor and windows) both non-insulated as well insulated alternative solutions were considered in the analysis and the total costs and benefits are compared in the CBA-analysis [13].

4.2 LCA and LCC calculations

The calculations of the new terraced house carried out both excluding and including the transportation during the use phase of the dwelling. Costs related to the transportation during the use phase include transport of the inhabitants to work and back, and for other purposes like shopping and leisure. A transportation scenario was defined for an average Belgian family and processed to obtain the financial and environmental cost per year, per m2 floor area. From these calculations we can conclude that transportation during the use phase is enduing an important financial and environmental cost. The financial transport cost is average responsible for 53% of the life cycle financial cost. The environmental transport cost is also responsible for 58% of the life cycle environmental cost. However, since the transport scenario for the new terrace house is identical for all the different element solutions that will be analysed for the newly built terraced house, it has been excluded from the results that will be presented in the next sections.

4.3 New terraced house – cost optimisation

The results for the cost optimisation (environmental and financial) of the new terraced house are discussed in this section. Fig. 2 shows the results comparing the initial cost to the life cycle cost. This figure is presented in the paper to show the way the different dwelling options are presented in a so-called cost optimisation graph. These options (green en blue dots in Figure 3) all refer to different options at the element level or a the level of the different working sections of the building elements, that are used to build the new terraced house.

The initial cost is plotted on the horizontal axis, while on the vertical axis, the life cycle cost is plotted. For both the initial cost as well as the total life cycle cost different cost parameters has been considered and plotted: only environmental costs, only financial costs and finally also the total costs (environmental + financial).

All costs are expressed per m² floor area per year. The results are given both for a service life of 60 years (right grouped solutions presented by the green cloud of dots) and for a service life of 120 years (left grouped solutions presented by the blue cloud of dots). Indeed the yearly initial cost per m2 floor area is lower for a lifespan of 120 years in comparison with a life span of 60 years, which explains the left and right groupings in the graph.

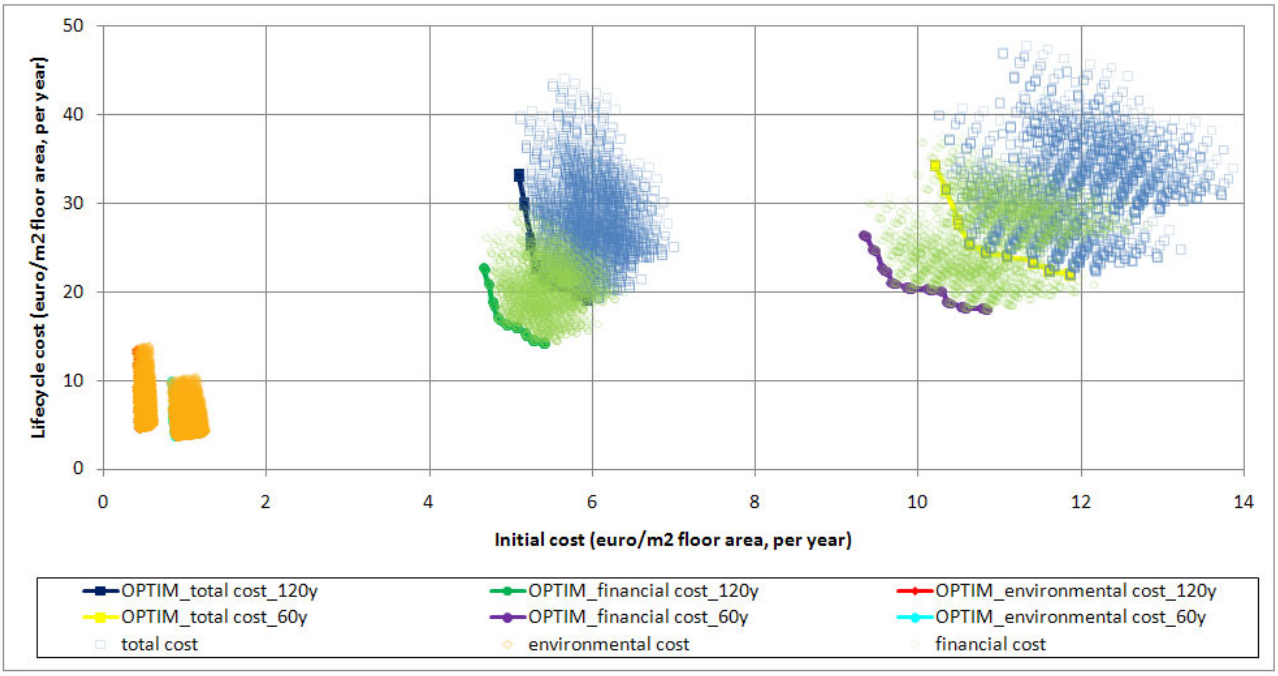


Fig. 2 Pareto front for the initial costs versus total life cycle costs for the new terraced house

In the following paragraphs the results for the new terraced house with a lifespan of 120 years are elaborated more in detail.

4.3.1 Financial cost

Financial costs are related to the investment costs, the periodical costs and the costs for transport and treatment at the end-of-life. The dwelling option with the lowest investment cost is called the reference dwelling and proves to be the one which is not insulated except for the inclined roof (type 2), with inner walls of wood skeleton, an intermediate floor of wood structure, a flat roof of wood structure, normal double glazing and carpet as floor finish in the living room and bedrooms.

According to the results starting from this reference dwelling, the best initial investment for the new terraced house is to opt for another type of inner walls, namely building bricks instead of the wood skeleton. This option leads to the highest reduction of the financial life cycle cost for the lowest increase of financial initial investment cost. Different insulation options are considered in the analysis: from no insulation to a thick insulation layer (two extremes). This is the reason why priority is given to the change of the inner wall type instead of more insulation the dwelling. Better insulation the dwelling leads to a higher financial investment cost compared to the changing of the type of inner walls.
If it is financially feasible (higher investment cost) one should preferably invest in flat roof insulation. Flat roof insulation requires a higher initial investment cost than choosing inner walls of building bricks, but it leads to a higher reduction of the total life cycle financial cost. Insulating the exterior walls, combined with flat roof insulation and interior walls of wood skeleton is the next best initial investment. This is followed by adding insulation in the ground floor and choosing for thermally improved glazing. Finally one should opt for an intermediate floor of a concrete structure instead of wood structure. All these options will lead to relatively higher initial investment costs but they will eventually lead to lower total financial costs (initial and periodical costs).

4.3.2 Environmental cost

The environmental costs can be divided into initial environmental costs and periodical environmental costs. The initial environmental costs are related to the production of the building materials, the transportation of these materials to the building site, the construction of the building, the transport to an end-of-life treatment and the end-of-life treatment itself. The periodical environmental costs are related to the use phase of the dwelling (maintenance, energy consumption, refurbishment, replacement, etc.).

The dwelling with the lowest initial environmental cost is completely not insulated and has been built with inner walls of sand-lime bricks. From an environmental point of view, the first initial investment one should make is to opt for thermally improved glazing. This should be followed by insulating the flat roof. In a next step one should insulate the exterior walls, the flat roof and finally the ground floor. All these solutions have systematically higher initial investment costs but lead finally to lower total environmental costs (including both initial as well as periodical costs).

The most optimal solution is the one with following technical solutions:

- External wall: wood skeleton + facing bricks, insulated
- Flat roof: concrete slab, insulated
- Ground floor: insulated
- Interior wall 2: sand-lime brick
- Intermediate floor: concrete slab
- Thermally improved glazing
- Carpet in the bedrooms and living room

4.3.3 Total cost (financial and environmental costs)

The total cost consists of the total financial cost (initial and periodical) and the total environmental cost (initial and periodical). So the analysis is repeated considering the total cost instead of only the financial cost or the environmental cost. The results on the Pareto front revealed to be identical to the ones on the Pareto front based on financial costs.

Fig. 3 shows a more detailed analysis of the solutions on the Pareto front as resulted from the optimisation for a dwelling lifespan of 120 years. For each option the importance of the different life phases is shown. This graph clarifies the contradiction mentioned above between financial and environmental optimisation. The figure shows that the initial cost is mainly determined by the financial part, while heating the dwelling induces a financial and environmental cost that are more evenly distributed. The relative small negative values are due to the credits that are given to recycled materials or to incineration with energy recovery at the end of life.

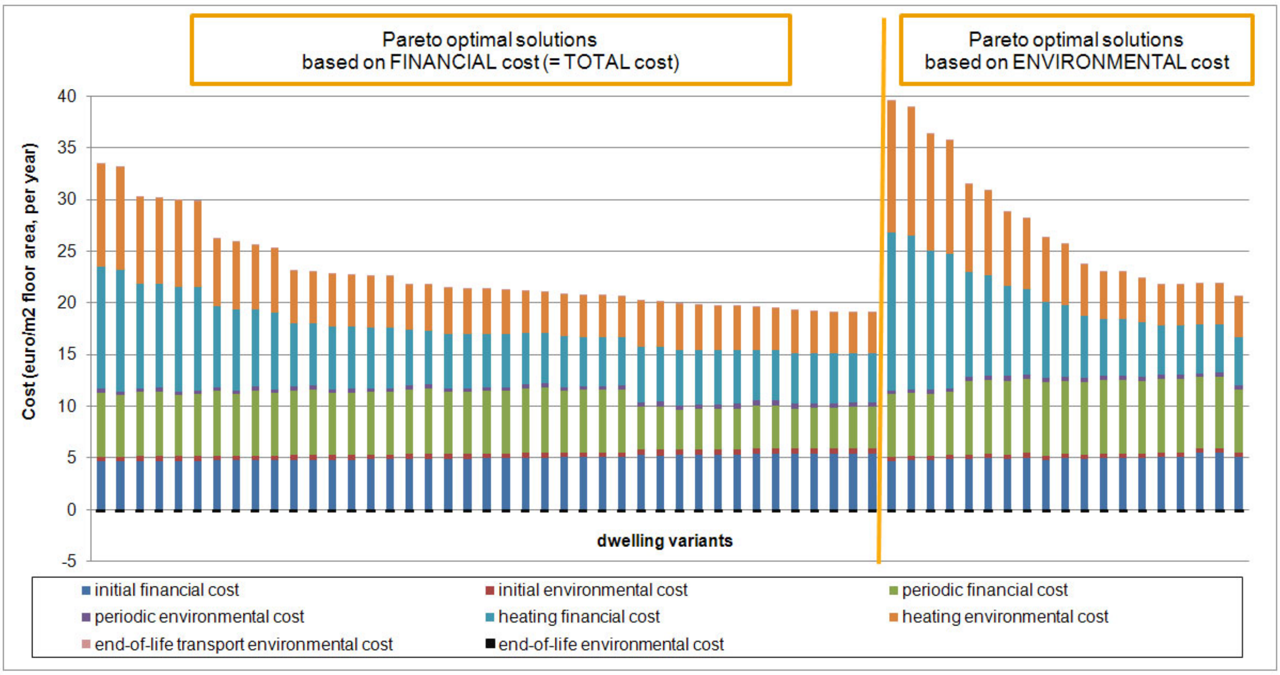


Fig. 3 New terraced house: detailed analysis of the Pareto optimal subset of dwelling options, indicating the importance of the different life phases

4.4 CBA analysis - cost/quality optimisation

In the previous sections the optimisation was based on costs only. Now the optimisation will be based on both costs and benefits (qualities in the SuFiQuaD project). So the Pareto front (most optimal solutions) optimizing costs and qualities is plotted in Fig. 4. On the X-axis the life cycle costs are plotted. On the Y-axis the quality scores are for each dwelling option are plotted. For the total cost: the total financial cost, the total environmental cost and the sum of both are considered.

The results as shown in Fig. 4 represent the new terraced house with a lifespan of 120 years. The same optimization approach is used for definition the Pareto front. During optimisation we are looking for the highest quality increase for the lowest additional cost.

It can be clearly seen in Fig. 4 that the quality scores are identical for many dwelling options. The reason for this is that the analysed alternatives for technical solutions for the new terraced dwelling do not influence the quality to a great extent. However, the quality evaluation will be more important when optimising the layout of the dwelling and when comparing the different dwelling types (for instance new terraced house versus apartment). It is important to remark however that the Pareto front solutions resulting from the cost/quality analysis differs from the ones based on cost considerations only.

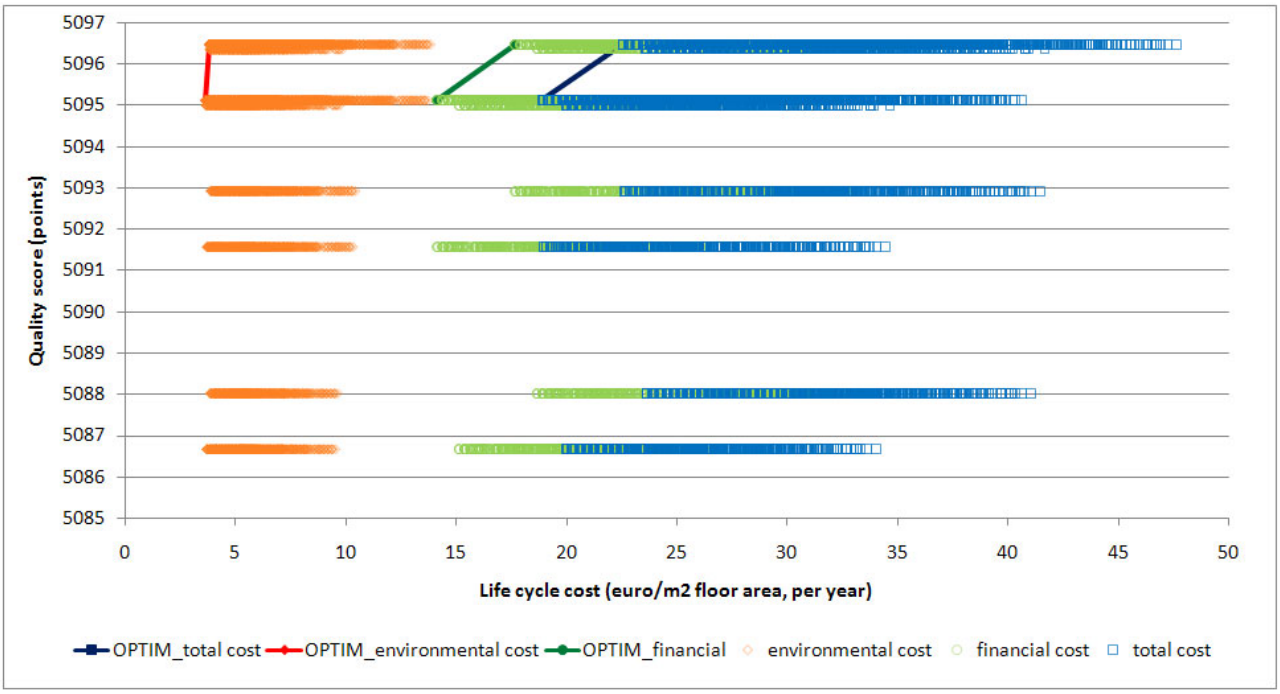


Fig. 4 Pareto front for life cycle costs versus qualities of the new terraced house

5. CONCLUSIONS AND FURTHER RESEARCH

As for the above described new terraced house, an analysis was made of a new freestanding house, a renovated terraced house and an apartment. A full comparison of these different dwelling types was not yet possible, since at this moment (first of the project), not yet all aspects were included (e.g. radiators, cleaning and maintenance costs). The aim of this first series of assessments was however not to make a full and complete comparison of different dwelling options (for one specific dwelling type), and different dwelling types, but to test the developed methodological approach and the simulation tool that we developed up till now. From these analyses, it can be concluded that the methodology and simulation tool are valid, but some further refinement is still necessary.

The decisions based on the optimisation of the different parameters (environmental cost, financial cost, total cost and quality) revealed not to be always in line. It seemed that decisions based on financial costs were not identical as the ones based on the environmental costs, whereas the decisions based on total costs were more or less in line with decisions based on the financial costs. The steps to evolve from the reference dwelling to the most optimal final dwelling are however not always identical. This means that within a limited budget, the measures taken based on total cost can differ from the measures taken based on financial cost only. Furthermore, the optimal solutions based on cost optimisation were not identical to the optimal solutions taking into account the quality of the dwelling. This can be explained by the fact that from quality perspective, there are other priorities to be considered than those which can be addressed by cost optimisation (e.g. ease of maintenance, acoustical performance).

For the determination of the Pareto front solutions, we started with a reference dwelling, defined by the lowest initial cost (in the case of cost-optimisation or lowest total cost in the case of Q/C-optimisation) and searched for the solutions with the highest life cycle cost decrease for the smallest extra investment cost (in the case of cost-optimisation or highest quality increase for lowest total cost increase in the case of Q/C-optimisation). However the analysis of the new terraced house revealed that the last Pareto front solutions resulted in a high increase of the investment cost for a small decrease of the life cycle cost. The question has risen if it is worthwhile to take these last measures. Based on these findings, it was decided that extra conditions are needed to determine which minimum extra reduction of the life cycle cost should be achieved for the extra investment made (or thus: what should the minimum inclination be (marginal efficiency) on the Pareto front). This will be further elaborated during the analysis of different representative dwelling types during the second phase of the SuFiQuaD project.
Furthermore for the analysis of the new terraced house, we always made an analysis based on total cost, financial cost and environmental cost. However, considering financial cost only does not seem to contribute to the improvement of the sustainability of the dwelling stock. Moreover considering environmental costs only, is only relevant if the dwelling owner has no financial budget restrictions at all. Therefore the analysis of the representative dwelling types will mainly be based on total costs. The differentiation between financial and environmental cost will only be done for some specific cases to make a detailed analysis of both separately if this seems relevant.

So during the second phase of the SuFiQuaD project (from January 2009 until December 2011), a series of representative dwelling types for the Belgian dwelling stock will be analysed. The results of these analyses will allow a comparison of different dwelling types and, within each dwelling type, between the different building elements and technical solutions. As such, priority actions for improvements can be identified and recommendations will be formulated to steer the Belgian policy to strive for a more sustainable dwelling stock.

6. ACKNOWLEDGEMENT

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Print your name here: Carolin Spirinckx

Date: 28th of November 2008

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The SuFiQuaD project - Sustainability, Financial and Quality evaluation of Dwelling types

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Keywords: life cycle assessment, life cycle costing, quality assessment, multi-criteria analysis, dwelling types

Context
In Belgium, as in other countries, the construction sector is responsible for an important part of the total environmental impact, of which housing represents a significant fraction. Most of the current approaches aiming at a sustainable development of the (building and) housing sector, are focusing on one or sometimes a combination of a few aspects (materials, energy use of end users, etc.), but do not consider the complex interrelations between housing typology, lifestyle, spatial characteristics, technical solutions for elements and financial and ecological consequences. The SuFiQuaD project (Sustainability, Financial and Quality evaluation of Dwelling types) therefore takes an integrated approach as the starting point, with the aim to identify the optimal solutions from environmental, financial and dwelling quality viewpoint. The methodology will be based on optimisation techniques. The aim is to optimise quality versus the total cost of different dwelling types. The total cost represents the sum of the environmental costs and the financial costs during the whole life cycle of the dwellings.

Objectives
This research no longer wants to focus on the energy use of buildings only, nor to limit the study to the reduction of the environmental impact of building materials. The aim is neither to draw conclusions for housing in general, nor to impose a detailed environmental analysis of each building. The proposal departs from the need for an integrated approach aiming at a typology-specific analysis concerning the reduction of the environmental impact of the building and housing sector, taking into account the building performance and financial consequences.

'Integrated': analysis at the building level
In contrast to existing approaches, the SuFiQuaD approach starts from the insight that the analysis should be carried out at the level of the building. This starting point is seen as crucial since this level overwrites all sustainability effects on lower levels.

'Integrated': taking into account all actors
A second important characteristic of the SuFiQuaD 'integrated' approach is that all actors of the building process and their interrelations are taken into account. It will be examined how each player can contribute to a more environmentally friendly building. This means that not only the responsibilities of each player will be determined, but also how these are linked and dependent on the performance of the other players and how they can be influenced.

'Integrated': taking into account all environmental aspects
The research is not only focusing on a single aspect such as energy or CO2-emissions, but takes into account all definable environmental effects, such as depletion of resources, waste production, emissions, land use, etc. Environmental Life Cycle Assessment (LCA) is considered as an appropriate tool for describing all relevant effects over the entire lifetime of a building. Picturing an overview of a wide range of effects offers little support for decision makers. A methodological challenge is to

propose a ‘transparent’ and ‘adaptable’ decision making tool e.g. an indicator or an eco-cost.

‘Integrated’: financial, environmental and quality aspects
The awareness that the financial consequences of environmental improvements are an important issue for the stakeholders as well as for policy makers, leads to the necessary integration of the financial costs in the analysis. Both the investment cost and the operational costs are of interest, in terms of budget restriction and financial efficiency respectively and are integrated in the evaluation. The costs will be calculated based on Life Cycle Costing (LCC) principles. Finally a quality evaluation is seen as an essential part of the ‘integrated approach’ since on the level of the building no identical ‘functional units’ are definable. Different typologies represent different qualities, but also within a certain typology different qualities can be obtained depending on the design, size, choice of building materials, etc. Moreover quality is a precondition for sustainable buildings. Indeed, an empty building is not sustainable at all, and the life span of a building is partly determined by its quality. The quality evaluation will be done by carrying out a Multi-Criteria Analysis (MCA).

‘Typology-specific’ recommendations
In order to solve the continuing limited action by the stakeholders (users in the first place), the proposed research wants to lead to ‘identifiable’ results instead of general statements. To reach this aim, the research will focus on different dwelling typologies, amongst others apartments, freestanding houses and terraced houses. Recommendations specific for a certain typology are expected to lead to recognizable actions and are therefore more directly linked to one’s personal situation. This holds for the (future) users of the building, as well as for those who design and build it and for the interrelation between all. To make the results more meaningful for users, a reference case will be defined for each type. This allows comparing one’s own situation with a reference situation, which stimulates actions of improvement. The spatial planning of urban and other areas influences the amount of infrastructure needed to be built and maintained for transportation of people and goods. Moreover it determines the distances of transportation needed for the mobility of occupants. Within the research field of housing, this is linked to the choice of housing typology and is therefore seen as part of this research proposal. An overview of existing typologies in Belgium will be sketched and representative types will be selected for further analysis. Dwelling types which are representative for the whole country will be selected since these differ significantly in the different regions.

Summarized, the aim is to develop and apply a methodology to evaluate both the initial and future costs (financial and environmental) and benefits (building qualities) of different housing types. Investigating a number of technical, spatial and user behaviour parameters will lead to identifiable recommendations for the stakeholders and form a basis for policy formulation.

The following paragraphs describe the different elements of the integrated assessment approach, i.e. environmental impact assessment using Life Cycle Assessment (LCA), financial cost evaluation using Life Cycle Costing (LCC) and the quality evaluation using a multi-criteria analysis (MCA).

Environmental impact assessment by using LCA
The environmental impact assessment is performed by using a Life Cycle Assessment (LCA) [1-6] of the dwelling. The total life cycle of the dwelling is analyzed: from the extraction of primary raw materials to the final demolition and end-of-life treatment. Derived from the function of the dwellings, the functional unit is defined. The functional unit should measure the performance of the different dwelling types and should provide a reference to which all the environmental inputs (use of raw materials and energy) and outputs (emissions to air, water, soil, other) can be normalised. Since dwellings fulfil more than one function, the choice of the functional unit is not simple. Different functional units occurred in studies reviewed within the literature. In the REGENER project [7], for example, the whole building, located at a certain point in a given region, is considered as the basic functional unit. For this SuFiQuaD project we will use one square meter of the total gross floor area. To be able to compare dwellings with a different life expectancies the environmental impact per square meter of the total gross floor area per year will also be calculated. In addition, the SuFiQuaD method

also calculates the results per inhabitant to correct any appearance that larger buildings are more sustainable than smaller ones. For all dwellings that will be assessed within the SuFiQuaD project we assume an average service life of 60 years, which is an accepted average for the Belgian context [8]. Sensitivity analyses will be performed to assess the impact of other service years (60, 90 and 120 years) on the final results.
During the collection the of the environmental data (life cycle inventory - LCI-data) related to the entire life cycle of the building we rely mainly on the Ecoinvent database [9]. For the life cycle impact assessment of the inventoried inputs and outputs; we used the eco-indictor 99 method [10]. In addition we developed a method to translate the environmental burdens and impacts into monetary values (euros). In order to cover as many environmental aspects as possible we combine different existing methods for the translation of environmental aspects into monetary terms. Therefore we call it a "hybrid" method [13]. The method is based on a combination of the impact assessment as used within the series of the European ExternE projects [11], the Eco-indicator 99 approach [10] and other research projects on monetarisation [12].

Financial cost evaluation by using LCC

The aim of the financial cost evaluation is to evaluate the financial costs over the whole life cycle of the dwelling. This should be seen as an analysis at the micro-economic level. For a more detailed description of Life Cycle Costing, we refer to literature [14-16]. Additional to the financial cost evaluation, the aim of the SuFiQuaD project is also to search for the most efficient additional spending, starting from the cheapest acceptable solution, to reduce the total financial costs. Moreover, the importance of the contribution of the different life phases of the dwelling to the total financial cost is also reported and visualised. Prices for building elements are based on a publicly available database with prices for work sections for Belgium [17-18]. Where data were lacking, specific contractor prices have been used.

Quality evaluation by using MCA

The functional unit of the dwellings that will be analysed within the SuFiQuaD project has been defined as one square meter of total floor area per year. Since dwellings are multi-functional and the performance of a single square meter of total floor area is thus not identical for different analysed dwellings, it has been decided to also include a so-called quality evaluation of the dwellings. The quality evaluation is based on an existing method for housing in Belgium [19] and is based on a multi-criteria analysis.

Optimisation approach

This optimisation starts from a defined reference dwelling (for each of the different dwelling types considered) and is based on comparative analysis of different technical solutions. For each dwelling analyzed preference will go to the solutions with the lowest environmental impacts and financial costs and with the highest qualities. To do so a cost-benefit analysis (CBA) is used as optimisation method within the SuFiQuaD project. In the CBA-analysis the benefits are considered as the qualities and the costs are considered as the total life cycle costs (both financial and environmental costs). During CBA-analysis we will determine those dwelling options which offer the highest marginal quality improvement for the lowest additional cost. The other dwelling options on the Pareto front are inferior to those optimal solutions and can only be interesting if there are no budget restrictions.

Results of first analysis of one specific dwelling type

The methodological approach that we developed with SuFiQuaD has been applied to a number of dwelling types in order to test their applicability and viability. The conclusions from this first application exercises led to further improvement and refinement of both the methodology as well as the simulation tool.

Description of dwelling type

The new terraced house is a two-storey house, with an unused attic. The dwelling consists of a living room, kitchen, storage room, entrance hall with staircase, night hall, bathroom, three bedrooms and a garage. A terrace is adjacent to the living room and kitchen. The habitable surface of the dwelling is 144 m². Different options (technical solutions) for most of the building elements are considered and compared in the CBA-analysis. For the facades for example (front and back) cavity walls consisting of bricks (both inner and outer layer) are compared with other facade finishes like wood claddings and cement fibre board) and with other structural solutions, like for example a wood skeleton for the inner layer.

Cost optimisation

The results for the cost optimisation (environmental and financial) of the new terraced house are presented in Figure 1. The technical solutions (green en blue dots) all refer to different options at the element level or a the level of the different working sections of the building elements, that are used to build the new terraced house. The initial cost is plotted on the horizontal axis, while on the vertical axis, the life cycle cost is plotted. For both the initial cost as well as the total life cycle cost different cost parameters has been considered and plotted: only environmental costs, only financial costs and finally also the total costs (environmental + financial). All costs are expressed per m² floor area per year. The results are given both for a service life of 60 years (right grouped solutions presented by the green cloud of dots) and for a service life of 120 years (left grouped solutions presented by the blue cloud of dots). Indeed the yearly initial cost per m2 floor area is lower for a lifespan of 120 years in comparison with a life span of 60 years, which explains the left and right groupings in the graph.

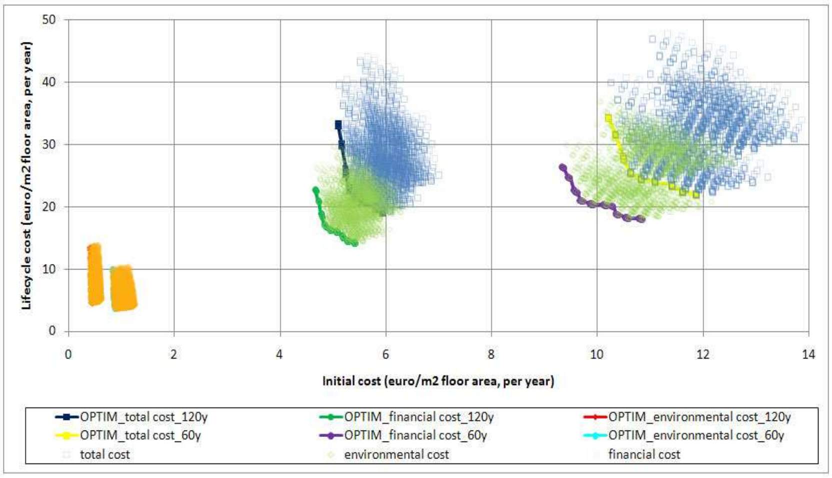

Figure 1: Pareto front for the initial costs versus total life cycle costs for the new terraced house

Financial cost

Financial costs are related to the investment costs, the periodical costs and the costs for transport and treatment at the end-of-life. The dwelling option with the lowest investment cost is called the reference dwelling and proves to be the one which is not insulated except for the inclined roof, with inner walls of wood skeleton, an intermediate floor of wood structure, a flat roof of wood structure, normal double glazing and carpet as floor finish in the living room and bedrooms. According to the results starting from this reference dwelling, the best initial investment for the new terraced house is to opt for another type of inner walls, namely building bricks instead of the wood skeleton. This option leads to the highest reduction of the financial life cycle cost for the lowest increase of financial initial investment cost. Different insulation options are considered in the analysis: from no insulation to a thick insulation layer (two extremes). This is the reason why priority is given to the change of the inner wall type instead of more insulation the dwelling. Better insulation the dwelling leads to a higher financial investment cost compared to the changing of the type of inner walls. If it is financially feasible (higher investment cost) one should preferably invest in flat roof insulation. Flat roof insulation requires a higher initial investment cost than choosing inner walls of building bricks, but it leads to a higher reduction of the total life cycle financial cost. Insulating the exterior walls, combined with flat roof insulation and interior walls of wood skeleton is the next best initial investment. This is followed by adding insulation in the ground floor and choosing for thermally improved glazing. Finally one should opt for an intermediate floor of a concrete structure instead of wood structure. All these options will lead to relatively higher initial investment costs but they will eventually lead to lower total financial costs (initial and periodical costs).

Environmental cost

The environmental costs can be divided into initial environmental costs and periodical environmental costs. The dwelling with the lowest initial environmental cost is completely not insulated and has been built with inner walls of sand-lime bricks. From an environmental point of view, the first initial investment one should make is to opt for thermally improved glazing. This should be followed by insulating the flat roof. In a next step one should insulate the exterior walls, the flat roof and finally the ground floor. All these solutions have systematically higher initial investment costs but lead finally to lower total environmental costs (including both initial as well as periodical costs).

Total cost

The total cost consists of the total financial cost (initial and periodical) and the total environmental cost (initial and periodical). So the analysis is repeated considering the total cost instead of only the financial cost or the environmental cost. The results on the Pareto front revealed to be identical to the ones on the Pareto front based on financial costs. Figure 2 shows a more detailed analysis of the solutions on the Pareto front as resulted from the optimisation for a dwelling lifespan of 120 years. For each option the importance of the different life phases is shown. This graph clarifies the contradiction mentioned above between financial and environmental optimisation. The figure shows that the initial cost is mainly determined by the financial part, while heating the dwelling induces a financial and environmental cost that are more evenly distributed. The relative small negative values are due to the credits that are given to recycled materials or to incineration with energy recovery at the end of life.

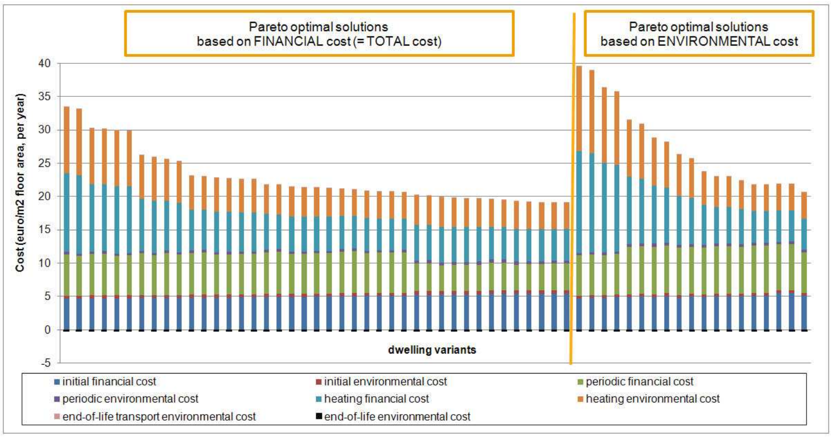

Figure 2: New terraced house: detailed analysis of the Pareto optimal subset of dwelling options, indicating the importance of the different life phases

Conclusions and further research

As for the above described new terraced house, an analysis was made of a new freestanding house, a renovated terraced house and an apartment. A full comparison of these different dwelling types was not yet possible, since at this moment (first of the project), not yet all aspects were included (e.g. radiators, cleaning and maintenance costs). The aim of this first series of assessments was however not to make a full and complete comparison of different dwelling options (for one specific dwelling type), and different dwelling types, but to test the developed methodological approach and the simulation tool that we developed up till now. From these analyses, it can be concluded that the methodology and simulation tool are valid, but some further refinement is still necessary.

The decisions based on the optimisation of the different parameters (environmental cost, financial cost, total cost and quality) revealed not to be always in line. It seemed that decisions based on financial costs were not identical as the ones based on the environmental costs, whereas the decisions based on total costs were more or less in line with decisions based on the financial costs. The steps to evolve from the reference dwelling to the most optimal final dwelling are however not always identical. This

means that within a limited budget, the measures taken based on total cost can differ from the measures taken based on financial cost only. Furthermore, the optimal solutions based on cost optimisation were not identical to the optimal solutions taking into account the quality of the dwelling. This can be explained by the fact that from quality perspective, there are other priorities to be considered than those which can be addressed by cost optimisation (e.g. ease of maintenance, acoustical performance).
Furthermore for the analysis of the new terraced house, we always made an analysis based on total cost, financial cost and environmental cost. However, considering financial cost only does not seem to contribute to the improvement of the sustainability of the dwelling stock. Moreover considering environmental costs only, is only relevant if the dwelling owner has no financial budget restrictions at all. Therefore the analysis of the representative dwelling types will mainly be based on total costs. The differentiation between financial and environmental cost will only be done for some specific cases to make a detailed analysis of both separately if this seems relevant.
So during the second phase of the SuFiQuaD project (from medio 2009 until December 2011), a series of representative dwelling types for the Belgian dwelling stock will be analysed. The results of these analyses will allow a comparison of different dwelling types and, within each dwelling type, between the different building elements and technical solutions. As such, priority actions for improvements can be identified and recommendations will be formulated to steer the Belgian policy to strive for a more sustainable dwelling stock.

Acknowledgement
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Methodology for optimising the sustainability of buildings

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Abstract

The four-year project SuFiQuaD has developed a methodology that can be applied to optimise dwellings, taking into account their environmental impact, financial cost and their quality considering the entire life cycle. This paper describes the main principles of the developed methodology, and illustrates the LCA-LCC analysis that can be carried out on both building and element level. As an example, the results are presented for a variation of the structural part and insulation (materials and thickness) of exterior walls. The initial costs/impacts are compared to the life cycle costs/impacts, thus indicating which initial investments are most effective. These results indicate that it is possible to optimise the technical building solutions towards the ultimate objective of zero-impact buildings.

Keywords: life cycle assessment (LCA), life cycle costing (LCC), optimisation, integrated approach, building level, element level

1 Introduction

As in other sectors, sustainable development has become an important topic in the construction sector. There is however still a long way to go before reaching the ultimate goal of zero-impact buildings: Buildings are still insufficiently insulated, and the environmental impact of the applied building materials is often not known. Furthermore, the amount of construction and demolition waste is enormous and the importance of transport is highly underestimated. Although people are more conscious than a decade ago, no overall change is noticeable. It is therefore important to show not only the possibilities of reducing the environmental burdens of buildings, but also to raise awareness on the financial consequences of this environmental optimisation process and to emphasise that environmentally friendly and cost efficient buildings can also bring the same qualities to the building users.

The four-year research project SuFiQuaD (**Su**stainability, **Fi**nancial and **Qua**lity evaluation of **D**welling types) [1] has developed a methodology for such an integrated assessment of the life cycle environmental and economic performance of Belgian dwelling types. The methodology combines an LCA and LCC approach with a quality evaluation on dwelling level.

2 LCA-LCC modelling

2.1 Life cycle of the building

The approach for the environmental and financial assessment is very similar. In both cases, the entire life cycle of the building is taken into account, subdivided into the initial phase (before use of the building), the use phase and the end of life phase. This principle is illustrated in Fig. 1.

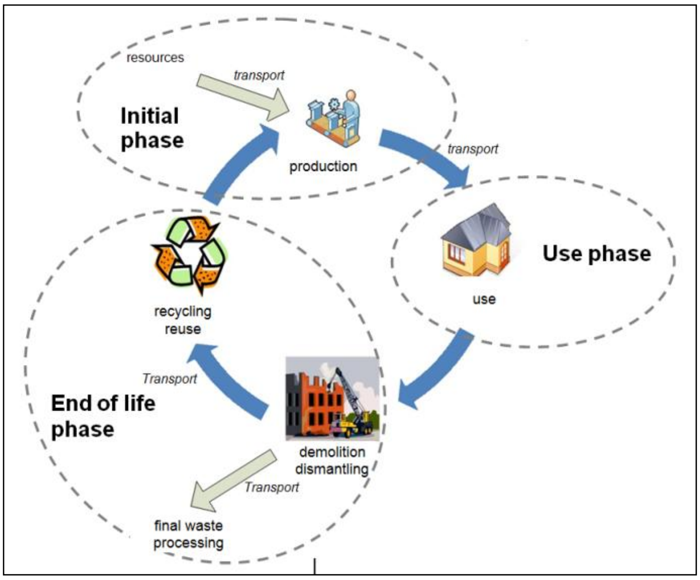

Fig. 1 Life cycle of a building [2]

For the LCA analysis, the initial phase is further subdivided into the production of construction products, including extraction of resources and transport of these resources to the production plant, transport of construction products to the construction site (using default scenarios for a series of product groups) and the on-site construction processes (limited to taking account of construction losses). For the LCC analysis, the initial phase comprises both the material costs and the labour cost for installing the products in the building.

The use phase is included in a similar way in the LCA and LCC calculations. On the one hand, there are material related burdens (environmental and financial) for cleaning, maintenance and replacements. For the financial costs, it is assumed that all actions are being paid for, in order to ensure fair comparisons. On the other hand, there are burdens related to the energy use of the building (only heating, sanitary hot water and ventilation).

With regard to the environmental assessment of the end of life (EOL) phase, a distinction is between demolition/dismantling activities, transport of the waste materials and final waste treatment. Reuse and recycling are also considered. For the calculation of the environmental impact, both the impacts related to the recycling process and the avoided impacts for the avoided production using primary resources are taken into account.

The financial data are mostly taken from the Belgian database for construction costs ASPEN [3]. In case of lacking data, price offers from contractors are used as a data source. The environmental data are mainly based on the Swiss Ecoinvent database [4]. Some modifications were made to the original data records to reflect the Belgian situation (e.g. change of electricity mix) better.

2.2 Monetary valuation

The interpretation of the results of an LCA is rarely unambiguous. This is due to the fact that in most cases a set of environmental impact categories is used to express the environmental impact of the object of the assessment, i.e. a construction product, building element or complete building. When comparing different alternatives, it is often difficult to draw a straightforward conclusion of which alternative is preferred. For, one alternative might have the best score for some of the impact categories while the other alternative scores best for other impact categories. To overcome this ambiguity, the different indicators are weighted and aggregated in a single score.

Different methods exist to calculate such an aggregated single score. In this research, monetary valuation is used. This means that each of the environmental impacts are translated into an environmental cost, which allows adding all impacts into an overall environmental cost. This principle is illustrated in Fig. 2. A hybrid monetary valuation method is developed in the SuFiQuaD project, by combining impact assessment as used within the series of the European ExternE projects [5] and the Ecoindicator 99 [6] approach. The valuation is based on the willingness-to-pay approach and for the assessment of human health aspects mainly applies the monetary values of the CAFE project for the Belgian context. The monetary values for the quality of ecosystems and depletion of resources is based on several other sources.

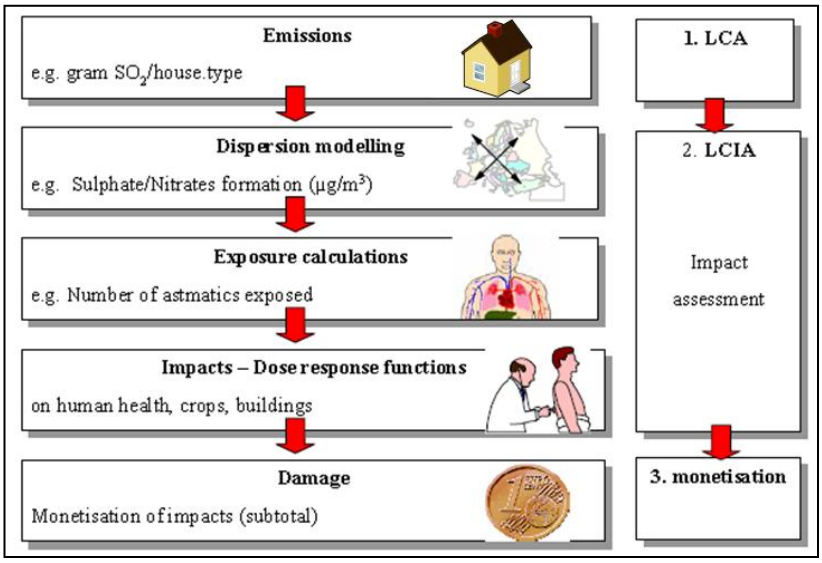

Fig. 2: Monetary valuation of environmental impacts [8]

Thanks to the monetary valuation step, it is possible to integrate the LCA and LCC results, as both the environmental and financial results are expressed in the same unit, i.e. costs in Euros. A separate analysis of environmental effects and financial costs can still be made, but also the total costs can be determined.

2.3 Building level versus element level

For the LCA-LCC analysis of a building, the building is decomposed into the main building elements (exterior walls, interior walls, floors, roofs, ...). Each element is then further subdivided into components or so-called “work sections” (e.g. brick masonry, screwed gypsum boards, etc.). At the lowest level, each work section is composed of a number of construction products/materials. A brick masonry wall for example consists of bricks and mortar, in a specific ratio. By determining the amount of each of the building elements and by linking environmental and financial data to each of the products and materials, the LCA and LCC analysis can be done at building level.

Numerous technical solutions exist for each of the building elements. The SuFiQuaD project aims to mutually combine possible technical solutions for the different elements in order to identify which overall solutions lead to the best result (from environmental and financial perspective) on building level: the optimal solutions are those for which the initial investments (environmental and/or financial costs) lead to the biggest reduction in life cycle costs (Pareto optima). However, combining all possible solutions on building level would result in an enormous amount of building variants, which are difficult to manage and interpret. To overcome this problem, an optimisation analysis is first carried out at the level of building elements.

At element level, an extensive overview is made of all possible technical solutions for the different sub-components of an element (structure, insulation, finishing, ...). Through an analysis of the possible combinations at element level, the mutual relations between the performances can be identified. The identification of the optimal element solutions then allows selecting a limited number of element combinations for further analysis at the building level.

An important point of attention for the analysis at the element level is energy use, which is normally assessed at the building level. If energy use is not included in the analysis at the element level, an increased insulation level only leads to an increased environmental and financial burden. The energy savings should however also be considered. The energy use is therefore included in the LCA-LCC analysis at the element level by using the equivalent degree days method. The principle of this method is that the heating demand of a building is seen as proportional to the number of “equivalent degree days”. The number of “degree days” is defined as the sum of the product of the days where heating is required with the temperature difference between indoor and outdoor. After accounting for the positive effect of solar and internal gains, the “equivalent degree days” can be used as a starting point to calculate the heating demand caused by the transmission losses (Q_T) through the building element. The energy consumption caused by the transmission losses is then equal to the heating demand, divided by the global installation efficiency (Q_T /

η_{global}). The results presented hereafter are based on the assumption of a specific number of equivalent degree days (in this case 1200).

To illustrated the methodological principles described above, the results of one series of LCA-LCC analysis are described in the following section.

3 Analysis of exterior walls

3.1 Introduction

Exterior walls are composed of different materials, which can be grouped into a number of sub-components, i.e. interior finishing, structural part, insulation, cavity and cavity infrastructure (where applicable) and external finishing. More than 250 different technical solutions are inventoried for the different sub-components of exterior walls. Mutual combination of all of these solutions would lead to an enormous amount of possible exterior wall compositions. The analysis is therefore subdivided into several series, in which each time one of the subcomponents is varied. This allows comparing the different possible solutions for the individual subcomponents, both from financial and environmental viewpoint. The following paragraphs give a summary of the analysis of a variation of the structural part (4 alternatives) and insulation (alternative materials and thicknesses) of the exterior wall.

The results of the LCA and LCC analysis are presented in a similar way. First, an overview is given of the financial costs of the analysed exterior wall alternatives. Fig. 3 shows the initial costs (IF) versus the life cycle costs (LF). The same is done for the environmental costs (Fig. 4 - IE versus LE). The results presented hereafter are based on a service life of 120 years.

3.2 Financial costs

In Fig. 3, the four alternatives of the structural part are identified by different types of outlining (see grouping legend). It can be concluded that there are no large differences in life cycle financial costs for different insulation materials applied in the same thickness with a specific structural part. Another general conclusion is that the life cycle financial cost decreases as the initial cost increases. This can be explained by the increasing initial cost with increasing insulation thickness, which leads to a reduction of the heating demand (and associated costs). There are however remarkable differences between alternatives from the four structural types.

At first, a significant decrease in life cycle financial costs is noticed for the brick alternatives with increasing insulation thickness (and initial cost). However, an optimum thickness (if there is no budget restriction) of insulation is reached for some materials. For these, an increased insulation thickness no longer results in a further decrease of life cycle financial costs. For other materials, this optimum is not yet reached.

With regard to the wood skeleton alternatives, the graph shows the same decrease of life cycle costs with increasing insulation thickness (left grouping – e.g. series “wood skel GW”), and the lowest possible life cycle financial cost appears not to have been reached yet when the skeleton is filled completely with insulation. Adding another layer of insulation on top of the skeleton, again placed between a wooden structure, does not seem to be a good solution to further decrease the life cycle financial costs (right grouping – e.g. series “wood skel GW”). A better solution might be to increase the thickness of the structural wood skeleton and completely fill this with insulation. Although this alternative was not investigated, TJI profiles with higher thicknesses are analysed as alternative (see further).

The conclusions for the metal skeleton are similar to those for the wood skeleton. A lower life cycle financial cost seems possible for even higher insulation levels..

The wooden TJI beams, considering three thicknesses (30, 36 and 41 cm) and completely filled with insulation, result in a higher initial cost than traditional wood skeleton (+10%). The life cycle costs of the thinnest alternative are however comparable or even slightly lower than those of a wood skeleton structure completely filled with insulation. Furthermore, it seems that with increasing thickness, the life cycle cost is now increasing instead of decreasing. In other words, this investment is no longer profitable.

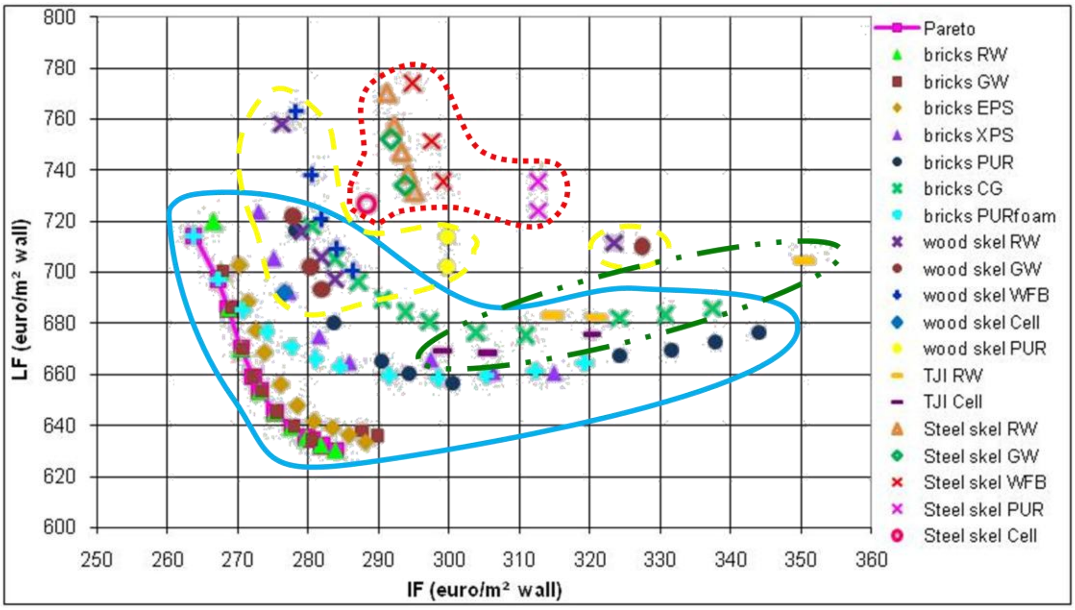

Fig. 3: Initial Financial cost (IF) versus Life cycle Financial cost (LF) for a variation of structural part and insulation of exterior walls

Grouping legend:

	Structural part = brick masonry
	Structural part = wood skeleton
	Structural part = TJI beams
	Structural part = steel skeleton

3.3 Environmental costs

Similarly to the financial cost analysis, the initial environmental impacts (costs) are compared to the life cycle environmental costs (see Fig. 4). Again, the four groups of structural types are identified. Important to notice is that there are only small differences in initial environmental cost. There is however a large spread in the life cycle environmental costs. The most important conclusion from the graph is that, for each of the structural solutions, the life cycle environmental cost decreases with increasing initial investment. It also seems that for a very limited additional initial environmental cost of applying extra insulation (e.g. from 10.5 to 12 € per m²), the decrease in life cycle environmental costs is much larger (from 65 to 30 €). The additional insulation therefore proves to be a very efficient environmental investment.

Fig. 4 also shows that even lower life cycle environmental costs might be possible, although the slope of the curve is in the end decreasing for the wall solutions with extreme thickness of insulation (e.g. TJI beams). For most wall solutions however, a further increase in insulation thickness would lead to a further decrease of total life cycle environmental impact. This is in contrast with the financial analysis, where these higher insulation levels result in a higher life cycle financial cost. Careful considerations have thus to be given to which financial investments are worthwhile to achieve certain environmental objectives.

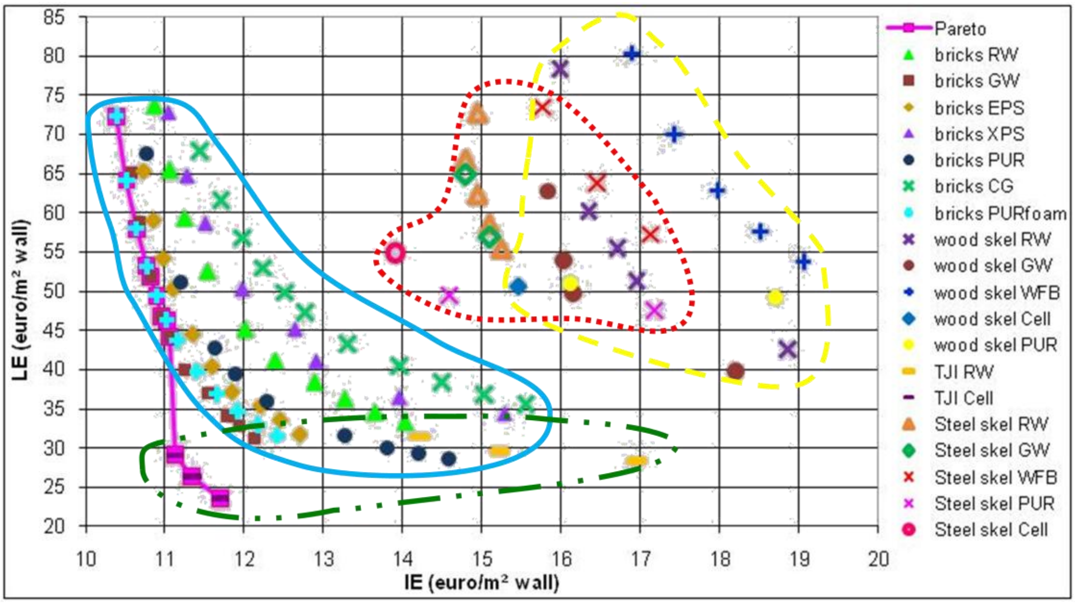

Fig. 4: Initial Environmental cost (IE) versus Life cycle Environmental cost (LE) for a variation of structural part and insulation of exterior walls

4 Conclusions

The LCA-LCC analysis shows that it is always important to look at both environmental and financial aspects in an integrated way in order to make the right decisions on the long term. To drastically improve the environmental performance over the life cycle, little initial additional environmental impacts (costs) are required. However, reaching this objective might not always be possible because of financial restrictions.

Finally, it is clear that reaching the ultimate goal of zero-impact solutions will not be possible, as there are initial burdens associated with the production of materials. The analysis shows however that large reductions of the life cycle impacts can be achieved for only a minor extra investment (both on financial and environmental level). Looking at the more distant future, a further shift towards “greener” energy production combined with new technological innovations would bring us closer to this final goal.

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Towards 0-impact buildings: a caste-study based analysis

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Abstract

To efficiently evolve towards 0-impact buildings it is important to investigate which are the actions in order of priority. The latter can be defined as measures which lead to the highest reduction of the impact for the smallest increase in cost. This paper elaborates on the reduction potential of different environmental impacts of buildings throughout their life cycle based on a set of case studies. The case studies concern typical dwellings in the Belgian context. A life cycle assessment is used for the evaluation of the impacts, while a life cycle cost analysis is applied to determine the financial cost. The impacts are translated into a single score expressed in monetary values. This should be interpreted as an external cost which is not accounted for to date.

Keywords: residential buildings, life cycle assessment (LCA), life cycle costing (LCC), Pareto optimisation, integrated approach

1 Introduction

The paper elaborates on the findings of a PhD research at its final stage. Within the research a methodology is developed to assess the environmental impact, financial cost and qualities of buildings using an integrated approach. The method is applied to different dwelling types within the Belgian context to gain insight in the optimisation potential of both existing and newly-built dwellings. The PhD research is carried out within the four-year research project SuFiQuaD (**Su**stainability, **Fi**nancial and **Qua**lity evaluation of **D**welling types) (BELSPO, 2010). The methodology developed is briefly summarised in the paper entitled '*Methodology for optimising the sustainability of buildings*' (Putzeys, K. et al.) within this SB10 conference. A life cycle assessment and life cycle cost analysis are combined with a quality evaluation.

Although 0-impact buildings are not the focus of the research, the research findings are of interest when searching for a ranking of the most important measures to move towards 0-impact buildings. The findings of the case studies, which are of importance in view of this objective, are summarised; preceded by the description of methodological aspects of interest and of the selected case studies.

2 Assessment methodology

2.1 Environmental impact

The impact assessment method developed is an endpoint approach, expressing the impacts in external costs. The endpoint approach is preferred to a midpoint approach for its greater relevance for decision support. A single score furthermore allows straightforward decisions in case the impacts lead to contradictory conclusions. The translation into monetary values improves communication and enables an integrated approach, combining environmental impact assessment with cost and quality evaluation.

The method developed consists of a combination of existing methods in order to allow the consideration of all impacts which are of importance (as known to date) within the context of buildings. It is mainly based on the CAFE project (Holland, M. et al., 2005) and in consequence includes human health effects due to the emission of CO_2-equivalents (based on the CML method), SO_2, NO_X, PM2.5, NH_3 and VOC. Besides these, human health effects due to carcinogens, respiratory effects, ozone layer depletion and climate change are considered due to other emissions than the pollutants of CAFE. Furthermore human health effects due to radiation are considered and the impact on the quality of ecosystems (ecotoxicity, acidification and eutrophication, land use) together with the depletion of resources (minerals, fossil fuels and freshwater) are included in the analysis. The assessment of the latter effects is based on several sources (European Commission, 2008), (Davidson, M., Hof, A., and Potjer, B., 2002), (Torfs, R. et al, 2005), (Ott, W. et al, 2006), (European Commission, 2006) and (De Nocker, L. et al, 2007).

Based on the above reflections, 0-impact buildings are conceived as buildings which have no (or a minor) impact on each of these environmental effects.

2.2 Financial consequences

Beside the search for the most efficient measures to move towards 0-impact buildings from an environmental viewpoint, it is evenly important to investigate the financial costs. For, if these measures are un-affordable or not of interest from a life cycle cost perspective, the questions rise who will be prepared to make the investment and if no other investments (e.g. beyond the construction sector) are more efficient. Therefore, both the initial and life cycle financial cost of the measures which are of interest from an environmental point of view are investigated.

For the estimation of future costs (e.g. heating costs) the assumptions regarding the economic parameters, such as for instance the increase (or decrease) of the (energy) prices, are important. For the results reported in the subsequent paragraphs the following is assumed (yearly real rates): the discount rate equals 2%, the growth rate for energy prices equals 2%, the growth rate for material costs equals 0% and the growth rate for labour costs equals 1%. For the future environmental costs, the (social) discount rate is assumed to be lower than the market discount rate and equals 1%.

2.3 Pareto optima

The efficiency of the measures is investigated based on the Pareto concept (Figure 1). From all possible measures those options are identified which lay on the Pareto front. In a second step, on this borderline the reduction in life cycle cost for each additional initial investment is evaluated. In first instance, this is done for the environmental cost, mentioning the financial consequences. A similar analysis is made based on initial and lifecycle financial cost, based on the initial financial cost versus life cycle environmental cost and based on life cycle financial versus life cycle environmental cost.

An example of the Pareto optimisation process is illustrated in Figure 1. The initial environmental cost is plotted against the life cycle environmental cost, expressed in euro per m² floor. Moreover, for the options of interest, the financial consequences are indicated. Since heating was found to be an important contributor to the environmental cost, the K and E value (according to the Flemish norms) are mentioned too.

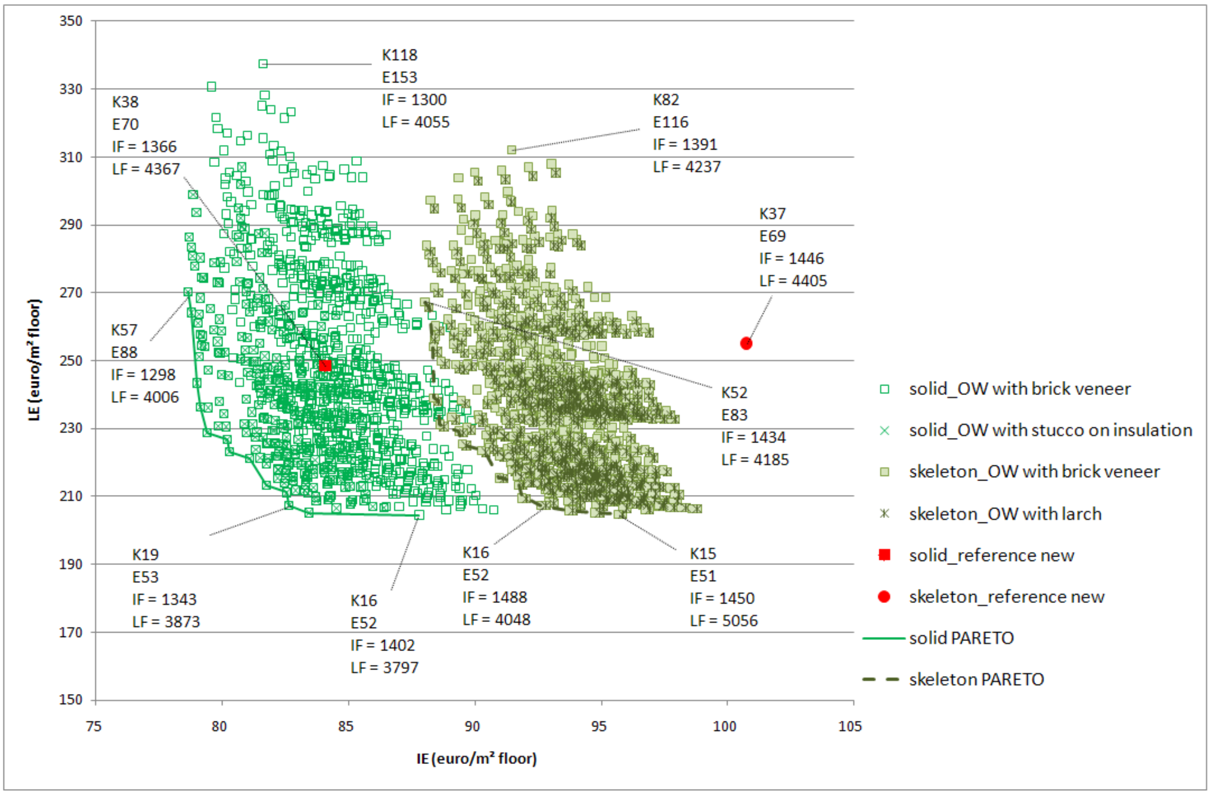

Figure 1 Illustration of the Pareto optimisation process for one of the case studies.

Every point on the graph in Figure 1 represents one alternative of the considered dwelling. The graph differentiates between dwelling alternatives composed of a skeleton structure and of a solid structure. In this graph, for each of both considered construction method, the dwellings with a different exterior finishing of the outer walls are distinguished. The environmental costs of the dwelling according to current practice are also indicated on the graph.

3 Case studies

Since the Belgian housing market is mainly characterised by private investors, the dwelling stock is heterogeneous. Consequently, a limited number of dwellings cannot represent the whole dwelling stock. Despite this observation, 16 dwellings are selected differing in type (detached, semi-detached, terraced and apartment) and construction period (< 1945, 1945 – 1970, 1971-1990, 1991-2001) in line with available statistics. Although these dwellings do not exactly represent the complete stock, these do enable to gain insight in the order of priority of actions to move towards a more sustainable dwelling stock. The dwellings differ moreover in layout, size (floor area and volume), compactness and window area. The divergence of the selected case studies is illustrated in Figure 2. Only future costs and impacts are considered. In consequence, the environmental impact of the existing dwellings is limited to the 'remaining' costs, which are these due to further use of the dwelling and the end-of-life treatment. For the same type newly built dwellings according to current practice are analysed using the Pareto approach as described above.

For each of the dwellings several measures are investigated: the insulation level, the material choice and the technical installation for heating (including the production of hot sanitary water) and ventilation. The investigation assumes materials currently available on the market and therefore only considers current technology. The same applies to the energy production processes considered. The results are based on an assumed life span of the dwellings of 60 years.

Figure 2 A selection out of the 16 analysed dwellings.

4 Results

The analysis reveals that the optimisation based on environmental cost most often requires a limited extra financial investment (0-33%, with an average of 4%) compared to current practice. The life cycle financial cost, on the other hand, is by average reduced by 11%, but for some dwellings increases up to 2%. This is illustrated in Figure 1. If one only considers the skeleton variants, the option corresponding with K15/E51 environmentally performs better than the option characterised by K16/E52 on the Pareto front. However, the life cycle financial cost of the former is higher.

The analysis reveals that the most important impacts of the existing dwelling stock and newly built dwellings are due to the emission of CO_2 equivalents, SO_2, NO_x and PM2.5. Furthermore respiratory effects due to inorganic compounds, ecotoxicity, acidification and eutrophication, depletion of fossil fuels and land use reveal to be important impacts. The other considered effects are proved to be negligible. This is illustrated in Figure 3 for a terraced dwelling. A similar result is obtained for the other dwellings. For this terraced dwelling the most important environmental cost of the existing dwelling (built before 1945 and not renovated yet) is due to the CO_2 equivalents, which are responsible for 49% of the remaining environmental cost. This is followed by the SO_2 emissions (15%) and the depletion of fossil fuels (12%). For an identical building, constructed according to common practice to date, the most important environmental cost is still due to the CO_2 emissions, which are responsible for 48% of the life cycle environmental cost. However, the CO_2 emissions caused during the whole life span (including the construction) of this newly built dwelling is 75% lower than these caused by the use of the old dwelling for the coming 60 years (without any renovation measure). The analysis furthermore revealed that the CO_2 emissions could be further reduced by improving the insulation level. The optimum for this dwelling leads to a further reduction of 33%.

Although less important, the reduction of the SO_2 emissions is even larger: a reduction of 87% is identified for currently built dwellings compared to the remaining impact of the existing dwelling and a further reduction of 22% is achieved for the optimum defined for this dwelling.

The reduction of the depletion of fossil fuels equals 75% for the newly built and an extra 27% for the optimised dwelling. The NO_x emissions are reduced by 77% and 24% respectively and the PM2.5 emissions by 60% and 39%.

Despite the reduction of most impacts, some increases are identified too. The emission of NH_3 has increased with 20% for both the reference for newly built and the optimised dwelling. The ozone layer depletion of the newly built reference is 915% higher compared to the existing dwelling, but remains unimportant (less than 1% of the life cycle environmental cost).

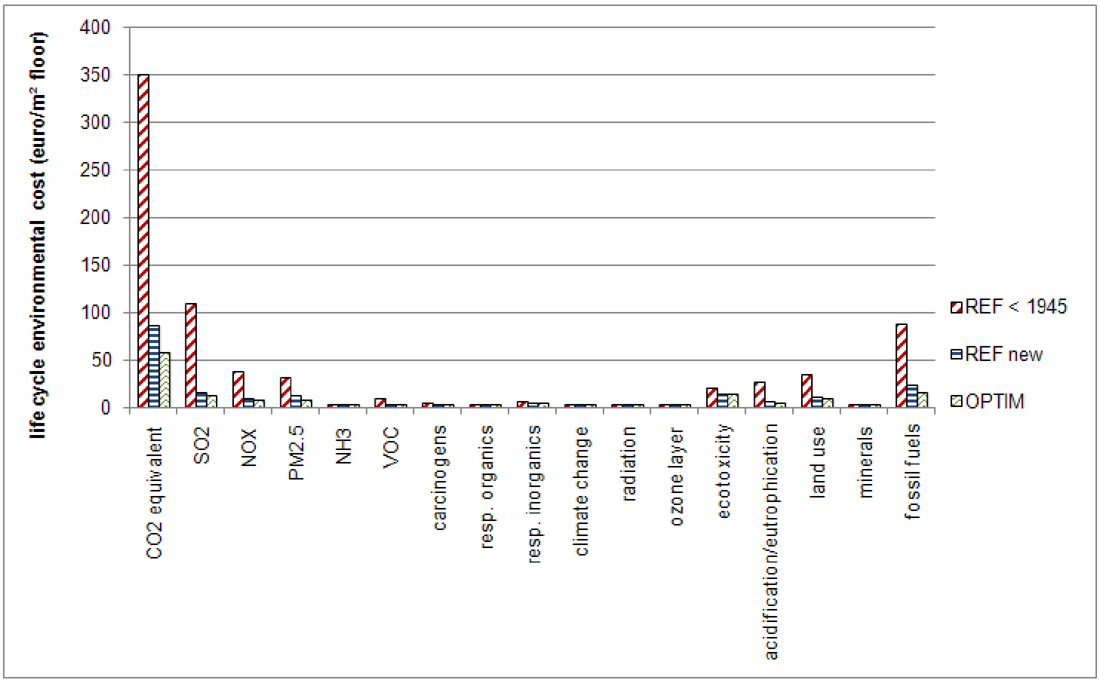

Figure 3 The environmental cost of the different impacts considered for an existing dwelling, newly-built dwelling according to common practice to date and the optimised dwelling.

As mentioned before, for both the existing dwelling stock and newly built dwellings according to common practice to date, the heating demand reveals to be the most important contributor to the environmental cost. This is illustrated in Figure 4 for three of the analysed dwellings. This phenomenon is strongly pronounced for the dwellings built before 1945 and for the detached dwellings (with low thermal compactness). Therefore, a reduction of the energy demand should be the primary focus (assuming no change in energy production process). The analysis of other cases has revealed that the actions in order of priority are dwelling type, layout, size and window area, followed by an improvement of the insulation level and finally a better technical installation for heating and ventilation.

The analysis moreover reveals that the optima based on environmental and financial considerations differ. While the net heating demand should be reduced to approximately 30 kWh per m² floor, year based on environmental cost, the optimum based on financial cost equals 40 kWh per m² floor, year. Of course, a different evolution of energy prices in future will change this financial cost optimum.

For the optimised dwelling, the environmental cost due to the production of the materials becomes approximately equally important as or even more important than the heating cost. Therefore, the focus for further optimisation may shift for these optimised dwellings. Furthermore, the impact due to freshwater use and electricity is now in the same order of magnitude as heating and the production of the materials.

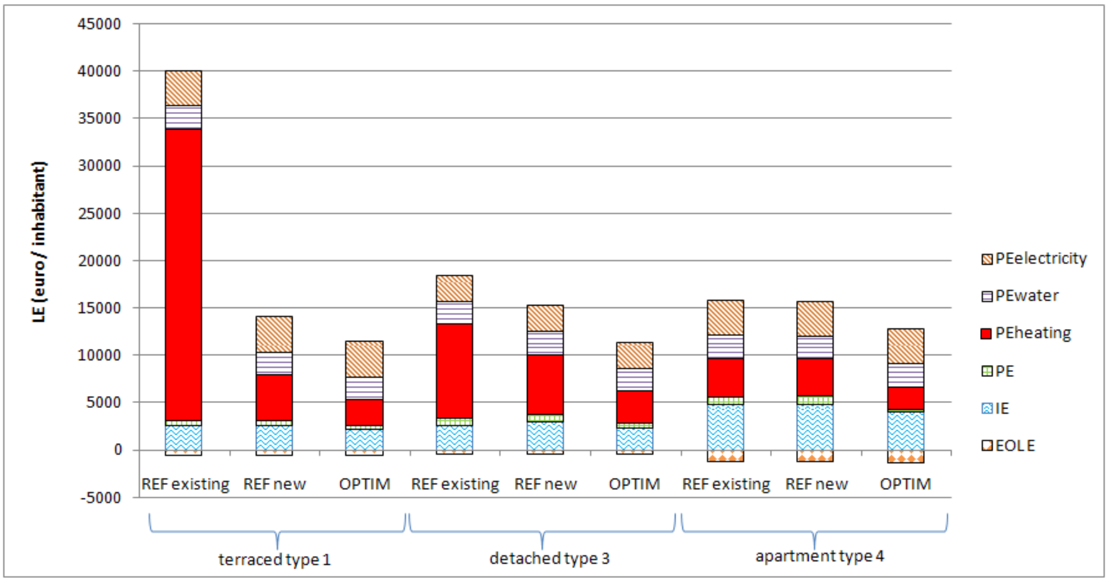

Figure 4 Three of the analysed dwellings: environmental cost of the different processes/phases, expressed in euro per inhabitant - for the reference for the existing dwelling, the reference for newly built common practice to date and the optimised dwelling.

As can be seen from Figure 1 the Pareto front shows first a steep slope downwards and, followed by - for higher initial costs - an almost horizontal slope. The last Pareto options require a high extra initial investment for only a minor decline of the life cycle cost and can therefore be questioned. Other measures (e.g. related to the optimisation of the dwelling location and the induced transport, or beyond the housing sector) might be more efficient. For all dwellings and for all cost criteria considered an identical form of the Pareto front is identified. In consequence, 0-impact buildings based on current technology are not of interest. To move towards 0-impact buildings innovation of both the production processes of the building materials and of the energy production processes proves to be required.

5 Conclusions

The life cycle analysis of 16 dwellings in the Belgian context shows that the environmental impact and financial cost should both be considered in an integrated way. This integrated approach allows evaluating actions in order of priority to improve sustainability of buildings. The most important impacts of buildings to date relate to the emission of CO_2-equivalents, SO_2, NO_x, PM2.5, respiratory effects due to inorganic compounds, ecotoxicity, acidification, eutrophication, depletion of fossil fuels and land use. The heating demand proves to be the primary focus for improvement both for the existing and newly built dwellings. A net heating demand of approximately 30 kWh per m² floor, year is identified as optimum based on environmental cost, while the optimum based on financial cost reveals to be higher and equals 40 kWh per m² floor, year

The analysis furthermore reveals that 0-impact buildings are yet a bridge too far with current technology. To move towards 0-impact buildings (if technology is not drastically improved in the near future) one should focus on improved dwelling types, layout and size. Actions in order of priority are furthermore improvement of the insulation level, opting for a more efficient heating installation, and finally reduction of electricity and freshwater consumption. Furthermore, the analysis proved that transport during use phase, related to the choice of location of the dwelling, is another important optimisation parameter.

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AN INTEGRATED APPROACH FOR FINANCIAL AND ENVIRONMENTAL COST OPTIMISATION OF HEATING SERVICES

Recommendations for a Belgian dwelling case

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Abstract

A four-year project has started in 2007 to develop a methodology that can be applied to optimize the Belgian dwelling stock. The aim of the project is to optimise buildings concerning their environmental impact, their financial cost and the quality they offer over the whole life cycle, from the production of primary raw materials to the final demolition and end-of-life treatment. In the first phase of the project the optimisation methodology is developed; i.e. environmental impacts are analysed by means of life cycle assessment (LCA); financial costs are calculated based on life cycle cost analyses (LCC); and the quality evaluation is based on multi-criteria analyses (MCA). The aim of the optimization is to realize the highest marginal quality improvement for the additional financial and environmental cost. In a second phase the developed methodology is translated into a work instrument and applied to different dwelling types. This paper goes more deeply into the role heating services play in the environmental and financial costs. For a typical Belgian dwelling initial and life cycle costs for commonly used as well as advanced heating configurations are compared. Since energy consumption for heating is dependent of the way the building envelope is built, the analysis is performed on two dwelling configurations with a different insulation level.

Keywords

Life Cycle Assessment, Life Cycle Costing, Element method, Pareto optimisation, heating services

1. Introduction/Background

The construction sector typically provides 5 to 10% of employment through construction jobs and generates 5 to 15% of GDP at national level (UNEP 2006; ILO 2010). However, the impact of the built environment – including housing – on nature and society is vast. Not only is energy use in buildings responsible for more than one third of global greenhouse gases; construction, maintenance and renovation activities also account for 40% of world's material flows (UNEP 2007). It is even more alarming that barely 20% of the world's population, i.e. the richest countries, is responsible for the consumption of 86% of world's material resources (Fernandez 2003).

Meanwhile an accelerated trend of urbanisation and expansion of cities is visible. Although in some cities environmental issues, such as commuting, are easier dealt with, in most urban areas they are intensified. A city with a million inhabitants consumes daily 9.500 ton fossil fuel, 625.000 ton water, 32.000 ton oxygen, emits 29.000 ton CO_2 and dumps 500.000 ton used water (Battle 2007). Despite urban development, adequate accommodation is still unaffordable for a large part of the world population. The UN Human Settlements Program (UN-HABITAT) estimates that 600 million urban residents and 1 billion rural dwellers in developing countries live in inadequate housing. The main cause may be attributed to poverty [Brown 2003].

In many European countries affordable and adequate housing are hot topics too. High-density countries such as Belgium and the Netherlands can be considered as an extensive built-on region, where building plots are scarce and expensive.

Despite serious efforts, such as cleaner production techniques for building materials, more severe energy performance regulations for buildings and social loans for renovating dwellings, limited changes are noticeable. This can partly be attributed to the long service life of buildings - causing very slow changes. Nevertheless, more and better orientated actions should be taken. It is however very difficult to identify the impact of measures.

2 Aim of the study

The aim of the study presented in this paper is to formulate a scientific basis for policy formulation for a more sustainable dwelling stock in Belgium. In order to do so the three widely recognised aspects of sustainability have to be addressed in an integrated way.

Indeed, environmental improvements come at a certain cost. Both the investment cost and the operational costs are of interest, in terms of budget restriction and financial efficiency respectively. Furthermore, an environmental and financial sane building lacking quality is a building with a limited service life.

In order to quantify environmental impacts, financial costs and qualities of the current Belgian housing stock in an integrated way and to formulate sane recommendations for a more sustainable one, a new evaluation method has been developed in 2007 during a four-year research project sponsored by the Belgian Science Policy (BELSPO). This methodology is presented in this paper.

This paper focuses on the role **heating (sub) systems** play in the environmental impacts and financial costs of a typical Belgian dwelling. In addition, recommendations will be given to enhance the environmental and financial performances of heating systems, in relation to the entire life cycle of a representative dwelling. In this study the quality of the dwelling is left constant.

3 Methodology

In order to evaluate environmental impacts (EI), financial costs (FC) and qualities of the current Belgian dwelling stock and to provide federal and local governments a scientific basis to optimise it, three existing methods have been integrated in a single evaluation methodology, named "Sustainable, Financial and Quality evaluation of Dwelling types" (SuFiQuaD). For the calculation of FC and EI the whole life cycle of a reference dwelling is considered, by carrying out **Life Cycle Assessment** (LCA) and **Life Cycle Costing** (LCC) respectively. This implies that production of building materials, transportation, construction, use, maintenance, replacements and end-of-life treatments are considered. For the quality evaluation a **Multi-Criteria Analysis** (MCA) is conducted.

In the following sub paragraphs all aspects of the SuFiQuaD methodology are further described.

To focus on the environmental and financial performances of a single building element – or a combination of some elements – without losing the relation to the whole building, the **element method** is integrated in the SuFiQuaD methodology. The element method is a well known technique in the construction sector, used for cost calculation and cost control (Flanagan 1997).

By multiplying the environmental impact or financial cost per unit of element with the ratio of that element (i.e. amount of element per square meter of total floor area of the dwelling), the environmental impact or financial cost per square meter of floor area for that specific element is determined. The limitation to one (or some) element(s) can be useful when trying to optimise that (those) specific building element(s).

3.1 Life cycle assessment

The environmental impact assessment is done by performing a Life Cycle Assessment (LCA) (ISO 2006a; ISO 2006b; Guinée et al 2002; REGENER 1997; SETAC 2003) of the dwelling. Derived from the function of the dwellings, the functional unit is defined. The functional unit should measure the performance of the different dwelling types and should provide a reference to which all the environmental inputs (use of raw materials and energy) and outputs (emissions to air, water, soil, other) can be normalised. Since dwellings fulfil more than one function, the choice of the functional unit is not simple. Different functional units occurred in studies reviewed within the literature study. In the REGENER project (1997), for example, the whole building, located at a certain point in a given region, is considered as the basic functional unit. Within the SuFiQuaD methodology “one square meter of the net floor area” is considered as basic functional unit. To be able to compare dwellings with a different life expectancies the environmental impact per “square meter of the net floor area per year” is also calculated. In addition, the SuFiQuaD method also calculates the results per inhabitant to correct any appearance that larger buildings are more sustainable than smaller ones. For all dwellings that are assessed an average service life of 60 years is assumed. According to (Ammar et al 1980) this is an acceptable average for the Belgian context. Sensitivity analyses are performed to assess the impact of other service years on the final results.

The collection of the environmental data (i.e. life cycle inventory - LCI-data) is mainly related to the ecoinvent database (2007). For the life cycle impact assessment of the inventoried inputs and outputs; the Eco-indictor 99 method (Goedkoop et al 2001) is used. In addition, a method is developed to translate EI into monetary values (i.e. euros). In order to cover as many environmental aspects as possible a selection of different existing methods for the translation of environmental aspects into monetary terms are combined. This hybrid method is based on a combination of the impact assessment as used within the series of the European ExternE projects (Bickel et al 2005), the Eco-indicator 99 approach (Goedkoop et al 2001) and other research projects on monetisation based on “willingness to pay for environmental damage” (Ott et al 2006).

3.2 Life cycle costing

To calculate FC over the whole life cycle the sum of the present values is calculated. Both the initial cost as the total cost are analysed in terms of budget restriction and cost efficiency.

$$LF = IF + \sum_{t=0}^{t=LS} PV(PF_t) = IF + \sum_{t=0}^{t=LS} \frac{PF_t \times (1+g_F)^{(t)}}{(1+d_F)^{(t)}} \tag{1}$$

With:

LF = financial life cycle costs

PV = Present Values of costs

IF = initial investment cost

PF_t = periodical (future) financial cost

g_F = growth rate (annual) on periodic financial costs

d_F = discount rate (annual) on periodic financial costs

t = time (in years)

LS = life span of dwelling or element

In analogy to Equation (1), the environmental life cycle costs are defined in the following way:

$$LE = IE + \sum_{t=0}^{t=LS} PV(PE_t) = IE + \sum_{t=0}^{t=LS} \frac{PE_t \times (1+g_E)^{(t)}}{(1+d_E)^{(t)}} \tag{2}$$

With:

LE = environmental life cycle costs

PV = Present Values of costs

IE = initial environmental cost

PE_t = periodical (future) environmental cost

g_E = growth rate (annual) on periodic environmental costs

d_E = discount rate (annual) on periodic environmental costs

t = time (in years)

LS = life span of dwelling or element

The initial costs (IF and IE) include the material cost, production cost and transportation cost of the processed materials, as well as construction costs of the building (labour cost, indirect costs, etc.). The periodical costs (P_t) are costs during the use phase of the dwelling and include cleaning, maintenance and replacement costs. The growth rate of costs differs for processed building products and energy costs. The time value of money is incorporated by defining a discount rate. The characterisation of growth and discount rates are different for environmental and financial costs.

Finally, the total initial costs (IT) and total life cycle costs (LT) are considered by adding up the corresponding environmental and financial costs: respectively IE and IF; and LE and LF.

3.3. Quality evaluation

The qualities of a building are a complex clew and are user and context specific. In the SuFiQuaD methodology it is evaluated by carrying out a Multi Criteria Analysis (MCA). To make the quality assessment as transparent as possible, a hierarchal structure is adopted.
Within the SuFiQuaD methodology all dwelling qualities are divided in four main aspects: dimensional, functional and technical characteristics and the surroundings of the dwelling. Each aspect is subdivided in different sub-aspects. Each criterion within each sub-aspect is evaluated using a score function and graded on a scale from zero to ten. The different scores are then weighted and aggregated into a final single score for the quality performance of the dwelling. (Spirinckx et al 2009)
Since the dwelling qualities for the research presented in this paper are left unchanged, the MCA within the SuFiQuaD methodology is not further discussed. More information about it can be found in (Allacker et al 2006).

3.4 Pareto optimisation

For the determination of the most preferable measures for one type of dwelling or element, the basic approach is to search for the highest marginal quality improvement for the additional cost. This means that one starts from a reference building or element and compares the alternatives with this reference. The subset of options that is more preferable than the other options is graphically represented by the **Pareto front**. (Allacker et al 2008)
Different optimisation criteria are considered: initial financial cost (IF), initial environmental cost (IE), life cycle financial cost (LF) and life cycle environmental cost (LE), initial total cost (IT) and life cycle total cost (LT), with and without the inclusion of the quality evaluation. It is possible that these different criteria will lead to a different ranking of the optimal options.

4 Case study

4.1 Selection of a representative Belgian dwelling

The Belgian dwelling stock is very heterogeneous. According to national statistics (NIS 2001) a freestanding dwelling is the most common dwelling type in Belgium (29.3%), closely followed by terraced dwelling (25.6%), flat (25.3%) and semi-detached dwelling (19.9%).

While most semi-detached and terraced dwellings are older than 1945 (together 15.5% of the entire dwelling stock), most freestanding dwellings and apartments are built later, respectively in the period 1971-1981 (6.0% of the entire stock) and after 2001 (3.2% of the entire stock). In other words, a single archetypical dwelling for Belgium does not exist.
In the SuFiQuaD methodology this issue is tackled by the selection of 16 different reference dwellings, subdivided according to the dwelling type (freestanding, semi-detached, terraced and apartment) and the construction period (<1945, 1945-1970, 1971-1990 and 1991-2007).

For the analysis detailed in this paper, a compact and south-oriented freestanding dwelling of 123m² floor area for a family of 4 persons from the period 1991-2000 is used as reference. A representation of the architectural plans is shown in Figure 1.

Figure 1: representation of referential detached dwelling (dimensions in cm) (Allacker 2010)

4.2 Technical services

In the framework of the SuFiQuaD project the term '**technical services'** (TS) comprises the following systems: space heating (SH), domestic hot water (DHW), ventilation, provision of electricity, water treatment and evacuation, and elevator system (only for apartment blocks).
Due to the fact that lighting and movable electric devices are not or only in a minor way building dependent, these services have been further excluded from the assessment.
In the framework of the SufiQuaD project, the analysis of TS is somewhat different than the analysis of other dwelling elements. Compared to walls, floors and roofs, the above mentioned sub systems consist of a vast amount of processed materials. Whereas structural or skin elements are principally a combination of a few layers of processed materials – all measured in m² – TS are made of a complex network of linear, surface and volume components – quantified in different units and consisting of a multitude of materials.

Furthermore, the complexity of the analysis is increased because the choice of TS sub systems is often related to other building parameters, such as the insulation level, air tightness and the orientation of the dwelling. Therefore analysis of TS is carried out on building level, through which a distinction is made between two contrasting dwelling cases:

- A **non-insulated** dwelling (K100), i.e. worst case scenario
- A **highly insulated** (and air tight) dwelling (K20), i.e. best practise

The analysis detailed in this paper is carried out for a life span of the dwelling of 60 years. Sensitivity analyses using a life span of 120 years are carried out on element level.

4.2.1 General parameters

Due to technical evolution services are prone to 'frequent' replacement over the lifespan of the building. In this study it is assumed that all technical components are replaced over a period of *30 years*.

Different VAT rates are used over the lifespan of the dwelling: *21%* for the initial production, installation and/or construction, *6%* for the refurbishment or replacement of the technical components. Taking into account the Belgian situation in 2008 the following financial costs for energy carriers are used:

Table 1: Considered energy cost for each energy carrier

Energy carrier	Cost without VAT and taxes [€/MJ]	Overall cost* [€/MJ]
electricity	*0,0426*	*0,0548*
gas	*0,0113*	*0,0139*
oil	*0,0131*	*0,0164*
pellets	*0,0113*	*0,0137*

*a VAT rate of 21% is incorporated in the overall financial energy costs

4.2.1 Description of studied Space Heating systems

The space heating system (SH) is characterised by a set of sub systems: type (A), production (B), distribution (C), emission (D) and control (E). The flowchart below gives an overview of all studied SH configurations.

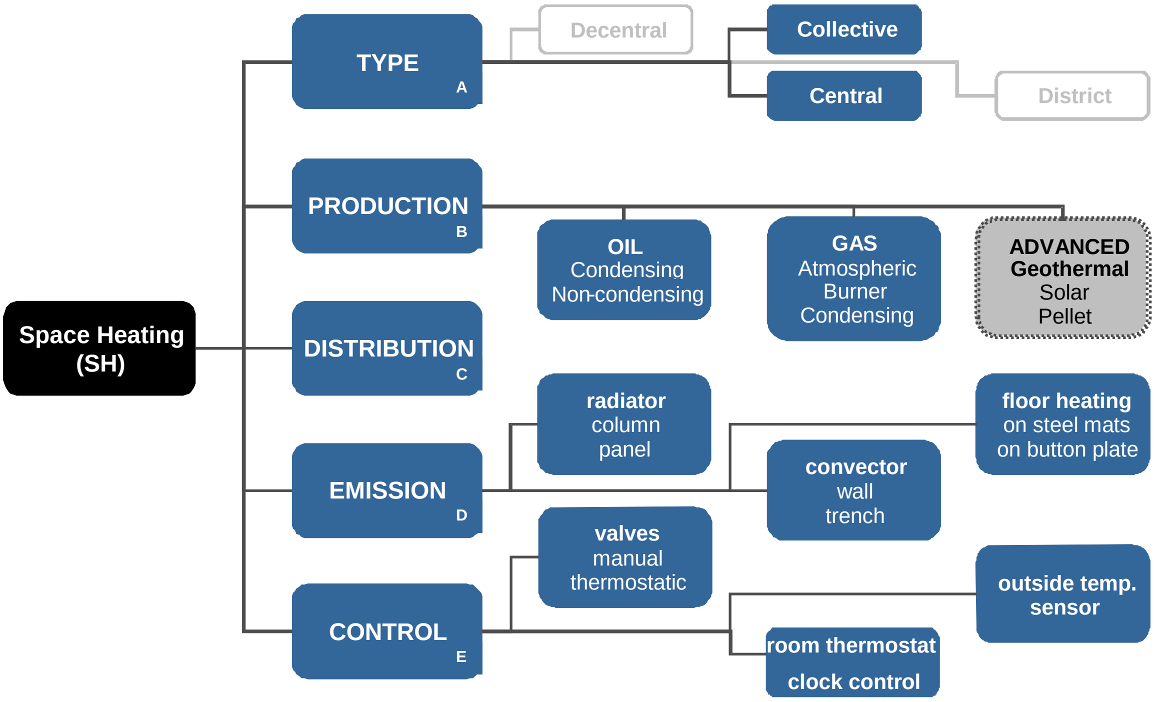

Figure 1 Configuration flowchart of space heating system

In all studied configurations central heating is considered for individual dwellings (A). An important distinction is made between commonly used production systems and advanced ones (see grey dotted box in flowchart), i.e. based on renewable energy sources or biomass. The advanced ones are only considered in the well-insulated dwelling. For all studied configurations the same distribution components (C) are used, i.e. a double-pipe octopus-system. Each emission device is connected with local collectors in a loop via PE ducts. The PE ducts in reality differ in diameter, but are simplified to a fixed outer diameter of 16mm and a thickness of 2mm. The same type of ducts is used for the supply of water. Contribution analyses showed that these distribution components only have a minor influence on both financial and environmental costs. The following group of variations is studied:

Production system (B):

- Oil boiler: non-condensing or condensing (both floor models)
- Gas boiler: non-modulating classic atmospheric (floor model), non-modulating gas burner (floor model) or modulating condensing (wall model)
- Heat pump: ground/water (with vertical or horizontal heat exchange), air/water, air/air (only for passive house)

- Pellet furnace: non-condensing or condensing (both with storage silo and automatic supply)

Emission system (D):

- Column radiator: cast iron or steel plate
- Panel radiator: steel plate
- Wall convector: aluminium
- Trench convector: PET or steel with aluminium or Merbau grid
- Floor heating: PE-RT on steel mats or on button plate

Control system (E):

- Manual valves + room thermostat (MV+RT)
- Manual valves + room thermostat + outside temperature sensor (MV+RT+OS)
- Thermostatic valves + clock control (TV+clock)
- Thermostatic valves + clock control + outside temperature sensor (TV+clock+OS)

It is difficult to separate the overall efficiency of heating systems in efficiencies of the sub systems, since production, distribution, emission and control components influence each other. Van der Veken and Hens (2010) showed that the combination of some control and production systems is better avoided due to a low overall efficiency.

For example, in a well insulated dwelling the constant, but low energy demand by thermostatic valves during milder days causes a non-modulating high efficiency boiler to cycle the whole day – and so producing high boiler losses at times when little or no heat is needed. In order to reduce the boiler working time, it is better to control heating through a central thermostat in combination with manual valves (and outside temperature sensor). On the other hand, the highest overall efficiency using a (modulating) condensing boiler is obtained with thermostatic valves (and outside temperature sensor), since the boiler can operate on partial load during milder days. Combing the thermostatic valves with a clock control switches the boiler on/off in function of the time (e.g. day/night). (Van der Veken et al 2010)

According to the European standard EN 12831 (CEN 2003) on heating systems, the K100 and K20 dwellings have a design load of respectively 14kW and 5kW. The required capacity of the selected heat production system and the sizing of the emission devices are calculated according to (Hens 1996). (Allacker 2010)

4.2.2 Description of studied Domestic Hot Water systems

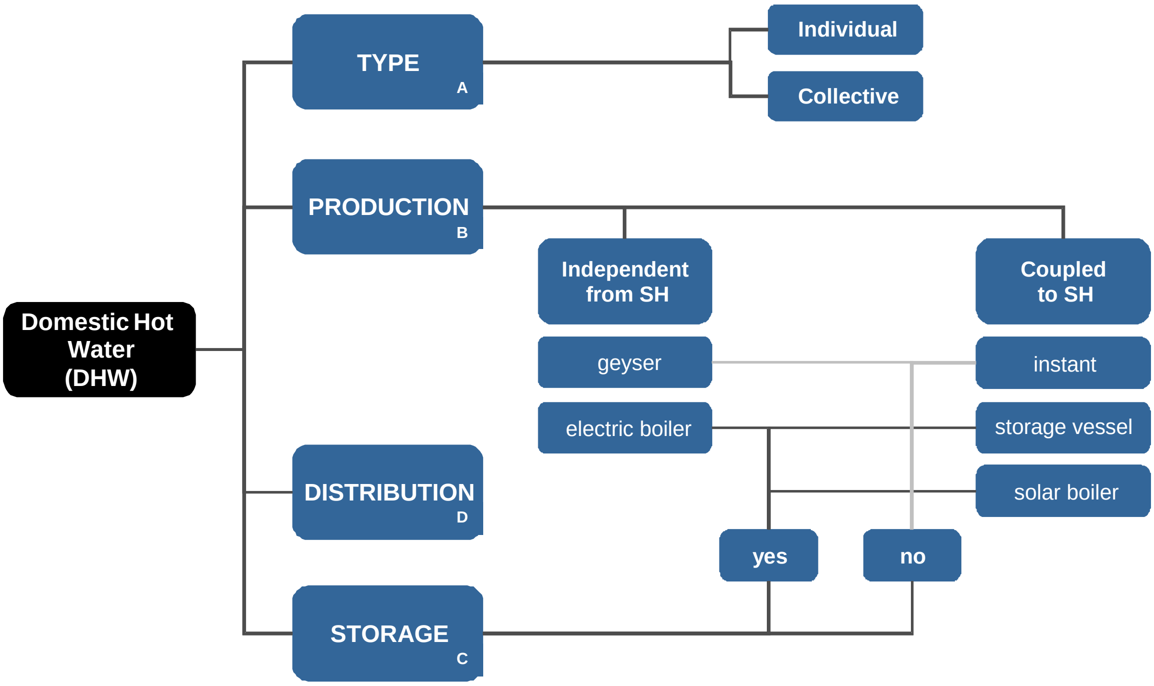

Figure 2 Configuration flowchart of domestic hot water system

Similar to SH, the domestic hot water system is characterised by different sub systems: type (A), production (B), storage (C) and distribution (D). The flowchart in Figure 2 gives an overview of all DHW configurations. Complementary to SH, only individual installations (A) are analysed and the same distribution components are used for all combinations.

- Production system (B) – Storage system (C):
  - Independent from SH:
    - i. *gas geyser[1], i.e. without storage*
    - ii. *electric boiler, 120l*
  - Coupled to SH:
    - iii. *Instant (i.e. without storage)*
    - iv. *storage vessel, 120l for an oil and gas generated furnace or 300l for a heat pump or pellet furnace [2]*

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[1] The capacity of the geyser is 14l/min for ΔT = 25K or 7l/min for ΔT = 50K
[2] In order to reduce the on/off switching of the heat pump a larger storage vessel is chosen compared to a gas or oil boiler.

v. *solar boiler, using an existing or external storage vessel, 120l for an oil and gas generated furnace or 300l for a heat pump or pellet furnace.*

For a proper comparison of heating systems, SH and DHW are always looked at together. Components for exhaust of gasses (i.e. ducts and chimney) and supply of gas and oil (i.e. pipes and oil storage tank), as well as supplementary parts, such as circulation pumps and expansion vessels are taken into account in the assessment.

5 Analysis Approach

In order to have a better understanding of the impact of heating services on the environmental and financial life cycle cost of the reference dwelling and to formulate clear enhancement measures, the analysis is carried out in four distinct phases:

1. Analysis of the contribution of representative heating services and other building components in the environmental, financial and total life cycle costs for both dwelling cases (i.e. K100 and K20)
2. Definition and interpretation of the Pareto front of all configurations for the entire heating system. Two different configuration groups are made: (a) commonly used and (b) advanced configurations
3. Comparison of the relative life cycle cost profile of all configurations for each heating sub system
4. Formulation of scientifically based recommendations

6 Results

6.1 Overall impact of services on the reference dwelling

To analyse the contribution of energy and technical services to the total dwelling cost, an instant coupled condensing gas boiler with low temperature panel radiators and controlled by thermostatic valves in combination with an outside temperature sensor is selected as reference. As will be shown in §6.2 this selection is justified since it appears on all Pareto fronts – i.e. EC and FC for both insulation levels. Since in the reference case a natural ventilation system is selected and no photo-voltaic panels are used, the energy consumption and supply related to TS is mainly related to the heating services (SH and DHW).

In Figure 3 and Figure 4 the relative importance of heating services and energy in the life cycle cost of respectively the non-insulated (K100) and well-insulated (K20) detached dwelling is shown. Heating costs can be more or less halved by (highly) insulating the dwelling.

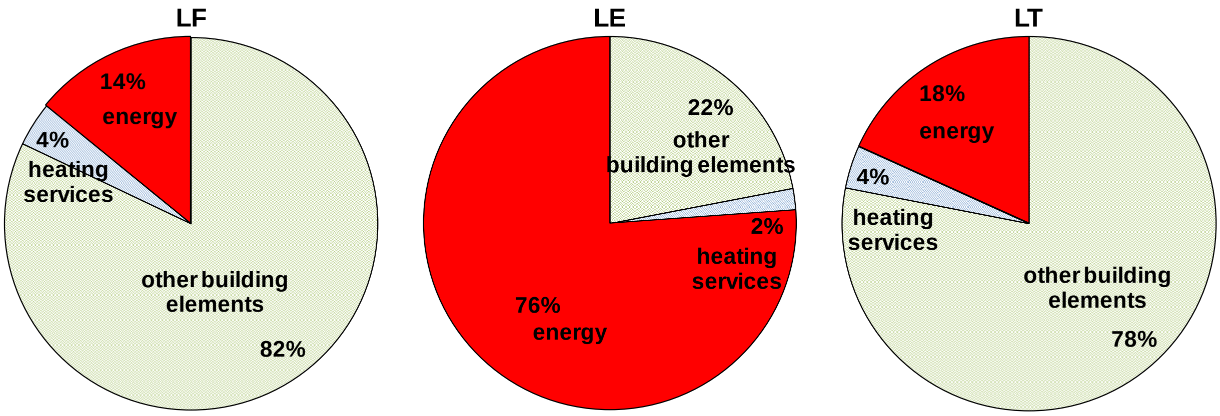

Figure 3 Relative importance of heating services in the (financial – environmental – total) life cycle cost of a representative non-insulated detached dwelling (K100) (Allacker 2010)

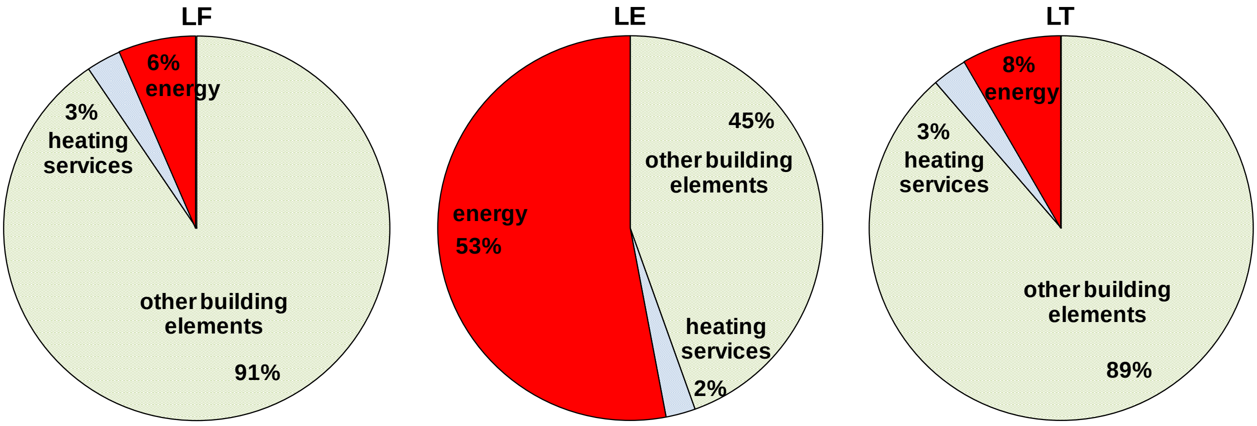

Figure 4 Relative importance of heating services in the (financial – environmental – total) life cycle cost of a representative well-insulated detached dwelling (K20) (Allacker 2010)

Compared to other building elements, heating services represent circa 3% (K100) to 4% (K20) of the financial life cycle costs. Even when the net energy demand is halved by highly insulating the dwelling, energy during use of the dwelling plays a non-negligible role in the life cycle cost profile. Due to the relatively low gas prices (see Table 1) heating costs are responsible for 6% (K20) to 14% (K100) of LF. From an environmental point of view, energy represents the most important part of the life cycle cost, ranging from 53% (K20) to 76% (K100), due to the Belgian energy mix. Heating services are responsible for 2% of LE; while other building elements represent circa 22% (K100) to 45% (K20) of LE. Given that overall environmental costs play only a minor role in the total life cycle costs of dwellings (circa 6%), the relative importance of energy costs is reduced to 8% (K20) and 18% (K100) of the total life cycle costs.

The argumentation above justifies a more thorough assessment of the impact of TS on the financial and environmental costs of both reference dwellings. In the following paragraphs the importance of heating services is further detailed and some measures to reduce environmental and financial costs are suggested.

6.2 Overall impact of heating configurations

6.3.1 Overall impact of heating configurations on non-insulated dwelling

Based on the heating system parameters detailed in §4.2, 111 different heating system configurations are defined for the non-insulated dwelling. In order to present legible graphs, these configurations only consider panel radiator as emission component – occasionally combined with floor heating on steel mats. As will be shown in §6.3 no substantial differences in the overall cost profile are discerned between all studied emission alternatives. The following Pareto fronts of the financial and environmental costs (in €/m² net floor area) have been identified.

Table 2: Pareto front of financial costs (IF versus LF) for the non-insulated dwelling (K100) with a life span of 60 years

configuration SH	**configuration DHW**	**IF (€/m² fl net)**	**LF (€/m² fl net)**
gas atmospheric; panel radiator; MV+RT+OS	instant coupled	*74,6*	*861,1*
gas condensing; panel radiator; TV+clock	instant coupled	*80,7*	*792,1*
gas condensing; panel radiator; TV+clock+OS	**instant coupled**	***81,1***	***769,4***

* MV = manual valves; TV = thermostatic valves; clock = clock control; RT = room thermostat; OS = outside sensor

Financially seen, an instant coupled atmospheric gas boiler with panel radiators operating with manual valves and a room thermostat combined with an outside temperature sensor offers relatively low energy consumption for the lowest investment. The second Pareto minimum consists of a condensing gas boiler controlled by thermostatic valves. A small investment in a more sophisticated control system, i.e. an outside temperature sensor in combination of thermostatic valves and a clock in the living room, provides the lowest financial life cycle cost. Compared to the atmospheric gas boiler option, a reduction of 8%

and 11% in financial life cycle cost is discerned respectively for the two condensing gas boilers.

Table 3: Pareto front of environmental costs (IE versus LE) for the non-insulated dwelling (K100) with a life span of 60 years

configuration SH	**configuration DHW**	**IE (€/m² fl net)**	**LE (€/m² fl net)**
gas burner; floor heating; MV+RT+OS	instant coupled	*5,6*	*279,8*
gas burner; floor heating; MV+RT+OS	instant coupled + 1 geyser	*7,3*	*278,9*
gas burner; floor heating; MV+RT+OS	2 geysers	*9,1*	*278,1*
gas condensing; floor heating; TV+clock+OS	**instant coupled**	***10,7***	***236,0***
gas condensing; floor heating; TV+clock+OS	instant coupled + 1 geyser	*12,4*	*235,1*
gas condensing; floor heating; TV+clock+OS	2 geysers	*14,2*	*234,3*

* MV = manual valves; TV = thermostatic valves; clock = clock control; RT = room thermostat; OS = outside sensor

Environmentally seen, a (high performance) instant coupled gas burner working with floor heating and a sophisticated control system (i.e. MV+RT+OS) offers the lowest IE. On the level of emission system, floor heating and panel radiator alternatives have a similar cost profile. The biggest reduction in LE is generated by a condensing gas boiler controlled by an outside temperature sensor combined with thermostatic valves and a clock in the living.

Only a slight reduction in LE is noticed by using gas geysers (with or without instant coupled DHW), i.e. less than 1%. This means that environmentally seen, an instant coupled gas condensing boiler is preferred.

In Figure 5 and Figure 6 initial and life cycle costs for the non-insulated dwelling (K100) are depicted according to the type of SH production system. These graphs illustrate the wide spread of the related costs of all configurations. The Pareto front of the total costs (IT vs. LT) is similar to the one of the financial costs.

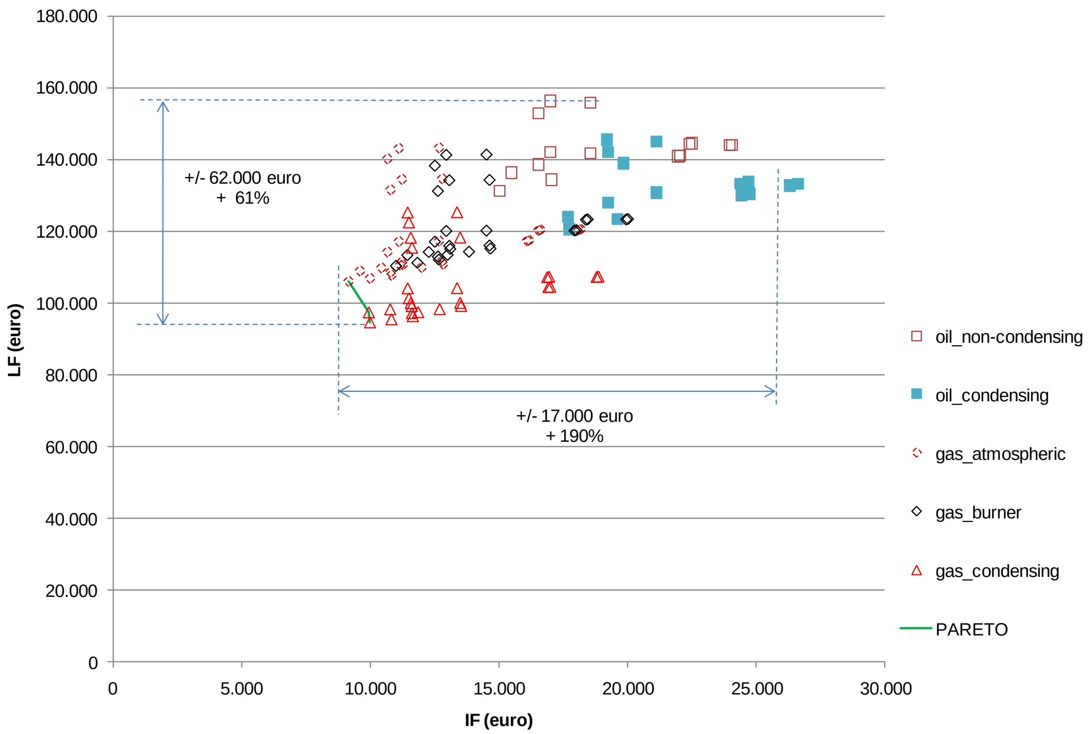

Figure 5 Initial financial cost (in €) versus life cycle financial cost (in €) of all commonly used heating system configurations (SH+DHW) for the non-insulated dwelling (K100)

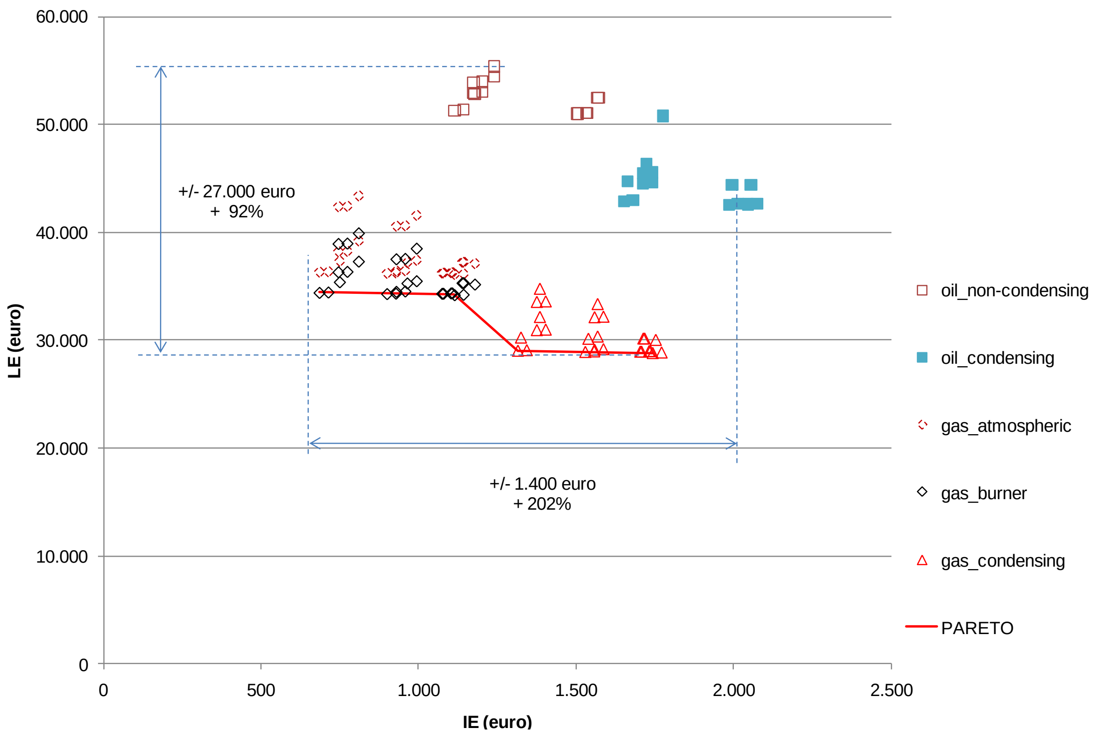

Figure 6 Initial environmental cost (in €) versus life cycle environmental cost (in €) of all commonly used heating system configurations (SH+DHW) for the non-insulated dwelling (K100)

6.3.2. Overall impact of heating configurations on well-insulated dwelling

For the assessment of the highly insulated dwelling not only conventional, but also advanced heating systems are looked at. Once a dwelling is well insulated a heat pump is an interesting solution to minimise energy production. Furthermore, due to the improvement of heating techniques, pellet furnaces become more popular. These relatively new heating solutions are compared with the commonly used ones. In total 117 heating configurations are studied.

As mentioned in §4.2, the design heat load for space heating for the well-insulated dwelling (K20) is low, i.e. 5kW. The capacity of the boiler for space heating is therefore about 8-10 kW. However, for the options where the domestic hot water production is coupled to the space heating installation, the dimensioning of the capacity of the boiler also depends on the need for domestic hot water production. For an instant boiler, a capacity of 24.4kW is assumed (equal as for the stand-alone geysers); while for the system with storage vessel the capacity of 8-10 kW of the boiler is assumed sufficient. For some of the boiler types, no such small devices are available on the current Belgian market. For these, the smallest available is selected.

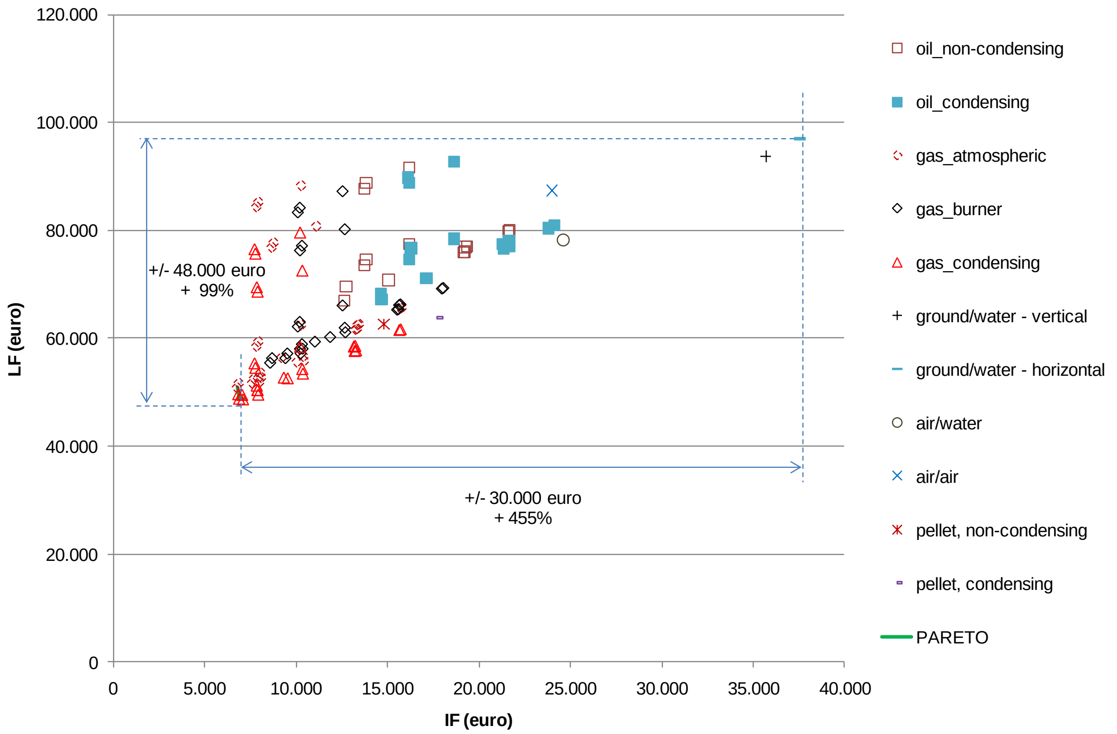

Figure 7 Initial financial cost (in €) versus life cycle financial cost (in €) of all commonly used heating system configurations (SH+DHW) for the well-insulated dwelling (K20)

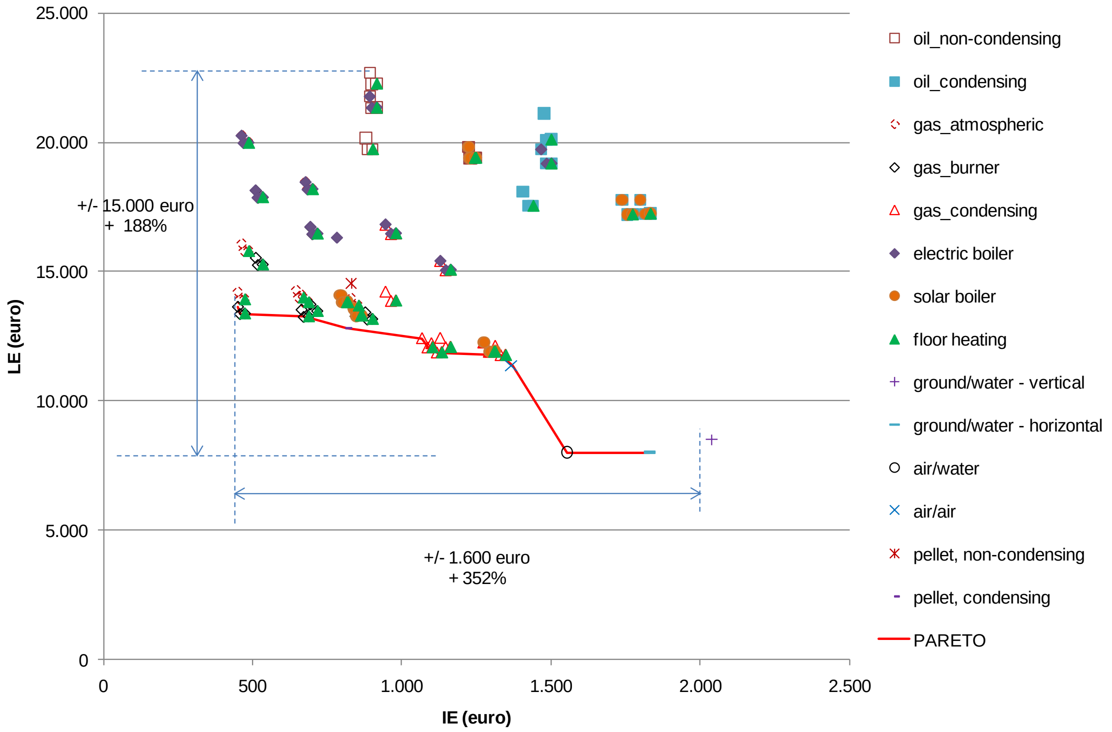

Figure 8 Initial environmental cost (in €) versus life cycle environmental cost (in €) of all commonly used heating system configurations (SH+DHW) for the well-insulated dwelling (K20)

From a financial point of view similar conclusions can be drawn as for the non-insulated dwelling. Although an instant coupled condensing gas boiler with a separate geyser in the kitchen is added as an extra Pareto minimum, the gain in financial life cycle cost is too small (i.e. less than 1%) compared to the former Pareto sub optimum.

Table 4: Pareto front of financial costs (IF versus LF) for the well-insulated dwelling (K20) with a life span of 60 years

configuration SH	**configuration DHW**	**IF (€/m² fl net)**	**LF (€/m² fl net)**
gas atmospheric; panel radiator; MV+RT+OS	instant coupled	*55,0*	*413,2*
gas condensing; panel radiator; TV+clock	instant coupled	*55,9*	*403,4*
gas condensing; panel radiator; TV+clock+OS	**instant coupled**	***56,2***	***396,7***
gas condensing; panel radiator; TV+clock+OS	instant coupled + 1geyser	*57,9*	*395,6*

* MV = manual valves; TV = thermostatic valves; clock = clock control; RT = room thermostat; OS = outside sensor

Heat pumps and pellet furnaces have respectively 61-99% and 29-31% bigger financial life cycle costs, compared to the condensing gas boiler with the lowest LF. Both types of advanced solutions are characterised by a substantially bigger investment and thus also replacement costs. Furthermore, the high energy prices related to electricity (see Table 1) for heat pumps cancel out the benefit of consuming less energy during the use span of the dwelling (see §6.3). For this reason no alternative heating solutions appears on the Pareto front of the financial costs.

Table 5: Pareto front of environmental costs (IE versus LE) for the well-insulated dwelling (K100) with a life span of 60 years

configuration SH	**configuration DHW**	**IE (€/m² fl net)**	**LE (€/m² fl net)**
gas burner; panel radiator; MV+RT	instant coupled	*3,7*	*111,0*
gas burner; panel radiator; MV+RT+OS	instant coupled	*3,7*	*108,7*
gas burner; panel radiator; MV+RT+OS	instant coupled + 1 geyser	*5,5*	*107,8*
pellet condensing; panel radiator; TV+RT+OS	coupled storage vessel	*6,6*	*104,2*
gas condensing; panel radiator; TV+clock	instant coupled	*8,7*	*101,0*
gas condensing; panel radiator; TV+clock +OS	instant coupled	*8,8*	*98,1*
gas condensing; panel radiator; TV+clock +OS	instant coupled + 1 geyser	*9,1*	*96,5*
gas condensing; panel radiator; TV+clock +OS	2 geysers	*10,8*	*95,7*
air/air heat pump; RT+OS	coupled storage vessel	*11,2*	*92,3*
air/water heat pump; panel radiator; TV+clock +OS	**coupled storage vessel**	***12,6***	***65,1***
ground/water horiz. HP; panel radiator; TV+clock +OS	coupled storage vessel	*14,9*	*65,0*

* MV = manual valves; TV = thermostatic valves; clock = clock control; RT = room thermostat; OS = outside sensor

From an environmental perspective the Pareto optima somewhat differ from the ones for the K100 dwelling. For the well-insulated dwelling heat pumps and pellet furnaces do compete with commonly used boilers. Environmental costs (IE and LE) of the condensing pellet furnace are between those of the gas burner and condensing gas burner situated on the Pareto front. Further upgrading to an air/air heat pump is characterised with a reduction of 4% in LE for an equal increase in IE, compared to the condensing gas boiler with the lowest LE. At the end of the Pareto front only advanced solutions are found, i.e. the air/air heat pump, the air/water heat pump and the ground/water heat pump with horizontal exchange – all coupled with a storage vessel for DHW. Only a slight reduction (i.e. less than 1%) of LE is discerned between the last two named Pareto optima for an increase of 18% of IE. For this reason the air/water heat pump is environmentally speaking preferred.

6.3 Impact of heating sub systems

In order to understand the results shown in the previous paragraphs, the heating sub systems are assessed separately. A condensing gas boiler with panel radiators controlled by an outside temperature sensor in combination with thermostatic valves and a clock in the living is taken as a reference. For the commonly used configurations no heat storage is taken as reference for DHW. For the advanced configurations a coupled storage vessel is the reference DHW system.

Results are only shown for the highly insulated dwelling and a life span of the dwelling of 60 years. Similar conclusions can be drawn for the non-insulated dwelling. Based on the description of SH and DHW (see §4.2), a distinction is made between the following sub-systems: production type and fuel of SH; production type and storage of DHW; emission of SH and control of SH.

6.3.1 Production type and fuel of space heating

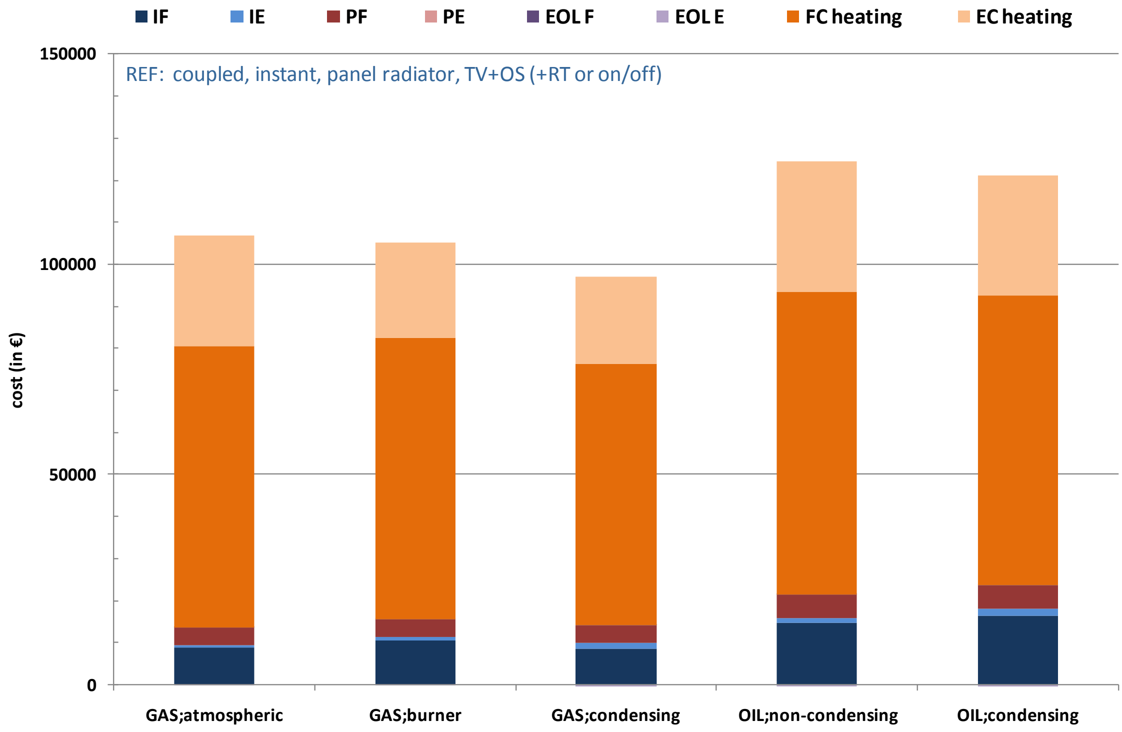

Figure 9 Comparison of production type and fuel sub systems of commonly used space heating systems (in €) for the well-insulated dwelling (K20) with a life span of 60 years

Looking at the graphical representation of the total life cycle cost, two major conclusions can be drawn regarding the selection of production and fuel type of a traditional SH.

First of all, the figures show clearly that oil furnaces have a substantially bigger overall cost than gas furnaces. Not only is the financial investment of an oil heating system bigger than a comparable gas heating system, financial and environmental costs for oil as an energy carrier are respectively 11% and 38% more expensive than for gas.

Beside the fuel choice, condensing boilers consume less energy for a small or negligible increase in initial costs, compared to non-condensing boilers. The environmental cost of production and replacement of condensing boilers is 1.5 times bigger than non-condensing ones, due to the use of stainless steel in these high performance furnaces. In the other furnaces cast iron and steel is used.

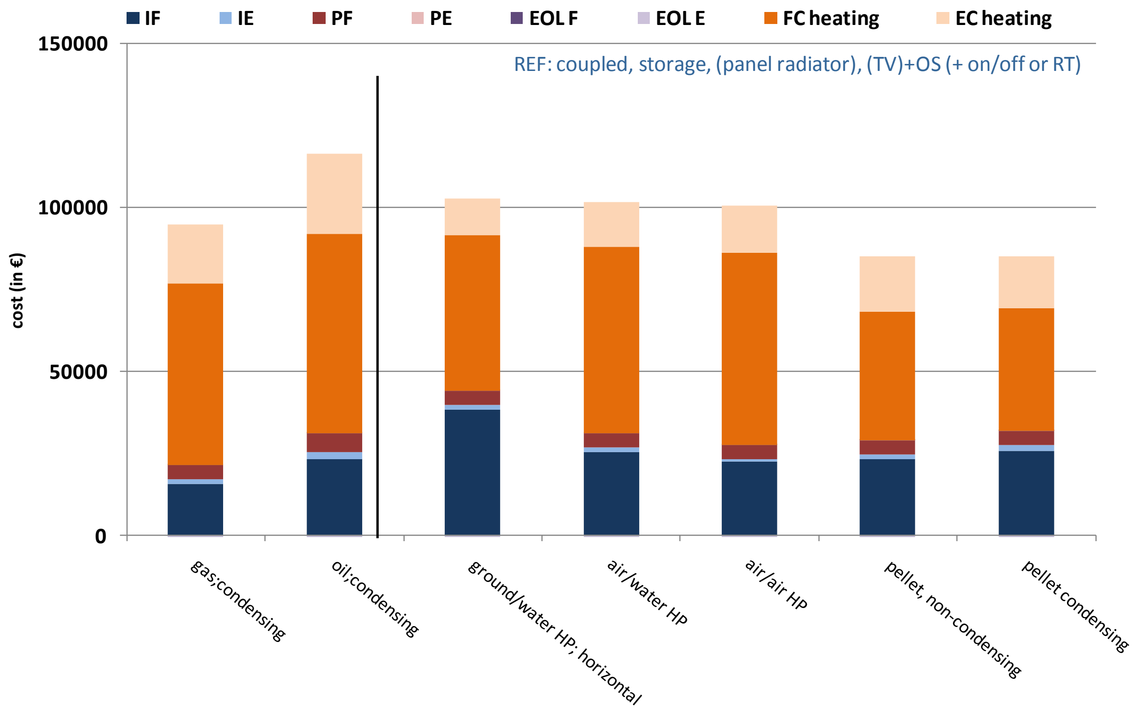

Figure 10 Comparison of production type and fuel sub systems of advanced space heating systems (in €) for the well-insulated dwelling (K20) with a life span of 60 years

The studied heat pumps consume 2.5 – 3.7 times less energy (for SH) than a condensing gas/oil boiler (see Table 6). However, over a life span of the dwelling of 60years, this benefit is more or less cancelled out due to the use of the Belgian electricity production mix, needed to activate the devices – and the combined effect of the discount and growth rate. Belgium's electricity production is characterised by a dominant share of nuclear, gas and hard coal. According to the *ecoinvent* data library, less than 10% of Belgium's electricity supply in 2007 comes from renewable energy sources. Compared to gas and oil as a heating source, electricity has an environmental cost that is respectively 2.4 and 1.6 times bigger.

Furthermore, Belgian electricity is substantially more expensive than gas and oil; financial energy costs are respectively 3.9 and 3.3 times bigger (see Table 1).

Table 6: Energy consumption (in MJ/m² net floor area) of alternative heating configurations with the reference for the highly insulated dwelling (K20) with a life span of 120 years

configuration SH	**Energy SH**	**Energy DHW**
REF: (coupled), solar boiler, (panel radiator), (TV)+RT+OS	**(MJ/m² fl net)**	**(MJ/m² fl net)**
gas condensing	*86,3*	*37,6*
oil, condensing	*85,9*	*36,1*
ground/water heat pump, vertical heat exchange	*23,4*	*20,4*
ground/water heat pump, horizontal heat exchange	*23,4*	*20,4*
air/water heat pump	*33,9*	*20,4*
air/air heat pump (separate, without radiators)	*34,7*	*20,4*
pellet, non-condensing	*119,1*	*25,2*
pellet, condensing	*111,8*	*25,2*

From all advanced heating configurations, pellet furnaces have the lowest total life cycle costs, i.e. 19% - 21% lower compared to heat pumps. In the case of existing remote houses where gas supply is not available, these relatively new systems are good alternatives for oil boilers. Furthermore, over a life span of 60 years pellet furnaces can even compete with condensing gas boilers. Similar conclusions can be drawn for a life span of the dwelling of 120 years.

6.3.2 Production type and storage of domestic hot water

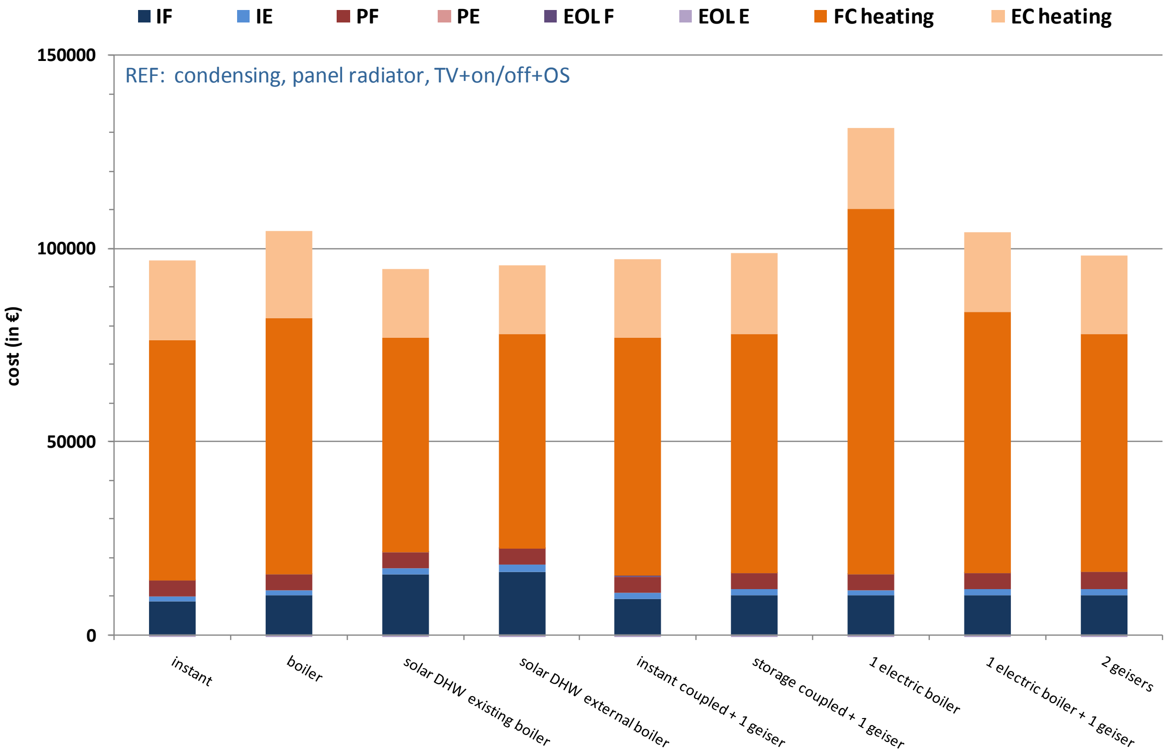

Figure 11 Comparison of production type and storage sub systems of domestic hot water systems (in €) for the well-insulated dwelling (K20) with a life span of 60 years

There is no substantial difference in overall costs between coupled and separate DHW systems over a life span of the dwelling of 60 years. Nor is there a clear preference for solutions with or without heat storage of water. Nevertheless, two distinct observations can be made. First, DHW systems with an electric boiler have to be avoided, due to the high energy prices for electricity (see Table 1). Secondly, the benefit of conserving energy by using a solar boiler is almost cancelled out, due to its higher financial investment cost. Similar conclusions can be drawn for a life span of the dwelling of 120 years.

6.3.3 Emission of space heating

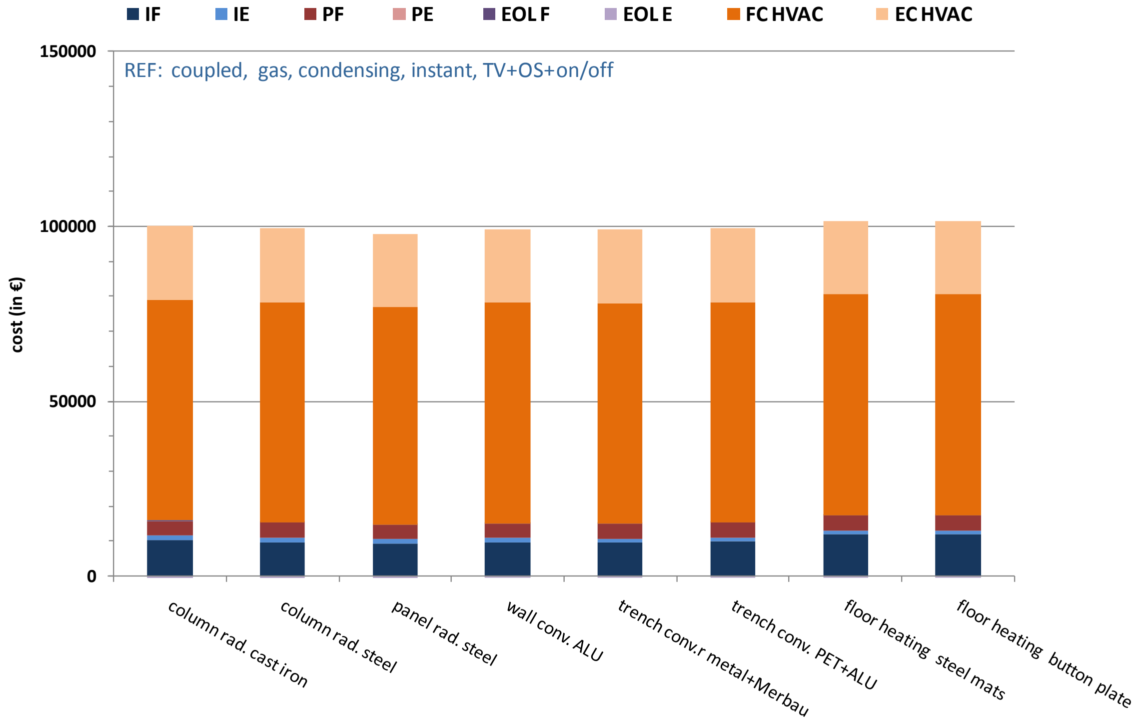

Figure 12 Comparison of emission sub systems of space heating systems (in €) for the well-insulated dwelling (K20) with a life span of 60 years

Although low temperature emission systems are more energy performing than high temperature ones, no substantial differences in the overall cost profile are discerned between all studied emission systems.

6.3.4 Control of space heating

Based on interdependency of heating sub systems (see §4.2.1), different sets of control systems are analysed. For a (modulating) condensing boiler, the influence of room thermostat and manual valves (whether or not combined with an outside temperature sensor) is analysed on the life cycle cost profile. Alternatively, for a (non-modulating) gas burner, the influence of thermostatic valves and a clock control (whether or not combined with an outside temperature sensor) is analysed.

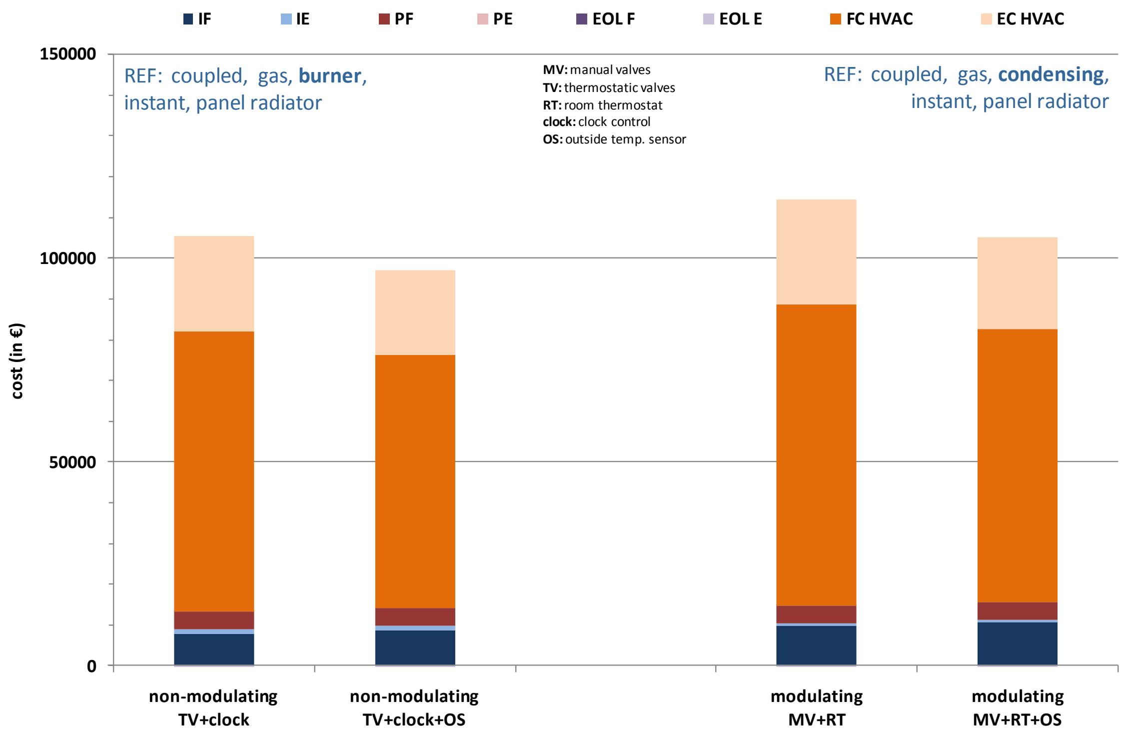

Figure 13 Comparison of control sub systems of space heating systems (in €) for the well-insulated dwelling (K20) with a life span of 60 years: (left) non-modulating gas burner; (right) modulating gas burner

The relatively small initial costs of control components (less than 10% of IF and 3% of IE) disappear in the total life cycle profile. Nevertheless, the initial selection of a heating control system does have a significant influence on the overall heating efficiency – and thus also the energy consumption over the life span of the dwelling. As shown in Figure 13 a more sophisticated control system – i.e. using an outside temperature sensor – for a well-insulated dwelling is responsible for a reduction of circa 7% of LF and 13% of LE – for both a modulating and a non-modulating boiler.

7 Concluding Recommendations

For the representative Belgian dwelling, assessed in this research, heating services and the related energy are responsible for 9-18% of LF and 55-78% of LE of the dwelling. Such diverse figures justify the necessity to better understand heating services and to seek solutions to reduce financial and environmental costs, without loss of dwelling qualities. In order to do so, systemic and parametric modelling is used to evaluate different heating measures on element level.

7.1. Recommendations on element level

From an environmental viewpoint, one of the most important measures to reduce life cycle costs is to enhance the **thermal insulation level** of the dwelling. By halving the net energy demand the environmental life cycle costs are on average reduced by 46%. Due to the relatively low financial energy prices the life cycle financial costs are only reduced by 4%. As a result, a good selection of heating services is crucial to further decrease life cycle costs. Choosing appropriate heating configurations can lead to a reduction of financial life cycle costs of 10% for the K100 dwelling and of 8% for the K20 dwelling.

For the selection of a **space heating system** a commonly used condensing gas boiler combined with a sophisticated control system (i.e. thermostatic valves combined with a clock and an outside temperature sensor) is preferred based on merely financial costs. Focusing only on the environmentally costs, advanced alternatives such as a heat pump and a condensing pellet furnace can compete with the previously named configuration, but only for a highly insulated dwelling (considering a dwelling life span of 60 years). Although heat pumps are characterised by a higher initial environmental cost, their corresponding life cycle costs are lower compared to non-renewable production systems. Looking at the total life cycle costs, once again, the common configuration with the condensing gas boiler is preferred above others. A condensing pellet furnace is the best advanced solution for the highly insulated dwelling. Based on environmental and total (life cycle) costs, we can conclude that there is no clear preference for any of the studied emission types. Although the emission type does not play a significant role in the life cycle cost profile, over-dimensioning of the emission components will lead to efficiency losses. Also the capacity of production systems dwellings needs to be chosen correctly. For highly insulated dwellings this is, however, problematic since small condensing gas and oil boilers are not (yet) available on the Belgian market. One of the measures to change this is to strongly involve the heating industry and installers into the determination of energy performance of dwellings.

For the supply of **domestic hot water** electric boilers should be avoided – if possible – due to the relatively high environmental costs, related to Belgian energy mix. When only initial costs are taken into account, solar boilers cannot compete with an instant system (coupled to CH) with or without a separate geyser in the kitchen or bathroom. However, from a life cycle perspective – including financial, environmental as well as total costs – these advanced systems can compete with the commonly used ones.

7.2. Recommendations on dwelling level

Besides the selection of appropriate SH and DHW and enhancing the thermal insulation level of the dwelling, a good implementation of dwelling characteristics such as building morphology, size and orientation as well as window area will further enhance energy performance of the dwelling. Since these characteristics are strongly related to the location of the dwelling, these aspects have not been taken into account in this paper. More information about these dwelling characteristics can be found in (Allacker 2010).

7.3 Internalisation of environmental costs

The environmental life cycle cost proves to contribute on average 6% to the total life cycle cost (with a minimum of 3% and a maximum of 10%). The contribution of the environmental cost to the initial cost equals on average 5% (with a minimum of 5% and a maximum of 6%). This implies that the **internalisation of environmental costs**, will not lead to unaffordable housing – provided that the energy demand of the dwelling remains low.

Since the monetisation of environmental impacts is based on the concept of "willingness to pay" for environmental damage, it is likely that the importance of environmental life cycle cost will increase in the future. In that case, environmental and total optima and sub optima will have to be adjusted. Some advanced heating systems, which are for the moment not interesting from a total life cycle cost point of view, would benefit from this change in public opinion.

8 Acknowledgements

The research presented in this paper is in line with the project "Sustainable and Financial Quality evaluation of Dwelling Types", which is financially supported by the Belgian Science Policy and involves three research partners: the department ASRO of the K.U.Leuven, the Belgian Building Research Institute (BBRI) and the Flemish Institute for Technical Research (VITO). The authors would like to thank all colleagues who contributed to this study.

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European Roundtable on Sustainable Consumption and Production

Basel, Switzerland, June 20-22, 2007

Workshop 8
Sustainable Building
21 June 2007

Starting Position

The workshop started with a presentation of SuFiQuaD, an ongoing research project in Belgium.
SuFiQuaD stands for Sustainable, Financial and Quality evaluation of Dwelling types.

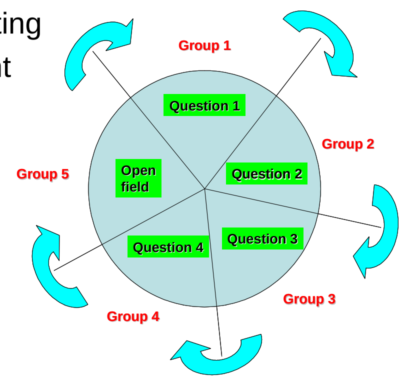
The overall aim of the research is to optimize the dwelling stock in Belgium, looking at environmental, financial and quality aspects.

Project commissioner: BELSPO, SSD
Project coordinator: KULeuven, ASRO
Project partners: VITO, WTCB-CSTC-BBRI
Project timing: 2007 - 2011

Objectives

The objectives of this workshop were the following:
- Presentation of the methodology used in SuFiQuaD
- Feedback on selected aspects of the approach, more in specific:
  1) Defining the functional unit of buildings
  2) Monetarisation of environmental impacts + discounting
  3) Quality evaluation and indoor air quality assessment
  4) Optimisation of costs/quality

The workshop was structured in three steps:
1) generation of ideas / brainstorming
2) selection of „best“ ideas
3) development of most relevant ideas



Results

The main results were the following:
1) Functional unit: inclusion of number of occupants, both EI for total building as per m2 floor area are important.
2) Monetarisation is needed: external costs are recommended.
3) Indoor air quality is getting more and more important (air thightness, insulation) and should be integrated in the environmental assessment.
4) Optimisation: stakeholder involvement is important in weighing the different sustainability aspects.
5) Other suggestions: different scenarios are needed for renters and dwelling owners.

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NATIONAL HIGHLIGHTS

SPAIN

As regards regulation and policies, the Spanish Plan on Green Public Procurement has been presented in January 2008 and the New Law on Natural Heritage and Biodiversity has been approved in November 2007.

One of the main events at international level will be the International Exposition in Zaragoza 2008. The main topic of this event is water management and sustainable development, and it will be celebrated from the 14th of June and the 14th of September of 2008 (www.expozaragoza2008.es). Within the Exposition, ICLEI's European Membership Convention will also take place in Zaragoza, on the 23rd – 25th of June 2008 (www.iclei-europe.org).

In the Basque Country, the IHOBE 2008 call for tenders for Innovative projects has awarded 16 projects. As for new policies, two main plans have been approved: the Hazardous Waste Prevention and Management Plan 2008-2011 and the Basque Plan to combat Climate Change 2008-2012 (4 programmes 120 actions).

Ibon Zugasti - Prospektiker

Basque Country, Spain

NETHERLANDS

The Netherlands has several large generic subsidy schemes for environmental innovation.

The Green Funds Scheme, which supports investments in sustainable projects, is due for a large update. Many new and updated descriptions of eligible green projects have been-drafted. The European Commission is currently checking the proposals for compliance with state aid regulation. The Green Funds Scheme supports 6 billion euro's in investments with tax relief of about 150M€ / yr.

For the activities which we carry out in the field of environmental innovation, we are interested in using and strenghtening our international contacts. For the subsidy schemes this would involve exchanging knowledge on categories of sustainable projects, criteria, innovative concepts and eco-innovation priorities. As an example, we are currently discussing a joint environmental innovation programme with the Flemish government. Other questions would be: how are lead markets chosen in your country? How to make the BREF process in Sevilla respond to innovations?

Akshay Patk

Ministry of Housing, Spatial Planning and the Environment, Netherlands

BELGIUM

SuFiQuaD - Sustainability, Financial and Quality evaluation of Dwelling types

VITO is currently working on a four-year project to develop an integrated methodology in order to optimise the Belgian dwelling stock. The optimisation includes different sustainability aspects: environmental impacts, financial costs and quality aspects. Improvements of buildings concerning their quality and their environmental impact and financial cost over the whole life cycle will be evaluated for the different representative dwelling types in Belgium. Environmental impacts will be analysed by means of life cycle assessments, financial costs will be calculated based on life cycle cost analyses and the quality evaluation is based on an existing method in Belgium and consists of a multi-criteria analysis. The metho-dology used provides the highest marginal quality improvement for the additional cost. Finally the developed metho-dology will be translated into a work instrument and applied to different dwelling types.

SCoPE (seriousness, corroboration, perception, and economy): an integrated assessment frame as science policy interface for decisions on (environment-related) risks.

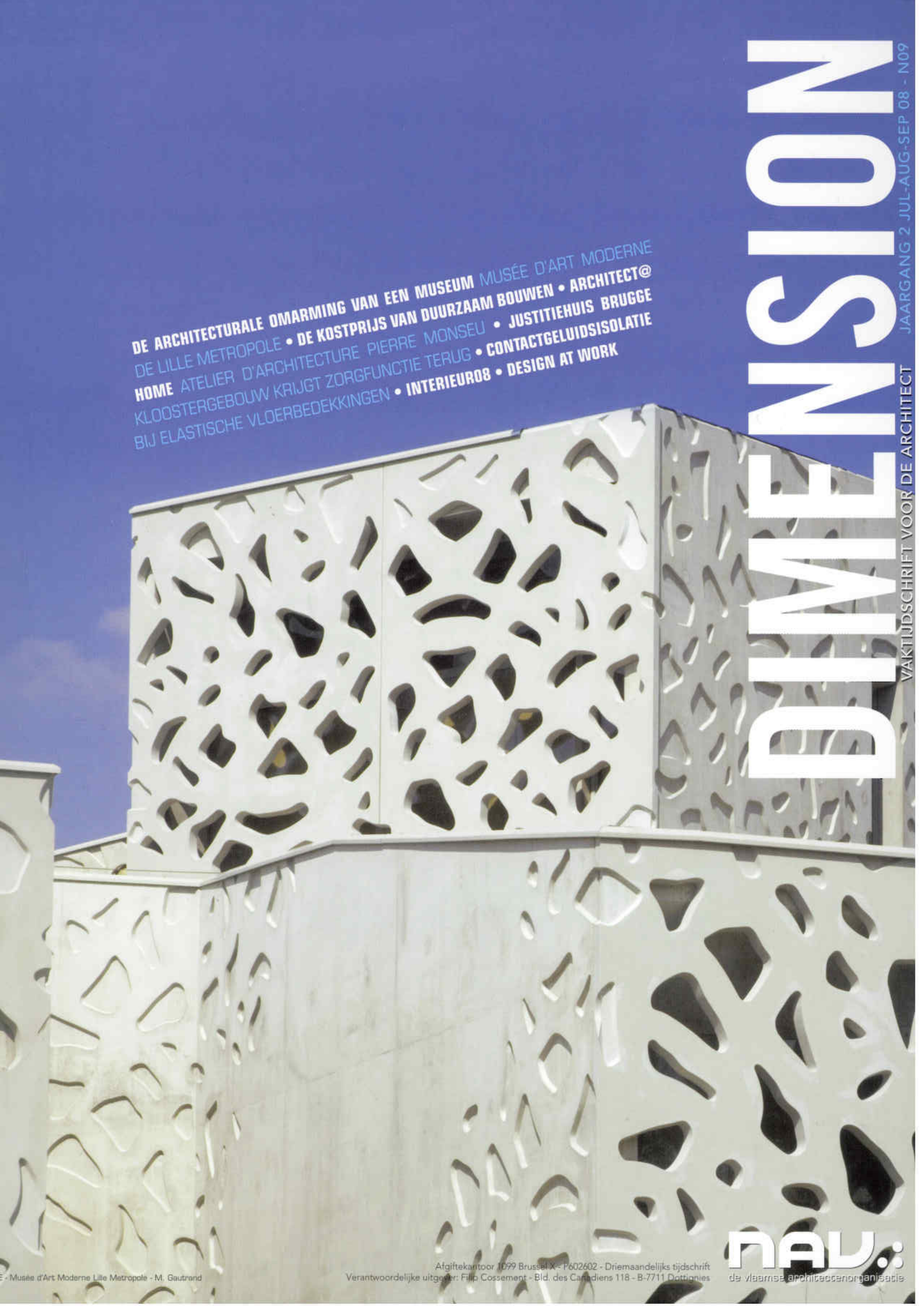
Within the four-year project for the Belgian Science Policy, VITO an SPIRAL are currently developing an assessment framework for decision makers to decide on environmental health-related risks (http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=SD/TA/10A). The aim of the assessment framework is help policy makers in setting environmental health priorities and taking balanced decisions; to improve transparency and communication between science, policy, and resource management communities and stakeholders; and to integrate different scientific disciplines / knowledge in a methodology:

- Severity and frequency of the health impact (~ risk assessment)
- Corroboration (~ (un)certainty or scientific assessment)
- Public perception (~ concern assessment)
- Economy (~ socio-economic assessment).

Johan Stessens

VITO, Flemish Institute for Technological Research

Belgium



DIMENSION

VAKTIJDSCHRIFT VOOR DE ARCHITECT

JAARGANG 2 JUL-AUG-SEP 08 - N09

DE ARCHITECTURALE OMARMING VAN EEN MUSEUM MUSÉE D'ART MODERNE DE LILLE METROPOLE • **DE KOSTPRIJS VAN DUURZAAM BOUWEN** • **ARCHITECT@HOME** ATELIER D'ARCHITECTURE PIERRE MONSEU • **JUSTITIEHUIS BRUGGE** KLOOSTERGEBOUW KRIJGT ZORGFUNCTIE TERUG • **CONTACTGELUIDSISOLATIE** BIJ ELASTISCHE VLOERBEDEKKINGEN • **INTERIEUR08** • **DESIGN AT WORK**

E - Musée d'Art Moderne Lille Metropole - M. Gautrand

Afgiftekantoor 1099 Brussel X - P602602 - Driemaandelijks tijdschrift
Verantwoordelijke uitgever: Filip Cossement - Bld. des Canadiens 118 - B-7711 Dottignies

nav.: de vlaamse architectenorganisatie

VAKTIJDSCHRIFT VOOR DE ARCHITECT
DIMENSION

INHOUD

ARCHITECTENLOBBY: Utopie of noodzaak?

Efficiënt te werk gaan, ideeën bundelen, competenties uitwisselen en samenwerken biedt altijd voordelen. Dit geldt ook voor partners uit de bouwwereld. Met bepaalde beroepsverenigingen lukt samenwerken gelukkig. Anderen, eerder enkelingen, kunnen het nog altijd niet laten om kritiek rond te strooien over al lang voorbijgestreefde gebeurtenissen. Zij lopen hopeloos achter op de feiten. Deze houding helpt ons enerzijds om zelfkritisch te zijn, maar uiteindelijk zegt het meestal meer over wie kritiek geeft dan over wie hem krijgt, want men hanteert hierbij vaak onjuist, verouderd en uit de context gehaald feitenmateriaal... Conclusie: samenwerken moet men niet alleen kunnen maar ook willen!

Voornoemde bedenking brengt ons naar de vaststelling dat het lobbywerk van de architecten eerder zwak overkomt ten opzichte van andere bouwpartners. Organisaties zoals Bouwunie, Confederatie Bouw, ... zijn beter georganiseerd. Ze dragen een eenduidige visie uit en bereiken hiermee gunstige resultaten. Helaas moeten wij vaststellen dat architecten nog te veel werken in verdeelde slagorde. Op deze manier kunnen we moeilijk onze stem laten horen en serieus genomen worden.

Een bijkomende tekortkoming is het ontbreken van een studiedienst. Toegepast en vergelijkend onderzoek kunnen een steun zijn voor het architectenberoep, zeker als dit dient om gefundeerde gesprekken aan te gaan met beleidsvoerders. Vermits hierbij vooral beroepsgerichte thema's nuttig zijn, hoort dergelijke dienst vooral bij de beroepsverenigingen thuis, en bij voorkeur ook onder beperkte vorm van samenwerking met de Orde, die blijkbaar momenteel over enige financiële armslag beschikt.
Zolang niet duidelijk is wat de wettelijke taken zijn van de Orde, is het volgens mij niet opportuun dat zij een eigen studiedienst oprichten.

Studiethema's zijn bijvoorbeeld reglementeringen op nationaal, regionaal en Europees niveau; de link tussen praktijk en opleiding; PPS-projecten; ...

Is een constructieve samenwerking binnen de architectuurwereld mogelijk, of toch nog steeds een utopie? NAV, stelt haar deuren alvast open.

Gilbert Van Hecke - Architect
Voorzitter NAV

| HOLLAND COMPOSITES INDUSTRIALS |
Raficlad: Bijzondere gevelplaten op maat

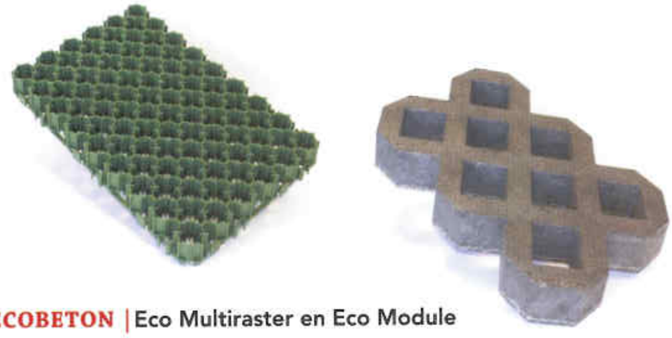
Steeds meer architecten gaan op zoek naar een bijzondere, blijvend fraaie gevelbekleding. Nu kunnen ze ook hun licht opsteken bij Holland Composites Industrials. Speciaal voor hen heeft dit composiet bedrijf Raficlad® ontwikkeld: lichtdoorlatende vezelversterkte kunststof panelen die voorzien kunnen worden van een inlage, zoals willekeurig georiënteerde vezels. Met behulp van een CNC gestuurde waterstraalsnijder kunnen de platen in elke gewenste vorm en contour gesneden worden en voorzien worden van bevestigingsgaten. De panelen worden projectmatig vervaardigd waardoor de architect/ opdrachtgever kleuren, structuur, inlagen en mate van translucentie volledig zelf kan bepalen. Raficlad® is duurzaam en heeft onbeperkte architectonische mogelijkheden. De fabriek staat in Lelystad (NL).

www.hollandcomposites.nl

| SUFIQUAD | Sustainability, Financial and Quality evaluation of Dwelling types

In opdracht van de Programmatorische Federale Overheidsdienst Wetenschapsbeleid werken de Katholieke Universiteit Leuven, departement Architectuur, Stedenbouw en Ruimtelijke Ordening (K.U.Leuven - ASRO), de Vlaamse Instelling voor Technologisch Onderzoek (VITO) en het Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf (WTCB) aan een onderzoek om verschillende woningtypes te optimaliseren op gebied van milieu-impact, financiële kost en kwaliteit. Het zogenaamde SuFiQuaD-project heeft als doel te streven naar meer duurzame woningen in België. Om aan deze doelstelling tegemoet te komen wordt een geïntegreerde aanpak beoogd. Hierbijwordt een analyse gemaakt van de complexe interacties tussen woningtype, levenspatroon, ruimtelijke kenmerken, technische oplossingen voor gebouwelementen enerzijds en de kwaliteiten, financiële kosten en milieu-impacten over de ganse levenscyclus van de woning anderzijds. De ontwikkelde methodologie wordt in een eerste fase getoetst aan de hand van een aantal extreme woningtypes. Na evaluatie hiervan, zal de methodologie uiteindelijk gebruikt worden om woningtypes, representatief voor de Belgische context, te evalueren. Het SuFiQuaD-project startte begin 2007 en loopt over 4 jaar. Op basis van de resultaten wordt een beleidsvoorbereidend document opgesteld.

www.belspo.be



| ECOBETON | Eco Multiraster en Eco Module

Ecobeton water technologies nv brengt het alternatief voor verhardingen zoals beton en asfalt in het kader van de Stedenbouwkundige Verordening Hemelwater van 01/10/2004 en de Stedenbouwkundige Verordening Vlaams-Brabant. Deze 2de generatie waterdoorlatende verharding in HDPE maakt belastingen tot 380 ton /m^2 mogelijk en is COPRO-gekeurd. Het Eco Multiraster is 100% waterdoorlatend en vulbaar met meerdere materialen zoals gras, grind of houtsnippers.
De voormontage per 4 stuks (+1m^2) zorgt voor een snelle en eenvoudige plaatsing. Het unieke kliksysteem aan de 4 zijden minimaliseert bovendien het verzagen van de bodemplaten.
Eco Module is een bodemversteviger vervaardigd uit gerecycleerde materialen en een op zijn beurt een alternatief voor de klassieke betonnen grasdallen: geen scherpe kanten, licht in gewicht met slechts 8,025 kg/tegel en eenvoudig te verzagen. Deze eigenschappen zorgen voor een snelle en eenvoudige plaatsing. Ook de Eco Module zorgt voor een optimale infiltratie. Deze tegel kan een belasting aan van 160 ton/m^2 waardoor zij uitermate geschikt is voor wegbermen.

www.ecobeton.be

| INFORMAZOUT | Luc Bouts wordt nieuwe voorzitter

Op de Algemene Vergadering van 19 juni werd Luc Bouts verkozen tot nieuwe voorzitter van de vzw Informazout met een mandaat van 3 jaar.
Samen met zijn broer staat hij aan het hoofd van het familiebedrijf Bouts n.v. uit Hasselt dat 21 medewerkers telt. Het bedrijf is actief in de verschillende segmenten van het petroleumgamma, vooral de gasolie verwarming. Luc Bouts is ondervoorzitter van de Lubricants Association Belgium en actief in verschillende federaties en sectororganisaties (met name BRAFCO, BPU en het Sociaal Verwarmingsfonds).

Luc Bouts volgt Thierry Van Coppenolle op die zelf 6 jaar voorzitter was van een niet vernieuwbaar mandaat.
Tijdens het voorzitterschap van Thierry Van Coppenolle werden de middelen en het proactieve communicatiebeleid van Informazout versterkt en de kwaliteitslabels Optimaz-elite, Optitank en MazoutExpert succesvol gelanceerd.

www.informazout.be

Title: Development of a methodology to optimize dwelling types in Belgium.

Keywords: LCA, LCC, multi-criteria analysis, optimization, dwelling stock

Abstract (400 – 500 words):

In Belgium a four-year project has started in 2007 to develop a methodology to optimize its dwelling stock. The optimization includes sustainability, financial cost and quality aspects. The aim is to evaluate improvements of buildings concerning their quality and their environmental impact and financial cost over the whole life cycle. The analysis will be executed on the different representative dwelling types in Belgium. This will result in typology specific recommendations, which are expected to be effective since these are directly linked to one's personal situation.

In a first phase the methodology is being developed and will be presented in this paper. One of the challenges is to translate environmental impacts into financial terms and to calculate the total cost by adding up both the environmental and financial cost over the whole life cycle of the building. Once this total cost can be estimated, different alternatives can be compared and one can search for the lowest total cost.

The *environmental impact* is estimated based on life cycle assessments and is expressed in EURO. The *financial costs* are calculated based on a life cycle cost analysis. The sum of the present values of all costs is calculated. Since buildings have a relatively long lifespan, the use phase is very important and should be investigated in detail. In spite of financial costs this means that both financial parameters (growth rate, discount rate) as energy prices should be carefully estimated and a sensitivity analysis should be performed. The *quality evaluation* is based on an existing method in Belgium and consists of a multi-criteria analysis, resulting in a single score. This quality evaluation is seen as an essential part of the analysis since a good quality is a requirement for sustainability but moreover since it is hard to define identical functional units when comparing buildings. The inclusion of the evaluation of the performance of a building enables comparative analysis.

The optimization is the last part in the development of the methodology. The basic approach is to realize the highest marginal quality improvement for the additional cost. For the cost different criteria are considered. The first criterion is the initial financial cost, the second is the sum of the initial financial and environmental cost, the third is the financial cost during the whole life cycle and the fourth is the sum of the financial and environmental cost over the whole life cycle. If the different criteria point to different solutions, additional rules for priorities have to be selected.

Finally the developed methodology will be translated into a work instrument and applied to the dwelling types in two steps. In a first step extreme housing types will be analyzed, while in the second step the methodology will be applied to representative housing types. These steps however are not elaborated in the paper since these are foreseen to be carried out from 2008 on.

Towards 0-impact buildings: a caste-study based analysis

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CONTEXT

0-impact buildings in the context of this research are defined as NET-0-impact buildings, considering both negative and positive impacts during the life span of the building. These should moreover be situated within a broader concept of sustainability considering costs and qualities of the buildings and social impacts of the construction sector.

To efficiently evolve towards 0-impact buildings it is important to investigate which are the actions in order of priority. The latter can be defined as measures which lead to the highest reduction of the impact for the smallest increase in cost. This paper elaborates on the reduction potential of the environmental impact of buildings throughout their life cycle based on a set of case studies.

This PhD research is carried out within the four-year research project SuFiQuaD, which stands for Sustainability, Financial and Quality evaluation of Dwelling types. Although 0-impact buildings are not the focus of the research, the research findings are of interest when searching for a ranking of the most important measures to move towards 0-impact buildings.

PROJECT COMMISSIONER

The SuFiQuaD project is financed by the Belgian Science Policy – Science for Sustainable Development (BELSPO - SSD).

PROJECT PARTNERS

- K.U.Leuven, ASRO
- VITO
- BBRI

PROJECT TIMING 2007 – 2011

APPROACH AND METHODOLOGY

Integrated approach

An integrated approach is selected in order to enable the assessment of the overall picture, more specific:

- from the cradle to the grave
- at the building level: including the influence of typology, location, orientation, dimensions, layout, …
- of as many environmental aspects as possible
- of both initial and life cycle financial costs
- of the building performance

Methodology

Environmental impact => environmental costs:
➡ *LCA / monetary valuation*
Financial costs: ➡ *LCC*
Optimisation: ➡ *pareto concept*

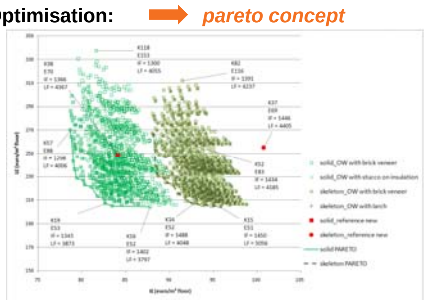

Figure: illustration of the Pareto front

CASE STUDIES

RESULTS OF THE CASE STUDIES

For both the existing dwelling stock and newly built dwellings according to common practice to date, the heating demand reveals to be the most important contributor to the environmental cost. For the optimised dwellings, the environmental cost due to the production of the materials becomes approximately equally important as or even more important than the heating cost. Moreover, the impact due to fresh water use and electricity is now in the same order of magnitude as heating and the production of the materials.

Conclusions

0-impact buildings are yet a bridge too far with current technology. To move towards 0-impact buildings (if technology is not drastically improved in the near future) one should focus on the dwelling type, layout and size. Actions in order of priority are furthermore increased insulation level, a more efficient heating installation, and finally reduction of electricity and fresh water consumption. Transport during use phase, related to the location of the dwelling, reveals to be even more important than the energy use for heating.

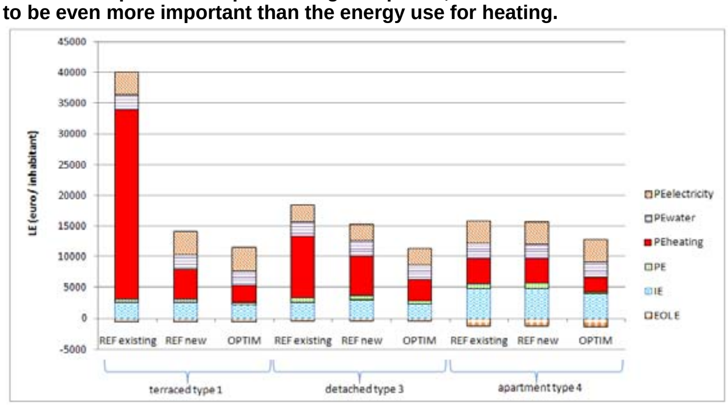

Figure: environmental cost of the different processes, expressed in euro per inhabitant - for the reference existing dwelling, newly built common practice to date and the optimised dwelling.

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