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Combining environmental impact and financial cost calculations with quality assessment at the building level.

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ABSTRACT

Buildings are complex products whereof most important design decisions are taken during the first design phase. Environmental impact (EI) and financial cost (FC) are therefore preferably evaluated at this moment. The complexity of buildings and the lack of information during the early design phase however make the evaluation difficult. In this paper a methodology is proposed to overcome these difficulties by incorporating EI assessment in the element method for cost control. This enables, in a first step, to evaluate the initial EI and FC of building elements, whereof the relation to the building is taken into account by expressing the EI and FC per m2 floor area. A building is in that sense simplified to independent elements and the lack of information is handled by refining rough first estimations to detailed calculations - for the elements of interest – later on in the design process. Moreover the aim is to include the whole life cycle of the building. Life cycle assessment (LCA) and life cycle costing (LCC) are combined, leading to a total EI and FC per m2 floor area. To enable comparative analysis, a final step is added: a quality evaluation is elaborated via a multi-criteria analysis. The proposed methodology is illustrated by a case study to improve comprehensiveness and prove its viability.

Key words: Life Cycle Assessment (LCA), Life Cycle Costing (LCC), element method, quality evaluation, multi-criteria analysis (MCA)

1 INTRODUCTION / BACKGROUND

In Belgium, as in many European countries, ‘sustainable architecture’ and ‘sustainable building’ have become key issues. Sustainability, for example, is one of the selection criteria in most architectural contests and nearly every producer of building products mentions one or more characteristics to convince clients that the product is sustainable or environmental friendly. This shows that not only government projects require sustainable constructions, but also architects, related industry and end users are increasingly environmentally aware.

It is clear that sustainability is more than theoretical. For example, in Belgium, the energy performance standard (EPB) was introduced in January 2006 (Anon., 2004, Belgisch Staatsblad). The aim of the EPB is to reduce the energy consumption in buildings during use phase, taking into account heating, possible cooling, warm sanitary water and ventilation. The design of the building, its orientation and the installation efficiency are considered in relation to energy use.

While the EPB regulates actions for which a building permission is required, the Belgian government also promotes other energy saving measures through subsidies and tax reduction. Insulating roofs and outer walls, improving the insulation value of glazing, replacing old heating installations or using renewable energy resources are qualifying measures (www.energiesparen.be).

Another initiative from the government is stimulating cleaner production of building products. The BATNEEC (Best Available Techniques Not Entailing Excessive Costs) studies evaluate current production processes and investigate which improvements can reduce the EI (Dijkmans, 2000). This has been undertaken for several industrial branches, including the building sector.

Initiatives taken by owners and architects on the other hand have led to an increasing number of passive and low energy dwellings in Belgium. The Belgian Passive House Platform offers guidance and awards the 'passive house' label if preconditions are fulfilled (www.passiefhuisplatform.be).

Despite the noticeable interest in sustainability, the building sector is still one of the most polluting industries. The slow improvement can partly be explained by the long lifespan of buildings. Nevertheless, the problem is urgent and a programme of reform is essential.

2. AIM

The aim of the research presented in this paper is to develop a methodology to analyse the sustainability of a building during the first design phase when most important design decisions are taken. The three widely recognised aspects of sustainability, namely ecological, economical and social aspects, should be included.

The method is developed to be applied by researchers and will be used to analyse the Belgian housing stock. The objective is to formulate recommendations for the different dwelling types. The analysis should lead to an indication of the most important fields of action. Moreover it should be clear why certain actions are not taken and how this can be overcome.

If the method seems useful, it may be further elaborated into a tool. Depending on the actor for whom the tool is needed, the tool should be structured differently. It is also possible that different tools, based on the same methodology, for different actors will be needed.

In this paper a preliminary case study is included which only serves as an illustration of the methodology and to improve comprehensiveness and prove its viability. Application of the methodology to a larger scale has not yet been carried out, but is planned for the coming years.

3. METHODOLOGY

The proposed methodology is based on the element method for cost control, which facilitates cost estimations and calculations in the building sector (Flanagan, Tate, 1997). The proposal is to extend this method to include EI calculations. For a description of this approach we also refer to a previous publication (Allacker, De Troyer, 2006).

To analyse the efficiency of possible measures, a comparative analysis is required. Within LCA comparative analysis is only feasible when identical functional units are defined. In the case of buildings, defining identical functional units is not simple, since buildings fulfil more than one function. In the REGENER project, one square meter of living area is used as functional unit for dwellings, assuming that the building is located at a certain point in a given region, is occupied and is comfortable without disturbing the user’s health and well-being. (REGENER, 1997)

SETAC (2003) mentions that different options for a functional unit are possible such as a single meter square of inner space or of the building, a single cubic meter building and number of inhabitants. (SETAC, 2003)

Since the proposed methodology is based on the element method for cost control, one square meter of floor area has been chosen as functional unit. Since the performance of this functional unit is not necessarily equal for all dwellings, a quality evaluation is added. The total score, defined by quality over EI for a certain FC, enables to compare buildings with a different quality. For the quality evaluation a multi-criteria analysis (MCA) is conducted.

For both the FC and EI calculations the whole life cycle is considered, by carrying out

Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) respectively. This implies that production, transportation, construction, use and end-of-life are considered. In the following paragraphs aspects of the methodology will be further described.

3.1 Element method

The main concept of the element method is to divide the building in independent building elements of which the ratio per square meter of total floor area is determined. As a result the FC per square meter of floor area is obtained. The advantage of the element method is that it can be used during the early design phase: first cost estimations are made, which are elaborated later in the design process. Moreover the analysis can be limited to one or more building elements of interest, since these are independently defined. This also implies that changing one element has no effect on other elements.

In this research EI calculations are added to the element method. As with the FC, the EI per independent element needs to be calculated and multiplied by the ratio of the element. As a result the EI per square meter of floor area is obtained. Finally, it is necessary to compare buildings with a different lifespan. Therefore total FC and EI are calculated per m2 of floor area per year.

3.2 LCA

The EI impact is calculated by carrying out a LCA, taking into account the whole life cycle of the building. The LCA is carried out following the ISO 14000 standard and exists of the following phases: goal and scope definition, inventory phase, impact assessment, normalisation and interpretation (ISO 14000, 1996). To improve communication the environmental impacts have been weighted and summed, resulting in a single score. This last step however is not in line with ISO 14000, since weighting is not allowed in comparative analysis. Although the weighting is included, the results are never shown without the unweighted values.

Within this paper eco-indicator 99 is used as impact assessment method, considering the damage to human health (HH), quality of ecosystems (QE) and resource depletion (R) (www.pre.nl/eco-indicator99). The results are normalised by dividing the results by the yearly impact of an average European citizen. For the weighting values it is supposed that HH is equally important as QE and that R is half so important (40%, 40% and 20% respectively). The single score is expressed in eco-points.

3.3 LCC

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

$$TFC = I_0 + \sum_{t=0}^{t=T} PV(P_t) = I_0 + \sum_{t=0}^{t=T} \frac{P_t \times (1+g)^{(t)}}{(1+d)^{(t)}} \quad (1)$$

With:
- TFC = Total financial Cost
- PV = Present Values of costs
- I_0 = initial investment cost
- P_t = periodical (future) cost
- g = growth rate (annual)
- d = discount rate (annual)
- t = time (years)

The initial cost includes the material cost, transportation cost of materials and construction of the building (labour cost, indirect costs, etc.). The periodical (future) costs are costs during use phase. The growth rate of costs differs for processed building products (including material, labour, indirect costs) and energy costs. The time value of money is incorporated by defining a discount rate.

3.4 Quality evaluation

For the quality evaluation an existing method for housing in Belgium is used (Anon., 1991). This method is based on an MCA and consists of three steps: selection of qualities, determination of scores and assignment of weighting factors.

The qualities are divided in five main categories: dimensional, functional and technical characteristics, the surroundings of the dwelling and the financial cost. Each category is subdivided in different aspects. The category 'dimensional characteristics' for example is subdivided in the aspects: size of rooms, room width, window size + orientation and efficient use of floor area. Each aspect is again subdivided in sub-aspects for which scores are given. Within the aspect 'size of rooms' for example, there is a score assigned to the floor surface area of each room.

Figure 1: Score functions for size of living room/kitchen and for the window size in the living room.

For the determination of these scores, score functions are defined, relating a physical characteristic with a score. In the figure above, some examples of score functions are shown (figure 1).

Finally the importance of the different qualities should be defined by assigning weighting factors. These are then multiplied by the score for each quality for the compared alternatives and summed to obtain a single score. The weighting factors in the existing method were defined by consulting expert commissions.

Within the existing quality evaluation method, the hygro-thermal characteristics are included as an aspect of the technical characteristics. Since this is mainly expressing the insulation value of the house, this has been left out in the application of the methodology within this research (weighting factor = 0). This is done to avoid double counting: the energy need is already incorporated in the EI and FC calculations. If certain qualities can be expressed quantitatively this gains the preference. Moreover the category 'financial cost' has been omitted in this research since the FC is evaluated separately. Again this is done to avoid double counting.

Category	**Aspects**	**Importance**
Dimensional characteristics		32,5 %
	Size of rooms	42%
	Room width	26%
	Windows size + orientation	20%
	Efficient use of floor area	12%
Functional characteristics		19,5 %
	Available length for furniture	33%
	Relation between the different rooms	40%
	Flexibility/adaptability	27%
Technical characteristics		22 %
	Ventilation and safety	12%
	~~Hygro-thermal characteristics~~	0%
	Acoustical performance	21%
	Technical installations	50%
	Surface of materials: maintenance	17%
Surroundings of the dwelling		26 %
	Direct surroundings	50%
	Broader surroundings	50%
~~**Financial cost**~~		0 %

Table 1: Qualities and their importance, as modified from the original methodology.

3.5 Total score: Q/EI for a certain FC

Finally the total score is calculated by dividing the quality (Q) score by the EI score. The best alternative is then defined by the highest Q/EI for a certain FC.

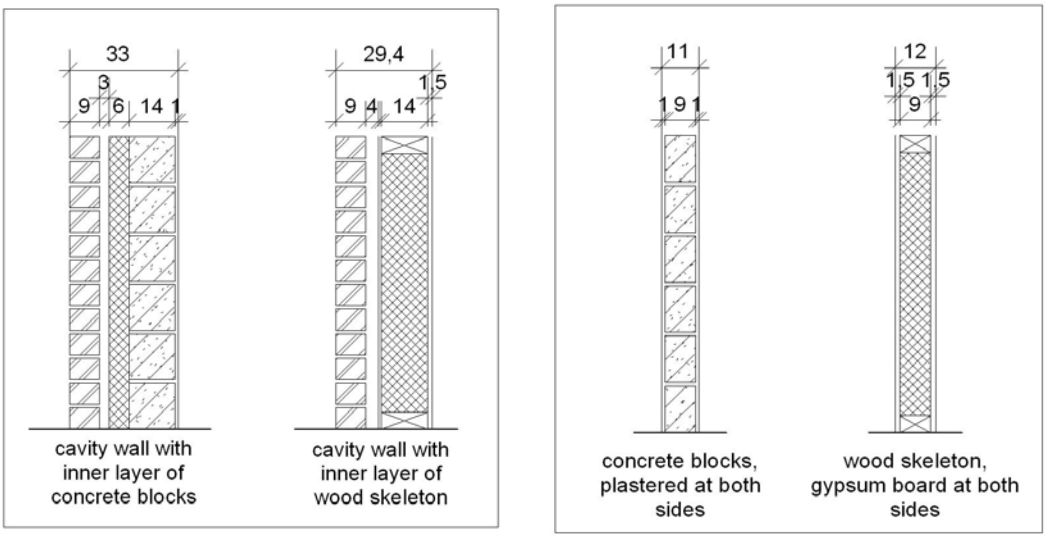
4. CASE STUDY

4.1 Description

As an illustration of the methodology, the analysis has been carried out for three elements, the outer walls, shared walls (if applicable) and inner walls, and this for both a detached house and a terraced house. For each element two alternative technical solutions are compared.

Because of the climatic conditions in Belgium, cavity walls are a common technical solution for outer walls. The analysed alternatives are therefore both cavity walls with an outer layer of facing bricks, but with different inner layers. The first one consists of an inner layer of concrete blocks (heavy alternative), the second one of wood skeleton (light alternative). Both alternatives are graphically presented in the figure below on the left (figure 2, left).

For the inner walls, again two alternatives are compared. The first one is a masonry wall of concrete blocks (9 cm), plastered (gypsum plaster) at both sides (heavy alternative). The second one is a wood skeleton wall with a thickness of 9 cm, filled with insulation and finished with gypsum board at both sides (light alternative). Both alternatives are graphically presented in the figure below on the right (figure 2, right).



cavity wall with inner layer of concrete blocks

cavity wall with inner layer of wood skeleton

concrete blocks, plastered at both sides

wood skeleton, gypsum board at both sides

Figure 2: Graphical presentation of the alternatives for the outer (left) and inner walls (right).

For the shared wall, only one alternative is analysed: a double-layered concrete wall of two times 14 cm and with 6 cm of thermal insulation in between. Only half of this wall is considered in the analysed terraced house, since the other half is assigned to the neighbouring dwelling. A ‘light’ alternative is not included, since for sharing walls, wood skeleton is prohibited in Belgium.

The analysed houses are supposed to have a lifespan of 75 years, are heated with natural gas with a global system efficiency of 65 % and are located in Belgium (1750 equivalent degree days). Both houses have a total floor area of 150 m2, divided over three floors for the terraced house, only groundfloor in the case of the detached house. The houses are presented in the figures below (figure 3 and 4).

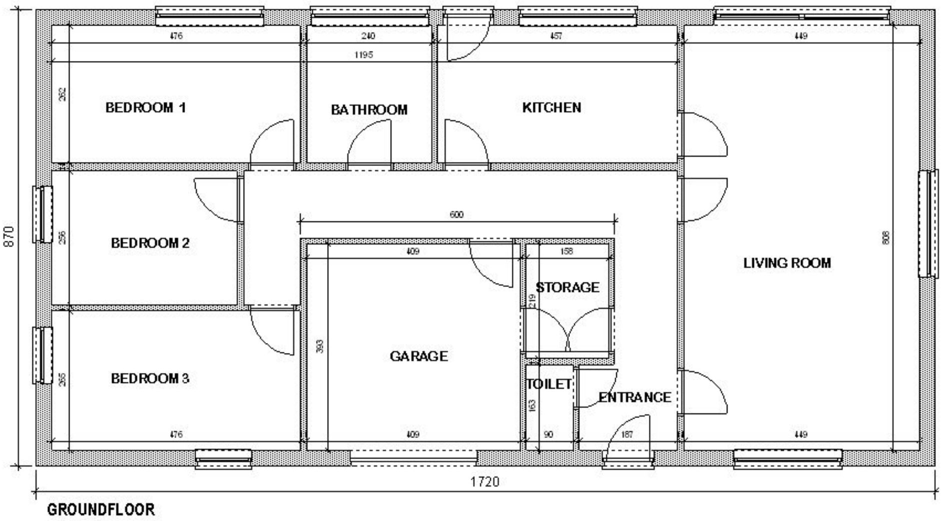


Figure 3: Graphical presentation of the detached house (floor plan).

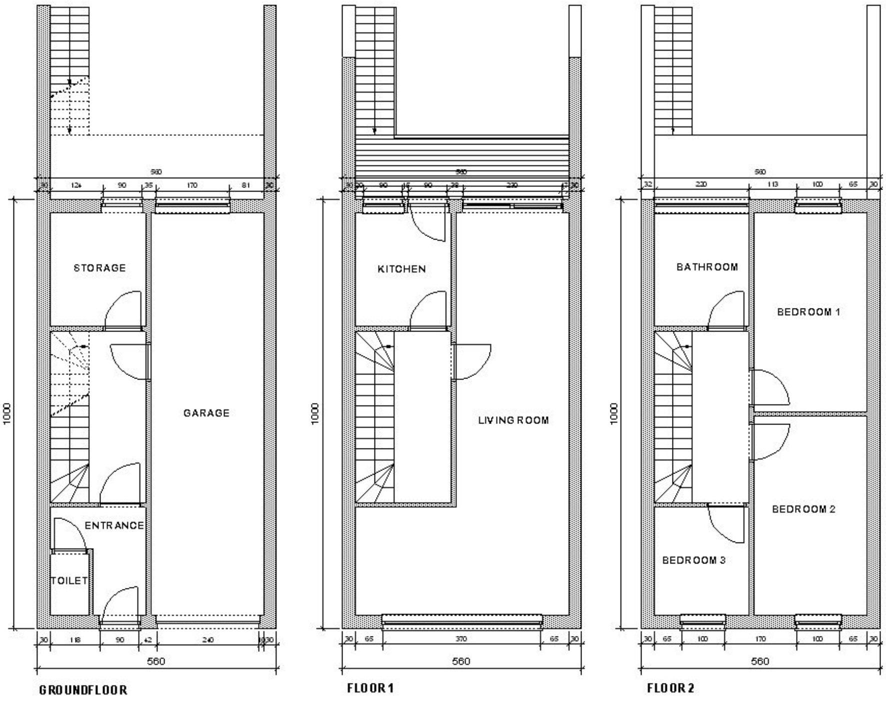


Figure 4: Graphical presentation of the terraced house (floor plans).

4.2 Data collection

For the LCA the production phase of the building materials, the use phase and end-of-life phase are considered, while the construction and demolition of the building are excluded from the analysis, since data were only limited available and unreliable. Moreover the EI of these phases is supposed to be minor in comparison to the other life phases. For the LCC the production, construction and use phase are included. The FC’s caused during the end-of-life phase are not considered since there was a lack of data. Moreover these are assumed to be unimportant since the present value of costs over 75 year is small.

During the use phase, only energy use due to heating, replacements and maintenance are incorporated, both for the LCA and LCC. Energy use for appliances and lighting is supposed to be identical for both cases and is therefore excluded. In the Belgian climate cooling is unnecessary for housing and is therefore not assessed. The energy consumption for heating during use phase is estimated by the equivalent degree days. Since the case study is limited to the above mentioned elements, only the transmission losses are included (for the outer walls).

For the LCA the database of Eco-invent (www.pre.nl/ecoinvent/default.htm) was used, while for LCC the database of ASPEN was applied. The latter is a database of FC of building elements for the Belgian context, updated every half a year. There is a database for reconstruction and for new constructions. For this case study the ASPEN edition February 2006 was used for new constructions (ASPEN, 2006).

The financial variables as well as energy prices are taken from national statistics for Belgium (www.statbel.fgov.be). The growth rate for material prices equals 1%, for energy prices 2%, the discount rate equals 6%. The energy price for natural gas is equal to 0,039 EURO/kWh (average for 2005).

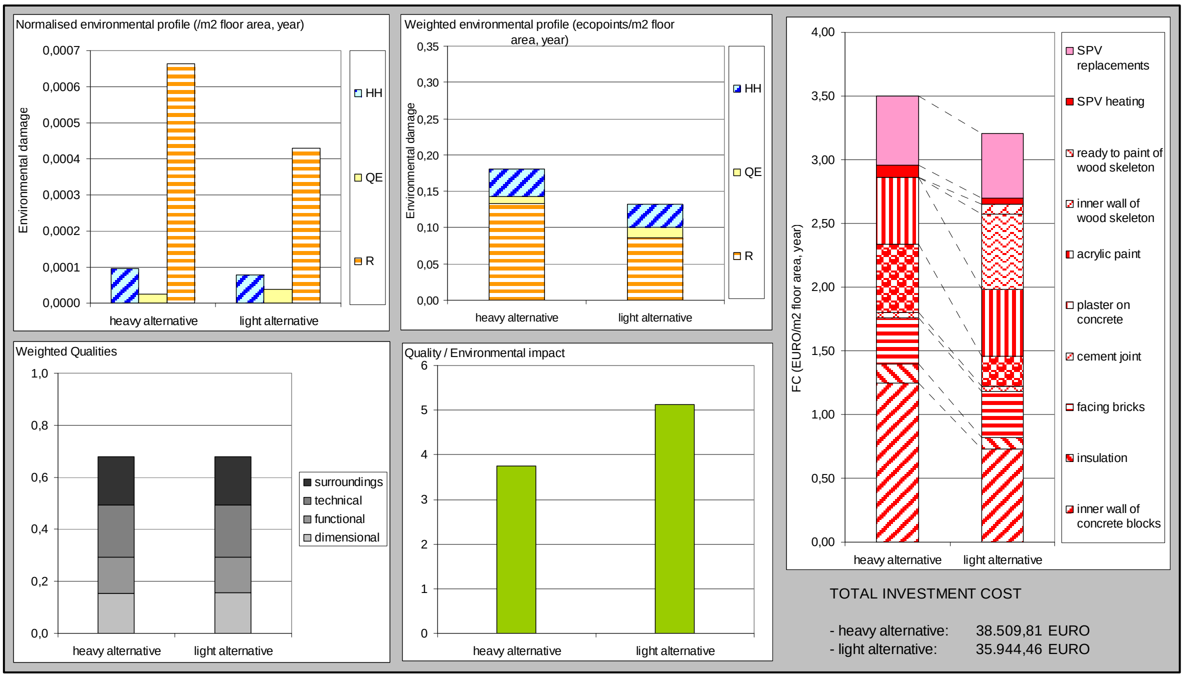
4.3 Results

In the following paragraphs the results of the case study are presented graphically. We compare the results of the ‘heavy’ alternatives with the ‘light’ alternatives and this for both the terraced house (TH) and detached house (DH).

4.3.1 Analysis of the ‘heavy’ and ‘light’ alternatives for the TH and DH

For each analysis there are five graphs presented: the normalized and weighted environmental profile, the quality evaluation, the total score (Q/EI) and the financial cost (FC). Moreover the total investment cost of the analysed elements is mentioned. In each graph the heavy and light alternative are compared. (figures 5 and 6)

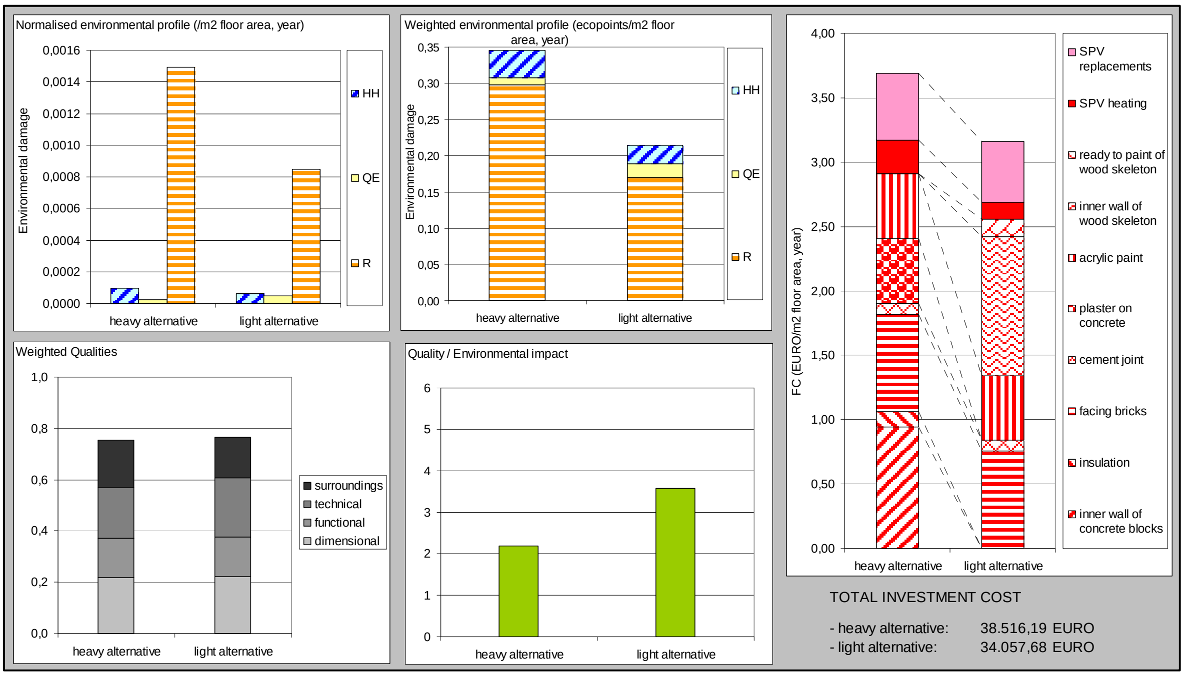
The normalised environmental profile shows that the highest EI is caused for the depletion of resources, with a higher impact for the heavy alternative.



TOTAL INVESTMENT COST

- heavy alternative: 38.509,81 EURO
- light alternative: 35.944,46 EURO

Figure 5: Results of EI, FC and Q for the terraced house.



TOTAL INVESTMENT COST

- heavy alternative: 38.516,19 EURO
- light alternative: 34.057,68 EURO

Figure 6: Results of EI, FC and Q for the detached house.

The reason is that the outer walls of the heavy alternative are insulated with only 6 cm of glass wool, while the light alternative consists of 14 cm of glass wool insulation. This means that energy use for heating is higher for the heavy alternative, leading to more depletion of the energy resources (natural gas).

Comparison of the weighted environmental profile shows that the detached house is leading to a higher total EI/m2 floor area per year than the terraced house and this for both alternatives. For both houses, the total EI/m2 floor area per year is highest for the heavy alternatives. This can again be explained by the fact that the outer walls are less insulated for the heavy alternatives than for the light alternatives.

For the Q evaluation, the surroundings of the dwelling are considered to be equal for both dwelling types. From the evaluation of the total quality score, it is clear that the difference between the heavy and light alternative is rather small. The heavy alternative has a better score for the acoustical performance, but performs worse for the dimensional and functional characteristics, since the outer walls are thicker and therefore less interior space is available. Comparing the quality of the TH with the DH shows that the DH is performing better. The total score Q/EI is then necessary to make a choice: the DH is performing better, but is also causing a higher EI.

From the total score Q/EI we can conclude that, for the assumptions made, the light alternative is preferable for both the TH and DH. Although the quality is better for the DH, the preference goes to the TH (for both alternatives).

Finally we need to evaluate the total FC. For both houses the total FC/m2 floor area per year is higher for the heavy alternative, under the assumptions made. The cost for the heavy alternative is higher for the DH than for the TH. For the light alternative however, it is the opposite way. This can be explained by the fact that for the TH the shared walls are constructed with concrete blocks, while for the DH all outer walls are of wood skeleton. The graphs also show that the greatest part of the costs are initial costs, the costs during use phase are much smaller.

It is interesting to know if the same phenomenon is seen for the EI: is the largest part of the EI also caused during the production and transportation of the materials or is it caused during the use phase. The contribution of the different phases is graphically presented in the figures below. (figures 7 and 8).

From the graphs we can see that the highest EI is caused during the use phase, for both alternatives and for both housing types. Since the heavy alternative is less insulated than the light one, the results from the figures can easily be understood. An important contrast is here seen between EI and FC: the highest EI is caused during the use phase, but the highest FC is caused during the production/construction phase.

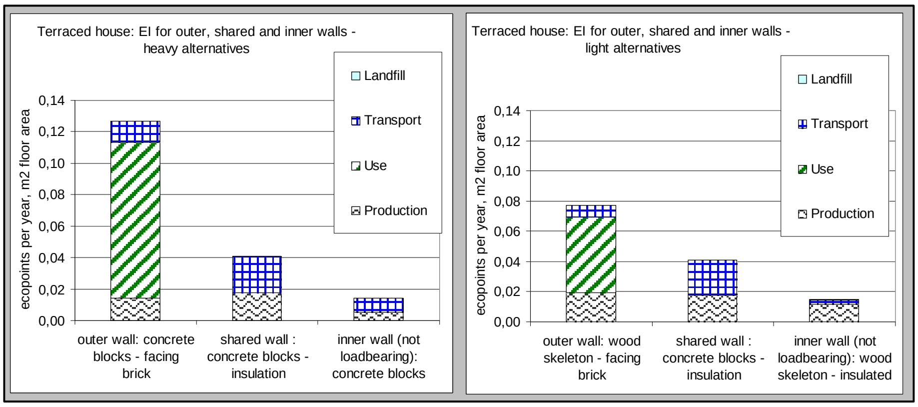


Figure 7: Weighted environmental profile for the terraced house, indication of the impact per phase, heavy alternative on the left, light alternative on the right.

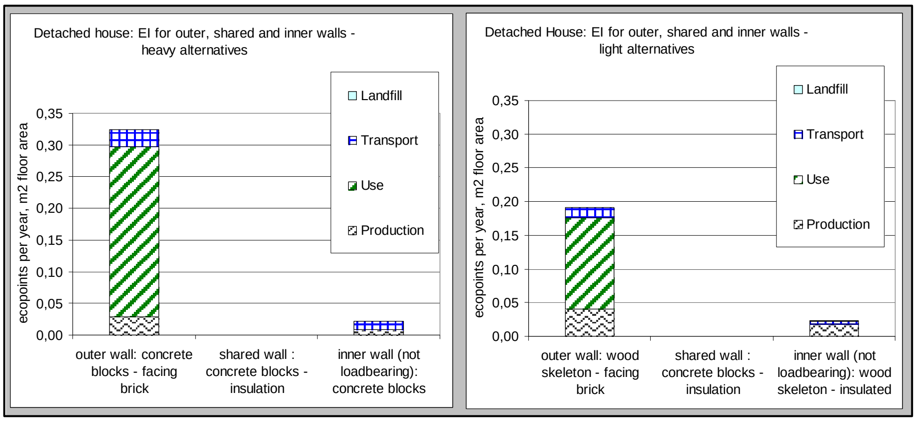


Figure 8: Weighted environmental profile for the detached house, indication of the impact per phase, heavy alternative on the left, light alternative on the right.

4.3.2 Analysis of heavy and light alternatives for the TH and DH with equally insulated outer walls.

In this last part of the case study, the same houses are analysed. Again the heavy alternative is compared with the light alternative. The outer walls however, are now equally insulated (14 cm glass wool). The shared and inner walls are not changed.

The results are shown in the figures below (figures 9 and 10). The weighted environmental profile shows that the EI/m2 floor area per year of both alternatives are now more or less identical, and this for both housing types. If we compare both types, we can see that the TH is causing a lower EI/m2 floor area per year than the DH. Comparison of figures 9 and 10 with figures 5 and 6 shows that the total EI/m2 floor area per year has decreased for the heavy alternatives and this to a greater extent for the DH (which can be explained by the fact that the ratio of the outer wall is higher for the DH than for the TH).

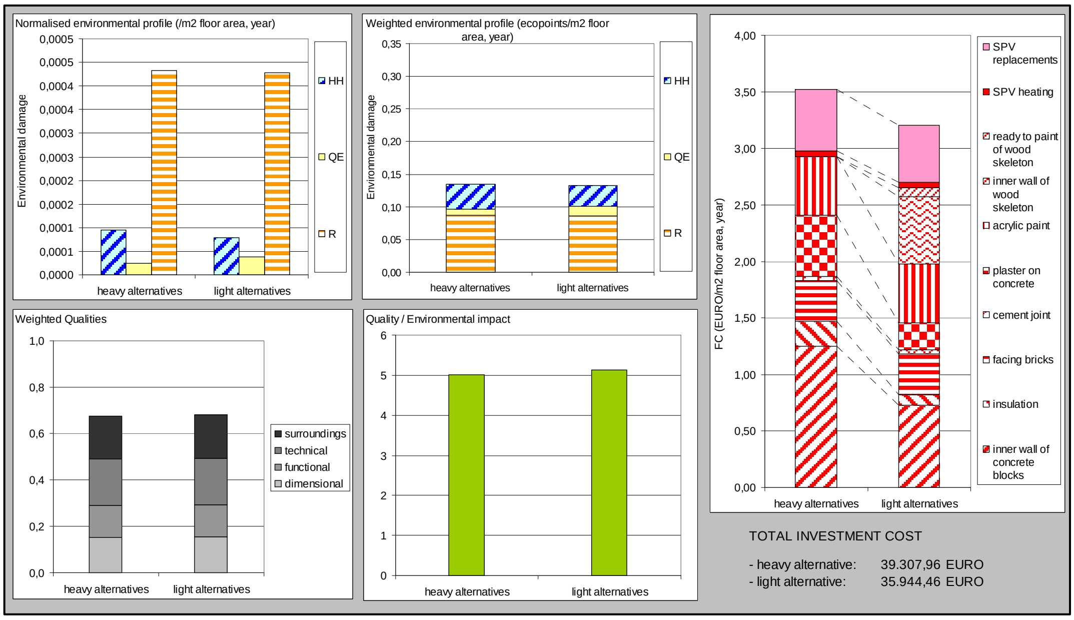


Figure 9: Equally insulated outer walls – results of EI, FC and Q for the terraced house.

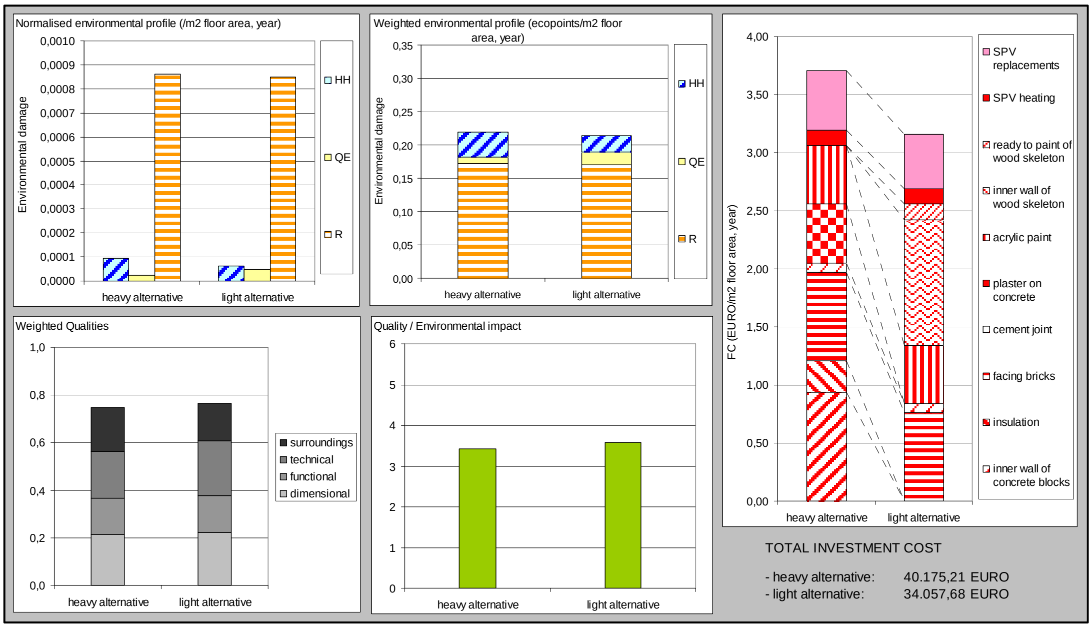


Figure 10: Equally insulated outer walls – results of EI, FC and Q for the detached house.

The quality of the heavy alternative has decreased a little, since more insulation means less interior space. The total score Q/EI is approximately equal for both alternatives, the TH is preferable.

The FC/m2 floor area per year shows that the heavy alternatives are more expensive than the light alternatives. For the light alternative, the TH is 2,4% more expensive than the DH, while for the heavy alternative, the DH is 4,6% more expensive than the TH. This can again be explained by the fact that the terraced house has shared walls in concrete blocks, while the DH has only outer walls of wood skeleton.

Comparing the FC of the less and better insulated heavy alternative (figures 5, 6, 7 and 8) shows that the total FC/m2 floor area per year has increased. For the TH there is an increase from 3,52 to 3,54 EURO/m2 floor area per year, for the DH from 3,69 to 3,71 EURO/m2 floor area per year. Of course this is under the assumptions taken.

Finally the contribution of the different life phases to the total EI is investigated (figures 11 and 12).

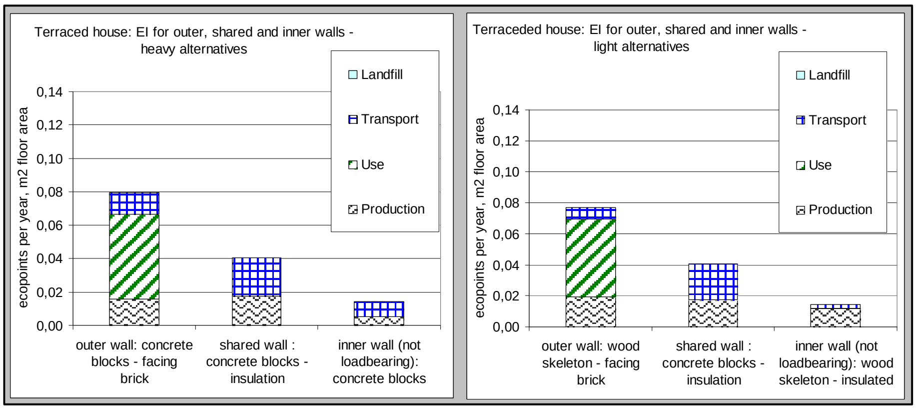


Figure 11: Equally insulated outer walls - weighted environmental profile for the terraced house, indication of the impact per phase, heavy alternatives on the left, light alternatives on the right.

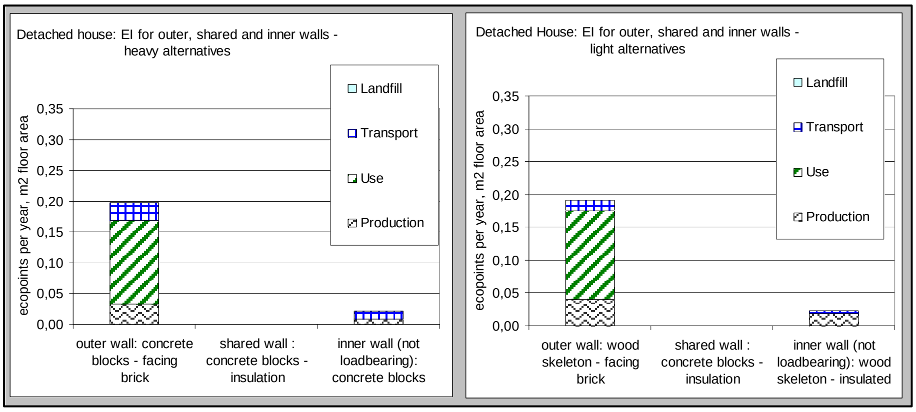


Figure 12: Equally insulated outer walls - weighted environmental profile for the detached house, indication of the impact per phase, heavy alternatives on the left, light alternatives on the right.

Comparing these figures with the figures 7 and 8 shows that increasing the insulation, has a major influence on the total EI. This illustrates the contradiction between EI and FC.

5. CONCLUSION AND REMARKS

This paper describes a methodology to analyse the sustainability of dwelling types, taking into environmental impact, financial cost and quality. This is based on the existing element method for cost control, which is extended to include a Life Cycle Assessment. A quality evaluation incorporating a multi-criteria analysis is used to conduct a comparative study. By using the element method, both financial cost and environmental impact are expressed per square meter of total floor area per year.

The methodology is illustrated by comparing the outer walls, inner walls and shared walls of a detached and terraced house. For the outer and inner walls, a ‘light’ and ‘heavy’ alternative are analysed. The choice to analyse commonly used alternatives led to different insulation values. To achieve a more complete analysis, a comparison of equally insulated alternatives was incorporated.

The case study included in the paper illustrates the methodology. To draw conclusions, more analysis is required, in which various influential parameters should be investigated to make a sensitivity analysis.

6. FURTHER RESEARCH

The methodology presented in this paper proposes the total score, Q/EI as evaluation criterion. It is suggested that one should evaluate the total FC as well, since the FC is an important decision criterion for most people. It would however be more interesting to calculate a total cost, including as well the financial cost as the environmental cost, and both seen over the whole life cycle of the building. If this is possible, the total score Q/C - where Q represents the total score on the quality evaluation, and C the total financial and environmental cost - could be calculated and would be a better decision parameter. To be able to calculate this C, it is necessary to translate environmental impact in financial cost. Methodologies are being developed to do this. This will be further investigated within this research project in the coming years.

7. ACKNOWLEDGEMENT

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