Evaluation of the Environmental Impact and Financial Cost of Buildings in the First Design Phase

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ABSTRACT

Since most important design decisions are taken during the first design phase, an evaluation of the total environmental impact is necessary at that moment. A first step in that direction is taken by the Flemish government through the introduction of the Energy Performance Norm (EPN) from January 2006 on. The EPN evaluates the overall energy consumption of buildings during the use phase instead of looking at thermal insulation and compactness only. However the environmental impact is not only caused during the use phase of the building, moreover not only energy consumption, but also emissions, depletion of resources, land use, etc. contribute to the environmental impact.

A methodology is being developed to evaluate all these aspects during the first design phase. It is based on different existing methods: life cycle assessment, life cycle costing and the element method. Moreover the financial cost is incorporated in the evaluation since it is often an important decision parameter. The marginal effects of the environmental and financial costs are used as criteria for ranking possible choices. The methodology will be described and illustrated by a case study.

KEYWORDS

EPN, Life Cycle Assessment, Life Cycle Costing, element method.

INTRODUCTION

In Flanders, the building related energy use (housing included) stands for 36-40% of the total energy demand in Flanders [3, pp 133]. Reducing this high amount of energy consumption is an important task to reduce the total environmental impact (EI) of the building sector. The Flemish government has developed energy performance regulations related to the use phase of buildings and which are applicable to both renovations as new buildings [1, 10].

The EI of the building sector, however, is not only caused by the energy use during use phase. The construction sector in Belgium for example constitutes 56% of the yearly extraction of sand [3, pp. 3]. A second initiative from the government are the studies concerning Best Available Techniques Not Entailing Excessive Costs (BATNEEC), which are carried out to achieve cleaner production techniques for, amongst others, building materials [4, 11].

ENERGY PERFORMANCE REGULATIONS

Regulations in Flanders related to energy use in buildings started after the energy crisis in the seventies. These first regulations focused on thermal insulation of the building skin and were based on the awareness that the energy demand due to heating was more or less linearly proportional to the thermal insulation quality of the building skin. A first improvement to these regulations was achieved in 1992 due to the introduction of the ‘isolatiedecreet’ (insulation-regulation), taking into account as well the thermal insulation as the compactness of the building. [7]

The new EPN does no longer simplify the energy demand due to heating to the insulation and compactness of the building, but takes into account the whole concept of the building together with the heating installation. This means that as well thermal insulation, compactness, ventilation, passive solar and internal gains as the efficiency of the installation and gains from active solar systems are taken into account. Moreover the efficiency of heat generation of the installation is taken into account, which enables to reward low temperature heating systems - which lead to a lower primary energy use. Besides heating, also the preparation of hot water and the energy for the functioning of the heating installation is taken into account. For utility buildings the energy use due to lighting, cooling and air treatment is also incorporated.

SCOPE

As described before, not only the energy use during use phase, although a very important aspect, is the only cause of the EI. There are other causes such as depletion of resources, harmful emissions, waste disposal, etc. and other life phases (production of materials, construction, renovations, demolition, etc.) which should be included in the EI evaluation of buildings.

In this paper a methodology is described which aims at taking into account all EI during the whole life cycle of a building. Besides the EI, the financial cost is taken into account, since this is an important decision parameter. Moreover the methodology is developed in such a way that it can be used during the first design phase. Some preliminary results of a case study are reported in order to make the proposed methodology more comprehensible and to illustrate its viability.

METHODOLOGY

The proposed methodology is a combination of existing methods: Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). Via the element method [5] the combined effect of lay-out and technical solutions for building elements upon costs or/and EI is estimated. The combination of these methods will be further explained in the following paragraphs.

Environmental impact

The long lifespan of buildings implicates that it is important to take into account the whole lifecycle when evaluating its EI. LCA, for that matter, is an important, scientifically based, tool. LCA however are most often carried out at the level of materials and components and not at the level of the building [9, pp. 2]. Since the design of a building (typology, layout, dimensions, orientation, location, etc.) determines the overall EI, it is not correct to equate a building to the sum of its constituting components.

Carrying out a LCA should be done following a strict methodology defined by ISO 14000 [8] and should be well documented. For a detailed description of this methodology the authors refer to ISO 14000 and to the SETAC publication about LCA in building and construction [9].

Basically LCA consists of four methodological phases: goal and scope definition, inventory, impact assessment and evaluation. Within the 'goal and scope', the functional unit (FU) needs to be defined. The FU is defined as '*quantified performance of a product system for use as a reference unit in a life cycle assessment study*' [14]. Since a building is a complex end-product, the definition of the functional unit is not evident. In this approach it was therefore decided to add a quality evaluation to the analysis and evaluate the total score: quality/environmental impact (Q/EI). This enables a comparison of buildings.

Once the functional unit is defined, the inventory can start. Firstly one has to define the system boundaries, secondly a list of in- and outputs (emissions, energy, resources, land use, etc.) needs to be established for the specified system. In this analysis the system is limited to the level of the building: this means that the urban level is not taken into account (for example transportation during use phase is not included). The construction and demolition of the building are also neglected because of their minor impact and uncertainty of data. Moreover the EI of the use phase is limited to the effects due to heating, maintenance and replacements. Electricity use for appliances/lighting and use (+ heating) of water is not included. This is decided because the EI of these aspects is low in comparison with heating and material use, and since these aspects are less determined by the design of the building.

Once the in- and outputs are listed, these need to be translated into EI. This is done in the impact assessment phase. In this proposal Eco-Indicator 99 is used as impact assessment method, which means that the damage to human health, to the quality of ecosystems and to the depletion of resources is taken into account [13]. As a result an environmental profile is drawn.

A last step in LCA is the evaluation of the results. The environmental profile, as a result of the previous step, is difficult to interpret since the three effects have different units: Disability Adjusted Life Years (DALY), Potentially Disappeared Fraction (PDF)/(m2,year) and MJ (surplus energy) respectively. The three values are normalized (compared to the yearly EI of an average European) so that the units become dimensionless: we obtain a normalized environmental profile. Finally a weighting of the three effects is carried out. This last step is subjective, since it is not easy to determine the relative importance of the three effects and is therefore excluded by ISO 14000. Despite this prohibition, in this research the weighting is done to improve communication, but is never shown without the unweighted values. The final result is a single score, expressed in Ecopoints. The higher the score, the higher the EI is.

Financial cost

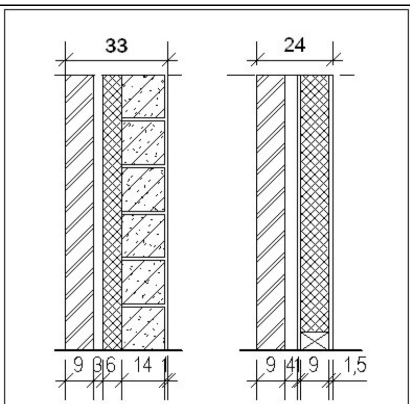
Besides the EI, the financial cost is analysed. As well the initial as the total financial cost are of interest, in terms of budget restriction and cost efficiency respectively. The sum of the present values of the initial cost and cost during use phase due to heating, maintenance and replacements is calculated to obtain the total financial cost.

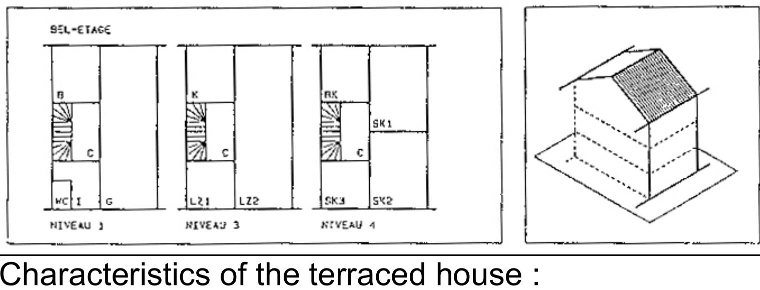
Element method

To compare different building designs, layouts, typologies, sizes, orientations, etc. the element method is used [5]. The element method is a well known method for cost calculation of buildings, but is used in this research for both financial cost and EI calculations. By using the element method, the EI and financial cost are calculated per square meter of (useful) floor area and therefore enables to carry out comparative studies. An extra advantage of the element method is that the analysis can be limited to one or more building elements of interest, for example exterior walls, roofs, floors, windows, etc. To compare buildings with a different lifespan, the yearly EI and financial cost are calculated, resulting in an impact and cost per m2 of floor area, per year.

CASE STUDY

To illustrate the methodology some preliminary results of a case study, analysing two commonly used alternatives of an exterior wall in Belgium, are shown.





Characteristics of the terraced house :
- façade width = 5 m
- depth = 10 m
- 3 floors (in total: 150 m2 floor area)
- heated with natural gas
- number of equivalent degree days = 1750

Figure 2: Two compared exterior walls (left) and terraced house (right).

Figure 2 (left) shows both alternatives: the first is a cavity wall of concrete blocks and facing brick, insulated with mineral wool, the second alternative is a cavity wall with an inner layer of wood skeleton insulated with mineral wool and an outer layer of facing brick. Both alternatives look identically from in- and outside. These walls are used for the front and back façade of a terraced house with characteristics as shown in figure 2 on the right. This is called the reference case.

The input data for both the EI as for the financial cost are taken from existing databases, Ecoinvent and ASPEN respectively in this case study [15, 2]. Verification with other databases is still to be done. For the economical parameters such as growth and discount rate, as well as for the energy prices, average data for the Belgian situation (average for 2005) are used, but should be updated frequently [16, 16a].

The figure below (figure 3) shows the results for both exterior walls. The cluster of four graphs on the left shows following information:

- Upper-Left-Corner: normalized environmental profile.
- Upper-Right-Corner: weighted environmental profile (EI/m2 floor area, year).
- Lower-Left-Corner: global quality score (Q).
- Lower-Right-Corner: ratio 'Q/EI'.

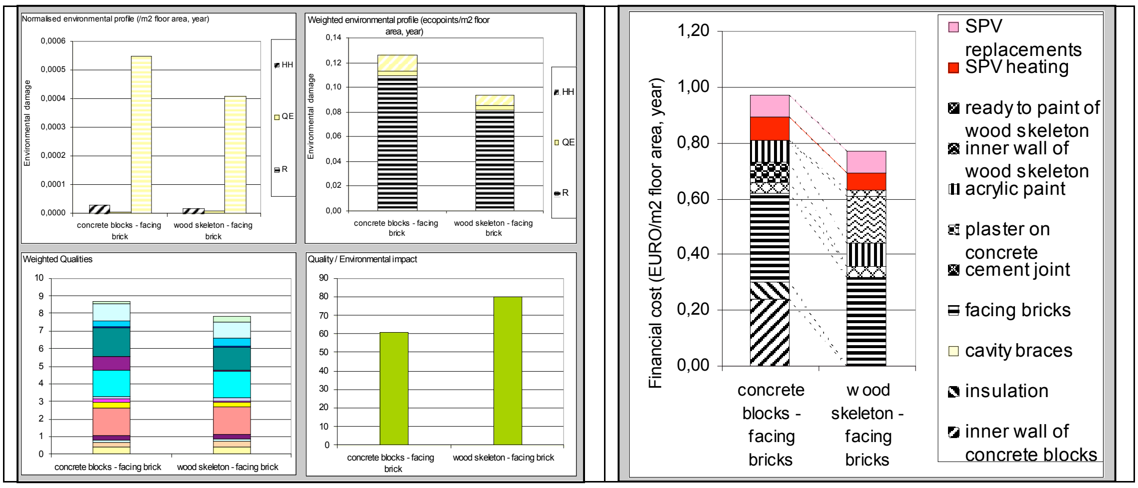


Figure 3: The EI (left) and financial cost (right) of the walls for the reference case.

The weighted EI is higher for the concrete blocks, but the quality is also better than for the wood skeleton. The total score Q/EI makes a decision possible: in this case the preference goes to the wood skeleton wall. The figure on the right represents the total financial cost (investment cost + present value of costs in use) for both walls in EURO/(m2 floor area, year), showing that the concrete block wall is more expensive than the wood skeleton wall.

These results are compared with the results of two walls with equal insulation layers: 14 cm. A comparison between figure 3 and 4 shows that the EI has decreased for both alternatives, but the financial cost has increased. Moreover the EI of both alternatives is nearly identical for the equally insulated walls, in contradiction to the reference case where the wood skeleton wall has a lower EI.

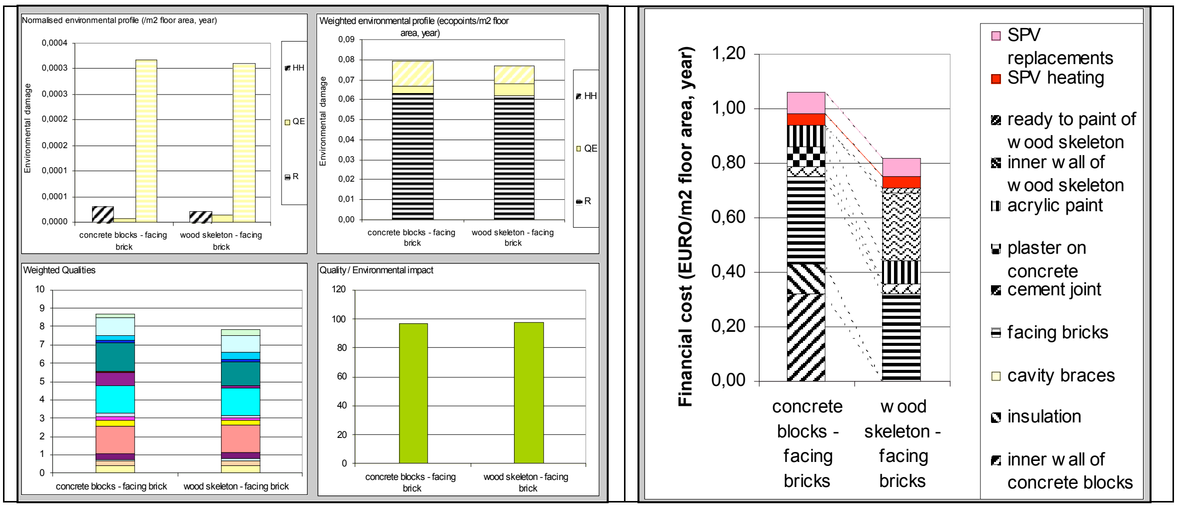


Figure 4: The EI (left) and financial cost (right) of the walls with 14 cm insulation.

An analysis of the contribution of each life phase to the weighted EI for both walls for the reference case and for the '14 cm insulation' case shows that the use phase is the most important cause of the EI, although production and transportation gain importance when better insulated. Percentage wise the importance of the use phase decreases from 75% to 65% when better insulated.

SUMMARY

This paper describes a methodology, illustrated by a case study, to evaluate the EI and financial cost at the building level during the first design phase. A LCA is incorporated in the element method to enable comparative LCA. Moreover a quality evaluation and LCC are seen as essential parts of the analysis.

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REFERENCES

[1] Anon. (2004). Decreet houdende eisen en handhavingsmaatregelen op het vlak van de energieprestaties en het binnenklimaat voor gebouwen en tot invoering van een energieprestatiecertificaat, Belgisch staatsblad, 30.07-ed. 3.
[2] ASPEN index, Nieuwbouw, editie 38, February 2004.
[3] De Herde, A. (2005). Dossier Cement, Febelcem, June, Brussels, Belgium.
[4] Dijkmans, R. (2000). A transparent and proven methodology for selection of Best Available Techniques (BAT) at the sector level by Guided expert judgment. *Journal of Cleaner Production*; **1**:11-21.
[5] Flanagan R., Tate B. (1997). *Cost control in Building Design*, Oxford, Blackwell, UK.
[6] Hens, H., Janssens, A. (2005). *Gebouwen, wonen en energie*, in: *Energie vandaag en morgen – Beschouwingen over energievoorziening en -gebruik*, Acco, Leuven, Belgium.
[7] Hens H, (2005), *Na een lange scheiding terug samen: gebouw en installatie*, in proceedings studiedag: Lage temperatuur en toch warm, TI, Belgium.
[8] ISO 14000 (1996), *Environmental Management - Life cycle assessment - Principles and framework*, ISO/DIS 14040.
[9] SETAC (2003). *Life-cycle assessment in building and construction: a state-of-the-art report*, SETAC Press, US.
[10] www.energiesparen.be/energieprestatie/index.php, accessed June 2006.
[11] www.emis.vito.be/index.cfm?PageID=390, accessed June 2006.
[12] www.milieurapport.be, accessed August 2005.
[13] www.pre.nl/eco-indicator99/, assessed June 2006.
[14] www.lcacenter.org/LCA/LCA-definitions.html, accessed June 2006.
[15] www.pre.nl/ecoinvent/default.htm, accessed January 2006.
[16] www.statbel.fgov.be, accessed June 2006.
[16a] Source: Federale Overheidsdienst Economie, KMO, Middenstand en Energie and year reports FIGAS.