COMPARING ENVIRONMENTAL IMPACTS FROM ENERGY AND MATERIALS EMBODIED IN BUILDINGS AND USED DURING THEIR SERVICE LIFE.

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ABSTRACT

Models calculating the environmental benefits of renovation and retrofitting of buildings are generally based on energy calculations and don't take into account the environmental penalty of demolishing and replacing parts of the building and its equipment. The environmental effect embodied in these activities is neglected and only the environmental benefits of a lower building related energy use are taken into account. In addition, energy use cannot be considered an environmental problem in itself, but causes several environmental impacts, which are not necessarily linearly related to the energy use. In this paper, the author studies the relative values of the embodied environmental impacts and the operational environmental impacts, as well as the relationship between energy use and environmental impacts. The calculations are based on a tool for energy use calculations and on EcoQuantum, a tool for life cycle assessment. Results are presented in terms of environmental payback times. The results are discussed and clarified based on two case studies. Recommendations are made about the necessity of a dynamic simulation procedure.

KEYWORDS

Environmental effect, Life cycle assessment, Building renovation, Embodied materials and energy, Operational energy.

INTRODUCTION

Most of the housing stock in the European Union was built after the Second World War. This post-war mass housing falls short of adequate quality to fill current needs, and is consequently being demolished or renovated. When undertaking urban renewal projects, decisions must be made between housing maintenance, with some minor interventions, and total housing re-development, demolishing the existing stock and replacing it with new houses. Simple renovations such as insulating walls or replacing single glazing with double glazing are only possible if the quality of the existing dwelling is sufficient to fulfil current needs. Consolidation and housing transformations may fill the gap between simple housing maintenance and demolition and new construction. In this paper we define consolidations as improvements of the building shell (such as insulation, without any change in the floor plan of the house or housing block). Transformations are improvements or interventions in a housing block or complex that go beyond a single individual house. Examples of this are joining apartments together horizontally or vertically.

In the current situation, however, the environmental effects of maintenance, consolidation, transformation, and redevelopment have not been compared. Very little is known about the environmental effects of renovation measures. Environmental effects are mostly considered from the viewpoint of energy use. However, energy use is not an environmental problem in itself, but causes several environmental impacts, which are not necessarily linearly related to the energy use. In this paper we discuss the basic assumptions of the model as well as the criteria for determining a simulation method with which it would be possible to relate energy use, environmental effects and renovation activities. The method is tested on two case studies.

CRITERIA FOR AN ASSESSMENT METHOD

The first step was to examine the literature to review the methods for calculating the environmental effects of interventions on housing stock. There are several qualitative methods, mostly based on numerical scores and on a holistic approach to sustainability. A few examples of these methods are The Green Building Label, Spear (Gowri, 2004), and national guidelines for sustainable buildings. But none of these methods were suitable for achieving the aim of this research, which is to generate quantitative data on the environmental effects of interventions on buildings. Life Cycle Assessment (or LCA) is a method for analysing the environmental burden of product systems (goods and services) from cradle to grave, including extraction of raw materials, production of materials, product parts and products, and discarding them by recycling, reuse, or final disposal (Guinée 2002, ISO 1997). The product system is the total system of processes needed for the product, which in this case is a house. Inputs and outputs are materials and energy, which enter and leave the product system. In the building research community, LCA is generally accepted as a legitimate basis for comparing building materials, components, elements, services, and entire buildings (Cole et al., 2000, Cole et al., 2005). Several LCA tools were developed in the past decade to assess buildings. An inventory of these methods can be found in Howard (2005). Despite this progress, it remains difficult to compare the environmental impact of interventions on buildings (Klunder, 2003) because there is no consistency or standardisation among current databases, and there is too much complexity in the buildings themselves (Kohler et al, 2002a). Buildings are much more complex than the simple goods for which the LCA method was primarily developed. Each building has its own characteristics and contains a very large number of components. Unlike simple goods such as a cup or even a computer, buildings have a long life span and during this period produce environmental effects that may represent a substantial part of their total environmental burden. The energy use of an Australian house has been analysed for a thirty-year life cycle in Treolar et al. (2000a), which stresses the relative importance of energy consumption with respect to the way the house is used and to household behaviour. The relative values of the embodied and operational energies are important factors in choosing design strategies, such as insulation (Fay, 2000). Tucker et al. (1994) compared the embodied energy in a refurbishment project with the embodied energy for demolition and new construction. These papers provided an analysis that focused on energy use, but did not consider other environmental effects. Peuportier (2001) considered environmental effects to compare three types of dwellings, but the results were aggregated for their entire life cycle. Some of the impacts that Peuportier used to determine the final environmental profile of the dwellings are interdependent (e.q. energy and global warming potential), possibly resulting in a distorted profile.

Unlike conventional consumer goods, buildings often change in the course of their life span. Components are replaced or removed, according to their technical and functional life cycles (Kohler et al 2002b). Life Cycle Assessment is a static method that sums up all environmental effects during the life cycle of the product (Klunder and Van Nunen, 2003). However, the behaviour of buildings is dynamic. Therefore, it is difficult to track the environmental effects of changes in buildings using a life cycle assessment (Dobbelsteen et al., 2003). Building designers need to cope with this dynamic behaviour to take well-founded decisions. The author shows in this research how important are these dynamic aspects and how LCA tools could be adapted to produce time dependent data.

SIMULATION METHOD

Tool to calculate the environmental effects of interventions

EcoQuantum, version 2.00 (SEV and SBR, 2002) was used in the current study. EcoQuantum is a LCA tool for assessing the environmental effects of buildings in terms of material use, energy consumption, water consumption and ten environmental impacts: depletion of abiotic resources, global warming, ozone depletion, photo-oxidant formation, human toxicity, aquatic ecotoxicity, sediment ecotoxicity, terrestrial ecotoxicity, acidification, and eutrophication. EcoQuantum uses a particular Dutch database of building materials maintained by IVAM. The impact assessment method is based on the CML-2 method. The role of the EcoQuantum tool with respect to other international LCA tools was discussed in Forsberg (2004) and Howard (2005).

Tool to calculate the operational energy and water use

In the first case study the operational energy use is calculated according to the Dutch energy performance regulation, taking into account the energy for space heating, water heating, ventilation, and lighting. The operational energy in this research is not the energy that the building owner or tenants pay for, but the primary energy use, which takes into account the entire energy chain, including power generation through power stations. For calculating the energy for space heating, transmission and ventilation losses are taken into account, as well as passive solar gains and internal gains. For lighting, energy, and water consumption standard values are used. The method is described in NEN 5128 (1998) and in Beerepoot (2002). In the second case study, a comparable, but somewhat simplified method is used, the so-called EPA (2002) method, and the energy use for lighting is not taken into account.

Life span and related problems

When comparing various interventions on housing stock, lifetimes of houses and their components are the most important issue because interventions such as maintenance or renovation are needed before the expected service life of a house will have expired. The principle for calculating the environmental effects of a house is illustrated in Figure 1. Each building component in the database has a particular life span, which is not necessarily the same as the life span of the entire building. For instance, the life span of a house can be estimated at 80 years. If the life span of the window frames is 40 years, they required one replacement over the service life of the house. In the available database the environmental effects of each of the building components is aggregated to one value for its entire life cycle. This means that the environmental effects of the window frame are calculated at 40 years, and include all maintenance interventions with a frequency lower than 40 years like regular paintwork. The left side of Figure 1 shows the environmental impact of the building over time, and the right side shows the environmental impact taken from the database. Figure 1 represents the usual maintenance. The vertical lines show the environmental impact of replacing a component, which includes the embodied environmental effects of removing the old component, adding a new one, and the activities related to the placement of this component and its maintenance (e.g. paintwork). The diagonal lines represent the environmental impacts in the use of the house. These effects are related to the operational energy and water use of the house and household. Figure 2 illustrates the transformation of a house in year X, and Figure 3 shows the demolition and rebuilding of the house in year X. In the three figures the life cycle of the house is assumed to be Y. The slope of the diagonal lines in Figures 2 and 3 is less than in figure 1, because transformation and new construction are expected to result in less environmental effects during the use of the house: the energy and water consumption should be less because of energy saving measures.

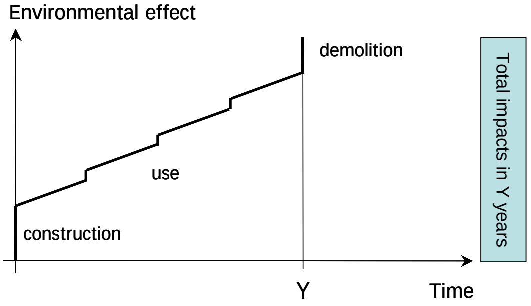


Figure 1: Environmental effects as a function of time: maintenance option

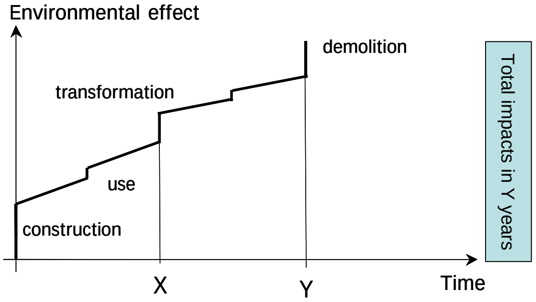


Figure 2: Environmental effects as a function of time: transformation option

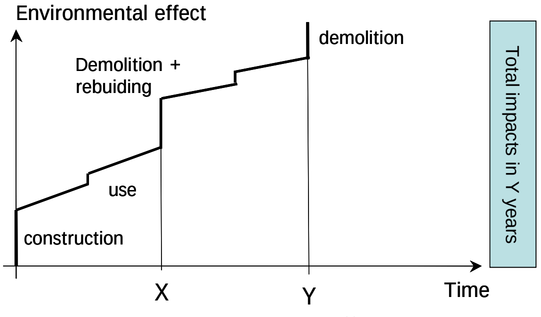


Figure 3: Environmental effects as a function of time: rebuilding option

One issue when calculating the environmental effects of buildings is determining which life span to use. In the Netherlands a 50-year life span is usually assumed for post-war neighbourhoods. In the first case study we used a life span of 50 years after renovation or rebuilding (see Figures 2 and 3, (Y – X) = 50). Transformations are intended to compete with new construction, so we assumed the same service life as for new construction. The comparison among maintenance, consolidation, transformation, and rebuilding is based on the same life span for all four options, including the consolidation option. Using the example of energy, we will show what information is not rendered when using static simulations. In the second case study, in which a specific life span is not chosen, we use dynamic simulations to study several renovation measures more in detail.

CASE STUDIES

First case study

The first case study, Poptahof in Delft, the Netherlands, is used to gain insights into the environmental impact of maintenance, consolidation, transformation, and rebuilding when considering the complete building and its whole life cycle from its construction 40 years ago to its future demolition. This is a conventional LCA approach. The building is a 40 years old apartment block to be renewed. The expected life span after renovation is 50 years. It is an eleven-storeys block with nine apartments on each storey.

The existing dwelling block (option “maintenance”) has brick masonry walls with cavity and wooden double glazing window frames. The Rc-values of outer walls, floor and roof is 1,25 m^2K/W (rock wool insulation). The building is connected to the available district heating system, which obtains its energy from industrial waste heat. The building uses natural ventilation.

In the option “consolidation”, wall, floor and roof are insulated to a Rc value of 2.5 m^2K/W, using polystyrene (EPS). All other items are identical to the option “maintenance”.

In the option “transformation” the apartments on the ground floor are joined vertically with the first floor apartments, in order to create housing for families. Wall, floor and roof are insulated to a Rc value of 2.5 m^2K/W, using polystyrene (EPS). The air tightness of the building is improved by replacing the window frames by new ones. Lowered ceilings for sound proofing are placed and a mechanical air exhaust system is placed. Electrical wiring is replaced, as well as kitchen, bathroom, closets, stairs and elevators. Non load-bearing inner walls are replaced as well (change of floor plan).

In the option “new construction”, the existing building is demolished and a new apartment block is rebuild with the same characteristics as in the option “transformation”.

In all calculations, a service life of 35 years is assumed for drains, sewers and ventilation ducts, 30 years for the heat distribution system, the lowered ceilings and the finishing’s, 25 years for inner walls and floor tiles, 15 years for the kitchen and wallpapers. All other items have a service life of 50 years.
The primary energy use for lighting is kept constant throughout the interventions (56 kwh/(m^2/year)), as well as the water flow rates of the taps. The net floor area is 6319 m^2.

Second case study

The second case study is a pre-war single family terraced house with a net floor area of 130 m^2. The dwelling has brick masonry walls with cavity and wooden single/double glazing window frames. The Rc-values of outer walls, floor and roof is 0.4 m^{2}K/W. The building is heated by a low efficiency boiler and high temperature radiators. A gas heater is used for hot tap water. The building uses natural ventilation.

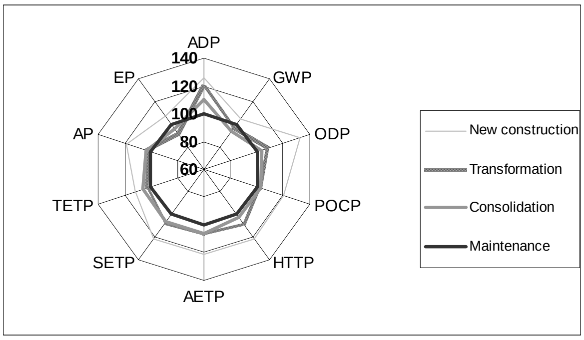
In this second case study, we do not calculate the environmental burden for the complete building and for its whole life cycle. We focus on the environmental effect of a few renovation options. These renovation options are insulation of the façade , insulation of the floor, insulation of the roof (Rc=2,25 m^{2}K/W for all), replacing the glazing by high efficiency glazing, replacing the old boiler and gas heater by a high temperature and high efficiency combination boiler (HE C. boi.l HT in the tables), replacing the old boiler and gas heater by a low temperature and high efficiency combination boiler (HE C. boil. LT) and finally replacing the old boiler and gas heater by a heat pump combination boiler (HP C. boil.).

In all calculations a service life of 35 years is assumed for the heat distribution system, 30 years for radiators and heat pump, 25 years for insulation and glazing, 15 years for the boiler and 8 years for the water pomp. All other items have a service life of 75 years.

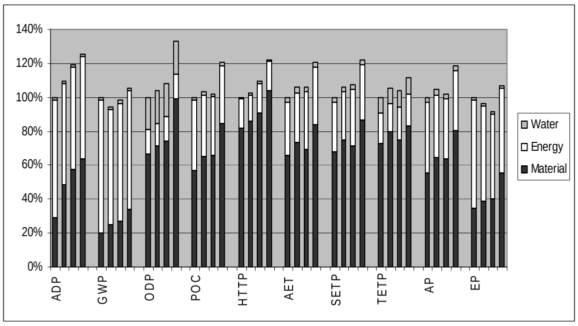
RESULTS AND DISCUSSION FOR CASE STUDY 1

Environmental effects considering the whole service life

The environmental effects are given per square meter gross floor area per year of the total service life of the building. The effects of the four scenarios on the ten types of environmental impact calculated by EcoQuantum have been plotted in Figure 4. The effect of operational energy and water use is included. All values for the maintenance option have been set at 100 per cent. The main result this diagram shows is that transformation seems to have less environmental impacts than does new construction. The explanations for this can be found in figure 5. In Figure 5 the environmental impacts as described here above for all scenarios are related to the use of materials, energy, and water. The maintenance option has again been set at 100 per cent. Energy use has the most effect on ADP (resource depletion), GWP (global warming potential), and EP (eutrophication). It should be expected that for ADP, GWP, and EP the three scenarios in which energy use has been reduced will perform better than the reference (maintenance). However, the increased use of materials negated this advantage. For the impact of all other components, the use of materials is the princi-



ADP depletion of abiotic resources, GWP global warming, ODP ozone depletion, POCP photo-oxidant formation, HTP human toxicity, AETP aquatic ecotoxicity, SETP sediment ecotoxicity, TETP terrestrial ecotoxicity, AP acidification, EP eutrophication.
Figure 4: Poptahof: environmental impacts per m^2 per year.



ADP depletion of abiotic resources, GWP global warming, ODP ozone depletion, POCP photo-oxidant formation, HTP human toxicity, AETP aquatic ecotoxicity, SETP sediment ecotoxicity, TETP terrestrial ecotoxicity, AP acidification, EP eutrophication.- Stack 1: maintenance; Stack 2: consolidation; Stack 3: transformation; Stack 4: rebuilding.
Figure 5: Poptahof: sources (material, energy, water) of environmental impacts per m2 per year.

pal factor, especially for ODP (ozone depletion) and ecosystem toxicity (AETP, SETP, TETP). Except for ODP and TETP, water use has little effect on the environment. These are the data that are obtained from life cycle assessment. From the viewpoint of a building engineer, an architect or any decision maker, these results are interesting but still a bit frustrating because using another service life would have lead to other results and because the service life of a building is difficult to predict. Next to dwellings with a service life of 75 years or more, it is becoming common practice in post-war neighbourhoods to demolish buildings already after 35 years. When renovation activities are planned it is important to know if they are really efficient in view of a possible short life of a building. On the one hand the results presented in figures 4 and 5 give too much information because the environmental effects of the building before renovation are included, which is of no interest for a building designer as he cannot influence the past. On the other hand the figures give not enough information because the main environmental risk in the renovation process, i.e. the length of the service life cannot be assessed. In the next section the effect on the primary energy use of the four renovation options are studied as a function of time.

Embodied and operational energy use as a function of time

The primary energy use for the building block has been plotted in Figure 6 as a function of time. Until the intervention (year 40), the primary energy use was identical for all options. The vertical lines represent energy embodied in the building or in the renovation intervention. The diagonal lines represent the operational energy use. There is almost no energy embodied in consolidation (only insulation materials), but this increases for transformation and new construction. The diagonal lines for operational energy use for the three options have the same slope because the same level of insulation has been assumed. The slope of these lines is less than for maintenance, in which the building is less insulated. Consolidation is paid off in energy use after about 7 years. Transformation always saves more energy than does new construction. Consolidation is better than transformation. Compared to maintenance, transformation pays off in 10 years. The new construction scenario pays off over maintenance after 55 years. The embodied energy represents about 18 years of operational energy, which is about 28 per cent of the total primary energy use in a life cycle of 40 years.

These results demonstrate that it is possible to take better-founded decisions by making a sensitivity analysis of the "energy" pay-back time of renovation measures. This approach is extended to environmental effects. In the next section.

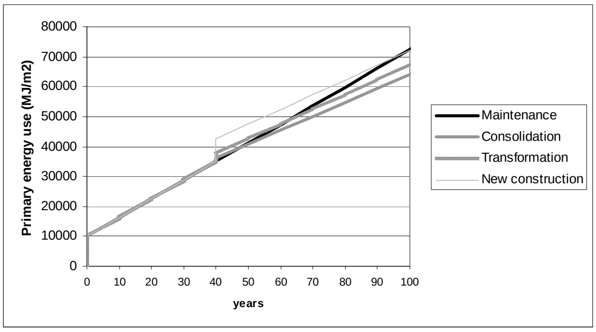


Figure 6: Poptahof: embodied and operational energy use as a function

RESULTS AND DISCUSSION FOR CASE STUDY 2

In case study 2 the environmental pay-back time of several renovation measures is studied for all environmental effects. Figure 7 shows the results for insulation measures and figure 8 the results for building services measures for the effect "Eutrophication". Year zero is the moment of intervention. The environmental effect of the reference at time zero is not zero, because we assumed that a number of building components and building services with a short service life would have been replaced however. These components are glazing and the heat

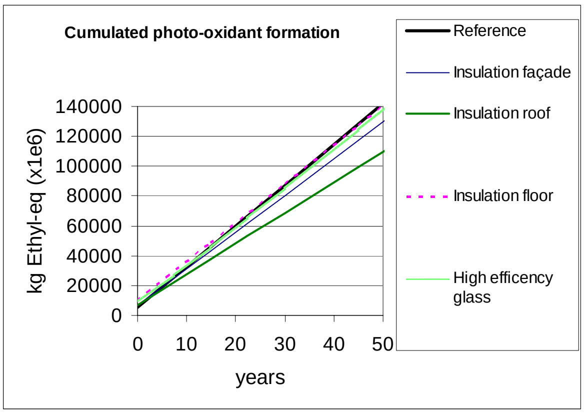


Figure 7: Embodied and operational photo-oxidant formation for several insulation measures

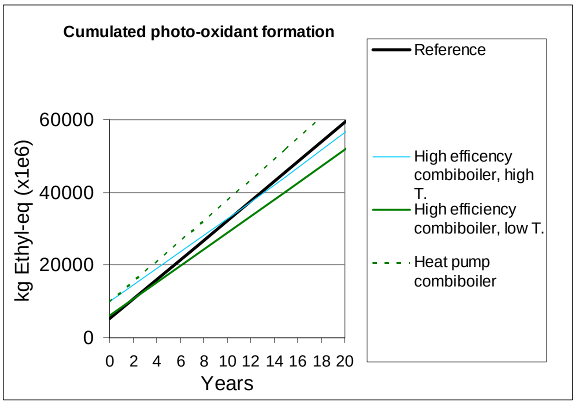


Figure 8: Embodied and operational photo-oxidant formation for several building services measures

generation system (boiler). Both are replaced on exactly the same way in all renovation measures, except that in the variant “High efficiency glass” the glazing is replaced by high efficiency glass and in the building services variants the heat generation system is replaced as indicated in the legend. The cumulated values shown in figures 7 and 8 take into account the regular replacement of glazing, heat generation system and all components belonging to the studied measure, as well as the environmental effect produced by the operational energy use. The insulation of the roof leads to a decrease of photo-oxidant formation by 21% after 30 years, with a pay-back time of only 3 years. This pay-back time does not represent any real costs. It just means that it will take 3 years before the lower energy consumption caused by roof insulation results in a decrease in photo-oxidant formation that is equal to the original increase in photo-oxidant formation due to the production and placement of the insulation material. Façade insulation and use of high efficiency glass are less efficient (savings of 8 and 2 % respectively and environmental pay-back times of 5 and 15 years). Insulating the floor turns out to have a slightly negative effect. The energy savings by floor insulation are not enough to compensate for the initial burden. Replacing the old boiler by a high efficiency one is only efficient when the whole heat distribution system is replaced by a low temperature one. In

Table 1: Environmental pay-back time (EPBT) and % savings after 30 years (insulation measures) and 15 years (building services) for resource depletion and global warming.

	Depletion abiotic resources		Global warming	
	EPBT (year)	% savings	EPBT (year)	% savings
Insul. facade	0,1	10,9	0,4	10,4
Insul. roof	0,1	27,7	0,2	26,5
Insul. floor	0,8	5,4	3	4,9
High eff. glass	0,4	14,0	0,6	13,1
HE C boil. HT	0,6	18,1	1,2	17,2
HE C boil. LT	0,5	16,1	0,4	16,1
HP C boil.	0,9	19,8	5	2,1

Table 2: Environmental pay-back time (EPBT) and % savings after 30 years (insulation measures) and 15 years (building services) for ozone depletion and photo-oxidant formation.

	Ozone depletion		Photo-oxidant formation	
	EPBT (year)	% savings	EPBT (year)	% savings
Insul. facade	7	3,6	5	7,7
Insul. roof	3	10,5	3	21,1
Insul. floor	75	-2,9	40	-1,4
High eff. glass	4	2,3	15	2,3
HE C boil. HT	50	***-8,1***	12	2,9
HE C boil. LT	5	8,4	2	12,3
HP C boil.	∞	***-148,8***	∞	***-13,1***

Table 3: Environmental pay-back time (EPBT) and % savings after 30 years (insulation measures) and 15 years (building services) for acidification and eutrophication

	Acidification		Eutrophication	
	EPBT (year)	% savings	EPBT (year)	% savings
Insul. facade	6	5,9	4	8,9
Insul. roof	4	17,0	2	24,1
Insul. floor	55	-3,0	32	-0,1
High eff. glass	5	5,4	2	11,6
HE C boil. HT	22	-3,6	2	15,0
HE C boil. LT	5	9,7	1	15
HP C boil.	∞	***-59,4***	14	0,7

Table 4: Environmental pay-back time (EPBT) and % savings after 30 years (insulation measures) and 15 years (building services) human and aquatic toxicity.

	Human toxicity		Aquatic ecotoxicity	
	EPBT (year)	% savings	EPBT (year)	% savings
Insul. facade	4	5,2	5	3,9
Insul. roof	2	14,0	3	10,7
Insul. floor	25	0,2	50	-0,5
High eff. glass	0	6,7	0	5,3
HE C boil. HT	50	***-9,1***	9	4,8
HE C boil. LT	9	5,9	2	13,4
HP C boil.	∞	***-142,7***	∞	***-197,1***

Table 5: Environmental pay-back time (EPBT) and % savings after 30 years (insulation measures) and 15 years (building service) for sediment and terrestrial toxicity

	Sediment ecotoxicity		Terrestrial ecotoxicity	
	EPBT (year)	% savings	EPBT (year)	% savings
Insul. facade	3	3,2	2	4,9
Insul. roof	3	8,7	1	12,9
Insul. floor	40	-0,5	17	1,2
High eff. glass	0	5,0	1	6,1
HE C boil. HT	13	1,6	90	***-11,9***
HE C boil. LT	2	12,7	8	6,3
HP C boil.	∞	***-210,2***	∞	***-205,2***

Table 6: Environmental pay-back time (EPBT) and % savings after 30 years (insulation measures) and 15 years (building services) for primary energy use

	Primary energy	
	EPBT (year)	% savings
Insulation facade	0,2	10,6
Insulation roof	0,1	27,0
Insulation floor	1,5	5,1
High efficient glass	0,4	13,6
HE combiboiler, high T.	1,5	17,3
HE combiboiler, low T.	0,5	16,0
Heat Pump combiboiler	3	9

that case the decrease in photo-oxidant formation after 15 years is 12 % with a pay-back time of 2 years. With a high temperature system, the savings are only 3 % and the pay-back time is 12 years. The heat pump combination boiler scores very poorly; it increases the photo-oxidant formation to such extend, that it can never be compensated by a lower energy use.

Such graphics as in figures 7 and 8 have been obtained for all environmental effects. The results are summed up in tables 1 to 5 in terms of environmental pay-back times and in terms of achieved savings after 30 years for the insulation measures and 15 years for the building services measures. Table 5 gives the energy pay-back times and the energy savings after the same periods. In this research energy is not considered as an environmental effect. The use of energy causes the environmental effects described above. The analysis of tables 1 to 5 leads to the following results:

Insulation measures have in general a positive environmental impact. When this is not the case, the extra burden is limited to about 5%. Considering the precision of the calculations, this should be considered neutral. For a pre-war terraced house roof insulation is the most efficient measure.

Measures related to the replacement of building services are less efficient than insulation measures for almost all environmental effects. Depletion of abiotic resources and global warming are exception to this. Replacement of the high temperature distribution system by a low temperature one is the most efficient measure. This replacement does not cause any strong decrease of the energy consumption for heating, but the burden caused by a low temperature system (polybutene piping) is that much lower than the burden of a high temperature system (steel piping), that the overall effect is high. Specific attention should be given to the heat pump boiler. It has a very negative impact on seven of the ten environmental effects, despite its reasonable energy savings (see table 6). This is because when replacing a gas boiler by a heat pump the energy consumption shifts from gas consumption towards electricity consumption. With the actual fuel mix for electricity production in the Netherlands (30% oil, 5% coal, 50% gas, 10% nuclear , 5% renewable), a limited consumption shift from gas to electricity already causes a noticeable increase in ozone depletion, photo-oxidant formation, acidification, humane toxicity and ecotoxicity. The environmental effects eutrophication, global warming and depletion of abiotic resources are the only effects that show the same trend as energy savings. A wrong conclusion would be that heat pump boilers have no potential. Their performances are poor with the actual fuel mix. However, the conventional gas technology has reached its theoretical limits with the high efficiency boiler. Further efficiency improvement can only be achieved by combined heat and power technologies or by electricity driven services like heat pumps that still have a high improvement potential. However, a real decrease in environmental effects can only be achieved by designing heat pumps with a very high coefficient of performance and by switching to a sustainable electricity production, based on a better fuel mix or on sun or wind.

CONCLUSIONS

In this paper an attempt was made to:

- Relate environmental effects to energy an material use of building renovations
- Relate embodied and operational energy use
- Relate embodied and operational environmental effects caused by renovation activities.

In the current practice of building simulation these items are not integrally modelled and studied. In the present study it was demonstrated that an integral model, taking into account energy simulation, life cycle analysis and the dynamic behaviour of buildings would be of practical interest to really achieve sustainable buildings. An attempt is made to show in which way LCA models could be adapted to conduct this type of simulation.

In the first part of the paper a comparison of the environmental effects of a housing block was conducted for four scenarios: ordinary building maintenance, consolidation (insulation measures), transformation (change of floor plan to accord with new needs), and rebuilding (demolition of the old building and reconstruction with a new floor plan). Transformation appears to be a much more environmentally efficient way to achieve the same result than are demolition and rebuilding. The embodied energy was about 28 per cent of the total primary energy use of the building for a life cycle of 40 years. This means that it is worth taking into account the embodied energy use when studying the efficiency of renovation options. The author suggests that the total environmental impact requires investigation for the relative values of the embodied environmental impact and the operational environmental impact. This would enable building designers to see how efficient the measures taken actually are. When taking energy-saving measures, for instance, it is important to check the effect of extra material use on the environment. These energy-saving measures may be offset by the quantity and effects of materials used for the renovation or by a shift from gas consumption towards electricity consumption.

We stressed that the real environmental problems are not material or energy use, but depletion of natural resources, ecotoxicity or another of the environmental impact studied with the LCA methodology. Examining these impacts may lead to different conclusions than when examining energy use only.

To perform calculations on the relative values of embodied and operational environmental impacts (that is, to calculate how long it would take for each measure to have a significant effect on the environment), there would need to be changes to the output structure of the data in the LCA databases, which should be disaggregated as time functions. As outlined at the beginning of this paper, this is a result of the dynamic and changing character of buildings, which should be considered as processes rather than as products. Such an environmental analysis could in the future also be linked to a cost analysis to allow for a real value analysis of several intervention scenarios. This type of study will also need to adjust for the uncertainties in the data available. It is also important to keep in mind that for anything as quantifiable as energy use and life span of components the values found for a building can easily vary by a factor two, depending on the behaviour of the household. It is therefore an uneasy task to make accurate predictions.

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