The Search for the Most Eco-Efficient Strategies for Sustainable Housing Construction

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1. INTRODUCTION

In recent years, a growing number of sustainable building projects has been realised. More and more, sustainable building becomes part of daily building practice. However, until now, (Dutch) sustainable building is predominantly based on a more or less intuitive approach without knowing the exact consequences for reduction of the environmental impacts. For example, in recent years some national packages of sustainable measures has been developed in the Netherlands, including a package for new construction of houses (SBR, 1996). In these packages options are given to bring sustainability into building practice. It has led to a broad application of sustainability principles. Nevertheless, it gains no insight in the magnitude of the environmental benefits. Therefore, optimal choices related environmental ambition levels are still difficult to be made. To give direction to this kind of choices, working with strategies to increase the environmental performance offers good opportunities. This paper aims to determine the potential environmental benefits of these strategies. The first results of calculations are presented. The focus is on houses. In the end, the research seeks for the most eco-efficient strategies for sustainable housing construction. The paper is based on a study, which is part of the research project Sustainable Construction and Renovation of Houses within the Delft Interdepartmental Research Centre 'The Ecological City' at Delft University of Technology. This research centre carries out pioneering and innovative research for a sustainable and liveable built environment.

This paper addresses the following questions.

- Which approach is followed to gain insight in the magnitude of environmental benefits of options for sustainable construction?
- Which strategies can be distinguished to improve the environmental performance of houses?
- What are the environmental benefits of these strategies?
- Which strategies offer good perspectives for sustainable housing construction?
- Which bottlenecks have to be solved to make other strategies more promising?

In the second section the research design is discussed. Strategies are chosen as an approach to steer the numerous options for sustainable construction. The environmental benefits of the strategies are discussed in the third section. Subsequently, the fourth section presents the conclusions. References are listed in the fifth section.

2. RESEARCH DESIGN

Figure 1 shows the research design of this study. Priorities, strategies and the environmental assessment tool are described in three successive sections.

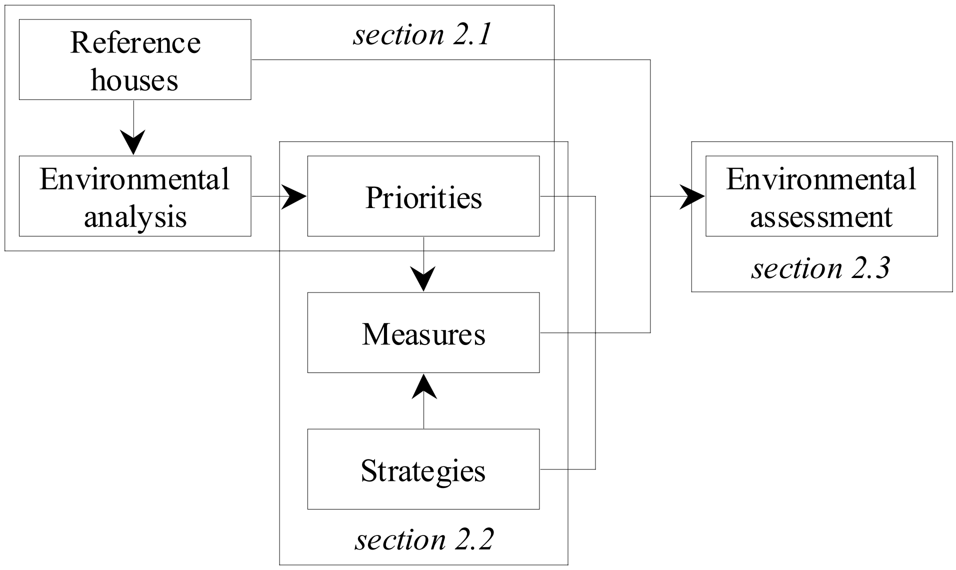

Figure 1 Research design

2.1 Priorities

A house consists of innumerable components and materials, which are not of great importance regarding the environmental impacts. Hence, the study started with the appointment of priorities for reduction of the environmental burden of houses. Material use, energy consumption and water consumption throughout the entire life cycle of the houses were taken into account. Major contributors to the environmental impacts were identified on the basis of environmental analysis of three reference houses: a terraced house, a semi-detached house and a gallery flat. These houses are a good reflection of traditional construction, as they represent a basic quality in construction and habitation (Novem, 1999a). The following findings result from this analysis (Klunder, 2001).

- Housing typology is not very relevant for identifying priorities for improvement of the environmental performance of houses.
- Priorities on material use relate mainly to components that involve large quantities of materials (for example foundation, floors and walls), but there are also some materials, which should be avoided regardless of quantity (including lead, copper and bitumen).
- Priorities on energy consumption relate to all energy functions (space heating, hot tap water, lighting, ventilation and auxiliary energy) belong to the priorities, because not only the energy consumption, but also the energy carrier (electricity or gas) is of great interest in assessing the environmental impacts.
- No priorities relate to water consumption, because the environmental impacts of water consumption are as good as negligible, compared to the environmental impacts of material use and energy consumption.

2.2 Strategies

To be able to answer questions such as ‘does the use of renewable energy or recycling and reuse lead to the largest environmental benefits?’ or ‘how important is the choice of materials for the environmental performance related to all other sustainable measures?’, strategies instead of measures for sustainable construction are applied as unit of environmental analysis. Four strategies are concerned with materials and another three strategies involve energy.

Sustainable material use is associated with integral chain management. Four strategies can be distinguished to meet this principle (Blaauw, 2001):

1. dematerialization (M1);
2. material substitution (M2);
3. extension of service lives (M3);
4. improvement of reusability (M4).

Dematerialization refers to minimisation of the size of the flow of materials in the building industry. Material substitution is directed towards reduction of the environmental impacts per unit of material through the entire service life. Next, as a consequence of extension of service lives the environmental impacts per functional unit decreases, because the environmental impacts are spread over a longer period. Improvement of reusability supports the use of building components and materials in a subsequent life cycle instead of dump or combustion.

Regarding sustainable energy consumption minimisation of fossil fuels is of major importance. The *trias energetica* presents three steps to come to that (Novem, 1999b):
1. reduction of energy losses (E1);
2. use of renewable energy (E2);
3. use of efficient techniques (E3).

Reduction of energy losses comprehends measures, which contribute to a low energy need. Renewable energy in housing notably means solar energy and warmth from soil, water and air. Finally, use of efficient techniques implies supply of the remaining energy need with an efficiency as high as possible.

2.3 Environmental assessment tool

Both priorities and strategies, combined with an inventory of actual technological developments, led to the composition of sets of measures from the national packages for sustainable building (see introduction), which were environmentally assessed. From international projects, for example, within the International Energy Agency (Knapen and Boonstra, 1999) and the Green Building Challenge (Cole and Larsson, 2000), it appears that the Netherlands goes ahead concerning the development of tools for environmental assessment of buildings. Therefore, the Dutch tool Eco-Quantum was used to make the calculations presented in this paper (Mak et al., 1999). The earlier mentioned reference houses were applied as a reference point for determining the environmental benefits of the strategies for sustainable construction. No weighing was applied in the assessments, so all environmental impacts were considered as equally important.

Eco-Quantum has the following features.

- It is a tool for environmental impact assessment of houses, meant for architects, clients and municipal councils who can use it for, amongst others, optimising designs, benchmarking and policy framing.
- It conducts an LCA of the flows of materials, energy and water in houses. The flow of materials regards the use of materials of all house components, including material-embodied energy. The flows of energy and water comprise energy consumption and water consumption respectively during the service life of the house.
- Twelve impact categories can be analysed with Eco-Quantum: depletion of raw materials, depletion of fuels, global warming, ozone depletion, photo-oxidant formation, human toxicity, ecological toxicity, acidification, eutrophication, energy consumption, non-hazardous waste and hazardous waste. The latter three are not really impact categories, but pressure indicators (MegaJoules and kilograms). Although such pressure indicators have a strongly recognisable function, this paper sets them aside to avoid double counting.

3. ENVIRONMENTAL BENEFITS OF STRATEGIES FOR SUSTAINABLE CONSTRUCTION

Section 3.1 presents the results of the environmental assessment of sets of measures per strategy for sustainable construction. Moreover, some housing concepts were calculated, which is discussed in section 3.2.

3.1 Materials and energy

The environmental benefits of the sets of measures per strategy are presented in Table 1. The first column contains the encoded strategies (see section 2.2), while the second column gives the accompanying set of measures. The next nine columns represent the environmental benefits per environmental impact. This is an average percentage of the three types of housing, because the differences between the environmental impacts of the various houses appear to be less important than the differences between the environmental impacts of the strategies for sustainable construction. Finally, the last column contains the average percentage of the nine environmental impacts. Percentages from 5% are considered as significant, so in all other cases no percentage is shown.

Table 1 Environmental benefits of strategies for sustainable construction in percentages

Strategy	*Set of measures*	*Environmental impacts*									
		M	*F*	*GWP*	*ODP*	*POCP*	*HC*	*EC*	*AP*	*NP*	*Average*
Materials											
M1	10% smaller dimension of load-bearing structure										
M2a	renewable materials: timber-frame construction			5	8				-5	-6	
M2b	plastics instead of lead and copper	54					14	47			13
M3a	90 years service life of house instead of 75 years	17	17	18	20	19	19	18	19	19	18
M3b	5 years extension of service life of components	8									
M4	reuse of foundation and interior wall	8		5		8	4		5	5	5
Energy											
E1	R_c=4.0 instead of 3.0 m^2K/W, U_{window}=1.2 instead of 1.7 W/m^2K		11	8							
E2	thermal and photo-voltaic solar-energy systems	-45	7	8	-20		-6		-7		-7
E3	low-temperature space heating and high-efficiency ventilation		5	5			6		6	5	

Explanation of abbreviations: M depletion of raw materials, F depletion of fuels, GWP global warming, ODP ozone depletion, POCP photo-oxidant formation, HC human toxicity, EC ecological toxicity, AP acidification, NP eutrophication.

The outcomes lead to the following findings.

- Dematerialisation does not result in a significant environmental benefit. Nevertheless, possible benefits are unambiguous, due to reduction of the amount of the same material.
- Regarding material subsitution an environmental benefit on the one environmental impact often goes together with an environmental disadvantage on the other environmental impact. Conversely, there are particular materials which cause a huge environmental burden, which can be reduced in a rather simple way.
- The substantial environmental benefits of extension of the service life of houses is a consequence of not needing a new house during the extended period. Extension of the service lives of both houses and house components always result in reduction of the environmental burden on all environmental impacts.

- Reuse brings about an improvement on six environmental impacts, but the average score only is significant with respect to the terraced house and the semi-detached house.
- Reduction of energy losses causes environmental benefits on energy consumption without worth mentioning environmental drawbacks on material use.
- Use of renewable energy leads to considerable environmental drawbacks, due to four environmental impacts, including depletion of raw materials. The environmental benefits are comparable to the environmental benefits of reduction of energy losses.
- Finally, use of efficient techniques results in smaller environmental benefits on depletion of fuels and global warming than the previous two strategies. To the contrary, environmental benefits on other environmental benefits are achieved.

3.2 Housing concepts

Housing concepts can be seen as a combination of strategies in a coherent way. Such concepts can yield larger profits than separate (sets of) measures, but (sets of) measures can also compete with each other. Therefore, some housing concepts were environmentally assessed with respect to the terraced house: an integral concept, a flexible concept and an energy concept. The integral concept reflects the possible environmental benefits by the current state of the art in technology. The flexible concept and the energy concept represent current popular solutions in sustainable building. Table 2 lists the sets of measures and environmental benefits as in Table 1.

Table 2 Environmental benefits of sustainable housing concepts in percentages

Concept	*Set of measures*	*Environmental impacts*									
		M	*F*	*GWP*	*ODP*	*POCP*	*HC*	*EC*	*AP*	*NP*	*Average*
Integral	see Table 1, except photo-voltaic solar-energy system	17	35	39	29	24	24	36	21	23	28
Flexible	house width 6.0 instead of 5.4 m, additional interior walls, service life load-bearing structure 150 instead of 75 years	-5	-9		11	7	-5	-6	-5	-4	
Energy	R_c=4.0 instead of 3.0 m^{2}K/W, Uwindow=1.2 instead of 1.7 W/m^{2}K, insulated door, heat pump, floor heating, solar-energy systems and high-efficiency ventilation	-105	43	34	-74	-21	-33	-19	-37	-17	-25

The findings are listed below.

- Application of all sets of measures in Table 1, joined in an integral concept, results in an average environmental benefit by 28%. Decrease of the environmental burden of material use equals decrease of the environmental burden of energy consumption. This implies that ambitions like ‘a factor of 20’, which means a twenty times higher environmental efficiency, is still far away.
- Flexibility and energy saving are commonly seen as promising ways to substantially reduce the environmental impacts of housing construction. However, the outcomes of calculations on the flexible concept and the energy concept show that this is contestable. The flexible concept does not lead to a worthwhile improvement of the environmental performance, while the energy concept even involves a considerable worsening of the environmental performance by 25%. Therefore, flexibility and energy saving may not be looked upon as indisputable solutions to achieve sustainable housing.

4. CONCLUSIONS

The following conclusions are drawn from this study, answering the questions posed in the introduction.

- Working with strategies seems to be a suitable approach to make optimal choices concerning measures for sustainable construction.
- Seven strategies can be distinguished to improve the environmental performance of houses: dematerialization, material substitution, extension of service lives and improvement reusability (related to material use) and reduction of energy losses, use of renewable energy and use of efficient techniques (related to energy consumption).
- The average environmental benefits of sets of measures belonging to these strategies amount to 13% for material substitution, 20% for extension of service lives, 5% for improvement of reusability and -7% for use of renewable energy.
- Dematerialization, reduction of energy losses and use of efficient techniques offer good perspectives for sustainable housing construction, because they yield positive consequences on all environmental impacts. Unfortunately, these consequences are marginal or restricted. The difficulty of material substitution is that substitutions alternately are favourable and unfavourable with respect to the environmental impacts.
- The huge environmental burden of the material use of installations has to be reduced to make use of renewable energy a more promising strategy. Furthermore, extension of service lives, flexibility and reuse seem necessary to make a leap forward in the environmental efficiency of houses. However, the ultimate environmental benefits have to be reached in the future, so these are associated with large uncertainties.

Two final remarks have to be made. First, the importance given to each environmental impact largely influences the ultimate choice of one or more strategies for sustainable construction. Second, further research should concentrate on other housing designs and construction techniques, both from the Netherlands and from abroad. Accordingly, this research has to be considered as start of the determination of the potential environmental benefits of eco-efficient strategies. The research will be continued in a PhD on optimisation of the environmental performance of houses.

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