Sustainable solutions for Dutch housing

Reducing the environmental impacts of new and existing houses

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Preface

When I graduated in 1997, I joined the OTB Research Institute for Housing, Urban and Mobility Studies, part of Delft University of Technology, on a two-year contract. Little did I suspect that I would find the work of a researcher so enjoyable, let alone that I would go on to study for a doctorate in this field. The prospect of spending four years immersed in books or sitting at the computer screen delving into just one subject was a particularly daunting one. What I did not yet realise was that a researcher enjoys great freedom of choice with regard to the topic to be studied and the depth of that study. Moreover, the OTB offers a marvellous 'middle road' between theory and practice, between academia and the requirements of today's society. This is why I decided to prolong my career as a researcher... which would eventually call for the production of this thesis.

I went on to spend over four years working on a number of research projects, the common theme of which was the quantification of the environmental impacts of housing. Somewhere at the back of my mind was the realisation that the combined results should one day lead to a doctoral thesis. Some of that time was spent within the setting of the Delft Interfaculty Research Centre on the Sustainable Built Environment – The Ecological City project – led by the late Prof. Ch.F. Hendriks. I published various articles, papers and books, but the first letter of the doctoral thesis was not still forthcoming. At the same time I had absolutely no idea what form it would take. In short, I had a severe case of thesis-writer's block. And although I still much enjoyed the freedom of this profession, I came to realise that a long-term academic career is not for me. When the opportunity arose to join the staff of the Netherlands Standardization Institute (NEN), I therefore decided that it was time to move on.

That this thesis has nevertheless seen the light of day is largely due to my research supervisors, Prof. Hugo Priemus and Prof. Nico Hendriks, who managed to persuade me that my goal was not quite as far off as I had imagined. I am most grateful to them both for their encouragement. They motivated me to transform the knowledge I had gained into this document. Although it meant giving up evenings and weekends for a few months, the sacrifice was well worth while.

I must also acknowledge the help and support of my colleagues at the OTB, notably Geert Vijverberg, Frits Meijer, Henk Visscher, Karin Blaauw, Minna Sunikka, Evert Hasselaar, Milou Beerepoot, Dirk Dubbeling and Esther Philipsen. Haico van Nunen, my fellow doctoral candidate from the Eindhoven University of Technology, and Inge Blom, studying at Eindhoven, cannot go unmentioned. Each made a contribution to my work in their own role, for which I thank them.

Finally, my life would not be complete without my family, friends, the Pingwins Table Tennis Club and the Tavenu Music Club. I would like to single out just one person in particular for a special mention: Antwan. Thank you, espe-

cially for all the months in which everything had to revolve around me!

The Hague, 12 January 2005
Gerda Klunder

Summary

Sustainable solutions for Dutch housing; reducing the environmental impacts of new and existing houses

Introduction

Countless measures for sustainable construction exist, but little is known about the extent of the environmental benefits they offer, or about which measures can best be applied in order to maximise those benefits. Tools to quantify the environmental burden of buildings have now been developed in many countries. However, the results produced by the various tools are not readily comparable. There is no systematic insight into the environmental benefits offered by sustainable construction. Moreover, there is a lack of methods and tools which address the housing stock. To date, sustainable construction and management practice has largely been based on an intuitive approach. This study examines ways in which the environmental impacts of sustainability measures can be quantified, and looks at concepts and strategies for both new-build and renovation projects. Its objective is to gain a better understanding of the environmental benefits offered by sustainable solutions thereof. All stakeholders in the construction sector, including project developers, contractors, local authorities and architects, will then be able to incorporate objective environmental considerations in the planning process. The general research question may be stated as follows: *how can the environmental performance of housing in the Netherlands be further improved?*

The first stage of the study identified the main causes of the environmental burden attributable to new houses, using an environmental analysis of three reference houses: a terraced house, a semi-detached house and a gallery apartment. This enabled various 'priorities' for sustainable construction to be identified. The environmental benefits presented by sustainable construction were then determined by means of a study of four demonstration projects. Furthermore, sets of measures were compiled, the environmental impacts being extrapolated to form seven strategies for sustainable construction. It then became possible to determine which of these strategies offer the best prospects for reducing environmental burden attributable to new construction of housing. No specific tools addressing renovation are currently available. Accordingly, a method was developed to quantify and compare the environmental impacts of interventions in the housing stock. This method is based on the LCA methodology. Two case studies were conducted, both concerning re-differentiation projects in the Netherlands: Morgenstond Midden in The Hague, and Poptahof in Delft. Finally, extensive desk study formed the basis for efforts to chart the role of the factor of time in the LCA methodology. All research findings could then be combined to provide input for a discussion of the current status of methods and tools to quantify environmental

Table 1 Absolute amount of flows in the reference houses

Flow	Terraced dwelling		Semi-detached dwelling		Gallery flat	
	Total	Per m²	Total	Per m²	Total	Per m²
Materials	205 ton	1.9 ton	254 ton	1.9 ton	153 ton	2.0 ton
Energy	4,157 GJ	37.4 GJ	5,252 GJ	39.2 GJ	2,680 GJ	35.7 GJ
Water	6,772 m³	61.0 m³	10,847 m³	81.0 m³	4,110 m³	54.8 m³

impacts. It appeared that serious comments should be made regarding the environmental analyses. Eco-Quantum, a Dutch LCA-based calculation tool, was used to quantify the environmental impacts attributable to material use during construction, maintenance and replacement, as well as those of energy and water consumption during occupation of the dwelling. Because this tool is still in development, two versions were used during the course of the study: Eco-Quantum versions 1.01 and 2.00.

Environmental impact of Dutch dwellings; priorities for reduction and benefits of sustainable construction

'Factor 20' represents a very ambitious increase in environmental efficiency with a view to meeting current and future social requirements, i.e. to halve environmental burden assuming a two-fold increase in the world population and a five-fold increase in prosperity. Such an ambition increases the need for quantitative information concerning the environmental benefits offered by sustainable construction. First, the environmental impact of the three reference houses was determined. The houses are typical of the Dutch housing tradition. Table 1 lists the quantities of materials, energy and water used in each housing type. It may be seen that the gallery apartment is relatively material-intensive, while the semi-detached house is responsible for relatively high energy consumption.

In nine environmental impact categories, material use contributes more than 50% of the environmental burden, while energy consumption does so in the case of three environmental impact categories. While environmental burden is greater in proportion to the size of the house, the relative contribution of each flow appears to be approximately the same. The main contributors are also identical for each type of house. Fourteen priorities apply in terms of material use: the foundation beams, outer leaves, inner leaves (only applicable to the semi-detached house), window and door frames, glazing, rain proofing in the facades, parting walls, load-bearing walls (terraced house and gallery apartment), ground floor, storey floors, floor overlays (terraced house and semi-detached house), roof construction (sloping for terraced house and semi-detached house, flat for gallery apartment), roof overlay (only for gallery apartment) and heat-generation installation. Not only materials used in large quantities are considered, but also a number which are used in only limited quantities. Five priorities apply to energy consumption: space heating, hot tap water, lighting, ventilation and auxiliary energy. These are all the energy functions. Although gas consumption accounts for some 75% of the overall energy consumption, electricity is the prime contributor to a number of envi-

Table 2 Environmental benefits of sets of measures for sustainable material use applied to the terraced house

Sets of measures		Environmental benefits in percentages								
		MD	FD	GWP	ODP	POCP	HTP	ETP	AP	EP
M1	10% smaller dimensions of load-bearing structure									
M2a	renewable materials: timber-frame construction			5	8				-5	-6
M2b	synthetic materials instead of lead and copper	54					14	47		
M3a	90 years service life of house instead of 75 years	17	17	18	20	19	19	18	19	19
M3b	5 years prolongation of service life of components	8								
M4	reuse of foundation and parting walls	8		5		8	4		5	5

MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication.

Table 3 Environmental benefits of sets of measures for sustainable energy consumption applied to the terraced house

Sets of measures		Environmental benefits in percentages								
		MD	FD	GWP	ODP	POCP	HTP	ETP	AP	EP
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	
E3	low-temperature space heating and high-efficiency ventilation		5	5			6		6	5

MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; R_c: thermal resistance; U: heat transmission.

ronmental impact categories. Water consumption is not among the priorities, since it is of far less significance than material use and energy consumption.

In order to determine whether current sustainable practices are appropriate, a number of measures being used to address three themes within current demonstration projects were projected onto the terraced house. The three themes are: 1) energy saving both by means of installation technology (the Energy balance project in Amersfoort) and constructional measures (energy efficient dwellings in Bakel), 2) reuse and increase of the life span (the 'Respekt' project in Tilburg), and 3) the use of renewable materials ('Ecosolar' in Goes). The environmental benefits provided by the energy-saving approach addressing installations was -10%, while that addressing constructional measures was 5%. Reuse and increase of the life span provided 5% benefits, and the use of renewable materials accounted for 15%. (A negative percentage indicates an increase in environmental impact rather than any decrease, i.e. a worsening of the situation.) In considering the orders of magnitude, it should be remembered that the differences in each environmental impact category can be very large, varying from a 77% increase in environmental burden to an 81% decrease.

The search for the most eco-efficient strategies; Dutch lessons in sustainable housing construction

A more systematic approach was used to identify the most eco-efficient strategies for new construction. Four strategies relating to sustainable material use were identified: dematerialisation (M1), material substitution (M2), prolongation of the service lives (M3), and improvement of reusability (M4). Three strategies for sustainable energy consumption apply: avoiding unnecessary energy consumption (E1), use of infinite energy sources (E2) and clean and efficient use of finite energy sources (E3). For each strategy, one or more sets of measures were compiled and the likely impacts calculated, based on current practice and/or technological possibilities. The results of this process are presented in Tables 2 and 3.

The strategies of dematerialisation, avoiding unnecessary energy consumption and clean and efficient use of finite energy sources produced a reduction in environmental burden in almost all environmental impacts, but the benefits thus made will be limited in future. In the case of material substitution, improvements in certain environmental impacts are almost always accompanied by a worsening of others. It was concluded that more attention should be devoted to material use in solar-energy systems. The environmental benefits provided by reduced energy consumption are largely obviated by the nature of the materials used. Service life prolongation and reuse are required if significant advances are to be made, although it must be remembered that the environmental benefits remain uncertain, since these will become apparent only in the distant future. It is therefore appropriate to use these two strategies in combination with others.

Tools for sustainable housing management: the case of the Netherlands and Finland

There are currently three tools for sustainable housing management in use in the Netherlands: Duwon, the National Package for Sustainable Housing Management and Green Investment. These tools give no more than indications of the environmental benefits offered by the management measures applied. In the Netherlands, the emphasis is on the quantifiable aspects of sustainable construction: the tools do not offer any information regarding the qualitative aspects of housing management. The quantitative approach is not in keeping with the management task itself, which comprises the restructuring of mostly post-war residential districts. This demands a more strategic set of tools. Finland has only one tool, still in development, to support sustainable housing management and to provide any indication of environmental benefits:

the Environmental Systems Guide for Real Estate Management. This tool takes the qualitative view of environmental benefits. However, the main management task in Finland is that of renovation, for which the quantitative approach would be far more appropriate. LCA-based tools can, in principle, be applied to renovation issues, but the existing tools do not address the strategic considerations.

Environmental impacts of interventions in the Dutch housing stock

Transformation can fill the gap between no intervention at all (other than maintenance) and demolition and new construction (redevelopment), since the necessary modernisation can be achieved while retaining as much as possible of the existing structures. Transformation is essentially the process of improving the quality of an entire housing complex, across the boundaries of the individual houses it contains (as in combining small houses to become larger houses). Transformation is often seen as more environmentally friendly than demolition. Because there were no methods and tools available to measure and to compare the environmental impacts of such interventions, a new method had to be developed to substantiate this claim. The calculations of the environmental impact of an improved house combined two construction phases, two occupancy phases and two demolition phases, i.e. before and after the improvement process. The environmental impacts attributable to those components demolished and removed during the improvement but still retaining some useful service life was included. In order to compare interventions of different planned service lives, the average annual environmental impacts were used as the basis for comparison. Finally, the comparison of the improvement process with that of demolition and new construction was based on the reconstruction of the houses after the improvement.

The method was applied in the two case studies: Morgenstond Midden in The Hague, a 1950s housing development of three-storey and four-storey tenements, and Poptahof in Delft, a 1960s district with high-rise and medium-rise apartment blocks. Both presented good opportunities for transformation, resulting not only in an amended floor plan but in several other improvements such as thermal and sound insulation, and replacement of installations. Although the interventions were extensive, the transformation process represented great savings in material use and waste production compared to demolition and new construction. In Morgenstond Midden, material use was 41% lower and waste production 86% lower. In the case of Poptahof, material use was 62% lower and waste production 91% lower. In both cases, foundation, facades, inner walls and floors accounted for 90% of the material use. Moreover, transformation has resulted in lower energy consumption than in the zero situation (i.e. no intervention at all).

In the case of Morgenstond Midden, the environmental benefits attributable to transformation were 0% to 17% compared to the zero situation, while those of demolition and new construction would vary between -9% and 30%. The environmental benefits of transformation as opposed to new construction are largely due to reduced energy consumption. The benefits are, however, smaller than might be expected on the basis of the reductions in material use and energy consumption. This indicates that the building components which are responsible for relatively high environmental impacts have been replaced. In Poptahof, the environmental benefits of transformation were comparable, at 0% to 20%, the only exception being depletion of a-biotic resources, for which burden increased by 9%. Demolition and new construction produces benefits of up to 25% in all environmental impacts. Both material use and energy consumption contribute to the overall environmental benefits. Here too, the environmental benefits are smaller than would be expected based on the reductions in material use and energy consumption achieved. However, the facades of Poptahof had to be replaced in their entirety, and this is the building component with the greatest contribution to most environmental impact categories. In both Morgenstond Midden and Poptahof, transformation of the housing stock may be seen to have produced better environmental performance than demolition and new construction, and better environmental performance than no intervention at all.

Between sustainable and durable: optimisation of life spans

Durability in the sense of a long service life, and sustainability in the sense of environmental friendliness are often regarded as two separate concepts. There is indeed some conflict of interests, since materials with a long service life may account for greater environmental impacts than those with a shorter service life. Some materials may cause relatively high environmental impacts but nevertheless be more readily reusable than those which cause less impacts but cannot be reused. The optimisation of life spans whereby both durability and sustainability are addressed in tandem can resolve this paradox. Accordingly, an analysis was made of the role of the service life of houses and house components within the overall environmental burden caused by the terraced house. The analysis revealed that the environmental benefits of houses with a longer intended service life decrease in proportion to the extension of that life, although the negative effect of a shorter service life remains greater than the positive effect of a longer service life. Moreover, prolongation of life spans will not always result in less environmental burden. This is due to the actual construction process itself, which accounts for the greatest proportion of overall environmental burden. With regard to the prolongation of the service life of components, it was found that a longer service life has less overall positive effect than a shorter life has overall negative effect. The use of components with longer life spans is clearly most appropriate in buildings which themselves have a longer service life. Recycling and reuse are also aspects of the optimisation of life spans. For example, a short service life can be compensated by the use of materials which are readily reusable. Although there is as yet no scientific basis on which to base the claim, this would tend to promote sustainability in the sense of environmental friendliness. The prolongation of service lives will certainly result in environmental benefits, but is not a decisive factor.

The factor of time in Life Cycle Assessment of housing

Regardless of the application, the LCA system has certain shortcomings in terms of allocation, weighting, reliability of data, bio-diversity and interference. In the construction sector, the long service life of buildings renders the LCA yet more complex. Besides it introduces many uncertainties. The factor of time is of significance here. Many aspects of the building will change over time. New construction materials and components will be introduced several times, old materials and components will be removed. Even where the replacements are exactly the same as those used in the original construction, innovations and trends will also cause various changes in form and use. Such factors are not currently considered in the LCA. We may therefore identify six aspects of the factor of time, three of which are static: design, redesign and technical service life. The other three are dynamic and relate to future developments: production technology, waste treatment technology and functional service life. In order to gain a complete picture of the environmental impacts of sustainable construction, all aspects must be included in the calculations. Existing knowledge relates mainly to the static aspects. A greater understanding of the role of the other, dynamic aspects of the factor of time may be obtained using scenarios, turning points, sensitivity analyses and potentials.

Discussion on the state of the art in quantifying environmental impacts

The LCA methodology was introduced in the construction sector as a response to the shortcomings of the tools which listed the materials for certain applications in categories, from 'first preference' to 'to avoid'. These lists were often incompatible or even contradictory. It was also realised that materials and their use should be considered over their entire service life. The step to implementing the LCA at building level was quickly made. One of the tools developed was Eco-Quantum. There have been several versions: Eco-Quantum 1.01 was based on the CML I-method; Eco-Quantum 2.00 is based on the CML II-method, published some ten years later. CML II makes use of the LCA standards developed in the meantime. Calculation of the environmental impacts of the same measure using the two versions produces a disturbing disparity in results. For example, the 52% environmental benefit in terms of depletion of a-biotic resources suggested by Eco-Quantum 1.01 is not reproduced by Eco-Quantum 2.00, while the 45% benefit in aquatic eco-toxicity is reduced to just 8% by the later version. Substantial increases in environmental impacts in terms of depletion of raw materials (55%) *ozone depletion* (25%), human toxicity (9%) and acidification (8%) are actually reversed to become decreased environmental impacts in depletion of a-biotic resources (8%) and eutrophication (6%).

It would appear that the disparities are mostly due to developments in the LCA methodology itself, whereby no distinction is now made between the depletion of raw materials and that of fuels. Depletion of a-biotic resources, human toxicity and eco-toxicity are now subject to completely different calculation methods. The criteria by which ozone depletion and photo-oxidant formation are assessed (comparing the substance having a supposed environmental burden to a reference substance) have also been modified. Changes to the Eco-Quantum method, including those to materials and waste data as well as to normalisation and weighting factors, seem to play a far smaller role. However, Eco-Quantum is not transparent enough to allow identification of all factors which are responsible for the different results produced by versions 1.01 and 2.00. Although the LCA methodology has seen major development over the past ten years, there are still further developments to come. This, together with the long service life of buildings, raises severe doubts concerning the usefulness of quantifying the environmental impacts at the level of the building. It would appear that the methods and tools used are not (yet) robust enough.

Conclusions and recommendations

In attempting to improve the environmental performance of residential property in the Netherlands yet further, material use and energy consumption are of equal importance. In both cases, the flows themselves do not provide enough information. We must look at the environmental impacts themselves. It would seem that even the materials (e.g. lead and copper) and types of energy (e.g. electricity) which are used in small quantities can have major environmental impacts. Moreover, the differences between the impact categories themselves are large, whereby much information is lost when expressing the overall environmental burden as a single figure. In the case of new construction, one problem is that the short-term environmental benefits will be relatively modest, while the long-term benefits can be substantial. It is therefore imprudent to concentrate solely on the strategies with highest environmental benefits, since these involve too many uncertainties. It is preferable to adopt a broad view of all opportunities for improvement. This study has provided an indication of the potential available, and of the pros and cons of certain strategies, whereupon a reasoned choice of sustainable construction approach can be made. Transformation results in major reductions in material use and the amount of waste produced. However, here too the environmental impacts show a smaller improvement than the flows analysis would suggest. Significant opportunities will be missed if transformation is regarded as offering greater environmental benefits than new construction in every case.

The aspect of service life plays a special part in answering the question of how the environmental performance of housing can be improved. Where the prolongation of the service life is adopted as a strategy, it must be remembered that the environmental benefits will only become apparent in the (distant) future and are therefore subject to uncertainty. Moreover, prolongation is not always useful. For example, there is no point in striving for a long service life for components being used in a building which itself has a short (remaining) service life. Achieving an appropriate balance between the service life of components and their host building is therefore something of a challenge. It would seem that the greatest environmental benefits to be had from service life prolongation are those which derive from not having to build a completely new property. However, construction products, construction processes and the nature of the houses themselves are likely to change considerably over time. It is therefore not possible to make any firm conclusions regarding the long-term environmental benefits. A further complication is that the LCA system is not yet fully developed. It is appropriate to devote attention to the concept itself. Quantification of the environmental impacts of houses is useful, but it must be realised that major uncertainties remain. Although the collection of empirical data concerning service lives can increase our understanding of cause and effect, there will always be wide 'bandwidths'. Accordingly, we must not concentrate too much on attempting to remove the uncertainties.

This research has produced various recommendations for policy. Firstly, the LCA methodology is too complex to be used as the basis for material-related performance requirements as part of the Dutch Building Decree. It would appear that performance agreements based on the Eco-Quantum system will be of more use to local authorities, although the authorities themselves would prefer to see binding national legislation. Using Eco-Quantum, it would be possible to impose certain requirements not only in terms of material use, but for energy and water consumption as well. Now that the Building Decree itself fails to address environmental issues directly, the government should allow local authorities to impose their own requirements in this area. It remains necessary to encourage the development of calculation tools, although the emphasis must be on their practical applicability. A significant omission is the lack of weighting factors. Preferably, these should be defined at the European or international level, rather than by the national government. Calculation tools can also form the basis for an eco-labelling system, enabling homebuyers and potential tenants to make a more environmentally aware choice. Finally, sustainability must be adopted as an assessment criterion for funding under the Dutch policy instrument Urban Renewal Investment Budget. If this is not the case, the housing stock will be subject only to the policy addressing energy efficiency and renewable energy. The housing stock has great potential to help the Netherlands achieve the targets of the Kyoto Protocol. However, to tap that potential will require increases in gas and oil prices in order to encourage sustainable construction and renovation.

Fewer recommendations can be made for practice itself, since the results of the research are subject to certain reservations. Local authorities can try to achieve their sustainability ambitions by means of performance agreements covering residential developments. Project developers can promote sales of sustainable houses by presenting the advantages: lower energy bills, greater comfort and better health. The challenge facing architects is to combine various sustainable construction strategies. To rely on just one strategy is not prudent, since each has both environmental advantages and environmental disadvantages. Contractors must be alert to construction faults, as must installers. The realisation of the great potential of the housing stock is a primary responsibility of housing managers. They must devote greater attention to the choice between improvement on the one hand, and demolition and new construction on the other. The environmental benefits can go further than the retention of the houses. Residents cannot be asked to contribute much to the sustainable construction process. However, resident behaviour should guide the choice of sustainable construction measures.

Finally, four recommendations for follow-up research can be made. Firstly, little is known about the influence of resident behaviour and management practice on the environmental benefits of sustainable construction. More research in this area is called for. Secondly, further research is required into the environmental impacts that derive from the location of the property, such as those caused by use of the private car for transport. Thirdly, the experiences to date with LCA of buildings suggest that alternative methods for quantifying the environmental impacts of housing must be sought. The LCA methodology was developed for consumer goods, not for houses. Moreover, it is essential to include the housing stock in any assessment. Knowledge concerning the environmental impacts of interventions in the housing stock is still in its infancy. Fourthly, it seems advisable to develop a model whereby environmental knowledge can be integrated into the planning processes for both new construction and redevelopment.

1 Introduction

1.1 Background

'Factor 20' is a familiar concept to all those working in Dutch policy and research in connection with the sustainability of the built environment. It forms a metaphor which refers to the aim of achieving a major improvement in environmental efficiency while continuing to address the requirements of society. The aim is to encourage long-term thinking which incorporates a high level of ambition with regard to environmental aspects. It is an expression of the formula which states that environmental burden is the product of population growth and increasing prosperity, i.e. the environmental burden per unit of prosperity (Commoner, 1971; Ehrlich and Ehrlich, 1990). If environmental burden is to be reduced by half by the year 2040, assuming that the population will double and prosperity will increase fivefold during that period, environmental efficiency must therefore increase by a factor of 20. This is the equivalent of a reduction in environmental burden of at least 95%. Although 'Factor 20' is more a manner of thinking rather than a concrete objective, the concept underscores the need for quantitative information about the environmental impacts of construction activities. Numerous measures have been formulated to promote sustainable construction, many of which are included in national publications and guidelines for the residential construction sector (SBR, 1996; SBR, 1997). However, little is yet known about the extent of the environmental benefits made by implementing such measures, nor about which new measures can best be introduced to achieve further progress.

The LCA approach is central to the quantification of environmental impacts (Guinée, 2002). LCA stands for Life Cycle Assessment, which entails the environmental impacts of a product, process or service are considered from its very inception until the end of its service life: from the acquisition of raw materials to the final disposal of the components used. In the construction sector, LCA was first adopted to determine the environmental impacts of materials. Gradually, it was realised that those materials had to be regarded in the context of their use, whereupon LCA-based tools were developed to quantify the overall environmental burden of buildings over time. Many countries have developed their own LCA-based systems. Examples include Athena in Canada, BEES in the United States, EcoPro in Germany and EQUER in France (Knapen and Boonstra, 1999a). The Netherlands has long been a frontrunner in terms of systems to quantify the environmental burden of buildings, Eco-Quantum and GreenCalc being among the best known.

The available tools are applied within projects, producing information about the environmental benefits of sustainable construction methods. However, that information has two shortcomings. The first is that results obtained using different systems are not readily comparable. This is partly due to the fact that each system relies on different methods and reference points, which are often not stated in the results. This is demonstrated by Annex 31 of the International Energy Agency, which calculates the environmental efficiency of buildings using various incompatible tools (Knapen and Boonstra, 1999b). The Green Building Challenge hopes to arrive at an internationally accepted general framework for environmental assessment systems, whereby it will become possible to make a direct comparison of environmental performance (Cole and Larsson, 2000). However, this will only be of use to those countries which are currently developing the relevant tools. The BEQUEST project (Building Environmental Quality Evaluation for Sustainability through Time) will identify those characteristics of the systems which are likely to contribute towards their transparency, but it will not obviate the problem (Deakin *et al.*, 2001). It is difficult to generalise the results from different countries, since building design and methods are so varied, as is the product, process and environmental information available.

The second shortcoming of the existing information is that it fails to present any systematic insight into the quantitative environmental benefits achieved by the measures, strategies and concepts currently applied in sustainable construction. Moreover, the vast majority of methods focus exclusively on new construction. Renovation projects present an entirely different context. The debate of whether it is better to renovate or to demolish and replace is very topical. Any sustainable approach to the housing stock still lags behind that applied to new construction. The European Sureuro project (Sustainable Refurbishment Europe) was an important initiative in terms of gaining greater attention for sustainable management (Sureuro, 2004). Here, sustainability is addressed by means of checklists and firm objectives based on quality levels for each environmental aspect. The project represents a qualitative approach to sustainable building management.

It may therefore be concluded that sustainable construction and management has, to date, been primarily based on an intuitive approach. Further to this conclusion, Van den Dobbelsteen (2004) has conducted a study of the environmental performance of office buildings. Such buildings present a totally different set of problems and solutions to those associated with residential properties. For example, one way in which the environmental performance can be improved is to ensure the most efficient use of the offices. This is not possible for residential properties. This thesis is therefore concerned with the quantitative substantiation of sustainable measures, concepts and strategies for housing, whether new-build or renovated.

This introduction presents a summary of the terms of reference of the research project, and describes the methods and results in brief. Each aspect is examined in greater detail in the respective chapters of the report. Two books (in Dutch) by the research author are presented as appendices. They set out the context of the research. The objective, terms of reference and research questions are to be found in Section 1.2. Section 1.3 describes the approach adopted. Section 1.4 describes the environmental assessment method, while Section 1.5 presents the structure of the thesis itself.

1.2 Objective, terms of reference and research questions

The objective of the research is to gain an insight into the environmental benefits offered by sustainable solutions in new construction and renovation of housing. This will enable all parties in the construction process – amongst others project developers, contractors, local authorities and architects – to include objective environmental considerations in the planning process.

The research terms of reference are therefore: *how can the environmental performance of housing in the Netherlands be further improved?*

The research questions themselves fall into three groups. The first relates to new construction, for which there are calculation tools available to quantify the environmental impacts. The following questions are to be addressed:

1. Which components of the house are the major contributors to environmental burden (Chapter 2)?
2. What environmental benefits do current sustainable houses present (Chapters 2 and 3)?
3. What strategies can best be pursued in order to further improve the environmental performance of houses (Chapters 2 and 3)?

The second group of questions relates to renovation projects. There are at present no tools specifically designed to address the housing stock. Accordingly, the research questions must be slightly different to those for new construction:

4. What is the current status of methods and tools for sustainable housing management (Chapter 4)?
5. How can the environmental impacts of interventions in the housing stock be compared (Chapter 5)?
6. What are the environmental impacts of interventions in the housing stock (Chapter 5)?

The third group of research questions addresses the Life Cycle Assessment methodology as applied to buildings. Because buildings generally have a long service life, the LCA can be a complex undertaking:

7. What is the role of the service life in terms of the sustainability of buildings and their components (Chapter 6)?
8. What role does the factor of time play in the LCA (Chapter 7)?
9. What is the current status of efforts to quantify environmental impacts (Chapter 8)?

1.3 Approach

The quantitative substantiation of measures, concepts and strategies to ensure the sustainability of new construction were investigated by means of a systematic approach whereby the environmental benefits were identified. This approach was expected to provide a clear understanding of these benefits. In principle, the same approach can be used to identify the most environmentally useful measures, concepts and strategies for renovation projects, albeit with some modifications to the calculation systems employed. Despite applying the same approach, it seemed likely that different results would be forthcoming given the different starting positions of new-build and renovation projects. One important difference is in the energy consumption of new and existing buildings. During the course of the research it became apparent that a renovation project requires one question to be addressed beforehand: what will be the environmental impacts of interventions in the housing stock? The answer to this question will form the basis for improvements, parallel to the process in new construction whereby the main contributors to environmental burden form the focus of the efforts. The research did not consider the process beyond this initial basis, since the necessary calculations would be extremely labour-intensive and time-consuming when using the resources currently available. The LCA for buildings also proved much more complex than anticipated. The outcomes of the Eco-Quantum analyses turned out to be far less firm than expected beforehand. One should keep that in mind when reading this thesis. Eventually, the following approach was adopted.

The main contributors to environmental burden in new construction were identified using an environmental analysis of three reference houses: a house terraced house, a semi-detached house and a gallery apartment (Novem, 1999a and b). The terraced dwelling is part of a series of houses in one row. The overall environmental burden of a house consists of the environmental impacts of material use during the construction process and in maintenance and replacements, the energy consumption during use, and the water consumption during use. The environmental burden is the accumulative total of the environmental impacts (see Section 1.4). The environmental analyses conducted resulted in a set of key features ('priorities') to which attention must be devoted in order to reduce the environmental impacts of houses (research question 1).

The environmental benefits represented by existing sustainably constructed houses was determined in two ways. First, the measures implemented in four demonstration projects were projected in terms of the terraced house and the environmental benefits calculated. Then, sets of measures were compiled for each of the strategies for sustainable construction. In the case of material use, four strategies were examined: dematerialisation, material substitution, prolongation of service lives, and improvement of reusability. In examining energy consumption, the three-step strategy was employed (after Duijvestein, 1998). This entails avoiding unnecessary energy consumption, use of infinite energy sources, and clean and efficient use of finite energy sources (research question 2). The aspect of water consumption was not further examined, since this is not one of the formulated priorities. Environmental benefits are defined as the reduction in the environmental burden caused by a house compared to that of a reference house. From the results, it was possible to deduce which strategies offer the best prospects for reducing the environmental impacts of houses (research question 3).

Case studies of tools for sustainable housing management in the Netherlands and Finland were conducted to identify the challenges in terms of the further development of such tools. In doing so, the relationship with the management task in the two countries was established (research question 4). The Netherlands and Finland were chosen, because they offer comparable, yet different policy approaches to sustainable building and have already acquired some experience. Throughout this thesis, the term 'sustainable' is viewed from the environmental perspective. Although there are many more facets to sustainability, these were not considered. From the case studies and some supplementary desk research, it became apparent that methods and tools whereby the environmental impacts of interventions in the housing stock may be compared are not yet available. Using the existing approaches as a starting point, a suitable method was then developed (research question 5). This method was applied in two case studies involving the re-differentiation of the housing stock: Morgenstond Midden in The Hague and Poptahof in Delft (research question 6).

As previously stated the environmental analyses should be seen in the light of serious comments. The issues surrounding the LCA of buildings in relation to the long service life were approached from two angles. The first examined the role of the service life in terms of the sustainability of housing. Both the service life of the property as a whole and that of its components were examined closely (research question 7). Next, the role of the factor of time itself was considered. Six aspects of the factor of time were identified and solutions were proposed whereby these can be incorporated into the LCA process (research question 8). The developments in current LCA practice and in the Eco-Quantum method, combined with the unusually long life cycle of buildings, raise certain doubts about the necessity and usefulness of the LCA approach when applied to buildings (research question 9). A discussion of the various aspects is presented, making use of all research findings.

Figure 1.1 offers a diagrammatic representation of all research components, the research questions being indicated between brackets. The research is based on the Eco-Quantum method, shown at the top of the diagram. The desired results of the research are shown at the bottom of the diagram. They include guidelines for the parties involved in the construction process. The quantification of the environmental impacts of houses enables certain lessons to be learned in terms of sustainable building practice, despite the disappointing results. Above all the research is intended to promote the further development of calculation methods and tools.

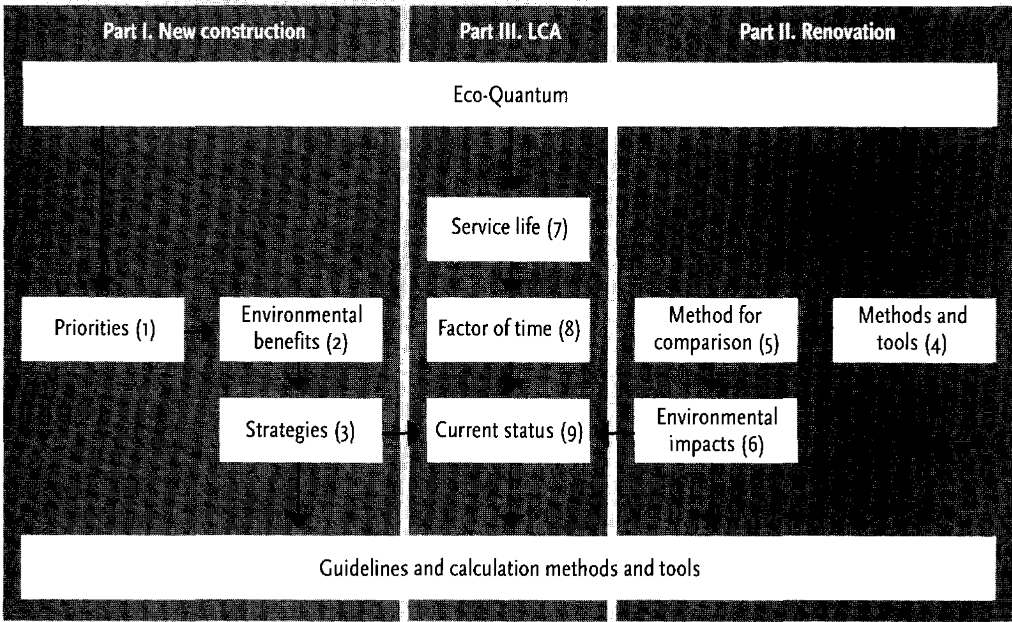
The research suffers from three significant limitations. Firstly, the factor behaviour has not been considered. Standard life cycles are assumed, together with standard maintenance and replacement schedules, construction losses and waste treatment scenarios, and standard estimated energy and water consumption. In the real life situation, all these aspects could vary significantly. Residents and managers have a major influence in terms of actual environmental impacts. Secondly, the location factor has not been taken into account. For example, the resident of a house in a suburban area is more likely to use a car (with all the environmental impacts that entails) than one living in a central urban district. This is not so much a question of the environmental impacts of the house itself, but that of the use of that house. Finally, the research is completely devoted to quantifiable environmental impacts. That singles out non-quantifiable impacts (as yet), such as nuisance.

1.4 Environmental assessment method

Eco-Quantum was used to determine the environmental impacts. It was selected because it is one of the first LCA-based systems and is specifically geared to Dutch building designs and construction methods. A comprehensive description of Eco-Quantum is presented in Section 2.3.

Eco-Quantum was still in development during the course of the research. Accordingly, different versions of the system were used. The calculations in Chapters 2, 3 and 6 were made using Eco-Quantum version 1.01. The calculations in Chapter 5 were made using Eco-Quantum version 2.00, which incorporates the latest developments in the LCA methodology. This is explained in further detail in Chapter 8. Furthermore, the standard EPC requirement was changed from 1.2 to 1.0 during the course of the study. EPC stands for Energy Performance Coefficient and is the standard imposed by Dutch building regulations for the energy performance of new-build residential properties and various other types of building. The new, more stringent standard effects the reference used. The environmental analysis of the reference houses in Sections 2.4 and 3.4.1, as well as the calculation of environmental benefits in Section 2.5 and Chapter 6 are based on the 'old' EPC of 1.2. Accordingly, the environmental benefits were estimated to be higher than would be the case in the current situation, since the assumed energy consumption of the reference was higher than is now permissible. However, the calculation of environmental benefits in Section 3.4.2 is based on the 'new' EPC of 1.0, reflecting

Figure 1.1 Research structure



the current situation.

Eco-Quantum is applied primarily at the level of environmental impacts, whereby only negative impacts are taken into account. Environmental impacts are the non-aggregated, un-weighted results of the LCA calculations. The process of aggregation requires weighting factors. It has proven difficult to reach agreement regarding such factors, although they will clearly have a significant effect on the final results. The environmental impacts level is therefore that at which the results are least contentious. However, it must be remembered that the extent and scope of each environmental impact category cannot be directly compared to that of any other impact category, and that the results do not reflect the extent or seriousness of the impact category in question. Nevertheless, a form of weighting has indeed been applied at several points in this thesis, it being possible to apply an average percentage of environmental benefits to the overall package of environmental impacts. However, this is no more than an average and should not be construed as a total percentage of environmental burden reduction.

Eco-Quantum version 1.01 calculates nine environmental impacts: depletion of raw materials, depletion of fuels, global warming, ozone depletion, human toxicity, eco-toxicity, acidification and eutrophication. Eco-Quantum version 2.00 examines ten impacts: depletion of a-biotic resources, global warming, ozone depletion, photo-oxidant formation, human toxicity, aquatic eco-toxicity, sediment eco-toxicity, terrestrial eco-toxicity, acidification and eutrophication. A number of environmental impacts are not considered because they are in fact not impacts but quantities. They include energy consumption, hazardous waste and non-hazardous waste, the environmental impacts of which are already taken into account within other impacts and

Table 1.1 Relationship between main thesis and appendices

Sustainable solutions for Dutch housing	How environmentally friendly is sustainable construction? (in Dutch)	Sustainable interventions in the housing stock (in Dutch)
1 *Introduction*		
2 Environmental impact of Dutch dwellings; priorities for reduction and benefits of sustainable construction		
2.3 *Environmental assessment method*	1.4 Environmental assessment method Appendix 1 Explanation of environmental impacts	1.5 Eco-Quantum Appendix 1 Explanation of environmental impacts Appendix 3 Procedure for the entry of intervention variants into Eco-Quantum
2.4 Environmental analysis of Dutch traditional housing and 3.4.1 Priorities for reduction of environmental impacts	3 Environmental analysis of traditional housing Appendix 7 Characteristics of components in the reference houses	
3 The search for the most eco-efficient strategies; Dutch lessons in *sustainable housing construction*		
3.4 Environmental benefits of Dutch sustainable construction	5 Environmental benefits represented by strategies for sustainable construction	
4 Tools for sustainable housing *management*: the case of the Netherlands and Finland		
5 Environmental impacts of interventions in the Dutch housing stock		

would otherwise be included twice. However, these three environmental impacts are indeed considered in the environmental analysis for the reference houses and in determining the environmental benefits of the four demonstration projects (see Chapter 2).

1.5 Structure of this thesis

The thesis is in three parts. There is one main thesis with two books which are appendices to the main body. This is the main thesis which, in addition to introductory and concluding chapters, comprises five previously published international academic articles (Chapters 2, 3, 4, 6 and 7), one submitted article (Chapter 5), and a discussion (Chapter 8). Chapters 2 and 3 present the results of the new construction study and answer research questions 1 to 3. Chapters 4 and 5 relate to the housing stock, addressing research questions 4 to 6. Chapters 6, 7 and 8 examine the role of the service life in terms of the sustainability of buildings and their components (research question 7), the factor of time within the LCA (research question 8) and the current status of

Sustainable solutions for Dutch housing	How environmentally friendly is sustainable construction? (in Dutch)	Sustainable interventions in the housing stock (in Dutch)
5.4 Environmental impacts of housing transformations in Morgenstond Midden		5 Sustainable interventions in Morgenstond Midden Appendix 7 Entry of reference block Hengelolaan in Eco-Quantum Appendix 8 Entry of transformation variants for Hengelolaan in Eco-Quantum Appendix 9 Entry of new construction variants for Hengelolaan in Eco-Quantum
5.5 Environmental impacts of housing transformations in Poptahof		6 Sustainable interventions in Poptahof Appendix 12 Entry of reference high-rise building Poptahof in Eco-Quantum Appendix 13 Entry of transformation variants for Poptahof in Eco-Quantum Appendix 14 Entry of new construction variants for Poptahof in Eco-Quantum
6 Between sustainable and durable: optimisation of life spans 7 The factor of time in Life Cycle Assessment of housing 8 Discussion on the state of the art in quantifying environmental impacts 9 Conclusions and recommendations		

methods and tools to quantify environmental impacts (research question 9). Chapter 9 presents conclusions and recommendations.

The chosen structure of this report, forming as it does a sort of anthology of articles, renders it almost inevitable that certain inconsistencies and repetitions will occur. Almost all articles include an explanation of the Eco-Quantum system. Furthermore, the classification of the environmental burden of the reference terraced house in terms of material use and energy and water consumption forms a recurring basis for the analyses of the environmental benefits. The most comprehensive description of these aspects is to be found in Chapter 2 (Sections 2.3 and 2.4). Many of the articles refer to the same sources. However, it was decided to include all articles in (more or less) original form, although occasional modifications have been made to the terminology, abbreviations, reference lists and the structure descriptions, in order to introduce greater consistency to the thesis as a whole. All references are listed together at the end of the thesis.

Two original books (in Dutch) form appendices to the thesis. Both are part of the DUP Science series: *Hoe milieuvriendelijk is duurzaam bouwen?* (How Environmentally Friendly is Sustainable Construction?; Klunder, 2002) and

Duurzaam ingrijpen in de woningvoorraad (Sustainable Interventions in the Housing Stock; Klunder, 2004). Both works have been reviewed and approved by an academic editorial board. They are included with this thesis because they contain a wealth of background information which is relevant to the context of the research, but which would be impossible to summarise within the scope of the individual articles. For example, there is a significant body of information relating to the development of sustainable construction and management techniques in practice, and about the policy adopted in these areas. It concerns the following chapters of the first appendix (How Environmentally Friendly is Sustainable Construction?):

- Chapter 2 Current status of sustainable construction practice.
- Chapter 4 Strategies and measures for sustainable construction.
- Section 6.3 Prospects.
- Section 6.4 Recommendations.

The second appendix (Sustainable Interventions in the Housing Stock) contains background information in:

- Section 1.3 Delineation and definition.
- Chapter 2 Towards a sustainable approach.
- Chapter 3 Current status of the sustainable approach.
- Section 7.3 Recommendations.

Moreover, the books provide a more detailed insight into the results presented in the articles. Table 1.1 illustrates the relationship between the appendices and the main body of the thesis. Footnotes in the relevant chapters and sections of this main body also refer to the explanatory chapters and sections in the appendices relating to the calculations.

2 Environmental impact of Dutch dwellings

Priorities for reduction and benefits of sustainable construction

Source: Klunder, G., 2001, Environmental impact of Dutch dwellings; priorities for reduction and benefits of sustainable construction, in: Maiellaro, N. (ed.), 2001, Towards Sustainable Building, *Dordrecht (Kluwer Academic Publishers), pp. 109-134. With kind permission of Springer Science and Business Media.*

2.1 Introduction

2.1.1 Aim

This paper[1] aims at identifying priorities to reduce the environmental impact of dwellings. It successively addresses the following questions: What is the amount of the flow of materials, energy and water of Dutch traditionally built dwellings?, What are the environmental effects of material use, energy consumption and water consumption?, Which building components and energy and water functions are the major contributors to the environmental impact? Furthermore, it discusses the environmental benefits of present Dutch sustainable housing in the light of the ambitious objective of the factor of 20. It deals with the next issues: What is the environmental performance of present Dutch sustainable dwellings?, What does this mean related to the objectives on the long term? Both point of views contribute to founding sustainable measures, concepts and strategies in housing, so a transition can be made from a merely intuitive approach with respect to sustainability issues towards a more reasoned approach.

2.1.2 Background

The need for a more reasoned approach is a consequence of thinking in factors. 'Factor 20' is a well-known slogan in Dutch science and policy related to sustainability in the built environment. It is a metaphor, which refers to a substantial increase of environmental efficiency with respect to societal needs. That is, it encourages long-term thinking with a very high ambition level. This is derived from Commoner (1971) and Ehrlich and Ehrlich (1990). Commoner stated that the global environmental impact depends on the population size, the average prosperity per person and the environmental impact

1 This paper is an updated and extended version of the papers submitted to the conferences Sharing Knowledge on Sustainable Building in Bari (Klunder and Blaauw, 2000) and Sustainable Building 2000 in Maastricht (Klunder, 2000a).

per unit of prosperity. Ehrlich and Ehrlich encapsulated this in a formula:

It = Po x Pr x Ip

Where It = global environmental impact
Po = population size
Pr = average prosperity per person
Ip = environmental impact per unit of prosperity.

So when a halving of the global environmental impact is wanted for the period from 1990 to 2040, a doubling of the population size by 2040 is assumed and average prosperity five times higher than in 1990, then we have to reduce the environmental impact per unit of prosperity by a factor of 20. A factor of 20 is equivalent to a reduction of the environmental impact by 95% with respect to the actual situation. The Dutch Ministry of Housing, Spatial Planning and the Environment uses 'Factor 20' to program the research agenda in the field of sustainable building (Lemmen and Pullen, 1999).

Thinking in factors increases the need for quantitative information about the environmental impact of building activities. Until now, Dutch sustainable building is predominantly based on a more intuitive approach without knowing the exact results with respect to the reduction of the environmental impact. For example, in recent years a number of national packages have been developed, including packages for new construction of dwellings and for renovation of dwellings (SBR, 1996; SBR, 1997). In these packages measures 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 extension of the environmental benefits. Therefore, optimal choices fitting within a certain ambition level are still difficult to be made.

Not only the Dutch ministry uses 'Factor 20', but also the Delft Interfaculty Research Centre The Ecological City of Delft University of Technology. This research centre aims for developing knowledge to be used for reduction of the environmental impact of building activities, so an important contribution to the improvement of environmental efficiency by a factor of 20 in the year 2040 will be delivered. An integral approach is assumed as a prerequisite to achieve this. Also the tools which are being developed are based on that thought (Hendriks and Kaiser, 2000). Research is being carried out on eight research themes: 1) design, 2) urban planning, 3) construction, renovation and management, 4) measures for dwellings and utility buildings, 5) measures for civil constructions, 6) environmental impact assessment, 7) steering arrangements and 8) scenario analysis.

Various research projects within The Ecological City are being carried out by the OTB Research Institute for Housing, Urban and Mobility Studies, including the project Sustainable Construction and Renovation. Within this project, sustainable dwelling concepts are being developed for both new construction and renovation.

2.1.3 Structure

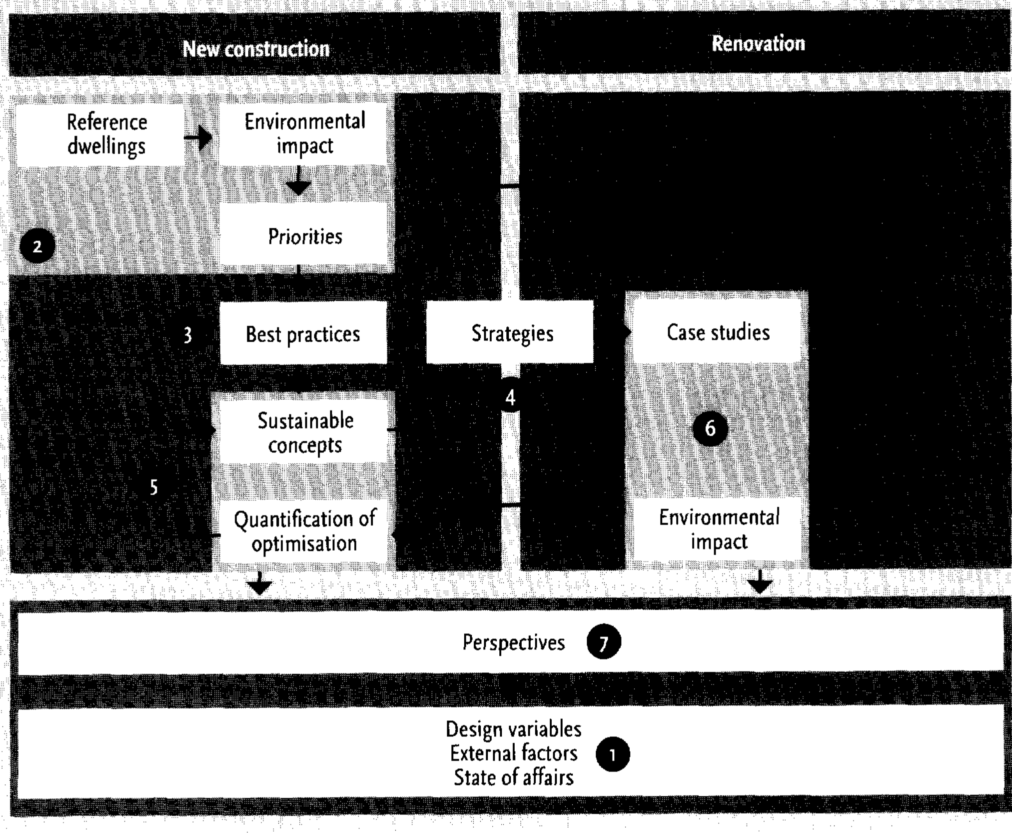
The research project Sustainable Construction and Renovation is described in Section 2.2. Subsequently, the method used for environmental impact assessment is coming up in Section 2.3. It will address the Eco-Quantum tool. Section 2.4 discusses the environmental impact of Dutch traditional housing by analysing three reference dwellings typical of current construction practice. After that, the state of affairs of sustainable housing in the Netherlands is described in Section 2.5. This section focuses also on a number of Dutch sustainable demonstration projects and the environmental performance, which is thereby attained. Finally, conclusions are drawn in Section 2.6.

2.2 Sustainable construction and renovation in The Ecological City

The central objective of the research project Sustainable Construction and Renovation within the research centre The Ecological City is identification of opportunities and obstacles for sustainable housing. Spearheads are the development of integral new construction and renovation concepts and environmental testing on the basis of the Life Cycle Assessment (LCA) methodology. The research is directed towards installation technology and constructional measures in the concepts for new construction and renovation of various types of dwellings. The project consists of the following seven parts, as shown in Figure 2.1:

1. Overview of the relevant design variables, external factors and state of affairs
   The design variables and the state of affairs serve as a starting point for the development of sustainable dwelling concepts. The environmental impact of various dwelling concepts is closely associated with external factors of influence. Six aspects are distinguished: the urban planning context, implementation aspects, inhabitants' behaviour, technological developments, the evaluation framework and developments in the housing market.
2. Analysis of the composition of the environmental impact of dwellings
   The composition of the environmental impact of dwellings was analysed for various dwelling types by means of the environmental impact assessment tool Eco-Quantum. This resulted in priorities for reducing the environmental impact of dwellings. In addition, attention will be paid to those aspects, which are not quantifiable as yet.
3. Identification of sustainable measures and concepts

Figure 2.1 Research design



Measures to reduce the environmental impact of dwellings will be identified on the basis of best practices and future developments envisaged.

4. Optimisation of sustainable measures and concepts
   Seven strategies will be used to handle the priorities into more sustainable dwelling concepts, i.e. coherent measures packages, which realise reduction of the environmental impact of housing: 1) energy saving and renewable energy, 2) dematerialisation, 3) use of renewable materials, 4) use of less environmentally damaging materials, 5) reuse, 6) increase in life span and 7) decrease in maintenance.
5. Development of dwelling concepts
   A number of dwelling concepts will be developed by confronting the optimisation strategies with the priorities for improvement of the environmental performance, together with the best practices. The environmental benefits of several demonstration projects have been figured out and will serve as a starting point for calculating the environmental benefits of sustainable measures and concepts.
6. Case studies for renovation
   Lessons learned with respect to new construction will function as input for sustainable renovation concepts. Case studies will be conducted not only to find best practices, but also to develop new concepts. The restructuring of

the neighbourhood Poptahof in Delft is one of the case studies. Environmental impact assessment will support the development of sustainable renovation concepts.

7. Set up of perspectives for sustainable construction and renovation
The concepts drawn up to reduce the environmental impact for the various dwelling types will be confronted with design variables, external factors and the state of affairs to come to perspectives for sustainable construction and renovation on the long term.

2.3 Environmental assessment method[2]

2.3.1 Methods and tools

The environmental impact of dwellings is related to the inflows and outflows in the dwelling construction. Within the research project Sustainable Construction and Renovation materials, energy and water are being studied on the input side and emissions and waste on the output side. Various tools have been developed for environmental impact assessment of buildings. Most of the instruments are based on the LCA methodology. In an LCA all environmental effects are taken into account during all phases of the life cycle, i.e. from 'cradle to grave'. The LCA methodology is internationally broadly accepted.

Methods and tools were discussed within the International Energy Agency (Knapen and Boonstra, 1999a). An overview of the currently existing LCA-based tools, the countries involved and the objectives of the tools, is given in Table 2.1. Several tools in particular intent to identify possibilities to improve the environmental performance of buildings. Others have especially been developed to quantify the environmental impact.

As follows from the table, Dutch tools for environmental impact assessment are Eco-Quantum and GreenCalc. However, GreenCalc addresses to offices instead of dwellings, so in this research project Eco-Quantum was used to determine the environmental impact.

Eco-Quantum is a calculation model, which analyses the environmental life cycle of buildings (Mak *et al.*, 1999). Eco-Quantum belongs to the so-called new generation of instruments for sustainable housing. It does not indiscriminately adopt priority measures listed in, for example, Anink and Mak (1993) – a manual for sustainable housing –, but widens the scope for design by using environmental achievements as its starting point. Consequently, it offers potential to compensate for choices elsewhere in the design, which are less

2 See also Section 1.4 and Appendix 1 in How Environmentally Friendly is Sustainable Construction?, and Section 1.5, Appendix 1 and Appendix 3 in Sustainable Interventions in the Housing Stock.

Table 2.1 LCA-based tools and their objectives

Instrument (country)	Objectives
Athena (Canada)	determining, analysing and improving the environmental performance of buildings
BEES (United States of America)	selecting building products on the basis of environmental effects and costs
EcoEffect (Sweden)	determining, analysing and improving the environmental performance of buildings
EcoPro (Germany)	determining, analysing and improving the environmental performance of buildings
Eco-Quantum (the Netherlands)	determining, analysing and improving the environmental performance of buildings
Envest (Great Britain)	determining, analysing and improving the environmental performance of buildings in an early design stage
EQUER (France)	indicating the environmental performance of buildings
GreenCalc (the Netherlands)	determining, analysing and improving the environmental performance of buildings
LEGOE (Germany)	determining, analysing and improving the environmental performance of buildings
Oekoprofile (Norway)	determining the environmental performance of existing buildings
OGIP (Switzerland)	determining the environmental performance of buildings
Optimize (Canada)	determining, analysing and improving the environmental performance of buildings
SBI tool (Denmark)	determining the environmental performance of buildings
TEAM for buildings (France)	determining the environmental performance of buildings
TIRA (Canada)	determining, analysing and improving the environmental performance of locations (buildings and infrastructure)

Source: Knapen and Boonstra, 1999a

environmentally friendly. The tool is intended for architects, clients and municipal councils who can use it amongst others for optimising designs, benchmarking and policy framing. Moreover, the Dutch government recognises Eco-Quantum as a potential method for determining the environmental performance requirements of materials used in the building sector. These requirements may be laid down in the Dutch Building Decree of 2002, which contains building regulations on the subjects of safety, health, usefulness, energy saving and sustainability.

There are always discussions when using Life Cycle Assessments with respect to the assumptions made, uncertainties and incompleteness. This is actually the case for every environmental evaluation method, as the discussions concerning the above mentioned priority-measures lists (or preference lists) have already shown. For example, the Dutch zinc industry reacted furiously, when zinc was positioned on this list as 'to avoid'. There is a strong need of easy-to-use information, such as priority-measures lists, but at the same time this kind of information is often controversial. However, an important advantage of the LCA methodology is the systematic insights, which this offers into the composition of the environmental impact and the underlying causes.

2.3.2 Input

Eco-Quantum calculates the environmental impact of the flow of materials, energy and water in buildings. To make these calculations it needs some general data on the building, namely: life expectancy, usable floor area, gross volume and the area of the site and garden. The environmental impact of the material flow is determined by the amounts, the life span and the waste treatment scenario of the various components used in the construction of the building. These have been organised into a building model shaped as a tree. A building is constructed from eight building parts (e.g. facades), twenty-five elements (e.g. facade openings) and eighty-one components (e.g. door/window frames). One thousand alternatives and sub-alternatives are available for the components.

A (sub-)alternative must be selected for each component (e.g. wood, durable, unstamped + paintwork, alkyd) and the quantities of each component must be entered (number of m, m^2, m^3, items or m^2 of usable floor area). A standard life span is normally applied, but it is possible to deviate from this. The current waste treatment scenario A is also routinely maintained; waste treatment scenario B is for the future situation. These scenarios show how the wastage is distributed over dumping, incineration, recycling and reuse.

The components are assembled from basic units (e.g. meranti profiles for door/window frames), auxiliary aids (e.g. alkyd paint and pinewood cladding for door/window frames) and maintenance aids (e.g. alkyd paint for door/window frames). The life span and waste treatment scenario of the individual parts (non-durable wood for door/window frames, finishing and clean wood) are also taken into account.

The environmental impact of the energy flow is determined by the primary use (in MJs per year) and the means of generation (gas or electricity). The energy flow relates to space heating, hot tap water, auxiliary energy, lighting, ventilation, refrigeration and humidification.

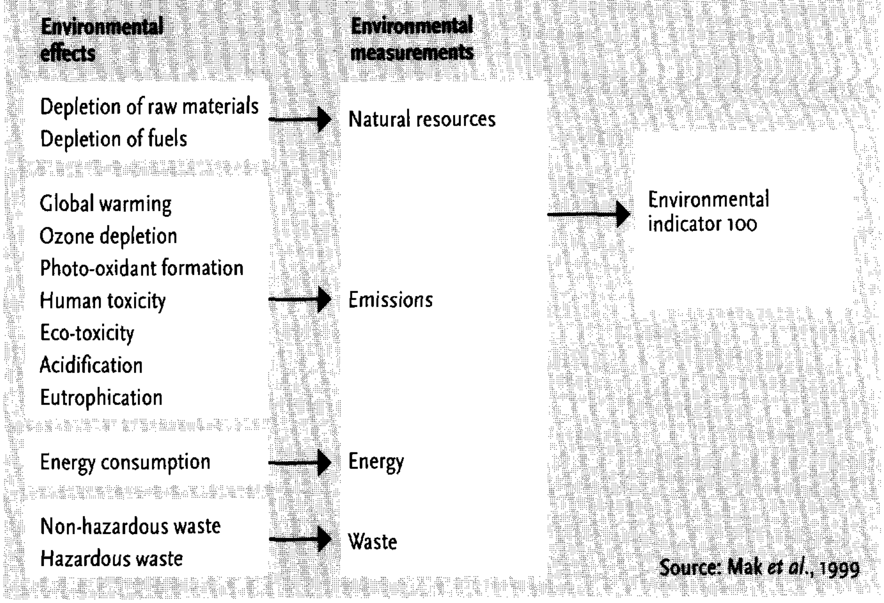
Finally, the environmental impact of the water flow is determined by the volume, the output and the length of the pipeline for the draw-off points, and the water source. The draw-off points are located at the bath, toilet, shower, washbasin, washing machine, garden and kitchen. Pipeline loss is also taken into account. The source may be tap water (groundwater and/or surface water), rainwater or grey water.

2.3.3 Output

Eco-Quantum expresses the results of the calculations in four ways: in volumes, in environmental effects, in environmental measurements and as an environmental indicator. The volumes represent the amount of materials per component (in kg), the amount of energy per energy function (in MJ) and the amount of water per water function (in m^3).

Eco-Quantum calculates twelve environmental effects: depletion of raw materials, depletion of fuels, global warming, ozone depletion, photo-oxidant

Figure 2.2 Aggregation levels in Eco-Quantum



formation, human toxicity, eco-toxicity, acidification, eutrophication, energy consumption, non-hazardous waste and hazardous waste. Eco-Quantum then aggregates these twelve effects into measurements for four environmental categories: Natural Resources, Emissions, Energy and Waste. Finally, an experimental environmental indicator aggregates the score for Natural Resources and Emissions.

Figure 2.2 shows how the environmental measurements are derived and how they come together in the environmental indicator. The reference is set at one hundred and descends as the building causes less environmental impact.

The results can be presented in three ways in order to select the right basis for optimising the same design or comparing different designs. That is, the results are calculated per square metre of usable floor area per year, per dwelling over the total life span or per cubic metre of gross volume per year.

2.3.4 Calculation model

Eco-Quantum is based on the LCA methodology, as developed by the *Centrum voor Milieukunde Leiden* (Leiden Centre for Environmental Studies) in Leiden (Heijungs, 1992). The LCA performs its calculations with fourteen environmental effects. Some of these are omitted in Eco-Quantum, because they are only locally applicable (e.g. odour and noise nuisance) or because they have not been operationalised (e.g. degradation of eco-systems and landscape). The LCA does not differentiate between energy consumption and hazardous and non-hazardous waste, because these are pressure-related instead of impact-related environmental interventions, and would then be counted twice.

Besides, the LCA methodology does not discuss ways of allocating recycling and reuse, normalising and weighting. Scientists and politicians have not yet reached an agreement on this.

Eco-Quantum uses the loop method to impute the benefits of secondary materials and products. The input of secondary materials and the output for recycling and reuse are both taken into account in the form of avoided environmental interventions.

Normalisation is essential as it expresses diverse environmental effects in a uniform way and allows us to draw comparisons. The normalisation step comprehends converting the environmental effects into scores related to the total environmental impact in a specific area at a specific time, so they can be summed up. Eco-Quantum normalises to Dutch and West European territory.

In order to arrive at one overall score it is necessary to weight the various environmental effects. Eco-Quantum does this by applying the MET points method, but other weighting systems may also be used. MET (Materials, Energy and Toxicology) points is a 'distance-to-target' method, which relates the score to desired (policy) objectives.

2.4 Environmental analysis of Dutch traditional housing[3]

2.4.1 Reference dwellings

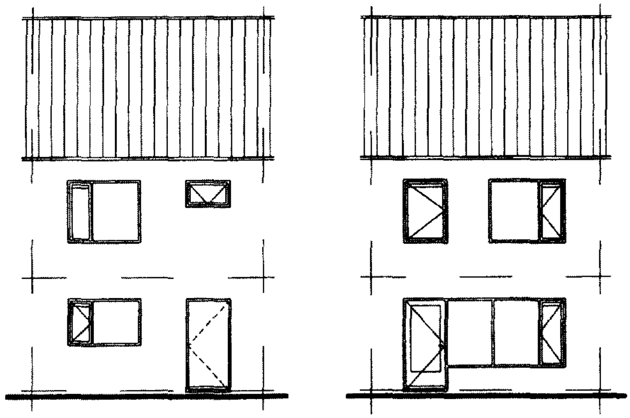
This paper focuses on new construction of dwellings. To gain insight in priorities to reduce the environmental impact and to determine the environmental benefits of various sustainable measures and concepts, so-called reference dwellings were used. Three types of dwellings characterise current housing in the Netherlands: the terraced dwelling, the semi-detached dwelling and the gallery flat. Not only the type of dwelling is of importance, but also the construction method in each case. The reference dwellings are a good reflection of traditional construction as they represent a basic quality in construction and habitation (Novem, 1999a).

The designs meet the minimum statutory demands (Building Decree) and the basic requirements of accessibility and adaptability (Consumer-Approved Senior Citizen Label), safety (Police-Approved, Safe Housing), sustainable building (National Package for Sustainable Building), flexibility and design. The construction materials and production techniques are based on the National Guidelines for the KOMO Process Certificate for cost-quality criteria in housing projects (BRL 5001).

A key principle in the construction of the reference dwellings is the energy-performance requirement (EPC ≤1.2), calculated by the Method for Determin-

3 See also Chapter 3 and Appendix 7 in How Environmentally Friendly is Sustainable Construction?

Figure 2.3 Drawing of the terraced dwelling



Source: Stofberg et al., 2000

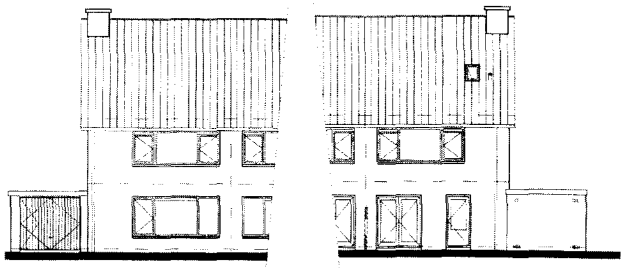
ing the Energy Performance of Dwellings and Residential Buildings (NNI, 1998). This requirement leads to the characterisations as follows:

- a thermal resistance value of R_c=3.0 m^{2}K/W for ground floors, facades and roofs;
- a heat transmission value of U=1.7 W/m^{2}K for windows;
- a heat transmission value of U=3.4 W/m^{2}K for doors;
- an air permeability factor of $q_{v;10}$=1.0 dm^3/s per m^2 of usable floor area;
- a high-efficiency combined boiler for heating and hot water with 100% efficiency at the low value without a pilot light and with a comfort class of CW category 3 for the terraced and semi-detached dwelling and a CW category 2 for the gallery flat;
- default values for the lengths of the hot-water pipes;
- mechanical ventilation by a ventilator with an alternating current;
- a fixed obstruction angle of 20°.

The terraced dwelling comprises of four rooms and three storeys. It has a saddle roof and a fixed stair leading to an attic, which can be divided into rooms (see Figure 2.3). The living room and the open-plan kitchen are on the ground floor. There are three bedrooms and a shower on the first floor. The terraced dwelling is one in a block of eight. The end houses have an entrance and an extra window in the living room on the end facade. The sheds are grouped in two. The inside width is 5.4 m for the middle dwellings and 5.6 m for the end dwellings. The dwellings are 9.3 m deep. The usable floor area is 111 m^2. The gross volume is 352 m^3 for the middle dwellings and 366 m^3 for the end dwellings. The middle dwellings have an EPC of 1.17, whereas the end dwellings have an EPC of 1.18.

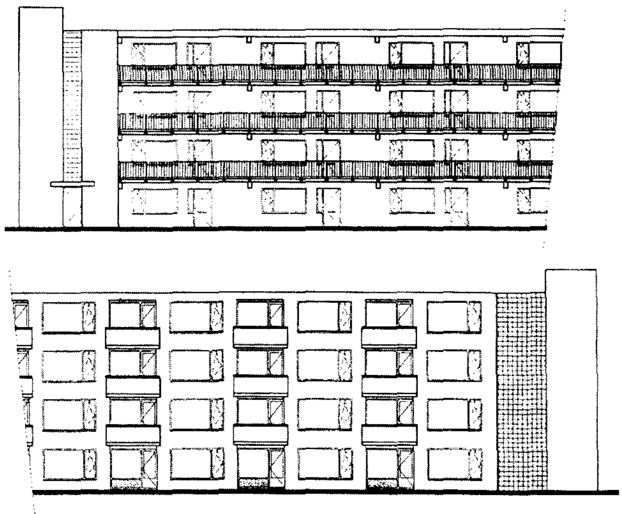
The semi-detached dwelling has four rooms and three storeys (see Figure 2.4). The living room and the open-plan kitchen are on the ground floor. The entrance is on the end facade. The first floor comprises of three bedrooms and a bathroom. Like the terraced dwelling, the semi-detached dwelling has a saddle roof and an attic, which can be divided into rooms. The garage is part-

Figure 2.4 Drawing of the semi-detached dwelling



Source: Stofberg *et al.*, 2000

Figure 2.5 Drawing of the gallery flat



Source: Stofberg *et al.*, 2000

ly attached to the house. The inside width and the depth are 6.0 m and 10.0 m respectively. The usable floor area is 134 m^2 and the gross volume is 452 m^3. The EPC is 1.18.

The gallery flat is one of a block of twenty-four, spread over four storeys (see Figure 2.5). There is a stair at either end and a lift at one end. Each apartment has a living room with an open-plan kitchen, two bedrooms, a shower, a storeroom and a partially protruding balcony. The sheds are built in groups of twelve and are separate from the main building. The inside width is 7.2 m for the middle apartments and 7.5 m for the end apartments. The apartments are 12.0 m deep. The usable floor area is 75 m^2. The gross volume is 224 m^3 for the middle apartments and 232 m^3 for the end apartments. The EPC for the block is 1.18. Below is a description of the components and materials for each building part of the reference dwellings.

Foundation – The reference dwellings are founded on beams and piles of concrete. The soil is sealed off with a layer of sand. The soil balance is equal.

Facades – The facades are constructed from an inner leave of sand-lime brick, rock-wool cavity insulation and an outer leave of masonry. The masonry on the facade openings is supported by concrete lintels. Masonry is also used for the facades of the sheds. The facades of the gallery flat are constructed from unstamped insulated multiplex sandwich plates. Frames, windows and doors are made of unstamped sustainable[4] wood and painted with alkyd paint. The frames have aluminium ventilation bolts. The rain proofing

4 To be understood as a durability category, and not to be confused with sustainably produced wood. In the latter case we speak of stamped wood.

consists of lead slabs and polythene film. Wet-glazed double glazing is installed everywhere, with the exception of the doors to the sheds and the stairs (single glazing), and the glass openings in the stairs of the gallery flats (glass bricks). The window sills are made of prefabricated artificial stone. On the outside are glazed ceramic tiles.

Inner walls – The load-bearing walls in the terraced and semi-detached dwelling are made of sand-lime brick. The terraced dwelling has a solid load-bearing wall; the semi-detached dwelling has an anchorless cavity wall. The load-bearing walls of the gallery flats are made of poured concrete. Plaster and sand-lime brick are used for the parting walls in the apartments and the sheds respectively. The walls of the kitchen, toilet and bathroom/shower are covered with glazed ceramic tiles. All the inside doors are hard honeycomb, hung in steel frames and covered with a layer of alkyd paint. The plasterwork consists of plaster on a synthetic resin basis. The walls are papered. Alkyd-painted unstamped wood is used for the carpentry.

Floors – The ground floors of the reference dwellings are made of ribbed waffle slabs fitted with EPS insulation. The floor of the shed of the terraced dwelling, and the shed and lift-well of the gallery flats are made of poured concrete. The garages have combination floors with contact strips of light-weight concrete. The storeys in all the dwellings have concrete hollow-core slab floors. The floors are covered with a layer of sand cement; the floors of the toilet and the bathroom/shower have ceramic tiles laid in mortar. The ceilings are finished with plaster on a synthetic resin basis and with latex paint in the stairs of the gallery flat block.

Roofs – The sheds and the garages have flat roofs constructed from wooden beams in a multiplex casing and covered with one layer of mechanically secured APP-modified bitumen. The facades of the garages have alkyd-painted fascias made of unstamped multiplex. The flat roof of the gallery flats is made of broad concrete slabs and is insulated with EPS plates and covered with a double layer of bitumen. It is gravel-ballasted. The sloping roof of the terraced and semi-detached dwelling is assembled from wooden roof elements clad with unstamped multiplex and is insulated with EPS plates. The roof is covered with concrete tiles. The join between the sloping roof and the chimney is rain proofed with lead slabs.

Transportation – The stairs in the terraced dwelling and the semi-detached dwelling are prefabricated from stamped wood – with and without risers – and alkyd-painted. The railings and banisters are made of the same materials. The stairs in the gallery flats have concrete steps.

Installations – The reference dwellings contain a low-NO_x combined boiler for space heating and hot water. The heat is distributed through galvanised steel pipes and emitted by radiators. Copper piping carries the tap water. The dwellings are fitted with a mechanical ventilation system with galvanised steel vents. Gas and electricity pipes are made of stainless steel and copper respectively. The terraced dwelling and the semi-detached dwelling both have zinc gutters. The rainwater conduits and the internal and external sewage pipes are made of PVC.

Interior – The kitchen units and working tops in the reference dwellings are made of chipboard with a synthetic covering. The sanitation facilities in all the dwellings consist of a toilet, a washbasin and a shower. The terraced dwelling and the semi-detached dwelling have an extra toilet with a small wash-hand basin. The semi-detached dwelling has a bath in addition to a shower. The reference dwellings are provided with a meter cupboard made of alkyd-painted unstamped wood. The paving consists of concrete slabs, laid on the paths and in parts of the garden. The terraced dwelling and the semi-detached dwelling both have privacy screens.

2.4.2 Priorities for reduction of the environmental impact

As the three types of dwellings differ in size, the construction materials are used in varying quantities. Some differences are not, however, solely related to size, but also to design and building methods. For instance, the design of the gallery flat outranks the design of the terraced dwelling as the foundation, the ground floor and the roof are shared by several households. Conversely, the gallery flat needs common space in the form of stairs and walkways. The semi-detached dwelling has an unfavourable overall surface area compared with the terraced dwelling and the gallery flat. Besides, some components appear in (more or less) equal quantities regardless of the type of dwelling, e.g. openings (frames, windows and doors) and interior (kitchen and sanitation).

The characteristic differences in design and building methods have repercussions on the analysis of the flow and the environmental impact. The figures reproduced in this paper represent the average score for one dwelling in a single block, i.e. eight terraced dwellings, two semi-detached dwellings or twenty-four gallery flats. Common spaces and (separate) sheds and garages are taken into account. The standard life span and waste treatment scenarios have been maintained. The life span of the dwellings has been set at seventy-five years.

Flow – The absolute amounts of the flow of materials, energy and water of the dwelling types are listed in Table 2.2, both for the total usable floor area during the entire life span, and per square meter of the usable floor area per year. It goes without saying that the semi-detached dwelling brings about the largest amounts of the flow of materials, energy and water, the gallery flat the smallest and the terraced dwelling in between, considering the entire life span of the dwellings. This is a direct consequence of the size of the dwelling. Therefore, the analyses are based on the usable floor areas of the dwelling types.

Table 2.2 Absolute amounts of flow in the reference dwellings over the total life span

Flow	Terraced dwelling		Semi-detached dwelling		Gallery flat	
	Total	Per m²	Total	Per m²	Total	Per m²
Materials	205 ton	1.9 ton	254 ton	1.9 ton	153 ton	2.0 ton
Energy	4,157 GJ	37.4 GJ	5,252 GJ	39.2 GJ	2,680 GJ	35.7 GJ
Water	6,772 m³	61.0 m³	10,847 m³	81.0 m³	4,110 m³	54.8 m³

It points out that design is also a key factor in reducing the flow. The semi-detached dwelling comes out worst in terms of energy flow, while the gallery flat comes out worst in terms of materials. The water consumption depends on the water functions in the dwelling. These are specifically related to presence rather than volume.

Environmental impact – The dwelling typology is of importance when comparing the environmental impact per square meter of the usable floor area of the flow of materials, energy and water. It appears that the semi-detached dwelling is most detrimental with respect to depletion of fuels, global warming, ozone depletion, eco-toxicity and energy consumption. The gallery flat is worse for the depletion of raw materials, photo-oxidant formation, human toxicity, acidification, eutrophication, non-hazardous waste and hazardous waste. This has much to do with the differences in the amounts of the flow of materials on the one hand and the amounts of the flow of energy and water at the other hand. The terraced dwelling scores in between on all environmental effects.

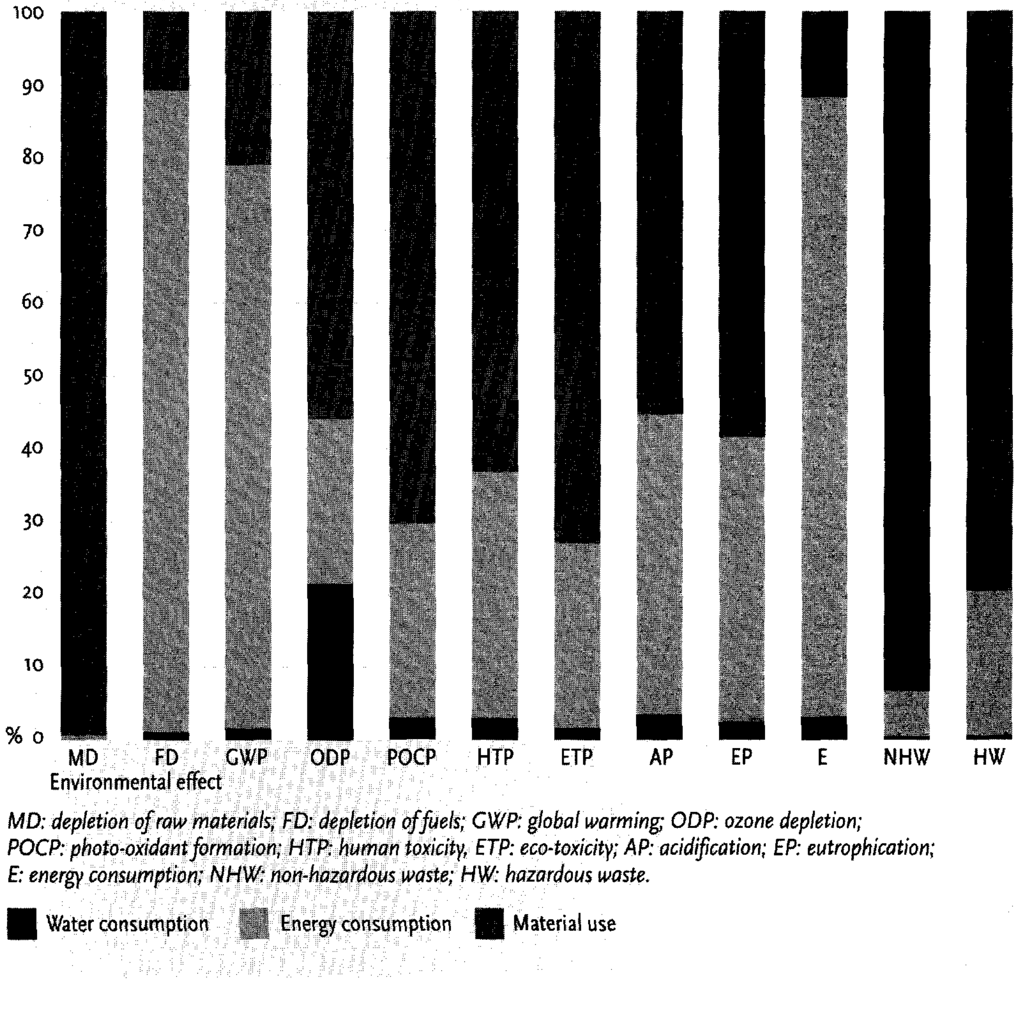
It is striking that the distribution among material use, energy consumption and water consumption of the dwelling types show substantial similarities, although the dwelling typology influences the environmental impact. This is also valid for the distribution among building elements as for material use, energy functions as for energy consumption and water functions as for water consumption. The distribution among material use, energy consumption and water consumption is shown in Figure 2.6 with regard to the terraced dwelling.

It can be seen that the material use contributes more than 50% to nine environmental effects, namely depletion of raw materials, ozone depletion, photo-oxidant formation, human toxicity, eco-toxicity, acidification, eutrophication, non-hazardous waste and hazardous waste. The environmental impact of energy consumption is more than 50% on depletion of fuels, global warming and energy consumption. The water consumption only has a notable share on one environmental effect, i.e. ozone depletion.

Priorities – The flow of materials and energy have a considerable share in the environmental impact. Comparatively speaking, water flow is far less important. Therefore, the priorities for reduction of the environmental impact of dwellings focus on the flow of materials and energy.

Fourteen building components have been identified as priority for the flow of materials: the foundation beams, outer leaves, inner leaves (only for the semi-detached dwelling), window and door frames, glazing, rain proofing in the facades, parting walls, load-bearing walls (terraced dwelling and gallery

Figure 2.6 Distribution among material use, energy consumption and water consumption of the environmental effects of the terraced dwelling



MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; E: energy consumption; NHW: non-hazardous waste; HW: hazardous waste.

Water consumption — Energy consumption — Material use

flat), ground floor, storey floors, floor overlays (terraced dwelling and semi-detached dwelling), roof construction (sloping for the terraced dwelling and semi-detached dwelling, flat for the gallery flat), roof overlay (only for the gallery flat), and heat-generation installation. These priorities relate mainly to components that are used in large quantities, but there are also some materials, which should be avoided regardless of quantity. This is because they exert a great influence on the total environmental impact. Therefore, a solution needs to be found for the rain proofing in the facades, because it makes such a high contribution to depletion of raw materials and eco-toxicity. The copper piping for the tap water distribution contributes erratically to eco-toxicity. Finally, the sand-cement floor overlays play a dominant role with respect to hazardous waste.

More than three-quarters of the energy consumption is related to the gas-fired functions of space heating and hot tap water. About a quarter is used by electricity for auxiliary energy, lighting, and ventilation. Nevertheless, electricity has a profound influence on various environmental problems. This is why all five energy functions have been turned into priorities.

2.5 Environmental benefits of Dutch sustainable housing

2.5.1 State of affairs

To obtain a state of affairs with respect to sustainable housing, some current Dutch demonstration projects were analysed, including the 'model projects' in the stimulation programme Sustainable and Energy Saving Building, initiated by the Steering Committee for Experiments in Public Housing (SEV) and the Netherlands Agency for Energy and the Environment (Blaauw, 1999). The focus was on the flow of materials and energy.

With regard to the flow of materials, there can be spoken of a 'standard measures package'. Concrete with 20% rubble granulate and less environmentally damaging plaster (plaster produced as a by-product from power station desulphurisation) are applied to almost every project. But there are also many materials, such as cellulose insulation and water-soluble paints, which are still used conservatively.

With regard to the flow of energy, the projects are not very progressive if looking at what is applied on a more or less standard basis. Many dwellings have super-insulated glass, an energy efficient heating system and a thermal solar system, they satisfy an EPC of 1.0 and an R_c of 3.0 m^2K/W. The current requirements amount to EPC=1.0 and R_c=2.5 m^2K/W. In addition, many installation applications, which are familiar in general terms, are still in an experimental stage. For example, this applies to balanced ventilation with heat retrieval, heat pumps and photo-voltaic solar systems. They enable EPC $\leq$1.0 to be reached. There have been even a few zero sum energy dwellings built.

To find out if this puts us on the right path, a number of eye-catching measures from some demonstration projects were projected onto a reference dwelling; then the environmental benefits were calculated. The terraced dwelling functions as the reference dwelling in this case. The projection of measures onto the same dwelling makes it possible to compare different approaches to reduce the environmental impact. Three themes were distinguished:

- energy saving (where an installation technology approach was set against a constructional approach);
- reuse and increase of the life span;
- use of renewable materials.

Below four demonstration projects are described, which are good examples of the above-mentioned themes. It has to be emphasised that these projects are

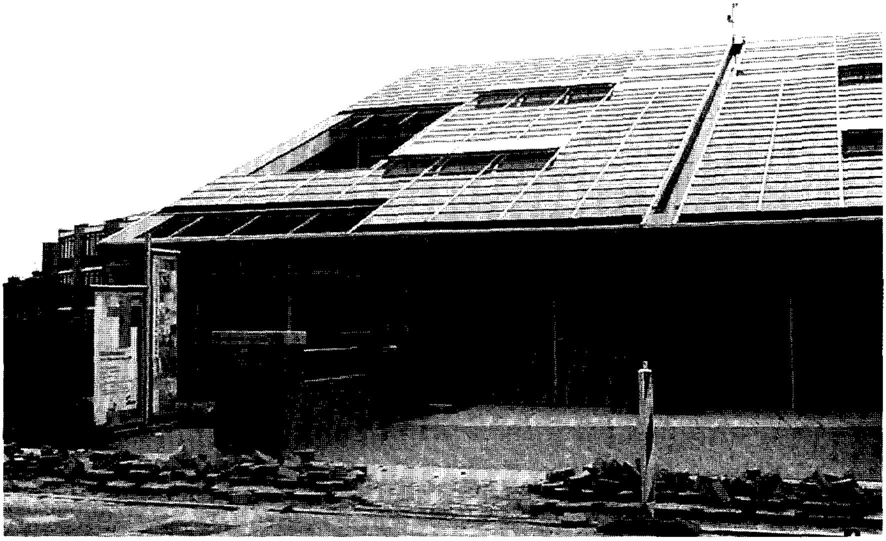


Figure 2.7 Energy balance dwellings in Amersfoort

only meant as an illustration and that the calculations do not relate to the total concept the dwellings are based upon.

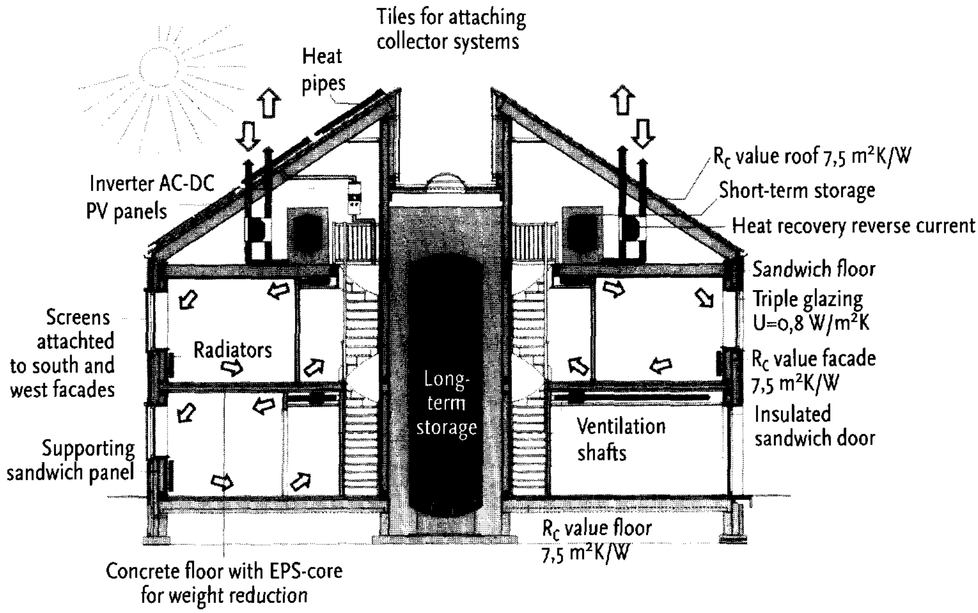
The Energy balance dwellings in Amersfoort (see Figure 2.7) illustrate the theme of energy saving through the use of many installations. For example, on the roof there are 78 m^2 ordinary solar panels and 15 m^2 transparent solar panels for generation of electricity. Furthermore, an area of 14 m^2 of solar collectors and two boilers of 300 l and 500 l are responsible for hot tap water and space heating. A heat pump is used to upgrade warmth stored in the soil. As a consequence, the net energy use of this type of dwelling is zero. That cutting back the energy consumption yields a substantial environmental advantage is clear, but the question arises how much environmental impact from all the materials used have to be set against that gain.

Emphasis on the constructional approach is another way to reduce the energy consumption. The Dutch construction company Unidek has built four energy efficient dwellings in Bakel (see Figure 2.8). These dwellings are extremely well insulated to R_c=7.5 m^2K/W for the facades, the roof and the attic floor and R_c=5.0 m^2K/W for the ground floor (R_c=2.5 m^2K/W is the already mentioned legally required minimum). The dwelling has been built from EPS construction sandwich elements. The windows are provided with triple glazing with a filling of krypton.

The theme of reuse and increase of the life span is illustrated by the Respekt dwellings in Tilburg (see Figure 2.9). These dwellings are characterised by the use of secondary materials, flexibility and future reusability. The dwelling comprises amongst others of dismountable partition walls and separated cable ducts.

The last theme discussed here is the use of renewable materials. On this point the Ecosolar dwellings in Goes are a good example (see Figure 2.10). Striking in this project is the attention paid to many aspects of sustainable building, including ecology.

Figure 2.8 Crosscut of the energy efficient dwellings in Bakel



2.5.2 Benefits of sustainable construction

Energy saving by means of installation technology – The photo-voltaic and thermal solar systems, the balanced ventilation system with heat retrieval and the heat pump represent the installation technology approach. This includes wall and floor space heating. The area of solar panels and solar collectors amounts to 6.0 m^2 en 5.4 m^2 respectively. The use of these installations lead to a reduction of the energy consumption by 11.6 GJ per dwelling per year.

In Figures 2.11 to 2.14 for each of the fourteen environmental effects the first bar in the diagram features the reference dwelling, whereas the second bar features the variant. Each bar comprises of three parts, which represent material use, energy consumption and water consumption respectively.

As can be seen from Figure 2.11 depletion of fuels (25%), global warming (24%) en energy consumption (26%) show the greatest reductions. An increase of more than 10% is established due to depletion of raw materials (77%), ozone depletion (39%), human toxicity (11%) and non-hazardous waste (16%). Without weighting of the environmental effects, the environmental impact increases rather than decreases. The order of magnitude of the environmental drawback amounts to 10% compared to the reference dwelling[5].

Energy saving by means of constructional measures – The insulation of the

5 This differs from the results in the conference paper, published in Urbanistica (Klunder and Blaauw, 2000). That is due to the use of the software in the test phase and the photo-voltaic solar system that was been left out of consideration then.

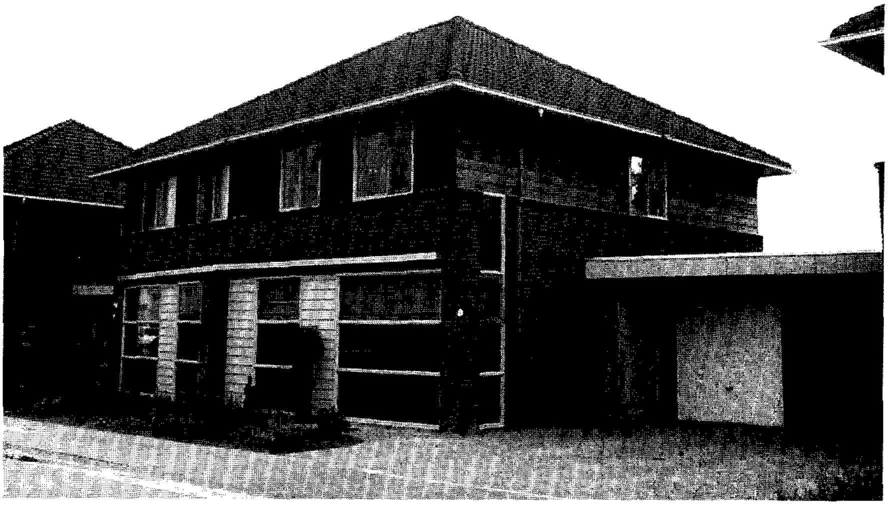


Figure 2.9
'Respekt'
dwelling in
Tilburg

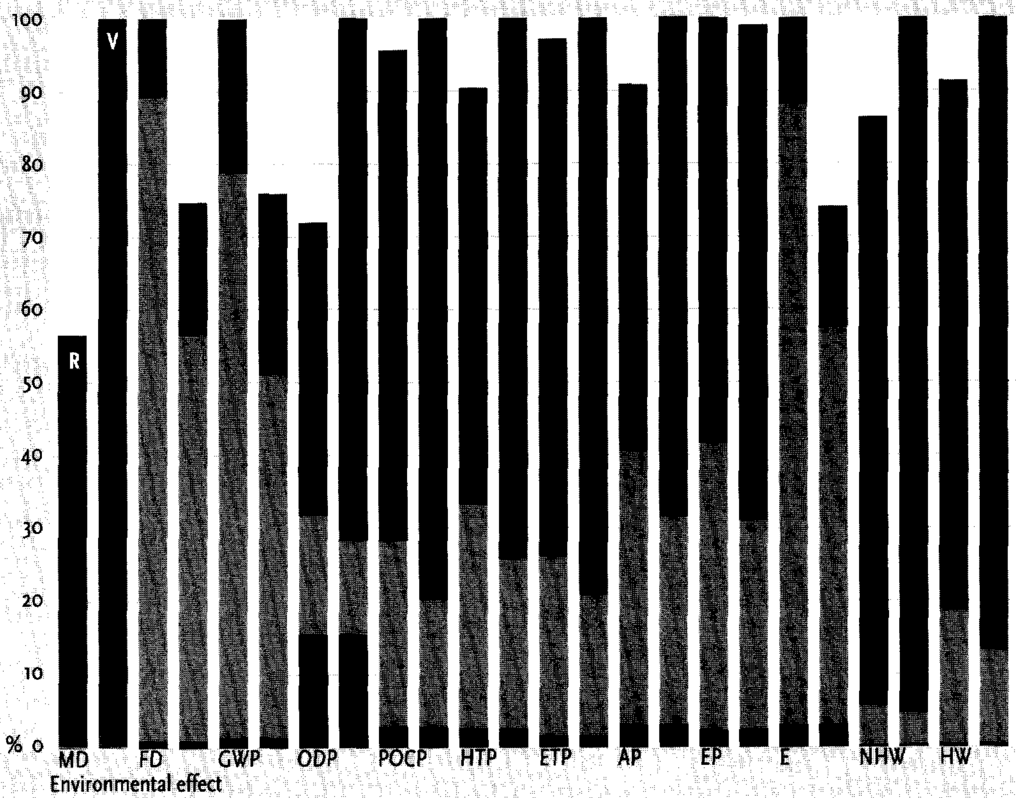
Figure 2.10
'Ecosolar'
dwelling in
Goes

ground floor, the attic floor, the roof and the parting wall with EPS in a wooden skeleton construction, have been calculated to determine the environmental benefits of energy saving by means of constructional measures. This results in a reduction of the energy consumption by 16.7 GJ per dwelling per year.

Figure 2.12 shows that substantial reductions are reached on depletion of fuels (28%), global warming (24%) and energy consumption (25%). However, a large increase on photo-oxidant formation (33%) is noticed. The order of magnitude of the environmental benefits on the theme of energy saving through constructional measures amounts to 5%.

The installation technology approach was compared to the constructional

Figure 2.11 Environmental impact of materials, energy and water of the installation technology variant (V) compared to the reference dwelling (R)



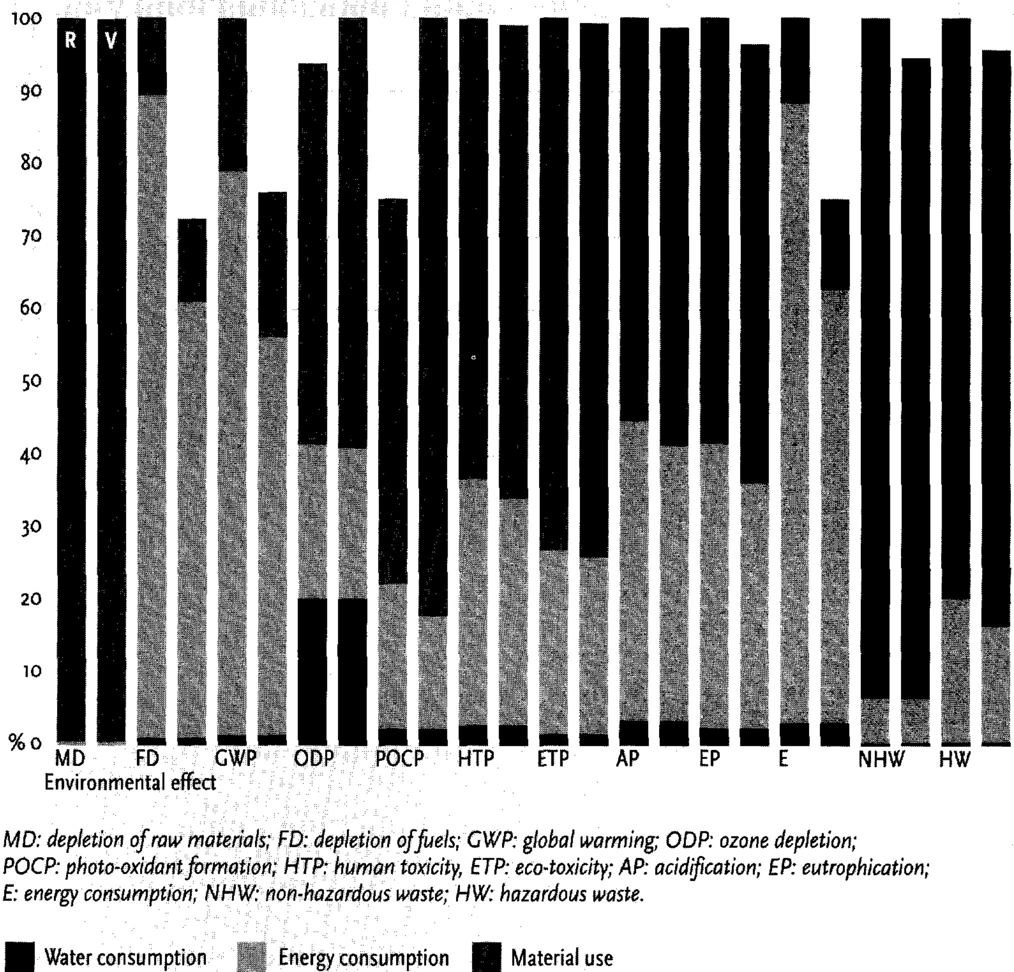
MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; E: energy consumption; NHW: non-hazardous waste; HW: hazardous waste.

Water consumption | Energy consumption | Material use

approach. While the energy performance of the installation technology variant is lower than the energy performance of the constructional variant (EPC=0.75 versus 0.82), insulation scores better than energy saving through installation technology in this case. Obviously, the environmental effects of energy use fall. Nevertheless, there is a difference, because the use of electricity and gas work through differently on the environmental effects (see Section 2.3). The share of electricity is greater in the application of many installations, because of the auxiliary energy required.

When the environmental effects of the use of materials are considered separately, it can be seen that the measures lead to deterioration in the environmental performance on almost every environmental effect. The extremely well insulated dwelling scores better than the installation technology variant with respect to the material use. Solar panels prove to be very environmentally unfriendly until now. It might be concluded that the order of magnitude

Figure 2.12 Environmental impact of materials, energy and water of the constructional variant (V) compared to the reference dwelling (R)



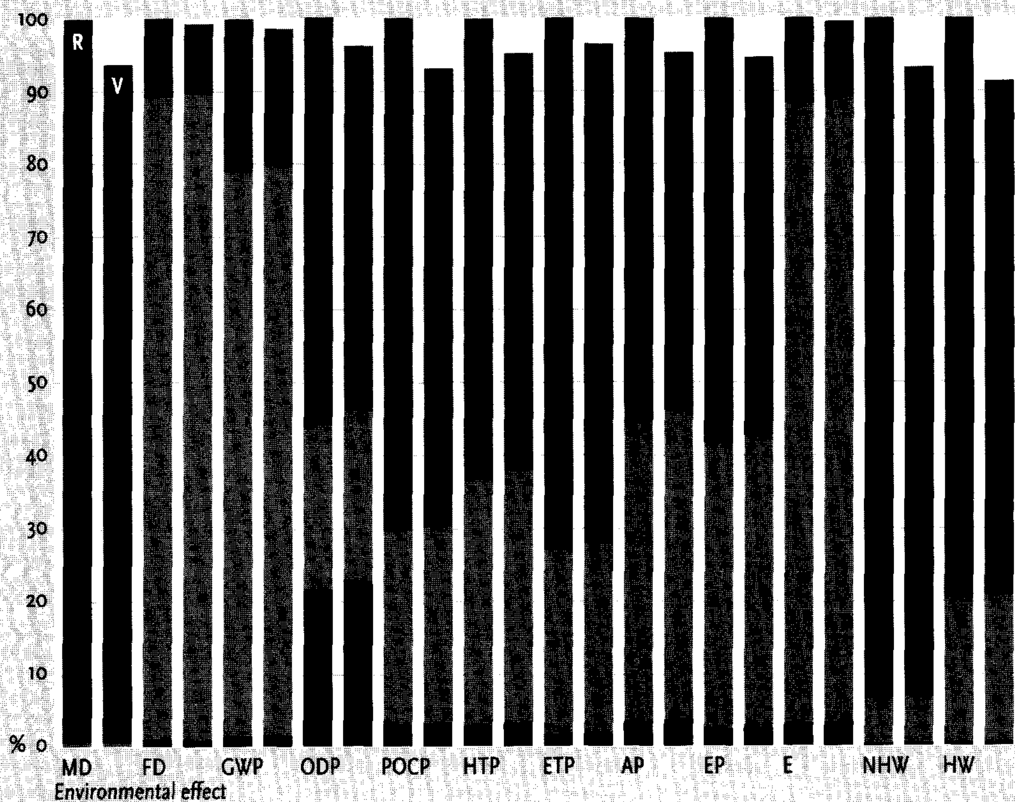
MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; E: energy consumption; NHW: non-hazardous waste; HW: hazardous waste.

of the environmental benefits on the theme of energy saving strongly depends on the way it is effectuated.

Reuse and increase of the life span – An operationalisation was made for the aspects reuse and increase of the life span. Reuse takes place through a more far-reaching waste treatment scenario than usual practice at the moment. Increase of the life span is achieved through assuming an enlarged dwelling with a longer life span, i.e. 85 years instead of 75 years. The larger dwelling translates itself in a greater use of materials, energy and water during the entire extended life span. The energy consumption increases by 7.5 GJ per dwelling per year.

For the dwelling as a whole, there is evidence of an improvement in the environmental performance on all environmental effects, as Figure 2.13 exposes. That means that an increase of the life span with ten years is sufficient to compensate for the extra material use. The environmental impact of the mate-

Figure 2.13 Environmental impact of materials, energy and water of the reuse and increase in life span variant (V) compared to the reference dwelling (R)



MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; E: energy consumption; NHW: non-hazardous waste; HW: hazardous waste.

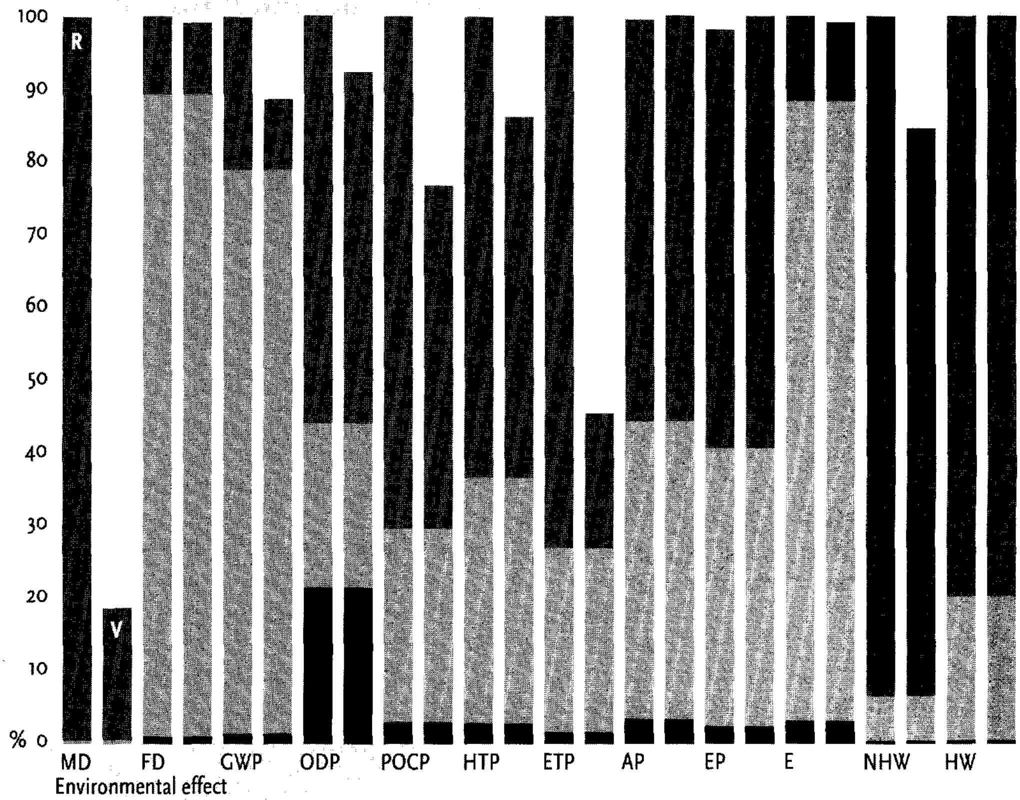
Water consumption   Energy consumption   Material use

rial use significantly decreases, while the environmental impact of the energy consumption slightly increases. The environmental impact diminishes most, i.e. more than 5%, on depletion of raw materials (6%), photo-oxidant formation (7%), non-hazardous waste (7%) and hazardous waste (9%). Accordingly, the order of magnitude of the environmental benefits on the theme of reuse and increase of the life span amounts to 5% compared to the reference dwelling.

Use of renewable materials – The measures package that is projected onto the reference dwelling consists of application of stamped wood, wooden skeleton construction, cellulose insulation in casing constructions, vegetation roof, solution-free and water-soluble paint, recycled PVC and concrete with 20% rubble granulate. Copper, lead and zinc are avoided. These measures are of no consequence for the energy consumption.

Figure 2.14 shows that the renewable materials variant scores better on all environmental effects, with the exception of acidification and eutrophication,

Figure 2.14 Environmental impact of materials, energy and water of the renewable materials variant (V) compared to the reference dwelling (R)



MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; E: energy consumption; NHW: non-hazardous waste; HW: hazardous waste.

Water consumption   Energy consumption   Material use

which show very little increase. A decrease of more than 10% is achieved on depletion of raw materials (81%), global warming (11%), photo-oxidant formation (23%), human toxicity (14%) and eco-toxicity (55%). The order of magnitude of the environmental benefits on the theme of use of renewable materials amounts to 15% compared to the reference dwelling[6].

However, from the identification of priorities to reduce the environmental impact of dwellings, we have already learned that there are some components, which have an outstanding influence on several environmental effects, including the rain proofing of lead and the piping for the distribution of hot tap water. If these materials are turned back into the reference dwelling

6 This differs also from the results in the conference paper (see previous note), because of the use of an adjusted reference then, wherein these materials already were substituted by alternatives.

again, the picture changes. The environmental benefits do not exceed 10% anymore regarding human toxicity, eco-toxicity and non-hazardous waste. The order of magnitude of the environmental benefits falls to 5% compared to the reference dwelling.

2.6 Conclusions

2.6.1 *Priorities and benefits*

Not surprisingly, the flow of materials, energy and water increases according to the dwelling size. However, clear differences are also created by the type of dwelling. Though the dwelling typology influences the ultimate environmental impact, it nonetheless suggests more or less the same priorities for reducing it. These priorities apply to the flow of materials and energy. The flow of water is of secondary importance.

The priorities are identified to reduce the environmental impact of Dutch housing. However, it has to be borne in mind that areas of attention may emerge in sustainable housing, which do not appear in the analysis of traditional housing. A case in point is the many installations and pipes, which are applied in many energy-saving dwellings and the double water pipelines, which ensure that drinking water is not used for low-grade purposes, such as flushing the toilet.

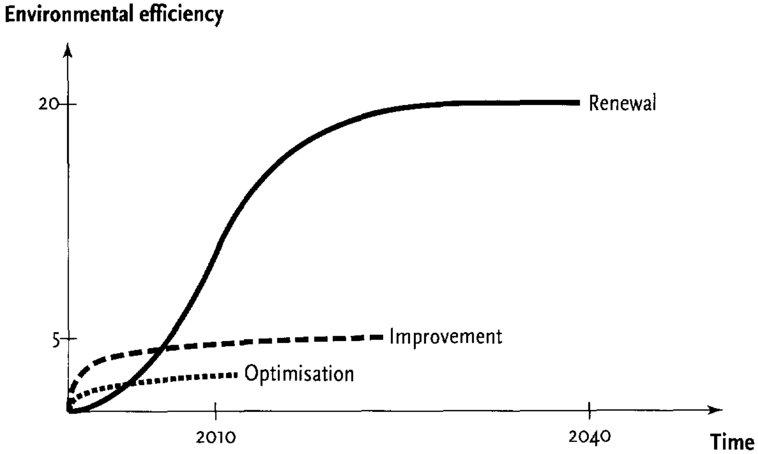
In addition, these priorities do not imply that the other components are totally unimportant. Many steps can be taken without incurring problems or extra costs. The environmental benefits that they bring may not be all that great to begin with, but they will become more significant when measures become standard.

2.6.2 A factor of 20?

To determine whether or not sustainable housing in the Netherlands leads to a substantial reduction of the environmental impact, the order of magnitude of the environmental benefits of the themes of energy saving, reuse and increase of the life span, and use of renewable materials were calculated. These vary between a raise of 10% and a decline of 15%.

The environmental benefits can be placed on the development curve, as Figure 2.15 shows. Three development levels are distinguished: optimisation of the existing situation; improvement of the existing situation; renewal. The first two levels are in accordance with most of the development paths currently implemented. For example, the economical use of natural resources and cutting back the quantity of waste through reuse belong to that level. With these paths no more than a factor of 3 to 5 will be attained. Introduction

Figure 2.15 Development levels with respect to environmental efficiency in time



Source: DTO, 1997, edited by OTB, 2000

of radical new developments will be necessary to achieve the envisaged factor of 20. The renewal line represents this.

The changes which would be necessary for such reductions are hardly predictable. Therefore, the research project Sustainable Construction and Renovation is oriented towards 2010. A derived ambition of a factor of 4 applies to this period. This figure is equivalent to a reduction of the environmental impact by 75%. The environmental benefits of present Dutch sustainable housing, as discussed in this paper, do not exceed a factor of 1.4 in 2010, but some remarks have to be made.

First, it has to be remembered that constantly one theme was held up to the light and a few measures have been singled out. On the one hand, this means that there are bottlenecks, which still have to be resolved in conflicting strategies for reduction of the environmental impact, while on the other hand it remains possible to create added value through an integral approach.

Furthermore, expressing something in terms of a factor makes it clear, but in doing so it may fail to notice the large differences within the environmental effects. This spread is of interest, because it shows that the potential to cut back the environmental impact differs per environmental effect. A normalisation step, as described in Section 2.3, will be added to determine precedence in environmental effects.

2.6.3 Future developments

Clearly, the objective of a factor of 4 in 2010 will not be achieved with the current state of affairs in Dutch sustainable housing. Technological improvements are certainly still possible. For the long-term objectives it is at least necessary to bring into action some radical changes right now. Energy developments with a renewal potential, such as renewable energy, are already being introduced. With regard to constructional concepts this is hardly the case.

To achieve a change in trend, this means that, on the one side, innovative constructional concepts are needed; conversely, an integral approach to materials and energy must be found. This approach will enable us keep our sights on synergetic solutions.

Acknowledgement
The research project Sustainable Construction and Renovation is being carried out in cooperation with Karin Blaauw (OTB Research Institute for Housing, Urban and Mobility Studies). She focuses on the reduction of the environmental impact related to materials, with special attention for recycling and reuse, whereas the author concentrates on environmental impact assessment.

3 The search for the most eco-efficient strategies

Dutch lessons in sustainable housing construction

Source: Klunder, G., 2004, The search for the most eco-efficient strategies for sustainable housing construction; Dutch lessons, in: Journal of Housing and the Built Environment, *19 (1), pp. 111-126. With kind permission of Springer Science and Business Media.*

3.1 Introduction

In recent years, a growing number of sustainable building projects have been realised and sustainable building is increasingly becoming part of common building practice. Plenty of measures are known for reducing the environmental impacts of building. There is, however, very little knowledge on the magnitude of the environmental benefits that these measures yield. This also means that we barely know which goals can be met and what the best solutions are to meet them. The aim of this paper is to present a framework for the search for the most eco-efficient strategies for sustainable housing construction and to discuss the environmental benefits of Dutch sustainable housing construction. Two questions are answered: Which goals regarding the environmental benefits of Dutch sustainable housing construction are currently feasible?, What are the most eco-efficient strategies to further improve the environmental performance of housing?

Section 3.2 deals with definitions, measurements and goals with regard to sustainable housing construction. In Section 3.3 the framework to find the most eco-efficient strategies is presented. Section 3.4 is concerned with the empirical results of the environmental benefits of Dutch sustainable housing construction and the most eco-efficient strategies to further improve the environmental performance of housing. In Section 3.5 conclusions are drawn. Section 3.6 contains a discussion.

3.2 Sustainable housing: definitions, measurements and goals

3.2.1 Definitions

The report Our Common Future (WCED, 1987) has led to a worldwide notion of the concept of sustainable development, defined as a "development which meets the needs of the present without compromising the ability of future generations to meet their own needs." The commission not only observed that environmental problems need to be addressed, but also social problems, such as inequity, poverty, non-prosperity and the violation of human rights, that are related to explosive population growth and the enormous expansion of environmental harms caused by human activities. According to the commission, solving these problems requires global economic growth whilst respecting ecological constraints.

It is difficult to handle the strategic concept of sustainable development with respect to operational decisions for a sustainable built environment. The ecological conditions strategy (Tjallingii, 1996) offers more opportunities to do so. It does not focus on future results, but on present steps being taken towards sustainability by providing guiding principles. Three dimensions of sustainability are distinguished: the durable diversity of areas, the sustained use of resources and the sustained involvement of actors. These dimensions are indicated in short as areas, flows and actors.

Nonetheless, narrowing the scope from the built environment towards buildings and building components requires sustainability to be translated as the responsible management of flows. After all, on the scale of the building and its components, areas and actors are of minor relevance compared to the scale of the neighbourhood or the city. The definition of sustainable construction, according to the Dutch Ministry of Housing, Spatial Planning and the Environment (1990), confirms this. The ministry explains sustainable construction as directed towards the reduction of the environmental and health impacts consequent to construction, buildings and the built environment. The focus on sustainable housing construction implies a perspective of flows. From this viewpoint, a sustainable house is characterised by the minimisation of the environmental impacts of material use, energy consumption and water consumption during the whole service life of the building.

3.2.2 Measurements

Life Cycle Assessment or LCA is a widely accepted method to assess environmental impacts. It is a method for the analysis of the environmental burden of products (goods and services) from cradle to grave, covering the extraction of raw materials, the production of materials, product parts and products, and discard, either by recycling, reuse or final disposal (Guinée, 2002). It is defined as the "compilation and evaluation of the inputs, the outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 1997). The product system is understood as the sum of the processes needed for the product – in this case, a house. Inputs and outputs are the materials and energy which enter and leave the product system.

The framework for LCA, which has been internationally agreed upon, distinguishes four phases (ISO, 1997):

1. The goal and scope of an LCA have to be clearly defined and geared to the intended use. An important part of the goal and scope definition is the

determination of the functional unit, which is the quantified function of the product system under study. The functional unit serves as a reference unit in an LCA, e.g. x m^2 floor system with a supporting power of x N/m^2 during x years.

2. Inventory analysis is the second phase of an LCA, in which the inputs and outputs of the product system are compiled and quantified, including natural resources and emissions to air, water and soil.
3. The third phase is concerned with the understanding and evaluation of the magnitude and significance of the potential environmental impacts of the product system. Impact assessment encompasses assignment of inventory data to impact categories (classification), modelling of inventory data within impact categories (characterisation) and, only if useful, aggregation of the results (weighting). Examples of impact categories are depletion of raw materials, ozone depletion, acidification and eutrophication.
4. Finally, the interpretation phase contains interpretation of the results of the inventory analysis and impact assessment in the light of the goal and scope definition in order to draw up conclusions and recommendations by means of completeness, sensitivity, consistency and other checks.

In many countries whole-building environmental assessment tools have been developed or are being developed for the environmental assessment of housing, including Eco-Quantum in the Netherlands, Envest in the United Kingdom, EcoPro in Germany and ESCALE in France. These tools have been designed for use in the determination, analysis and improvement of the environmental performance of buildings (Knapen and Boonstra, 1999a). Although these tools are based on the LCA methodology, building products and environmental data in databases connected to the tools are mostly country-specific. The applicability of tools in other countries is therefore very limited.

3.2.3 Goals

The ultimate goal for sustainable development is not to exceed the carrying capacity of the earth, as in the concept of environmental utilisation space (Opschoor and Weterings, 1994). Environmental utilisation means harvesting from the environment and putting waste into it. The environmental utilisation space stems from the regeneration and absorption abilities of the earth. These abilities will be smaller when environmental degradation is higher. Also the concept of the ecological footprint is based on the thought that we use no more resources than can be renewed and that we discharge no more waste than can be absorbed (Wackernagel and Rees, 1996). The ecological footprint is the land/water area required from nature to support the flows of energy and matter to and from any defined economy. According to this concept we would need at least three planets if everyone on earth lived like the average Canadian or American. Nevertheless the carrying capacity is not a steady state and the environment is a very complex system, so we do not know exactly what the earth can support.

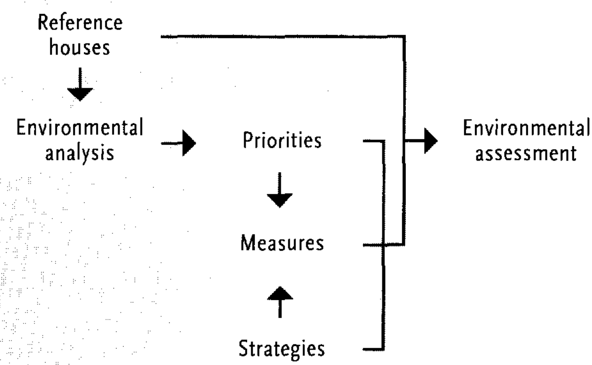
Despite uncertainties about the extension of the carrying capacity, there is a general concern that we are going far beyond that point (e.g. Carson, 1962; Commoner, 1971; Meadows *et al.*, 1972; Meadows *et al.*, 1992). A manifold increase in environmental efficiency or eco-efficiency is needed for sustainable development. 'Factor 20' is a metaphor which refers to such leaps. Ehrlich and Ehrlich (1990) stated that the global environmental impact depends on the population size, the average prosperity per person and the environmental impact per unit of prosperity. So when a halving of the global environmental impact is wanted for the period from 1990 to 2040, a doubling of the population size by 2040 is assumed and average prosperity five times higher than in 1990, then we have to reduce the environmental impact per unit of prosperity by a factor of 20. In the case of sustainable housing construction, the concept of eco-efficiency implies that a reduction in the environmental impacts of housing construction can be undone by trends such as an increase in the average size of houses, while the average number of persons per house is decreasing. These trends are not taken into account, so here the most eco-efficient strategies are defined as the strategies with the greatest potential of environmental benefits.

Weizsäcker *et al.* (1997) show several examples of technologies produced with only one-quarter of the energy and materials we presently use. This 'Factor 4' in resource productivity means that we can double wealth to solve the problems of poverty while halving resource use to return to an ecological balance on earth. It redirects the technological process from labour productivity to resource productivity in a profitable way. The examples reflect current possibilities for achieving a factor of 4 improvement in eco-efficiency.

Related to the 'factor thinking' Weaver *et al.* (2000) distinguish three innovation tracks with different time horizons and objectives. The first track is concerned with short-term optimisation or end-of-pipe measures. This track has a time horizon of up to five years and results in the improvement of environmental efficiency by no more than a factor of 1.5. In the medium term, between five and ten years, a factor of from 1.5 to 4 is achievable. This demands environmental technology to be directed towards process or product-integrated technological improvement and reorganisation. A fundamental renewal of technologies and organisational arrangements is needed for an improvement of environmental efficiency by a factor of 4 up to 20. Sustainable technologies involve redefining existing development paths and initiating new ones, so breaking with the past. The time horizon typically is twenty years or more.

It is clear, therefore, that incremental change is not enough to achieve sustainable development; rather it is renewed technological development that is

Figure 3.1. Research design



essential. The power of 'Factor 20' lies in the encouragement of long-term thinking with a very high ambition level. Nevertheless, it is not completely clear what the factor does address. For example, Reijnders (1998) wonders what the factor of X refers to, whether it makes societal sense, whether improvement of technology is sufficient and how to implement 'Factor X' technology.

3.3 Framework for the search

Summarising the discussion on definitions, measurements and goals, sustainable housing construction is defined as reducing the environmental impacts of material use, energy consumption and water consumption. The environmental impacts of traditional as well as sustainable housing construction can be determined by LCA. Environmental benefits can be derived from that and compared to 'Factor X' goals. The framework for the search for the most eco-efficient strategies for sustainable housing construction comprises four steps (see Figure 3.1):

1. Selection of reference houses
   To be able to compare sustainable housing with traditional housing, reference houses were selected. Three types of houses represent current Dutch housing construction: the terraced house, the semi-detached house and the gallery apartment (Novem, 1999a). Table 3.1 gives an overview of the most important construction and installation characteristics of the terraced house[7].
2. Determination of priorities for the reduction of the environmental impacts of housing construction
   The reference houses were environmentally analysed with Eco-Quantum to determine the priorities for reduction of the environmental impacts of housing construction. The major contributors to the environmental burden of material use, energy consumption and water consumption of Dutch tra-

7 These characteristics were used to determine priorities for the reduction of the environmental impacts of housing construction (step 2). In the meantime energy requirements in the Dutch Building Decree were strengthened. The mechanical ventilation system was replaced by a balanced ventilation system with heat recovery and the combined boiler for heating and hot water became more efficient, up to 107% (Novem, 1999b). These adjusted characteristics were applied for the environmental assessment of sets of measures (step 4).

Table 3.1 Construction and installation characteristics of the reference house

House component	Characteristics
Foundation	concrete beams and piles
Facades	inner leave of sand-lime brick, rock-wool cavity insulation and outer leave of masonry (R_c=3.0 m²K/W), frames, windows (U=1.7 W/m²K) and doors (U=3.4 W/m²K) of unstamped sustainable wood*
Load-bearing walls	sand-lime brick
Parting walls	plaster
Floors	ground floor of ribbed waffle slabs fitted with EPS insulation (R_c=3.0 m²K/W) and storey floors of hollow-core slabs
Roof	wooden roof elements clad with unstamped multiplex, insulated with EPS plates and covered with concrete tiles (R_c=3.0 m²K/W)
Heating and hot water	low-NO_x combined boiler
Ventilation	mechanical ventilation system

R_c: thermal resistance; U: heat transmission.
**) To be understood as a durability category, and not to be confused with sustainably produced wood. In the latter case we speak of stamped wood.*

ditional housing construction were established. All other contributors were subsequently not considered. The advantage is that sustainable measures have to be investigated for only some of the components. Nevertheless improvements that are easy to accomplish still must be implemented. The broad application of small improvements can also yield considerable environmental benefits.

3. Identification of strategies for sustainable housing construction
Strategies instead of single measures were chosen as the unit of the environmental analyses, so significant results could be gained despite method and data uncertainties[8]. By examining strategies and priorities sets of measures were chosen for environmental assessment.

Four strategies were distinguished for sustainable material use (Blaauw, 2001): dematerialisation, material substitution, prolongation of service lives and improvement of reusability. Dematerialisation refers to minimisation of the size of the flow of materials in the building industry. Material substitution is directed towards the reduction of the environmental impacts per unit of material throughout the service life. An extended service life means that the environmental impacts per functional unit decrease, because the environmental impacts are spread over a longer period of time. The improvement of reusability supports the use of building components and materials in a subsequent life cycle instead of dumping or combustion.

The *trias energetica* presents three steps to achieving sustainable energy consumption (Duijvestein, 1998): avoiding unnecessary energy consumption, use of infinite sources and clean and efficient use of finite sources. Avoiding unnecessary consumption involves measures which contribute to a low energy need. Renewable energy in housing notably means solar energy and warmth from the soil, water and air. Finally, the use of efficient techniques implies supplying the remaining energy need as efficiently as possible.

4. Environmental assessment of sets of measures

Eco-Quantum was used for calculations on the environmental benefits of sustainable housing construction. The Dutch tool Eco-Quantum is a tool for LCA of houses, meant for architects, clients and municipal councils where its uses include optimising designs, benchmarking and policy framing (Mak *et al.*, 1999).

The tool conducts an LCA of the flows of materials, energy and water during the service life. The flow of materials includes the use of materials for construction, maintenance and the replacement of all house components, including material-embodied energy. The flows of energy and water comprise energy consumption and water consumption respectively in the occupancy phase of the house. A standard service life of seventy-five years was assumed. Twelve impact categories can be analysed with Eco-Quantum: depletion of raw materials, depletion of fuels, global warming, ozone depletion, photo-oxidant formation, acidification, eutrophication, human toxicity, eco-toxicity, energy consumption, non-hazardous waste and hazardous waste [9].

The assessments were conducted on the level of these impact categories. Weighting factors were not applied to come to a single indicator, because these involve political choices and policy decisions. However the importance given to each environmental impact category has a large influence on the ultimate choice of one or more strategies for sustainable housing construction.

3.4 Environmental benefits of Dutch sustainable construction[10]

3.4.1 Priorities for reduction of environmental impacts

Not surprisingly, the flows of materials, energy and water increases according to the dwelling size, as is shown in Table 3.2. On the other hand the type of house also creates clear differences. In terms of the floor area the semi-de-

8 The strategies only refer to sustainable material use and sustainable energy consumption, because water consumption does not belong to the major contributors determined in the previous step.

9 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 does not include them to avoid double counting. However, the pressure indicators were included in the environmental analysis of the reference houses (step 2).

10 See also Chapter 5 in How Environmentally Friendly is Sustainable Construction?

Table 3.2 Absolute amount of flows in the reference houses

Flow	Terraced dwelling		Semi-detached dwelling		Gallery flat	
	Total	Per m²	Total	Per m²	Total	Per m²
Materials	205 ton	1.9 ton	254 ton	1.9 ton	153 ton	2.0 ton
Energy	4,157 GJ	37.4 GJ	5,252 GJ	39.2 GJ	2,680 GJ	35.7 GJ
Water	6,772 m³	61.0 m³	10,847 m³	81.0 m³	4,110 m³	54.8 m³

tached house comes out worst in terms of energy flow, while the gallery apartment comes out worst in terms of materials.

Figure 3.2 shows the distribution of the environmental impacts of the terraced house between material use, energy consumption and water consumption. The total environmental impacts are set at 100%. It can be seen material use contribute more than 50% to nine environmental impact categories, and energy consumption more than 50% to three categories. Water consumption only has a notable share on one environmental impact category. Although the housing typology also influences the environmental impacts, it appears that there are great similarities between material use, energy consumption and water consumption. Therefore the same priorities for reducing the environmental impacts can apply to all reference houses.

Priorities on material use mainly relate to house components that involve large quantities of materials. These are the foundation beams, outer leaves, inner leaves, window and door frames, glazing, parting walls, load-bearing walls, ground floor, storey floors, floor overlays, roof construction and heat-generation installation. There are also some materials which are very environmentally unfriendly regarding one or a few environmental impacts, including lead, copper and bitumen.

Priorities on energy consumption relate to all energy functions: space heating, hot tap water, lighting, ventilation and auxiliary energy. Although only a quarter of the energy consumption is electricity and three-quarters of the energy consumption is related to the gas-fired functions, both belong to the priorities. It appeared that the energy carrier is of great importance in assessing the environmental impacts.

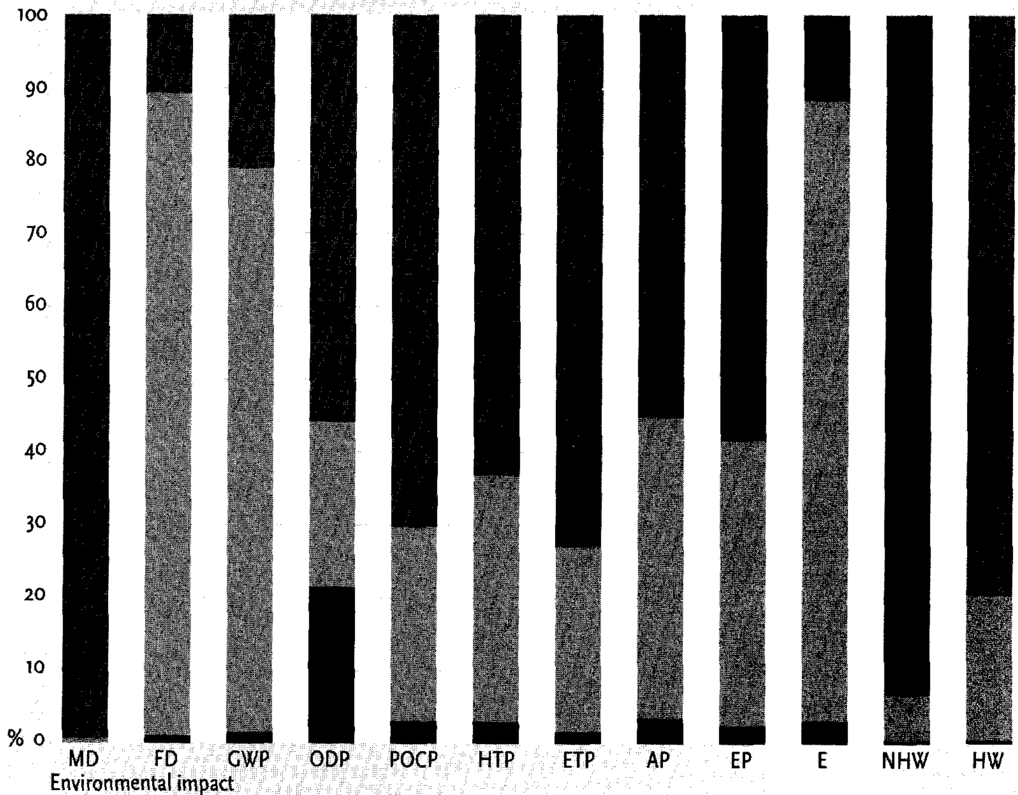
No priorities relate to water consumption, because the environmental impacts of water consumption are as good as negligible compared to the environmental impacts of material use and energy consumption[11].

3.4.2 Environmental assessment of sets of measures

By examining the priorities and the seven strategies for sustainable housing construction, sets of measures were composed for each housing type. To circumvent an irrelevant overload of figures as well as the notion that housing typology is of minor importance in this study, from now on this paper focuses

11 *It has to be mentioned that dehydration of areas is the most important environmental aspect involved with water consumption. This aspect is not taken into account in LCA.*

Figure 3.2 Distribution among material use, energy consumption and water consumption of the environmental impacts of the terraced house



MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; E: energy consumption; NHW: non-hazardous waste; HW: hazardous waste.

Water consumption   Energy consumption   Material use

on the terraced house, as the most common and desired house in the Netherlands.

The sets of measures for sustainable material use relate to current subjects of debate. For dematerialisation, 10% smaller dimensions of the load-bearing structure were assumed. This is contrary to flexible housing construction, which often means that more materials are needed in the construction phase. For material substitution, renewable materials as well as synthetic replacements for lead and copper were a set of measures. This reflects the dilemma between more environmentally sound materials with short service lives (e.g. renewable materials) and less environmentally sound materials with long service lives (e.g. heavy metals). Prolongation of service lives might concern both the service life of the house and the service life of its components. A prolongation of fifteen years of the house was studied. The service life of components with a major influence on the environmental impacts was also prolonged by five years. Finally improvement of reusability is possible for

Table 3.3 Environmental benefits of sets of measures for sustainable material use applied to the terraced house

Sets of measures	Environmental benefits in percentages								
	MD	FD	GWP	ODP	POCP	HTP	ETP	AP	EP
M1 10% smaller dimensions of load-bearing structure									
M2a renewable materials: timber-frame construction			5	8				-5	-6
M2b synthetic materials instead of lead and copper	54					14	47		
M3a 90 years service life of house instead of 75 years	17	17	18	20	19	19	18	19	19
M3b 5 years prolongation of service life of components	8								
M4 reuse of foundation and parting walls	8		5		8	4		5	5

MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication.

Table 3.4 Environmental benefits of sets of measures for sustainable energy consumption applied to the terraced house

Sets of measures	Environmental benefits in percentages								
	MD	FD	GWP	ODP	POCP	HTP	ETP	AP	EP
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	
E3 low-temperature space heating and high-efficiency ventilation		5	5			6		6	5

MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication; R_c: thermal resistance; U: heat transmission.

the foundation and the parting walls at present. Comparable with the dilemma earlier mentioned the question is whether application of less environmentally sound materials with good recycling or reuse possibilities is a better option than environmentally sound materials with bad recycling or reuse possibilities.

The sets of measures for sustainable energy consumption consist of technologies which are often applied in Dutch sustainable housing construction. An increase in the thermal resistance of the building envelope and a decrease in the heat transmission of the glazing refer to avoiding unnecessary energy consumption. The use of infinite sources in housing notably means solar energy, so thermal and photo-voltaic solar-energy systems were calculated. The use of finite sources was worked out as low-temperature space heating and high-efficiency ventilation.

Tables 3.3 and 3.4 present the results of the Eco-Quantum calculations on the environmental benefits of sustainable material use and sustainable energy consumption respectively. The figures represent the environmental benefits in percentages in comparison with the reference house. Negative values mean that a rise instead of a reduction of environmental impacts occurs. Empty cells mean that there are no significant changes (less than 5%). The results led to the following findings:

- A 10% smaller dimension of the load-bearing structure does not result in significant environmental benefits.
- Regarding application of renewable materials, environmental benefits in some environmental impacts go together with environmental disadvantages in others. Avoiding heavy metals pays off on particular impacts.
- The considerable environmental benefits of the prolongation of service lives of houses are a consequence of not needing a new house over the prolonged period. Prolongation of service lives of both houses and house components always results in a reduction in the environmental burden on all impacts. However, a five years prolongation of the service lives of the house components which exert a great influence on the environmental burden only leads to a significant decrease in the depletion of raw materials.
- Reuse of foundation and parting walls shows improvement on several environmental impacts.
- Insulation and efficient glazing causes environmental benefits on energy consumption with negligible environmental drawbacks on material use.
- Use of solar-energy systems leads to environmental drawbacks on four environmental impacts. This is due to the material use. The environmental benefits are comparable to insulation and efficient glazing.
- Application of low-temperature space heating and high-efficiency ventilation yields smaller environmental benefits in the depletion of fuels and global warming than the previous two sets of measures. To the contrary, larger environmental benefits on other impacts are achieved.

A closer look at the findings provides a better insight into the future perspectives of the strategies. A serious observation is that the strategy of using infinite energy sources saves fossil fuels, but the environmental impacts of the solar systems themselves are currently often ignored. The use of passive solar systems (e.g. orientation on the south) does not have these drawbacks. Thus more attention has to be paid to the material use of active solar systems (e.g. solar collectors and solar panels) to make the use of infinite sources a more promising strategy. Until now efficiency and comfort have been the main issues. There are plenty of options to improve the material performance, which are already under development, although not for environmental reasons. The strategy of material substitution is difficult, because it only occasionally yields positive consequences on all environmental impacts.

The strategies of dematerialisation, avoiding unnecessary energy consumption and the clean and efficient use of finite sources offer good perspectives at first, because these result in positive effects on certain environmental impacts with negligible negative effects on other environmental impacts. However, the advantages are limited since there comes a point where even more insulation or even smaller dimensions are not useful or desirable anymore. Therefore, the prolongation of service lives and improvement of reusability are needed to make a leap forward in the environmental performance of housing to achieve the target environmental benefits. For example, more materials are often initially involved in flexible houses, so to achieve the target environmental benefits the resident has to make use of the additional possibilities in functions or floor plans of the house. Another example concerns reuse: the question arises whether components which are suitable for reuse will really be reused in the future. This means that a very well reasoned approach is necessary. Due to the uncertainties involved with the strategies of prolongation of service lives and improvement of reusability, application of these strategies should be made together with other strategies.

3.5 Conclusions and discussion

Ambitions for sustainable technology development are often expressed in factors which refer to eco-efficiency. In the ecological conditions strategy eco-efficiency is concerned with the responsible management of flows. The factors can be calculated according to the LCA methodology. It turns out that goals such as factor 4 or factor 20 are still far from being achieved in Dutch sustainable housing construction, because the factors mean a reduction of the environmental impacts by 75% and 95% respectively, not including growing wealth. None of the environmental impacts show such reductions. Significant environmental benefits are achievable, but current Dutch sustainable construction practice does not go far enough to meet them. The prolongation of service lives and improvement of reusability seem the most eco-efficient strategies for sustainable housing construction. However, other strategies also need to be applied, because of the large uncertainties involved.

Although ambitious goals have not been realised yet it is very problematic to know how far away such ambitious goals are. For that we have to know what 'X' should be to prevent exceeding the carrying capacity and what the 'Factor X' refers to: new housing or the housing stock, single houses or neighbourhoods, districts and cities, or construction or living?

In 2000 the Dutch housing stock consisted of 6,588,100 houses. This stock will increase by a minimum of half a million houses up to 7.1 million in 2010 (Dutch Ministry of Housing, Spatial Planning and the Environment, 2000). This means that by 2010 new construction from 2000 on will amount to 13% of the housing stock. Although houses constructed in this ten-year period will form a considerable part of the future housing stock, there is a great potential in the present housing stock to improve the environmental performance of housing. Two million post-war houses have a far lower environmental performance than new houses. Moreover the number of houses in which improvements have to be realised is much larger.

Houses are just a small part of a neighbourhood, district or city. On these levels more solutions are possible to reduce the environmental impacts of housing. For example houses in a whole district can be heated by waste heat of industries. Such collective services in principle lead to larger environmental benefits than can be achieved in a single house. All scale levels are of equal importance and should be considered in an integral way. On higher scale levels conditions have to be created which make it possible to reach good environmental performance on lower scale levels. Sustainability of neighbourhoods or larger areas goes beyond flows. Also areas and factors have to be taken into account.

Finally big leaps in eco-efficiency, such as those illustrated by the 'Factor 20' metaphor cannot be achieved with sustainable housing construction or management. Sustainable development does not ask for decline, it demands fundamental renewal. Current innovation tracks mainly concern the optimisation and improvement of products and processes. System changes are necessary for such leaps or even changes in our set of norms and values. From that point of view it is not housing or urban planning that are subject to debate, but our way of living.

4 Tools for sustainable housing management

The case of the Netherlands and Finland

Source: Klunder, G., and M. Sunikka, 2003, Tools for sustainable housing management: the case of the Netherlands and Finland, in: Open House International, 27 (1), pp. 19-27.

4.1 Introduction

In both the Netherlands and Finland the level of attention paid to the sustainability of the existing housing stock lies far below that paid to new construction (Sunikka, 2001). Most good practice in sustainable building relates to new construction rather than housing management. Similarly, very few of the currently available tools focus specifically on housing management, although substantial environmental benefits could be extracted from this housing stock. In Europe, much of the present housing stock was built just after the Second World War; these early post-war dwellings are now in need of improvement. For example, Dutch households are faced with the challenge of reducing their CO_2 emissions by 25 million tonnes between 2000 and 2012; these targets cannot be achieved without the renovation of the existing housing stock. Tools to support sustainable housing management must therefore be developed soon. The questions which arise are: What kind of tools are needed to deal with these issues?, Would a mere broadening of the scope of the existing tools suffice?, Or conversely, are completely different kinds of methods required? (Sunikka and Klunder, 2001).

The aim of this article is to describe some of the future challenges to which the methods and tools that support environmental decision-making in housing management will have to respond. The study has been based on experience in the Netherlands and in Finland. The article addresses the following questions:

- What Dutch and Finnish tools focus on sustainable housing management?
- What developments in methods and tools have evolved, or have been foreseen, in the Netherlands and in Finland?
- What are the housing management tasks which have to be undertaken in the Netherlands and in Finland?
- What future challenges have to be met through the development of tools for sustainable housing management related to these tasks?
- What can be learnt from the developments in the Netherlands and in Finland?

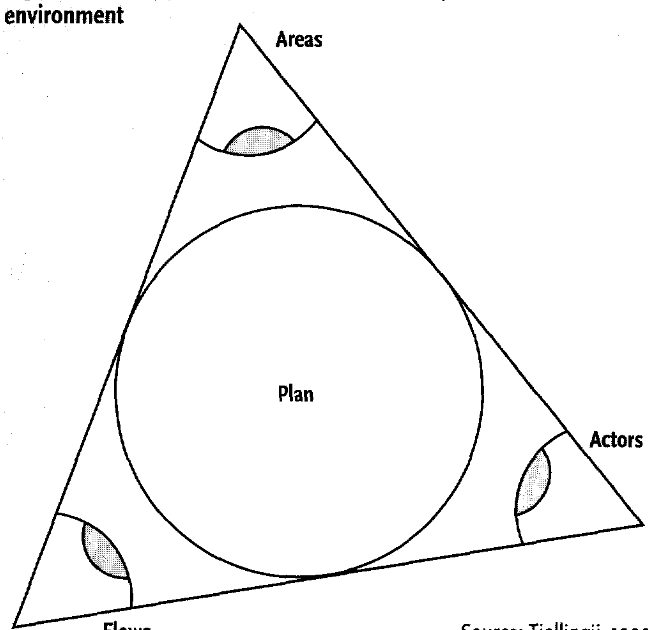
Section 4.2 presents a literature review of the approaches to sustainable building in a number of European countries. Section 4.3 explains the definitions used with respect to sustainable building, housing management, and tools. Next, Section 4.4 comprises a description of the currently available Dutch and Finnish tools for sustainable housing management, the development of methods and tools in general, and the housing management tasks in both countries. A comparative analysis of the Netherlands and Finland is reported. Finally, Section 4.5 contains the conclusions drawn and an outline of the future challenges to be met through the development of appropriate tools.

4.2 Literature review

The nature of most environmental problems is global, so developments should be undertaken through international cooperation and mutual exchange of experience. Members of the European Union have developed different strategies for sustainable building. Germany, for example, relies on a mandatory approach, based on norms and regulations. Its long-term environmental policy has helped Germany achieve partial results in the stabilisation of energy consumption and the regeneration of waste, despite the economic growth (German Federal Statistical Office, 2000). In contrast, the United Kingdom strategy for sustainable construction is market-driven and linked to the improvement of competence in the construction industry (British Department of Environmental Transport and the Regions, 2000). France is yet to develop an action program for sustainable building, despite an initiative known as the *Haute Qualité Environnementale* (High Environmental Quality; Association HQE, 2000). There is, however, no special HQE legislation or nomenclature; sustainability is a relatively new issue in France, and general consumer patterns and attitudes are not yet very ecological. In the Netherlands, the construction sector has been a target group for environmental policy since 1989 and some action plans have been published (Dutch Ministry of Housing, Spatial Planning and the Environment, 1995 and 1997). The Dutch government does not rely solely on voluntary measures for the implementation of strategy, but also has introduced new regulations. The Finnish strategy in promoting sustainable construction relies heavily on the environmental consciousness prevalent in the market. Finland published the Programme for Ecologically Sustainable Construction in 1998 (Finnish Ministry of the Environment, 1998).

The Netherlands and Finland serve as case studies in this article, because they offer comparable, yet different policy approaches to sustainable building and have already acquired some experience. Some sustainability tools have been developed in both countries. As can be seen in the development of tools, the Netherlands and Finland have specialised in different environmental themes. Because of the cold climate, energy saving has a high priority in sustainable building in Finland, whereas progress in material and waste

Figure 4.1 Three points of view in sustainability in the built environment



Source: Tjallingii, 1999

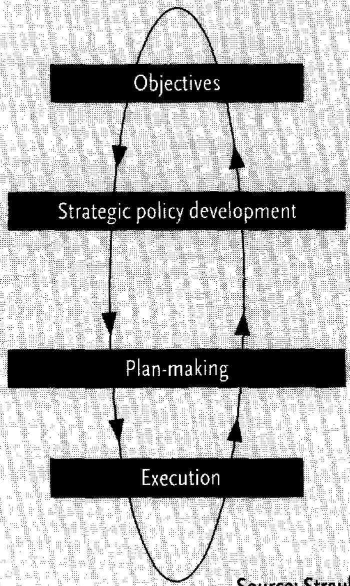
requirements lags behind the achievements with energy. In the Netherlands, the building industry has agreed to provide environmental information about products and materials themselves, but the energy efficiency of the existing stock is still fairly poor. The housing stock in the Netherlands and Finland differs, so the management tasks are dissimilar. These differences in the housing situations add interest to the comparison of tool development.

4.3 Definitions of concepts

This section defines the concepts of sustainable building, housing management and tools. Sustainable building is an ambiguous concept. It is sometimes interpreted purely in ecological terms, sometimes more broadly as high-quality building, or extended lifespan. The concept of sustainable building has evidently been derived from the expanding environmental consciousness resulting from an awareness of population growth and increased pollution associated with human activities. It is also evident that sustainable building does not just refer to technological solutions to diminish environmental burdens. Tjallingii distinguishes three points of view: flows, areas, and actors, as Figure 4.1 shows (Tjallingii, 1999). Flows represent environmental quality; areas, spatial quality; actors, process quality. These three aspects are equally important in a sustainable built environment. Spatial and process quality is difficult to measure and depends strongly on the specific area and actors involved. This article therefore concentrates on environmental quality.

Housing management comprises a range of activities keeping up and modifying the housing stock to fulfil accommodation needs during its use. The activities include maintenance, refurbishment, renovation, demolition, and new construction. Decisions have to be made at several management levels; these can be represented in a management cycle, as shown in Figure 4.2. Four levels of decision-making are involved in housing management processes: the objectives of the organisation, strategic policy development, plan-making, and execution of the plan (Straub, 2001). Decision-making takes place in both

Figure 4.2 Management cycle



Source: Straub, 2001

top-down and bottom-up directions, as is expressed by the cycle. Sustainability in housing management incorporates all decision-making levels. Sustainable housing management is defined as: "the maintenance, refurbishment, renovation, demolition, and new construction of houses in such a way that the burden on the environment by the actions taken, energy and water input, and materials used is limited to as little as possible" (Sunikka, 2001).

Sustainability in housing management increases the complexity of the management process. There are innumerable methods and tools, including checklists, design guidelines and evaluation tools, which can help bring about sustainable building. This article focuses however on tools which:

- support environmental decision-making in one or more levels of the housing management process;
- assess the environmental benefits in a qualitative or quantitative manner, regardless of the kind of indicator, and which can be classified in three categories: environmental pressures (for example energy saving), the environmental quality (as exemplified in the thickness of the ozone layer) or environmental impacts (global warming potential, for example).

4.4 Case studies: the Netherlands and Finland

This section presents the current tools for sustainable housing management in the Netherlands and in Finland together with the general developments in methods and tools. Some characteristics of the Dutch and Finnish housing stock are also studied. The housing tasks are derived from this, because tools should support these tasks.

4.4.1 The Netherlands

The state of the art in tools for sustainable housing management

In the Netherlands, three management tools have been developed which respond to the requirements described in Section 4.3: Duwon, the National Package for Sustainable Housing Management, and the Green Investment.

Duwon

Duwon consists of a manual which enables a housing manager to take environmental performance into account as a quality aspect in complex decision-making processes. These processes are related to strategic policy development at the housing stock level and planning at the level of a building. Duwon contains aspirations, strategies, and concepts. These are steps which have to be taken in a cyclical process to convert the management task into measurements (De Haas *et al.*, 1997). Aspirations are preferably performance requirements regarding, for example, energy saving, indoor climate, and life-span extension. Strategies direct the search for solutions to improve the environmental performance of buildings. Concepts are coherent measurement packages resulting from the aspirations and strategies. Concepts also facilitate insight into the consequences with respect to housing quality, the use of gas, and living costs before and after the implementation of the management plan. Seven concepts have been formulated, including maintenance, consolidation, and restructuring.

Duwon includes an environmental scale on which global indications of the environmental benefits of the concepts are scored. The criteria are the quality of the living environment, housing quality, indoor climate, use of materials, and energy and water consumption. Restructuring scores highest on this scale.

National Package for Sustainable Housing Management

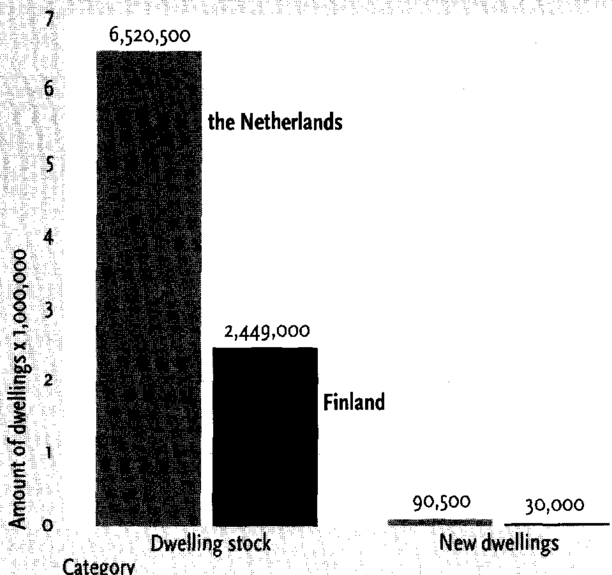
Duwon guides the planner when making choices from the National Package for Sustainable Housing Management (SBR, 1997). The package consists of measures related to the themes of materials, energy, water, and indoor climate; it includes costs. It connects the measures to four levels of housing management: repair, replacement, improvement, and addition. Examples of repair are the recovery of concrete components and the moisture treatment of masonry. Replacement includes insulation glazing when glazing or window framing has to be replaced. Improvement differs from replacement since improvement adds quality, such as enlarging the dimensions of the facade openings when framing has to be replaced. Addition means taking measures for environmental purposes only, such as the installation of a thermal solar-energy system, or the extra insulation of a dwelling.

The environmental benefits are given in a predominantly qualitative way, such as reduction of emissions. Energy and water saving measures are sometimes provided with quantitative data in m^3 of gas, kWh of electricity, or m^3 of water saved.

Green Investment

Green Investment refers to the financing of loans for the renovation or refurbishment of a dwelling at an interest rate lower than the prevailing market rate. A project has to meet high requirements with respect to use of materials, energy consumption, water consumption, and indoor climate if it is to ob-

Figure 4.3 Size of the housing stock in 1999



Source: Haffner and Dol, 2000

tain 'green *financing*'. Applications are judged on the basis of a scale provided by the National Package for Sustainable Housing Management. Points are allocated on the various measures in this package. A renovation or refurbishment project has to score a minimum of 125 points (Novem, 2000).

An added bonus of the system in terms of *environmental* benefits is that it indicates the value of the various measures as well as combinations of the measures. A ranking of options for sustainable housing management becomes apparent.

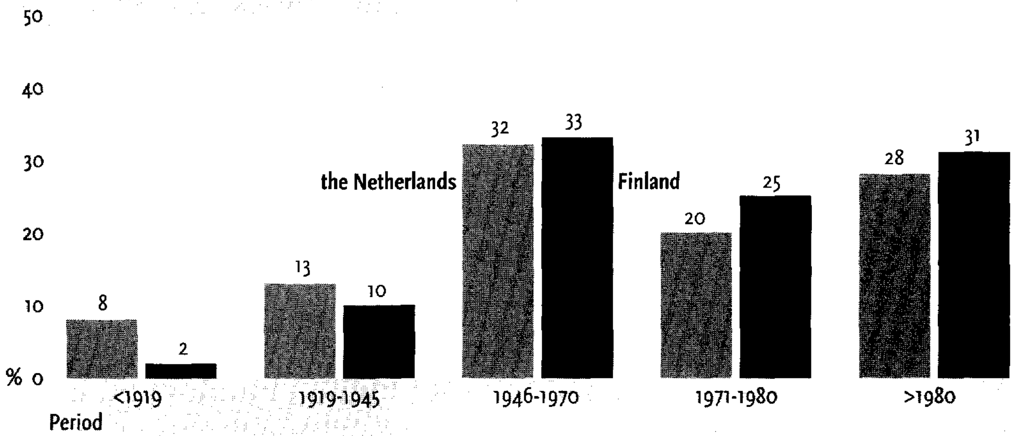
Developments in methods and tools for sustainable building

The Netherlands has an extensive history with regard to methods and tools for sustainable building. The development of tools started with a focus on materials. Classifications and checklists were developed to support environmentally sound choices. The need for this kind of easy-to-use information remains strong, although it has to be said that the data is often conflicting. The Life Cycle Assessment (LCA) has therefore become very important. In the LCA methodology, all environmental impacts have to be considered and accounted for during the whole life cycle of a product or process. Eco-Quantum and GreenCalc are new generation tools based on this methodology. Eco-Quantum, for example, facilitates the calculation of the environmental impact of the flows of materials, energy and water in housing during the whole life cycle. The tool is intended for architects, clients, and municipalities. They (and others) can use it for optimising designs, benchmarking and policy framing (Mak *et al.*, 1999). The existing stock is receiving increased attention; environmental assessment has adopted a broader view. Although there is an increasing awareness of the importance of processes and social issues, the emphasis is still on the quantifiable aspects of sustainable building.

Housing management tasks in the Netherlands

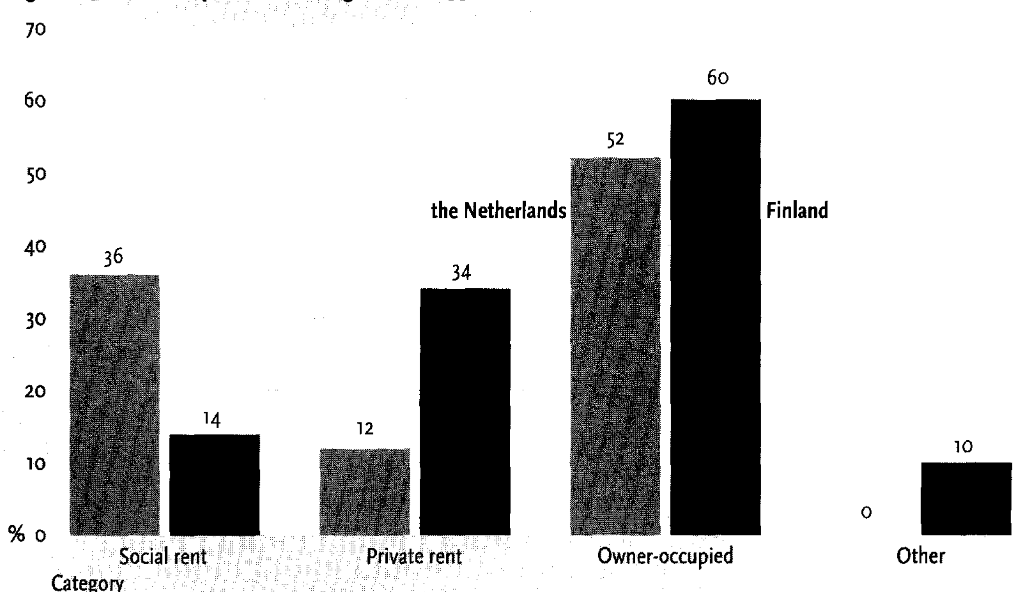
The housing stock of the Netherlands consists of more than 6.5 million dwellings. As can be seen from Figure 4.3, the newly-built dwellings form just a small part of the stock. In 1999, 90,000 dwellings were built. With respect to the existing stock, the Netherlands has a comparatively large share of post-

Figure 4.4 Age of the housing stock in 1999



Source: Haffner and Dol, 2000

Figure 4.5 Ownership of the housing stock in 1999



Source: Haffner and Dol, 2000

war housing, as Figure 4.4 shows. In Figure 4.5, it appears that the social rental sector in the Netherlands is about three times larger than the private rental sector (Haffner and Dol, 2000). The extent of the social sector owned by the housing associations makes it possible to influence the environmental performance of the housing stock.

In the Netherlands, the housing associations manage 36% of the total housing stock and 75% of the rental sector, involving 2.3 million dwellings in all. Usually, the environmental performance of these houses correlates with their

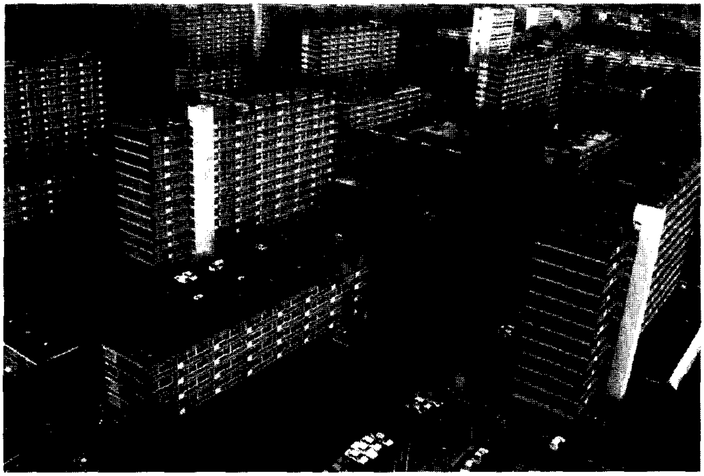


Figure 4.6
Poptahof in Delft, the Netherlands: neighbourhood to be restructured

age: the scores are lower for older housing than for more recently built housing (Quist and Van den Broeke, 1994). In the 1970s, energy became an important issue and since that time the environmental performance of housing has improved. However, the urban renewal undertaken in the 1970s and 1980s did not result in environmental improvements in the pre-war housing stock. Currently, the restructuring of post-war neighbourhoods is a major housing management task. These restructuring activities represent crucial opportunities to raise the environmental performance of the housing stock (see Figure 4.6).

4.4.2 Finland

The state of the art in tools for sustainable housing management
The Environmental Systems Guide for Real-Estate Management is a Finnish tool equivalent to the Dutch tools; it also responds to the requirements described in the previous section.

Environmental Systems Guide for Real Estate Management
The Environmental Systems Guide for Real Estate Management is a practical tool developed for housing managers in the day-to-day maintenance of housing. All the basic tasks of a housing manager are handled from an ecological point of view. By using the guidelines, managers can provide their clients with ecological services. The guidelines consist of four parts, three targeted respectively at developers, planners, and maintenance companies and one with guidelines for setting up an environmental management system. The guidelines have been written from a client's point of view, so the emphasis is on setting environmental requirements and evaluating their implementation (Suomen Kiinteistöliitto, 1999).

The Environmental Systems Guide for Real Estate Management is a qualitative tool. It does not contain any detailed information about the relationship between management activities and quantitative environmental impacts.

Developments in methods and tools for sustainable building
In Finland, energy efficiency is a major issue in sustainable building. Current environmental assessment methods usually deal with natural raw materials, energy, emissions, and waste with respect to production, products, and services – paying special attention to energy consumption. In addition to the LCA methodology, considerable effort has been put into the development of more

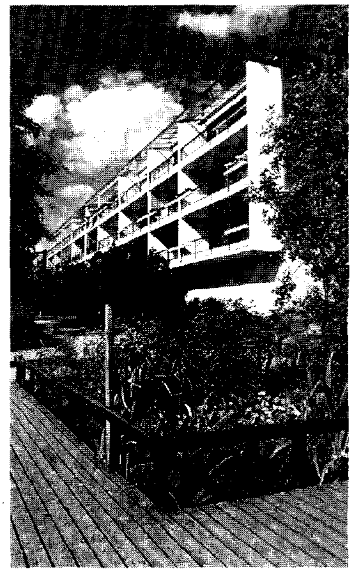


Figure 4.7
Vantaa in Finland: improving the image and comfort through renovation

holistic methods to measure the environmental performance of a building; aspects other than the purely technical, such as adaptability, are assessed. This effort has resulted in part from the Finnish government's programmes which focus on qualitative issues rather than quantitative targets. Soon the existing stock can be evaluated with an environmental classification from the point of view of natural resources, ecological impact, and health aspects (RAKLI, 2001). Housing managers can use the classification for the environmental labelling of their houses and for benchmarking. So far, the Finnish tools have focused on new construction.

Housing management tasks in Finland

The Finnish housing stock amounts to 2.5 million dwellings. In 1999, 30,000 dwellings were built, as can be seen in Figure 4.3. As a result, updating the housing stock is on a small scale. Furthermore, the existing housing in Finland was built relatively recently, as Figure 4.4 shows. In Finland, owner occupation and other forms of ownership commonly occur (see Figure 4.5). Nevertheless, the volume of social housing has recently increased slightly, because during the recession in the 1990s the government strongly supported the construction of new houses. In 1999, 42% of new dwellings were built for the social housing sector (Haffner and Dol, 2000).

The post-war housing stock is in need of updating. The renovation of the suburbs dating from the 1960s and 1970s could substantially improve the environmental performance of the housing stock (see Figure 4.7). During that period, most of the state subsidised housing was constructed relatively quickly and cheaply, using prefabrication technologies that enabled contractors to continue construction during the cold winter months. Since the 1970s, the housing stock has been renovated through improving the energy efficiency, appearance, and comfort of the houses, and repairing construction mistakes that have often led to moisture-induced damage and mould. The twenty to thirty year old housing stock constructed with state subsidies has now been modernised and brought up to the same standard as new construction. Investments in renovation correspond with those made for new building (Finnish Ministry of the Environment, 1999).

4.5 Comparative analysis

In order to identify future challenges for sustainable housing management, the situations in the Netherlands and Finland were compared with respect to the tools for sustainable housing management, developments in methods and tools for sustainable building, and the housing management tasks.

In both the Netherlands and Finland, sustainable building policies have focused on new buildings, despite the fact that the annual volume of new construction is small relative to the capacity of the existing stock. Consequently, the tools developed for the particular purposes of sustainable renovation and management are few. They comprise Duwon, the National Package for Sustainable Housing Management, Green Investment and the Environmental Systems Guide for Real-Estate Management. Duwon is a particularly interesting method, because it aims to create a step between strategic policy development and the practical implementation of environmental measures, making it easier for housing associations to establish sustainability as a policy element. All four tools seem capable of playing a key role in making sustainable choices in housing management. The tools guide housing managers through an inexhaustible list of options; their environmental consequences are however rather vaguely specified. In addition, the tools have adopted different approaches to sustainability, so that confusion and difficulties arise when information is compared. The objective of underpinning environmental benefits is still lacking in both countries.

The existing methods and tools for sustainable building are capable of being applied to existing housing. Eco-Quantum, for example, can be adapted to assess renovation and maintenance plans. The LCA methodology is highly suitable for this kind of question, although the definition of the existing stock is a major problem which needs to be resolved. The Finnish environmental classification system offers a holistic approach that can be used for environmental labelling or benchmarking. Despite the differences in their approach, the tools in both countries offer good starting points for the evaluation of sustainable options for housing management. This, however, has to be considered in the context of the housing management tasks.

With regard to the housing management tasks, in the Netherlands the restructuring of the post-war neighbourhoods is currently taking place on an extensive scale, whereas in Finland the management task is focused more on the refurbishment of individual buildings in the suburbs than on urban renewal as a whole. This concentration is connected with ownership patterns. In the Netherlands the housing associations manage a major part of the housing stock, whereas in Finland the ownership forms are more diverse. However, in both countries most of the housing stock was built soon after the war and now needs improvement. Renovation could lead to a substantial improvement in the environmental performance of the housing stock. With regard to the characteristics of the present tools, gaps can be identified in both countries in the development of tools. The final section addresses some of the challenges for the future within this framework.

4.6 Conclusions and recommendations

In this article, the future challenges for the development of tools for sustainable housing management are recognised, and ways in which the Netherlands and Finland can learn from each other about environmental assessment are identified. Updating the housing stock will be a major issue in the near future in both the Netherlands and Finland. Such updating heightens the need for management tools which can give sustainable housing management a serious impulse. In general terms, the tools differ in their approach and there is much for both countries to learn from each other's experiences. The Dutch methods put more emphasis on quantitative information, whereas the Finnish tools give more comprehensive and qualitative information. It is worthy of note that this difference in approach is in strong contrast with the respective housing management tasks. Finnish renovations, which are often building specific, can be assessed with a quantitative method, while Dutch restructuring requires a more comprehensive and qualitative approach. Consequently, the development of management tools in the Netherlands needs to take a more extensive and strategic view, while in Finland the need is for tools focusing on renovation at the building level.

Both the Netherlands and Finland lack tools capable of dealing with the environmental impact of decisions taken in policy development and planning in housing management. Moreover, a gap can be identified with regard to the environmental consequences of decisions on a more strategic level. For instance, an important management question is how to compare renovation with demolition followed by new construction from an environmental point of view. Such a decision goes beyond the building level, because other deliberations such as housing markets and tenant preferences have an impact on it. A transition from the building level to the neighbourhood level is required, making it necessary to take into account aspects of a different kind, such as demographic trends and the amount and type of housing. This kind of question cannot be answered just by widening the scope of the existing tools; other kinds of methods need to be developed (Klunder, 2000b). Consequently, more research about sustainable housing management tools is needed. The current tools leave too many questions open, so that housing managers could be absolved from managing in a sustainable manner when more support is needed for sustainable renovation and management.

To bridge the gaps in the development of tools, it is obvious that more research is needed focusing on environmental assessment of the housing stock. Besides, it is essential to ensure that the tools developed are used in practice. According to research on sustainable management in the housing associations in the Netherlands, most of the sustainability tools are considered to be good and useful by those who actually use them, but in many housing associations they are unknown (Sunikka and Boon, 2002). To promote dissemination of knowledge, there should be much more cooperation with end users. Finally, in order to support sustainable housing management and the use of tools, more attention needs to be directed to the existing stock in government policies for sustainable building. Environmentally sound housing management is the ultimate opportunity to achieve a sustainable built environment.

5 Environmental impacts of interventions in the Dutch housing stock[12]

5.1 Introduction

As shown in Figure 5.1 most of the housing stock in the European Union was built after WW II. Post-war housing shortages resulted in mass production on a huge scale. Nowadays the size of the housing stock is broadly sufficient, but the quality is poor. Post-war mass-produced housing, in particular, falls far short of the current needs and now faces the threat of large-scale demolition. In the Netherlands, urban renewal often amounts to a choice between maintenance with just a few minor interventions and total redevelopment. Renovation-based approaches are hardly ever considered an option.

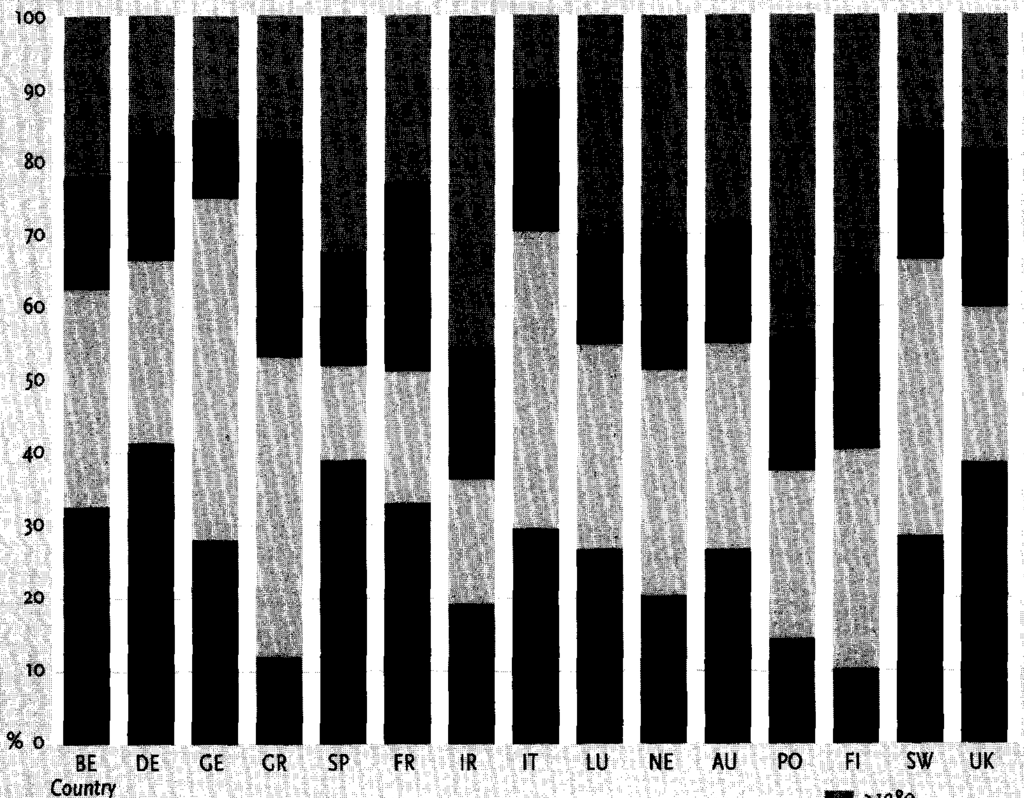
Thomsen and Van der Flier (2002) argue that, given the annual decline in housing production, it would be prudent to upgrade the housing stock by applying renovation-based strategies. In Europe, the annual housing production barely exceeds 1% of the total housing stock. Even if all this production were channelled into the replacement of demolished housing it would still take over a century to make up the discrepancy. Finally, they contend that environmental sustainability and the fulfilment of the energy targets set by the Kyoto Protocol support the case for renovation instead of demolition.

Housing transformations can fill the gap between consolidation (i.e. maintenance) and demolition and new construction (i.e. total redevelopment). Transformations are understood as improvements in (part of) an apartment block or complex which extend beyond a single dwelling. Examples are the horizontal and vertical combination of apartments. Te Velde (2003) maintains that sustainable urban renewal implies at least careful treatment of the housing stock. He sees transformation as a synthesis between old and new, a middle course between the consolidation and large-scale demolition of existing neighbourhood structures. Current physical and social structures may possess valuable characteristics and offer opportunities for preservation. A balance has to be sought between preservation and necessary renewal. Transformation means that at least the load-bearing structure of the housing will be preserved and the remaining components renewed. Such interventions can lead to re-differentiation of the housing stock and hence to greater variation in the type of housing and residents.

It would, however, be somewhat premature at this point to conclude that transformation is environmentally preferable to demolition as there are no methods or tools for comparing the environmental impacts of interventions in the housing stock (Klunder, 2003). Life Cycle Assessment or LCA lends itself for this purpose. The research carried out by Treloar on life cycle energy analysis of buildings (e.g. Fay *et al.*, 2000; Treloar *et al.*, 2000) is extensive but it

12 The author would like to acknowledge the valuable comments made by the anonymous reviewers of Building Research & Information.

Figure 5.1 Housing stock per building period per country in 2002



BE: Belgium; DE: Denmark; GE: Germany; GR: Greece; SP: Spain; FR: France; IR: Ireland, IT: Italy; LU: Luxemburg; NE: Netherlands; AU: Austria; PO: Portugal; FI: Finland; SW: Sweden; UK: United Kingdom.

Source: Dutch Ministry of Housing, Spatial Planning and the Environment, 2004

lacks a comprehensive view on the environment. LCA needs to be further refined before it can be used for assessing the environmental implications of interventions in the housing stock. A second problem is that LCA-based tools for the environmental assessment of buildings are geared to new construction rather than renovation. Though more attention is being paid to methodologies for assessing and comparing the environmental impacts of renovations, LCA is still to be properly fleshed out.

This paper presents a method for comparing the environmental impacts of interventions in the housing stock along with the results of a comparison between the environmental impacts of transformation on the one hand and new construction on the other. This will enable all parties involved in housing construction to take account of environmental factors in urban renewal plans. Section 5.2 explains the approach to the research. Section 5.3 discusses a method for comparing the environmental impacts of housing interventions. Sections 5.4 and 5.5 present two case studies on the environmental impacts of housing transformations compared with new construction. Section 5.6 draws conclusions and Section 5.7 offers a discussion.

5.2 Approach

First, a literature search was conducted to devise a method for comparing the environmental impacts of different types of intervention in the housing stock. The starting point was the LCA. Although several methods exist for quantifying the material (and energy) demands of the human economy upon the natural environment, as described in Daniels and Moore (2002), LCA is widely accepted in this domain. Material Flow Analyses or MFA is another important method, but it focuses on overall descriptions of the material basis of wider economic systems rather than on more microeconomic spheres, such as individual buildings (Daniels, 2002). LCA analyses the environmental burden of products (goods and services) from cradle to grave, covering the extraction of raw materials, the production of materials, product parts and products, and discard, either by recycling, reuse or final disposal (Guinée, 2002) – otherwise defined as the "compilation and evaluation of the inputs, the outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 1997). The product system is understood as the sum of the processes needed for the product – in this case, a house. Inputs and outputs are the materials and energy which enter and leave the product system.

Two fictional case studies were conducted to collect empirical data on the environmental impacts of housing interventions: Morgenstond Midden in The Hague and Poptahof in Delft, both Dutch post-war housing estates designated for renewal. Morgenstond Midden was built in the 1950s and consists mainly of three- and four-storey tenements. Poptahof was built in the 1960s and consists mainly of walkway flats. These locations were chosen as case studies because they are classic examples of a type of neighbourhood and housing which is prevalent in the Netherlands. Two hypotheses were tested: housing transformations have lower environmental impacts than demolition and new construction, and housing transformations have lower environmental impacts than consolidation.

Empirical data were obtained with Eco-Quantum, version 2.00 (SEV and SBR, 2002). Eco-Quantum is a Dutch LCA-based tool for assessing the environmental impacts of the use of materials and the consumption of energy and water in new housing. The need for country-specific data more or less ruled out the use of foreign tools, as data are often integrated in the tools. Eco-Quantum uses the environmental profiles of products and processes, calculated with SimaPro (Goedkoop and Oele, 2001). Eco-Quantum covers all housing-related profiles, including the energy and water consumption of the whole house. A single house, serving one household a time, from initial construction through demolition, was taken as a functional unit. Eco-Quantum assesses ten environmental impacts: depletion of a-biotic resources, global warming, ozone depletion, photo-oxidant formation, human toxicity, aquatic eco-toxicity, sediment eco-toxicity, terrestrial eco-toxicity, acidification and eutrophication. Assessment was based on CML 2 Baseline 2000 (Goedkoop *et al.*, 2001). No normalisation or weighting was applied. Before Eco-Quantum could be used for this research, a number of additional calculations had to be made manually in order to apply the method presented in Section 5.3.

5.3 Method for comparing the environmental impacts of interventions in the housing stock

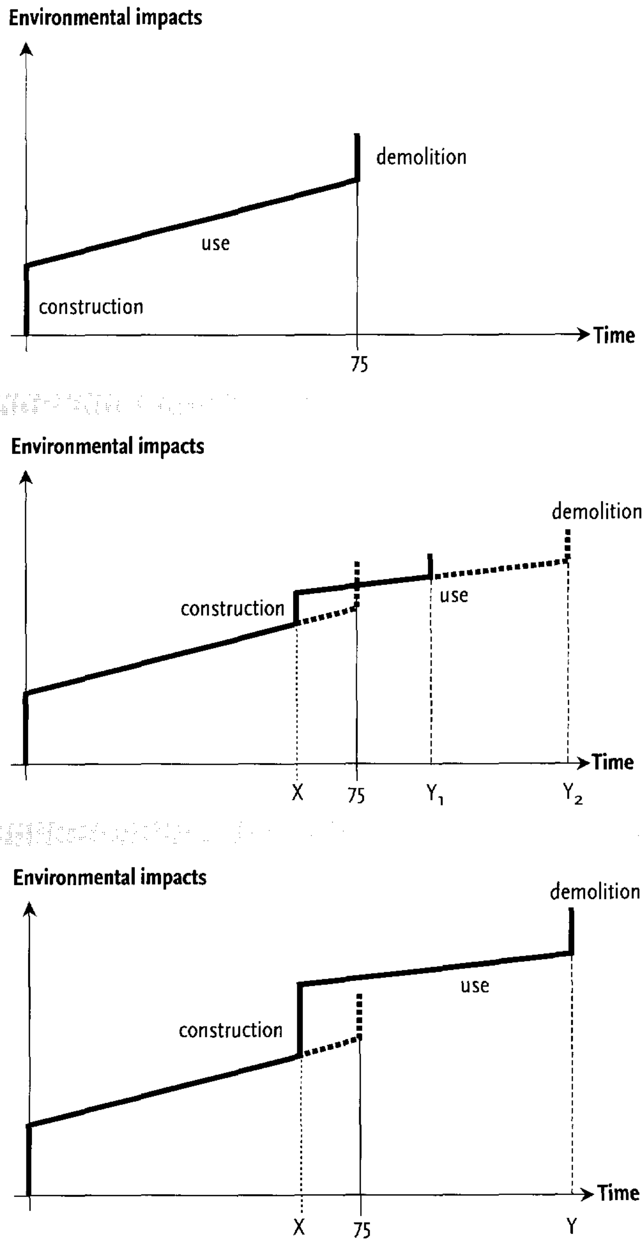
Working out the LCA of buildings is a complicated business because each building has its own special characteristics and consists of a very large number of components and materials. Besides, buildings have extremely long service lives compared with, for example, computers. Though many changes occur during the service life of a building, current whole-building environmental assessment tools do not take account of changes in building characteristics over time. On the contrary, they deal with the environmental impacts of a building during its service life on the basis of the original construction. They do not address the environmental impacts of transformations, even though these may totally upset the predicted life cycle (Klunder and Van Nunen, 2003).

Figure 5.2 shows how the environmental impact is affected by interventions in the original life cycle. The first graph shows the environmental impacts of an original house with an assumed service life of 75 years. These consist of: 1) the environmental impacts of construction in year 0; 2) the environmental impacts of replacements, maintenance, energy consumption and water consumption from year 0 till year 75; and 3) the environmental impacts of discard in year 75.

Intervention increases the environmental impacts of the original house in year X, while extending the life cycle at the same time (see second graph). So, intervention in year X causes the following changes: 1) the life cycle extends from year X to somewhere between year Y_1 and Y_2, depending on the quality of the intervention; 2) the environmental impact increases due to the addition of new components in year X; 3) due to the removal of components which no longer need to be replaced or maintained the environmental impact declines from year X to somewhere between year Y_1 and Y_2; and 4) due to alterations in the energy and water consumption the environmental impact changes from year X to somewhere between year Y_1 and Y_2.

The last graph represents new construction. Here, the environmental

Figure 5.2 Environmental impacts of interventions in the housing stock through time



impacts are expected to increase because of more construction activities compared to renovation and to decrease because of changes in water and energy consumption. As housing transformations are intended to compete with new construction, they may be assumed to have the same service life.

It is vital to be able to draw comparisons between the various interventions in the life cycle of the housing stock, principally because interventions such as renovation are often needed before the anticipated service life of a house has expired. This applies particularly to the renewal of the post-war housing stock. At least, the fact that environmental capital will be destroyed from year X till year 75 has to be taken into account. In fact, the environmental impacts have to be considered from year 0 till year Y_1 and Y_2. Often the period from year 0 to year X is left unconsidered (see e.g. Van den Dobbelsteen *et al.*, 2003). This method also contradicts current views that LCA implies looking at the same period of time (e.g. Hansen and Petersen, 2002). The selection of this period of time is, however, completely arbitrary, because we are dealing with different life cycles which do not necessarily have to be in the same phase. Comparisons based on the same timescale mean that life cycles have to be broken off indiscriminately. Accordingly, it is argued that the average annual environmental impacts from year 0 till year Y should be

Figure 5.3 Housing in Morgenstond Midden

looked at. Then the environmental impacts of interventions with different life expectancies can be compared.

Attempts to draw comparisons between housing interventions and new construction can also present problems due to the fact that the current designs and building methods differ from those of previous decades. For the sake of a clear comparison, new construction is regarded as the same as re-building the original house, including all the interventions. This means that new construction and renovation both lead to the same end result. The assumed service life of housing transformations and new construction is 50 years. It is further assumed that no other radical interventions will be necessary within this period to upgrade the quality. A standard service life of seventy-five years (as assumed by Eco-Quantum) is too long in this context.

5.4 Environmental impacts of housing transformations in Morgenstond Midden[13]

5.4.1 Housing transformation measures

Morgenstond Midden is a housing estate built in the 1950s, consisting mainly of three- and four-storey tenements (see Figure 5.3). According to the renewal plans almost all the housing in Morgenstond Midden is to be demolished. The area is to be transformed into a compact urban garden city (Municipality of The Hague, 2002b). This entails the demolition of 2,350 houses and new construction of 1,650 (Municipality of The Hague, 2002a).

The study on housing transformation options concentrated on one apartment block consisting of 152 houses on four storeys situated on the border of the estate. The storage basements are partly sunk in the ground. The apartment block contains 24 three-room apartments (type B), 24 two-room apartments (type C) and 8 five-room apartments (type A). Most of the apartments are very small, varying from 44-67 m^2. The current differentiation scheme is shown in Figure 5.4.

13 See also Chapter 5 and Appendix 7, Appendix 8 and Appendix 9 in Sustainable Interventions in the Housing Stock.

Figure 5.4 Current differentiation scheme in Morgenstond Midden

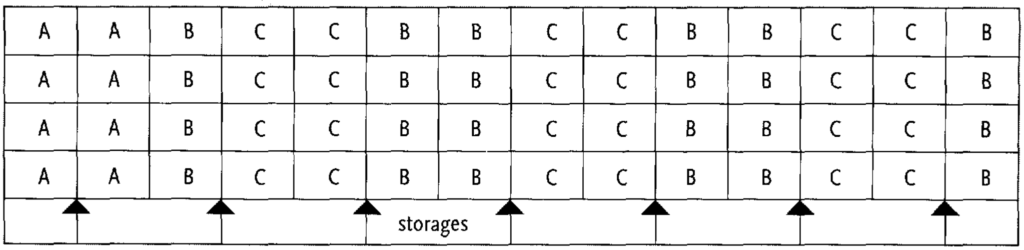


Figure 5.5 New differentiation scheme in Morgenstond Midden

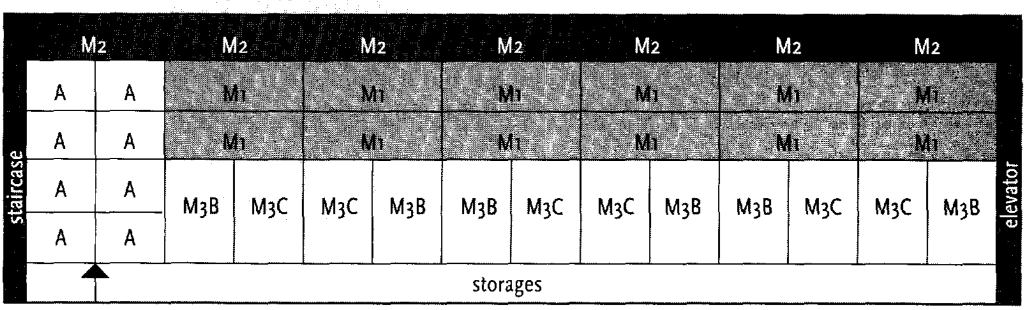
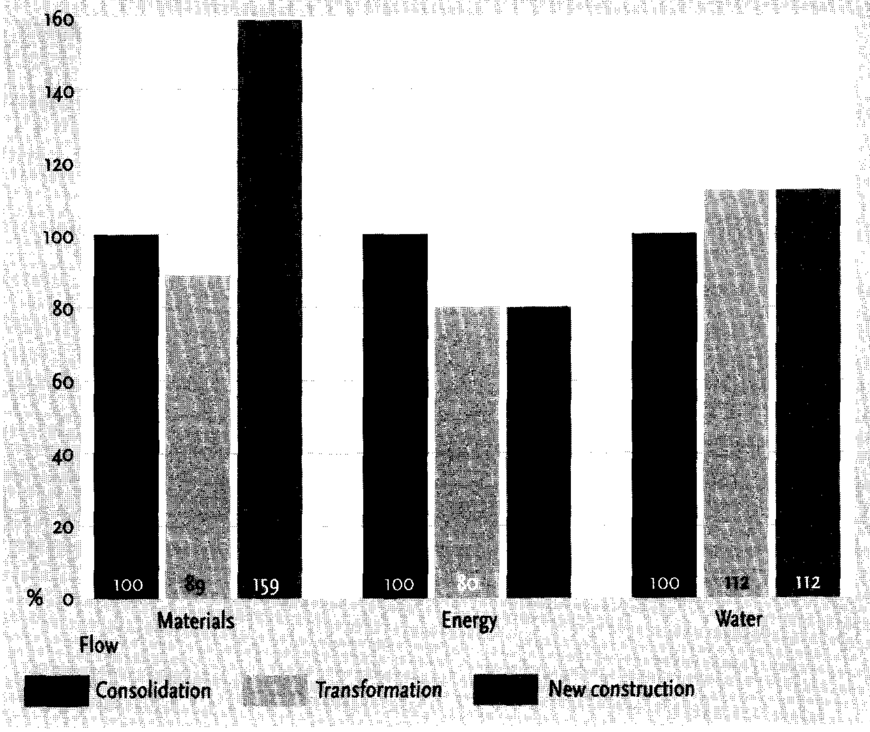


Table 5.1 Housing transformation measures in Morgenstond Midden

Measures	M1	M3B	M3C
Change of floor plan	x	x	x
New stair cases, one with elevator	x	x	x
Inside stairs		x	
Change of facade appearance	x	x	x
Balcony enlargement	x		
Construction of walkways	x		
Inside insulation of facade	x	x	x
Insulation of roof outside	x	x	x
Insulation of floor	x	x	x
Lowered ceilings for vertical sound proofing	x	x	x
Facing walls for horizontal sound proofing	x	x	x
A combined boiler for heating and hot water	x	x	x
Mechanical ventilation	x	x	x

It turned out that the apartment blocks offer good opportunities for transformation. The load-bearing structure and dimensions do not stand in the way of technical solutions which can attract new target groups. A suggestion for a new differentiation scheme is shown in Figure 5.5. Because the building is situated on the edge of the neighbourhood it is possible to add an extra storey. The installation of an elevator will then be feasible and the three upper storeys can be transformed to suit elderly target groups: every two houses on the existing storeys will then be horizontally combined (M1). The new storey can be built in the same style as the existing storeys (M2). The lower two storeys can be vertically combined into maisonettes for starters in the housing market (M3B and M3C). There is no need for major interventions in the five-room apartments. This is the only

Figure 5.6 Flows of materials, energy and water of consolidation, transformation and new construction



apartment type which has future value in its present state.

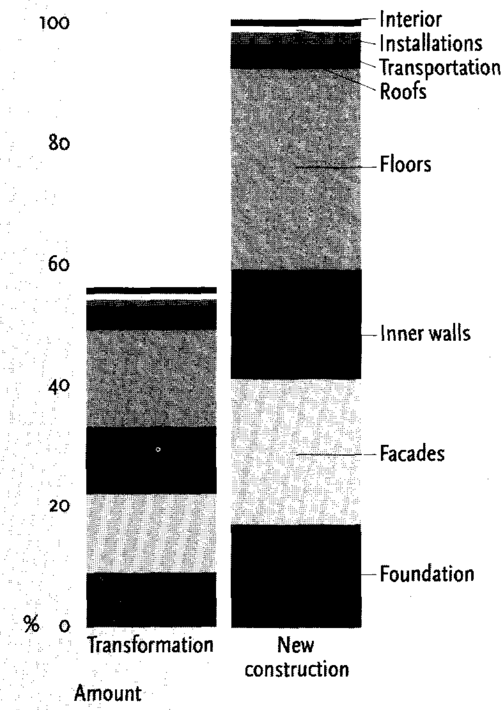
Table 5.1 lists the measures that need to be taken – except for M2, which involves new construction. Obviously, the new differentiation of the housing stock implies new floor plans and facades and improvement measures. After all, transformed housing has to be able to compete with new housing and comply with the latest building regulations. Thermal and sound insulation have to be improved anyhow. The quality of the transformation can be improved by adding private entrances, enlarging the outer space and renewing the installations.

5.4.2 Environmental impacts

The flows of materials, energy and water for consolidation, transformation and new construction are compared in Figure 5.6. It appears that the average annual use of materials is 11% less for transformation than for consolidation. For new construction the use of materials increases by 59%. Energy consumption decreases by 20% for transformation and for new construction, while water consumption increases by 12%. The use of materials for transformation amounts to 59% of the use of materials for new construction. Finally, transformation creates 657 tonnes of demolition waste, whereas new construction creates 4,621 tonnes. Hence, the waste caused by transformation is equal to 14% of the waste caused by new construction.

In Figure 5.7 the use of materials for transformation and new construction

Figure 5.7 Flow of materials per building part for transformation and new construction



is distributed across eight building components. The differences between transformation and new construction relate to the foundation (9% as opposed to 17%), the facades (13% as opposed to 24%), the inner walls (11% as opposed to 18%) and the floors (16% as opposed to 33%). In both variants these building components are responsible for 90% of the use of materials while the distribution of the use of materials over the building components is more or less equal. This is because, in both cases, the components which need to be renewed, i.e. the roof, the installations and the interior, contribute little to the use of materials.

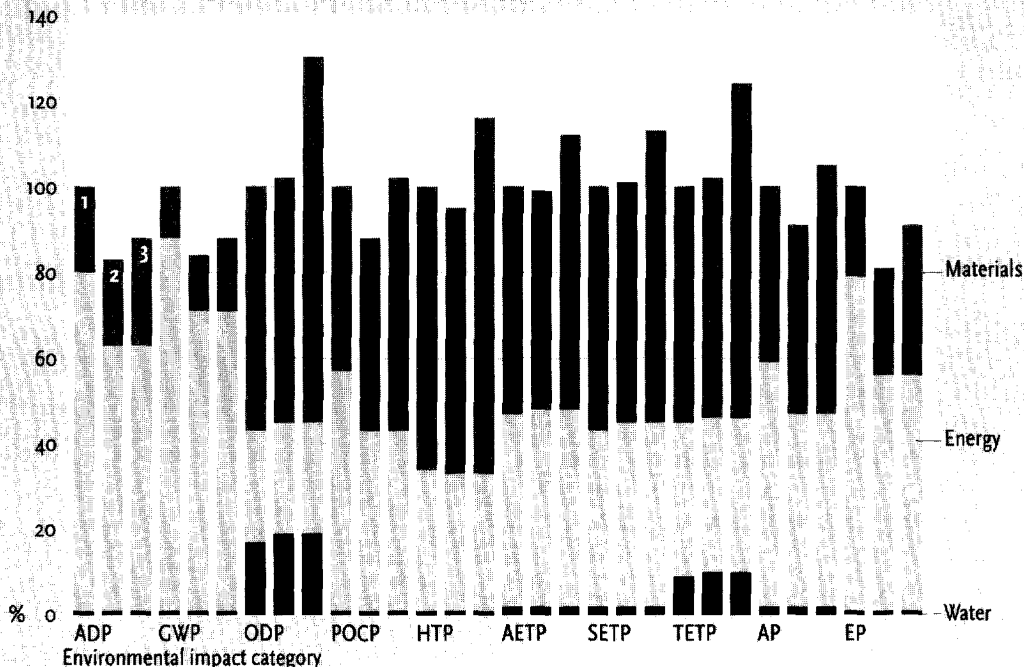
Figure 5.8 shows the environmental impacts. Per environmental impact category the first bar represents consolidation, the second bar represents transformation and the third bar represents new construction. The findings are as follows:

- Transformation as well as new construction scores 9-17% lower than consolidation in depletion of a-biotic resources, global warming and eutrophication.
- Transformation scores lower than consolidation in photo-oxidant formation (12%), human toxicity (5%) and acidification (9%) and scores no higher on any other impacts.
- New construction scores higher than consolidation in ozone depletion (30%), human toxicity (16%), sediment eco-toxicity (13%), terrestrial eco-toxicity (24%) and acidification (5%).
- The remaining scores do not differ significantly (less than 5%).

In transformation the contribution of the use of materials to the environmental impacts roughly equals the contribution of consolidation. In new construction the situation is reversed. The contribution of the energy consumption remains approximately the same or decreases. So, the ultimate environmental benefits of transformation are derived largely from the lower energy consumption. In new construction the higher environmental impact of the use of materials cancels out the lower environmental impact of the energy consumption.

In Figure 5.9 the environmental impacts of transformation and construction are subdivided according to building components. Roofs, installations and interiors are renewed in both transformation and new construction. The

Figure 5.8 Environmental impacts of consolidation (1), transformation (2) and new construction (3)



ADP: depletion of a-biotic resources; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity; AETP: aquatic eco-toxicity; SETP: sediment eco-toxicity; TETP: terrestrial eco-toxicity; AP: acidification; EP: eutrophication.

installations make a major contribution in a number of impact categories. Transportation plays a minor role in this. The differences relate to the foundation, the facades, the inner walls and the floors. The facades have the strongest influence on most impact categories, while the floors are also highly important in new construction.

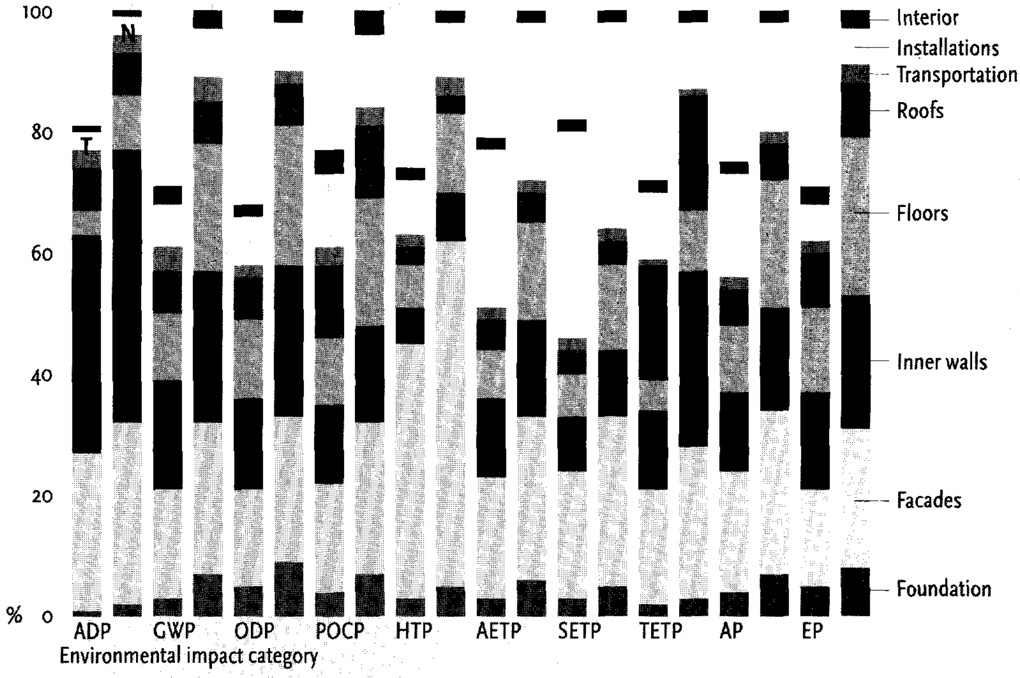
5.5 Environmental impacts of housing transformations in Poptahof[14]

5.5.1 Housing transformation measures

Poptahof was built in the 1960s and consists of walkway apartment blocks (see Fig. 5.10). One thousand and eleven (1,011) dwellings are spread over eight eleven-storey buildings, six four-storey buildings and four blocks of single-family homes. The urban renewal programme proposes to demolish the four-storey blocks and the single-family homes and renovate the eleven-storey blocks (Delftwonen *et al.*, 2003). The eleven-storey blocks form the sup-

14 See also Chapter 6, Appendix 12, Appendix 13 and Appendix 14 in Sustainable Interventions in the Housing Stock.

Figure 5.9 Environmental impacts of the material use per building part for transformation (T) and new construction (N)



ADP: depletion of a-biotic resources; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity; AETP: aquatic eco-toxicity; SETP: sediment eco-toxicity; TETP: terrestrial eco-toxicity; AP: acidification; EP: eutrophication.

Figure 5.10 Housing in Poptahof

Figure 5.11 Current differentiation scheme in Poptahof

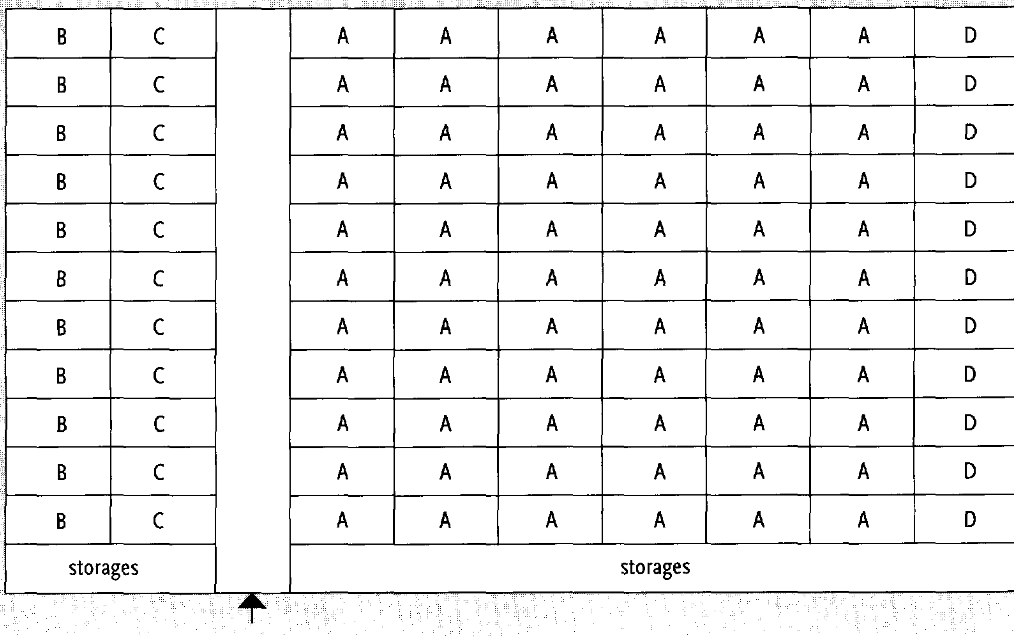
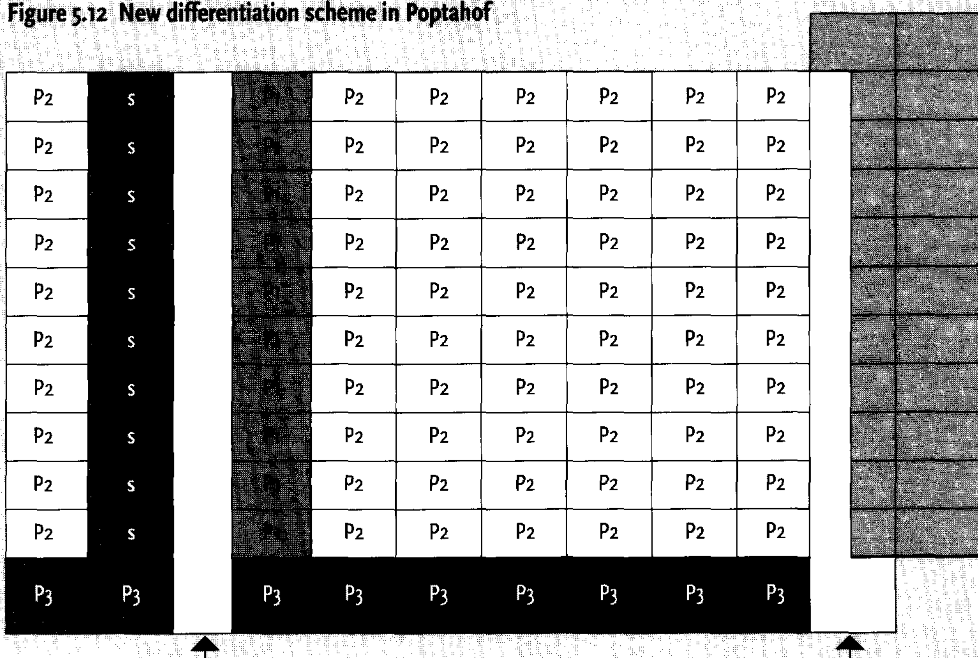


Figure 5.12 New differentiation scheme in Poptahof



porting framework for eight new sub-areas.

The study on housing transformation options concentrated on six eleven-

Table 5.2 Housing transformation measures in Poptahof

Measures	P1	P2	P3
Change of floor plan	x		x
Limited change of floor plan		x	
Replacement of storage basements	x	x	x
Inside stairs			x
New facades, including entry			x
Balcony enlargement			x
Installation of conservatory			x
Replacement of facade panels	x	x	
Insulation of roof outside	x	x	x
Insulation of floor	x	x	x
Lowered ceilings for vertical sound proofing	x	x	x
Facing walls for horizontal sound proofing	x	x	x
Connection to the grid of industrial waste heat	x	x	x
Boiler for hot water	x	x	x
Mechanical ventilation	x	x	x

storey blocks of the same type. Each block has a total of 99 dwellings: 77 with four rooms (type A and B), 11 with two rooms (type C) and 11 with three rooms (type D). The size of the apartments varies between 61-73 m^2. Storage basements are located on the ground floor. Figure 5.11 shows the current differentiation scheme.

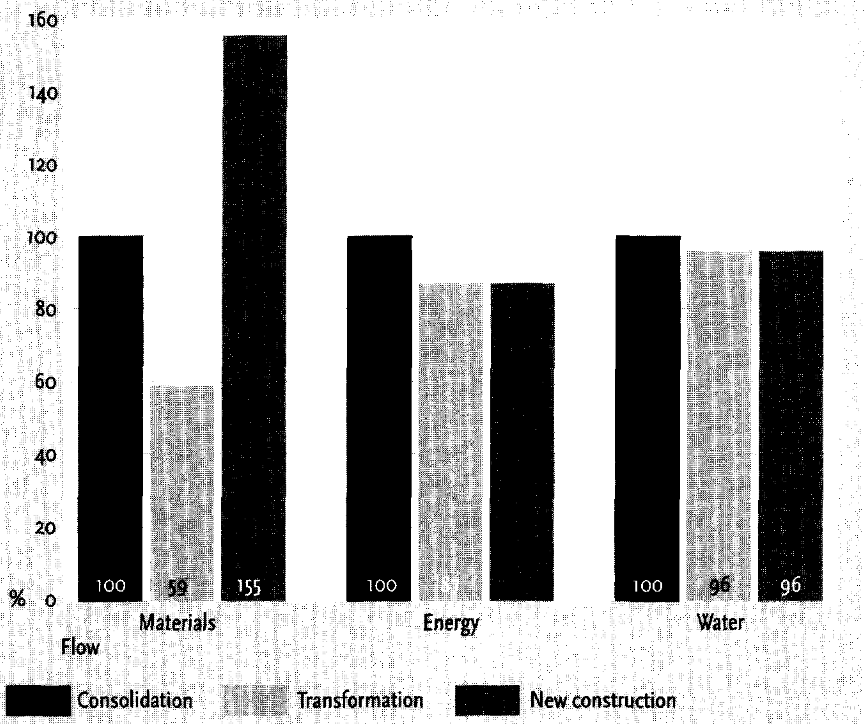
In general, the dimensions of walkway apartments from the 1960s are more appropriate than the dimensions of tenement apartments from the 1950s. The load-bearing wall in the apartments and the sizes of the hallways and corridors offer plenty of scope for transformation. A new differentiation scheme is shown in Figure 5.12 (Architektenburo voor Woningbouw en Stedebouw Henk van Schagen, 2000). First of all, the problem of the characterless ground floors needs to be addressed. Maisonettes for families can be created by using part of the storage basements to join the ground floor with the first floor (P3). The rest can be added to the small two-room apartments next to the elevator. The apartments on the other side of the elevator will then be suitable for renovation with a view to elderly residents (P1). Joint apartment and storage space complies with the requirements for this type of housing. A new entrance with an additional elevator relieves the load on the walkways. The conversion of four-room apartments into three-room apartments will be suitable for starters (P2). New construction at the head of the block can also be targeted for the elderly (hatched area). This was left out of the environmental assessment because it can take any number of shapes and forms.

Table 5.2 lists all measures involved in transformation of the housing in Poptahof.

5.5.2 Environmental impacts

The flows of materials, energy and water necessary for transformation and new construction are compared to consolidation in Figure 5.13. In transformation the average annual use of materials is considerably lower (41%) than in consolidation, while the average annual use of materials in new construction is considerably higher (55%) than in consolidation. Energy consumption in both cases decreases by 12%. Water consumption remains approximately the same. The use of materials in transformation amounts to only 38% of the

Figure 5.13 Flows of materials, energy and water of consolidation, transformation and new construction



use of materials in new construction. Furthermore, transformation creates about 1,047 tonnes of demolition waste, equalling 9% of the demolition waste caused by new construction (11,622 tonnes).

Figure 5.14 shows the use of materials per building component in transformation and new construction. The foundation, the facades, the inner walls and the floors cause by far the most environmental impacts (around 90%). The greatest differences between transformation and new construction relate to the foundation (4% as opposed to 12%), the inner walls (12% as opposed to 31%) and the floors (12% as opposed to 39%). Also, the distribution over the building components differs. Relatively speaking, the facades contribute more to the use of materials in transformation than they do in new construction. The facades are totally renewed in this transformation project. As a result, the foundation and the floors are more important in new construction than in transformation. The differences are negligible for the other building components.

The environmental impacts are shown in Figure 5.15. For each environmental impact category three bars show successively the consolidation scenario, the transformation scenario and the new construction scenario. The findings are as follows:

- Transformation scores lower than consolidation in global warming (9%), ozone depletion (12%), photo-oxidant formation (14%), aquatic eco-toxicity (7%), sediment eco-toxicity (5%), terrestrial eco-toxicity (5%), acidification (12%) and eutrophication (20%).

- Transformation scores higher than consolidation in a-biotic depletion of resources (9%).
- New construction scores higher than consolidation in a-biotic depletion of resources (16%), ozone depletion (25%), photo-oxidant formation (13%), human toxicity (21%), aquatic eco-toxicity (15%), sediment eco-toxicity (16%), terrestrial eco-toxicity (10%) and acidification and scores no lower on any other impacts.
- The remaining scores do not differ significantly (less than 5%).

For most environmental impact categories the contribution of the material use to the environmental impacts diminishes for transformation, while this rises for new construc-

Figure 5.14 Flow of materials per building part for transformation and new construction

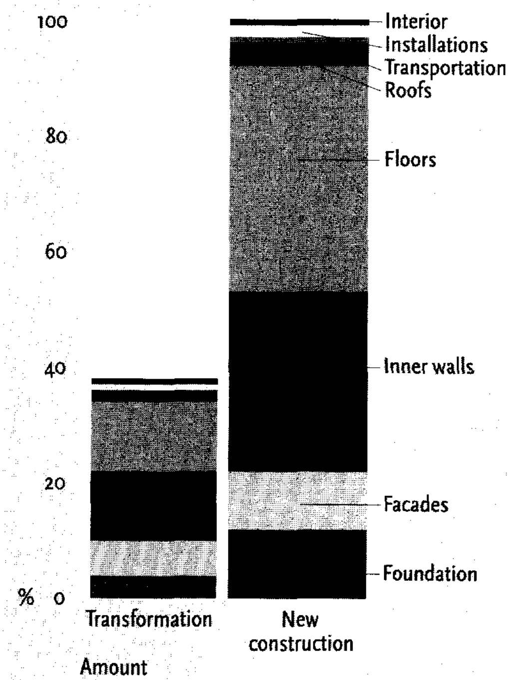
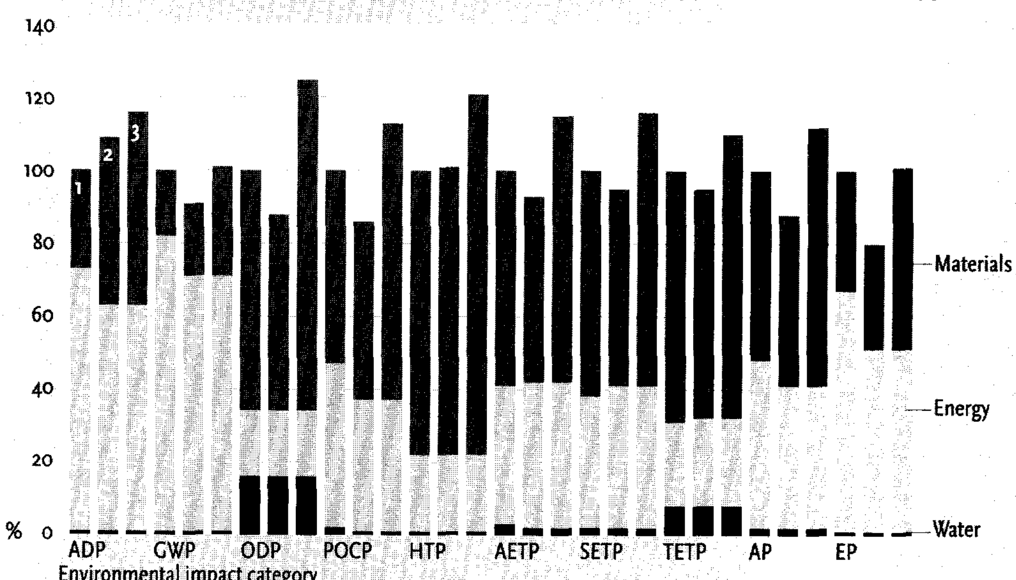
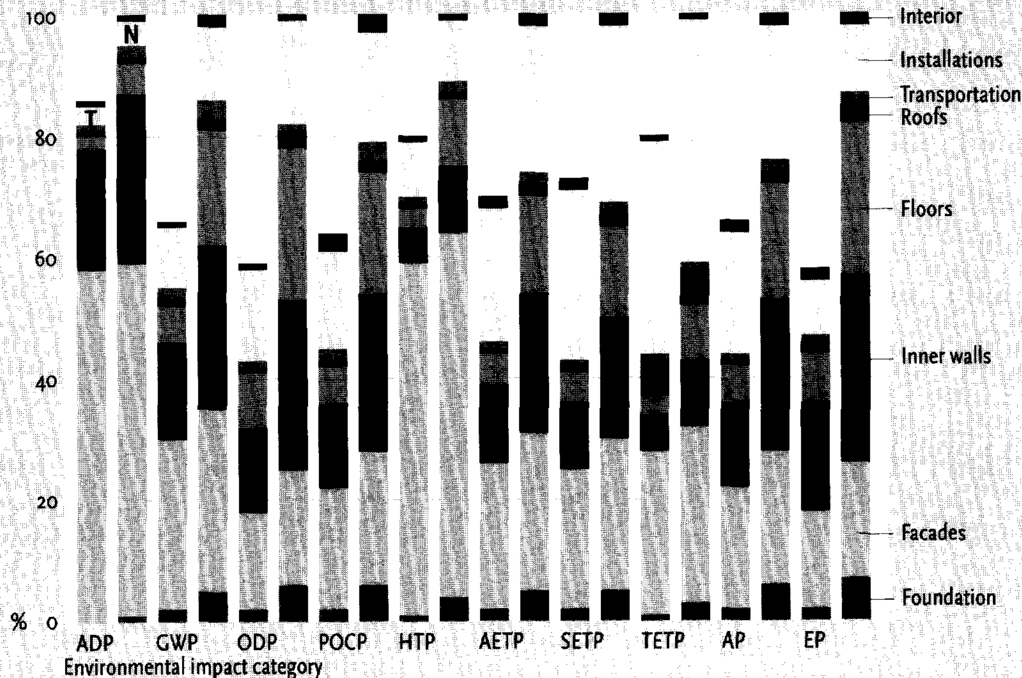


Figure 5.15 Environmental impacts of consolidation (1), transformation (2) and new construction (3)



ADP: depletion of a-biotic resources; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity; AETP: aquatic eco-toxicity; SETP: sediment eco-toxicity; TETP: terrestrial eco-toxicity; AP: acidification; EP: eutrophication.

Figure 5.16 Environmental impacts of the material use per building part for transformation (T) and new construction (N)



ADP: depletion of a-biotic resources; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity; AETP: aquatic eco-toxicity; SETP: sediment eco-toxicity; TETP: terrestrial eco-toxicity; AP: acidification; EP: eutrophication.

tion. Furthermore the contribution of the energy consumption to the environmental impacts decreases on a number of impact categories, but on other impact categories the contribution of the energy consumption more or less is unaltered. The material use contributes an equal amount or more than the energy consumption to the ultimate environmental benefits.

The distribution of the environmental impacts of the use of materials in transformation and new construction is shown in Figure 5.16. Foundation, roofs, interiors and transportation play a minor role. These building components will be largely conserved and hardly renewed. Installations have a sizeable influence on a number of impact categories, but are not entirely responsible for the differences between transformation and new construction. On the contrary, responsibility also lies with facades, inner walls and floors. Most of the time, the facades are the greatest contributor to the environmental impacts. Floors also play a major role in new construction.

5.6 Conclusions

So far, no method has been available for comparing interventions in the housing stock. In this research interventions were seen as an extension of the life cycle of a house. The environmental impacts of the total life cycle were calculated, including those of the original house. Interventions were compared on the basis of the average annual environmental impacts throughout the life cycle. Transformation and new construction were compared on the basis of the same housing programme.

Transformation can fill the gap between consolidation and redevelopment, which are often current practice. The case studies show that transformations are possible in Dutch post-war housing stock. Transformation can deliver substantial savings in the use of materials compared to new construction. However, this huge gain is less visible in terms of environmental impacts. This implies that the building components involved in the intervention have relatively large environmental impacts. Take, for example, the installations. They contribute little to the use of materials, but make a considerable impression on a number of environmental impact categories. Despite the differences in interventions and material savings the outcomes are roughly the same for Morgenstond Midden and Poptahof.

In both Morgenstond Midden and Poptahof, transformation has lower environmental impacts than demolition and new construction. It also has lower environmental impacts than consolidation. That means that the average annual environmental impacts of renovation are lower than the average annual environmental impacts of consolidation, due to differences in material use, energy consumption, water consumption and life cycles. The latter conclusion is not valid for new construction. The largest gain from transformation as opposed to new construction is the reduction in the use of materials and demolition waste. Analysis of environmental impacts, however, is needed in order to make choices which will realise these reductions in the most environmentally friendly way.

5.7 Discussion

Even though the research was limited to two case studies and the Dutch situation, the results are so clear, that one could reasonably expect them to be valid in a much broader range. From the environmental point of view it appears that renovation-based interventions in the housing stock are better options than consolidation and new construction. Of course it has to be borne in mind that transformation will rarely be chosen from an environmental point of view alone. Developments in the housing market are far more important. That said, the dissemination of knowledge on this subject will enable all the parties involved in management of the housing stock to take account of environmental factors. The method for comparing the environmental impacts of interventions in the housing stock is generally applicable, regardless of housing types, country et cetera.

The applicability of the research results has some limitations. First of all, the assumed life cycles are disputable. A service life of 75 years was set for the original house, while a service life of 50 years was set for transformation and new construction, but it is open to question, for example, whether major renovation will be needed again in 30 or 40 years. Sensitivity analyses are needed in order to derive more robust results. It goes without saying that more case studies need to be carried out. However, given the current stage of development of Eco-Quantum, a lot of time is consumed by calculations. It is therefore strongly recommended that Eco-Quantum and other tools will be expanded for use in environmental deliberations on interventions in the housing stock.

Another question pertaining to methodology is whether or not to take the original construction into account. One drawback is that it is almost impossible to get any sort of reliable historical data on the environmental impacts of the building at the time of construction. Furthermore, one might assume that it is equally valid to limit the comparisons to different scenarios starting from present, because, amongst other things, owners and architects of buildings can only influence the future. Additionally, one may feel that transformation might affect the functional unit. At all events, whole-building environmental assessment tools lack clear functional units and system boundaries. These are all interesting subjects for scientific debate.

Finally, the case studies indicate that it is more important to reduce the environmental impacts of energy consumption than of the use of materials. Besides, it appears that interventions aimed at improving the quality of houses, such as thermal insulation and sound proofing, are more important in determining environmental impacts than interventions aimed at re-differentiation of housing types and tenants. These two observations are interesting starting points for further research.

Acknowledgement
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6 Between sustainable and durable

Optimisation of life spans

Source: Klunder, G., 2002, Between sustainable and durable: optimization of life spans, in: Conference Proceedings 9th International Conference on Durability of Building Materials and Components, *17-20 March, Brisbane, Australia, CD-ROM.*

6.1 Introduction

Durability and performance of building components and materials have to be assessed in a much broader context nowadays. Not only building components and materials are being increasingly assessed as part of a building and over the total life cycle today, but also sustainability is an important consideration. Some people interpret sustainability purely ecological, others as prolongation of life spans. The point is that these interpretations are not contradictions, but representations of two aspects of sustainable building. In other words, durability is an aspect of sustainability, although sustainable does not have to mean durable and vice versa. For example, the XX office in the Netherlands was designed to last twenty years at maximum (Klomp and Post, 1999). After this period all materials have to be released, reused or recycled completely. This certainly is not durable, but it can very well be sustainable. The importance of integrating these approaches has already been emphasised (e.g. Duijvestein, 2000; Hendriks, 2000). This paper provides a more objective discussion. It aims at quantifying the potential role of durability in sustainable buildings and building components. It focuses on housing. The study is part of a PhD research about optimisation of the environmental performance of houses.

This paper starts with an explanation of the concept of sustainable development and its relationship to the built environment. It also sketches the paradox between durable and sustainable. Next, the paper elaborates on environmental impact assessment. It describes the methodology of Life Cycle Assessment and the Dutch tool Eco-Quantum. Furthermore, a reference house is introduced for the calculations presented in this paper. After that, the influence of life spans of houses and house components on the total environmental impacts of houses is accounted and compared to the environmental benefits of other strategies to reduce these impacts. Consequently, the paper addresses the problem of allocation of recycling and reuse. This is expected to have a major influence on the question raised in this paper. Methods for allocation are explained and judged upon their consequences for durability and sustainability. Finally, conclusions will be drawn with respect to the importance of life span as a decisive factor for sustainable houses or, in other words, the question is dealt with whether to build for eternity or temporality.

6.2 Linking sustainability and durability

6.2.1 Sustainable development

The report Our Common Future (WCED, 1987) has led to a worldwide notion of the concept of sustainable development, defined as a "development which meets the needs of the present without compromising the ability of future generations to meet their own needs." The commission not only observed that environmental problems need to be addressed, but also social problems, such as inequity, poverty, non-prosperity and the violation of human rights, that are related to explosive population growth and the enormous expansion of environmental harms caused by human activities. According to the commission, solving these problems requires global economic growth whilst respecting ecological constraints.

The concept of sustainable development has been adopted by a growing number of (international) companies, known as the *triple bottom line* approach (Elkington, 1998). The triple bottom line broadens the pursuit of profitability as the traditional bottom line with environmental and social added values. For that, the triple bottom line consists of society, economy and environment, also indicated as people, profit and planet. It conveys that society depends on the economy, whereas the economy depends on the global ecosystem. A healthy global ecosystem is the ultimate bottom line. Another approach is natural capitalism (Lovins *et al.*, 1999), which puts emphasis on solving environmental problems by radically more productive use of natural resources.

Although it is clear that sustainability is not only about eco-efficiency and companies are able to work with it, it is difficult to handle the strategic concept of sustainable development with respect to operational decisions for a sustainable built environment. The ecological conditions strategy (Tjallingii, 1996) offers more opportunities to do so. It does not focus on future results, but on present steps being taken towards sustainability by providing guiding principles. Three dimensions of sustainability are distinguished: the durable diversity of areas, the sustained use of resources and the sustained involvement of actors. These dimensions are indicated in short as areas, flows and actors.

Nonetheless, narrowing the scope from the built environment towards buildings and building components requires sustainability to be translated as the responsible management of flows. After all, on the scale of the building and its components, areas and actors are of minor relevance compared to the scale of the neighbourhood or the city. The definition of sustainable construction, according to the Dutch Ministry of Housing, Spatial Planning and the Environment (1990), confirms this. The ministry explains sustainable construction as directed towards the reduction of the environmental and health impacts consequent to construction, buildings and the built environment. The focus on sustainable housing construction implies a perspective of flows. From this viewpoint, a sustainable house is characterised by the minimisation of the environmental impacts of material use, energy consumption and water consumption during the whole service life of the building.

6.2.2 Durable or sustainable?

Prolongation of life spans of buildings and building components is one of the possibilities to minimise the environmental impacts. In that case, durability comes up, which means appropriate to exist a long time, without unacceptable degradation of relevant functional characteristics (Hendriks, 2000). It is obvious that a building with a life span of 75 years causes less environmental impacts than the same building with a life span of 50 years, assuming that the latter will be replaced by a new one. However, this is not that obvious when comparing two different buildings. In that case, it does not have to be that the building with a life span of 50 years causes more environmental impacts than the building with a life span of 75 years. That strongly depends on the materials used and the energy and water consumption. The same reasoning applies to building components, although energy and water consumption is left out of consideration at that level. Durable building components with a relatively long life span certainly can bring about more environmental impacts than sustainable building components with a relatively short life span. For example, a building component with a life span of 40 years with an environmental burden, which is three times higher than a building component with a life span of 20 years with a three times lower environmental burden, ultimately causes more environmental impacts. Within 40 years, the latter has to be replaced exactly once, so in the end the environmental burden is one third less than the first.

As well as striving for prolongation of life spans of the same building or building component in the same appearance, striving for reuse and recycling of building components and materials is an option to extent life spans. This is sustainable by means of reduction of the environmental impacts during the whole chain of subsequent life spans, but it does not have to be durable. Building components and materials might last shorter, provided that these will be reused or recycled, without compromising the total environmental impacts. Recycling comprehend all processes in the entire cycle of building components and materials, from 'new' to 'old' and from 'old' to 'new', in which the latter stands for secondary materials or products. Unlike recycling, reuse implies that used building components and materials will be used again for the same purpose as before or for an alternative purpose, but at the least in the same function, without further processing other than upgrading (Hendriks *et al.*, 1999b). Often durable materials, such as metals, cause relatively large

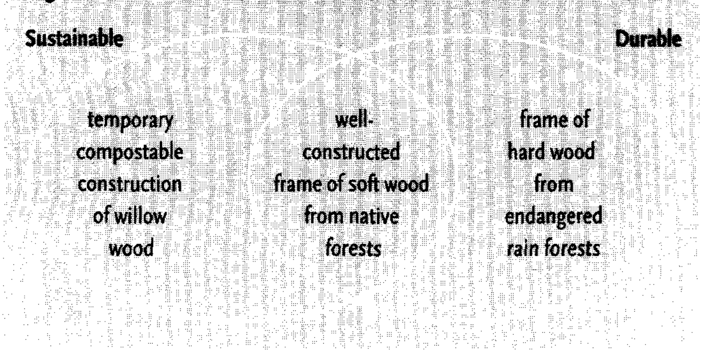


Figure 6.1 Between sustainable and durable

environmental impacts, while these are more suitable for recycling. This complicates deliberations about durability and sustainability. Moreover, buildings have relatively long life spans, which makes it very difficult to predict future reuse and recycling scenarios and innovative construction methods, such as IFD (industrial, flexible and dismountable construction), raising the potential for reuse and recycling.

It is certainly not either durable or sustainable, but it is important to compromise both of them. Duijvestein (2000) has catched this in Figure 6.1. It is essential to consider the entire life cycle to be able to find out the overlap between durable and sustainable. To what extent this overlap exists, is largely unknown. Life Cycle Assessment, or LCA, offers a framework to quantify the match between durable and sustainable.

6.3 Environmental impact assessment

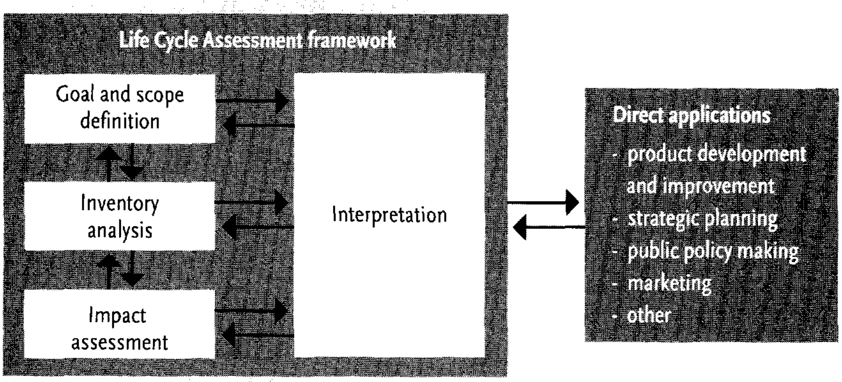
6.3.1 Life Cycle Assessment

LCA is a method for the analysis of the environmental burden of products (goods and services) from cradle to grave, covering the extraction of raw materials, the production of materials, product parts and products, and discard, either by recycling, reuse or final disposal (Guinée, 2002). It is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (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 respectively leave the product system.

The framework for LCA, which has been internationally agreed upon, distinguishes four phases, as is shown in Figure 6.2 (ISO, 1997):

1. The goal and scope of an LCA have to be clearly defined and geared to the intended use. An important part of the goal and scope definition is the determination of the functional unit, which is the quantified function of the product system under study. The functional unit serves as a reference unit in an LCA, e.g. x m^2 floor system with a supporting power of x N/m^2 during x years.
2. Inventory analysis is the second phase of an LCA, in which the inputs and outputs of the product system are compiled and quantified, including natural resources and emissions to air, water and soil.
3. The third phase is concerned with the understanding and evaluation of the

Figure 6.2 Phases of LCA



magnitude and significance of the potential environmental impacts of the product system. Impact assessment encompasses assignment of inventory data to impact categories (classification), modelling of inventory data within impact categories (characterisation) and, only if useful, aggregation of the results (weighting). Examples of impact categories are depletion of raw materials, ozone depletion, acidification and eutrophication.

4. Finally, the interpretation phase contains interpretation of the results of the inventory analysis and impact assessment in the light of the goal and scope definition in order to draw up conclusions and recommendations by means of completeness, sensitivity, consistency and other checks (ISO, 1997).

6.3.2 Eco-Quantum

From international projects, for example, within the International Energy Agency (Knapen and Boonstra, 1999a) and the Green Building Challenge (Cole and Larsson, 2000), it appears that the Netherlands goes ahead concerning the development of environmental assessment tools. Therefore, the Dutch tool Eco-Quantum was used to make the calculations presented in this paper (Mak *et al.*, 1999).

Eco-Quantum has the following features:

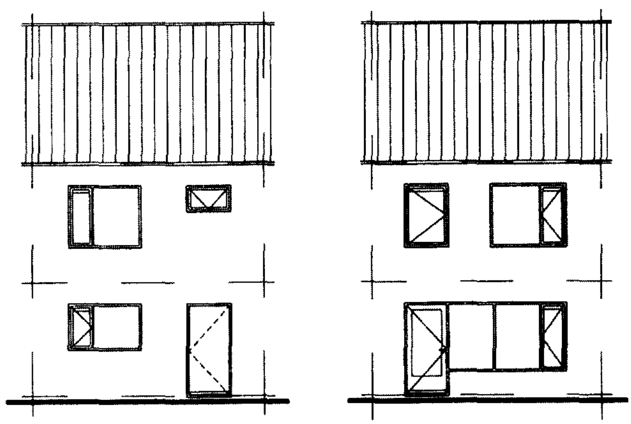
- It is a tool for environmental impact assessment of houses, meant for architects, clients and municipal councils who can use it amongst others for optimising designs, benchmarking and policy framing.
- It conducts an LCA of the flows of materials, energy and water in houses. The flow of materials regards 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 in the occupancy phase of the house.
- Twelve impact categories can be analysed with Eco-Quantum: depletion of raw materials, depletion of fuels, global warming, ozone depletion, acidification, eutrophication, human toxicity, eco-toxicity, photo-oxidant formation, energy consumption, non-hazardous waste and hazardous waste. The latter three are not really impact categories, but pressure indicators (Mega-

Table 6.1 Construction and installation characteristics of the reference house

House component	Characteristics
Foundation	concrete beams and piles
Facades	inner leave of sand-lime brick, rock-wool cavity insulation and outer leave of masonry (R_c = 3.0 m²K/W), frames, windows (U = 1.7 W/m²K) and doors (U = 3.4 W/m²K) of unstamped sustainable wood*
Load-bearing walls	sand-lime brick
Parting walls	plaster
Floors	ground floor of ribbed waffle slabs fitted with EPS insulation (R_c = 3.0 m²K/W) and storey floors of hollow-core slabs
Roof	wooden roof elements clad with unstamped multiplex, insulated with EPS plates and covered with concrete tiles (R_c = 3.0 m²K/W)
Heating and hot water	low-NO_x combined boiler
Ventilation	mechanical ventilation system

R_c: thermal resistance; U: heat transmission.
**) To be understood as a durability category, and not to be confused with sustainable porduced wood. In the latter case we speak of stamped wood.*

Figure 6.3 Drawing of the reference house



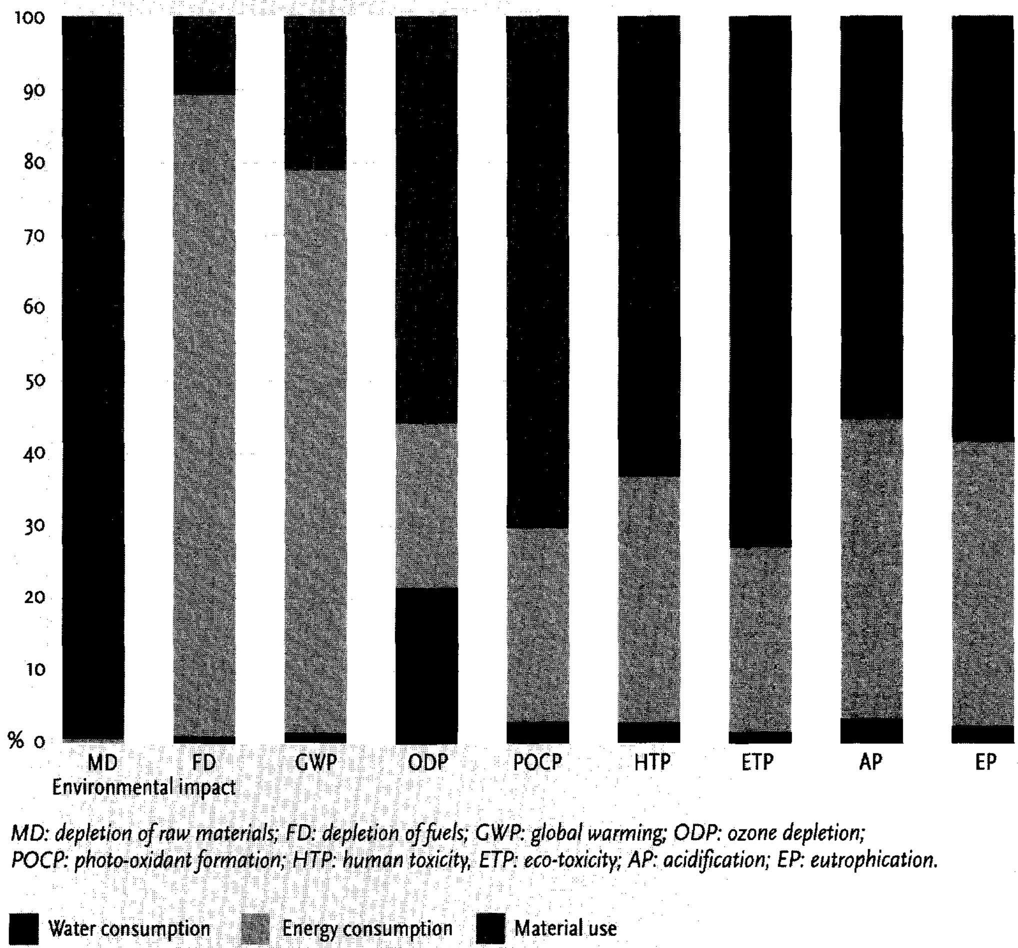
Source: Stofberg *et al.*, 2000

Joules and kilograms). Although such pressure indicators have a strongly recognisable function, this paper sets them aside to avoid double counting.

6.3.3 Reference house

A reference house was chosen to make the calculations. Three types of houses represent current Dutch housing construction: the terraced house, the semi-detached house and the gallery apartment (Novem, 1999a). The terraced

Figure 6.4 Distribution of environmental impacts among material use, energy consumption and water consumption



MD: depletion of raw materials; FD: depletion of fuels; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity, ETP: eco-toxicity; AP: acidification; EP: eutrophication.

house (see Figure 6.3) was set as a reference house for this study, as the most common and wanted house in the Netherlands. It has four rooms and three storeys. It holds a saddle roof and a fixed stair leading to an attic. The living room and the open-plan kitchen are on the ground floor. There are three bedrooms and a shower on the first floor. The usable floor area of the house is 111 m^2; the gross volume is 352 m^3. Table 6.1 gives an overview of the most important construction and installation characteristics of the house.

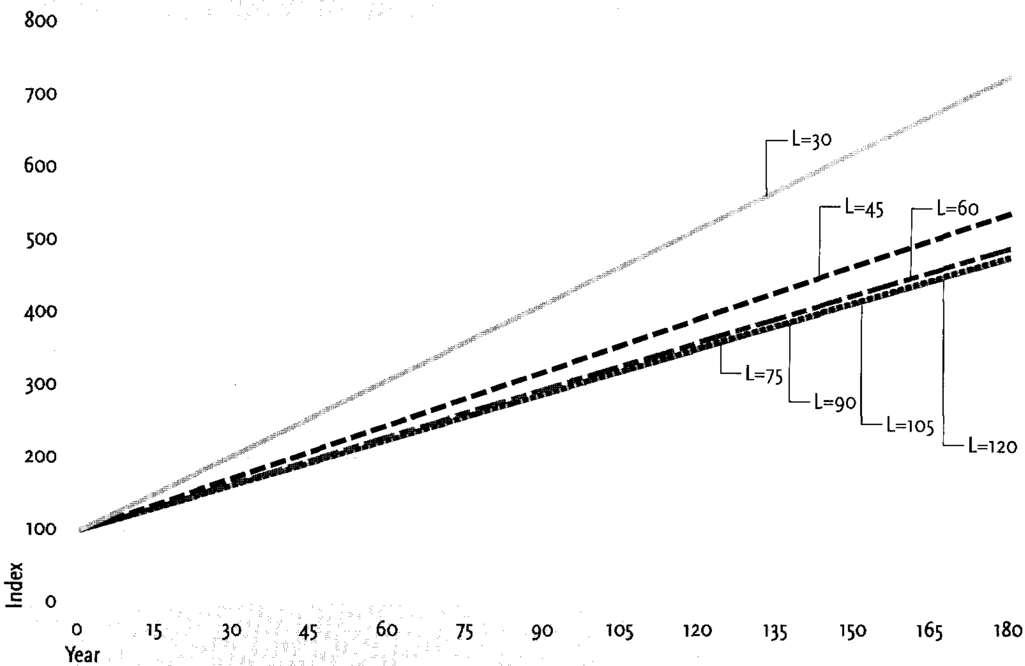
To identify the potential role of life spans of houses and house components on the total environmental impacts, the flows of materials, energy and water of the reference house were taken into account, including replacements and maintenance, but excluding renovations and refurbishments. Dutch houses have an average life span of seventy-five years, so this was assumed as standard life span. Figure 6.4 shows the distribution of the environmental impacts amongst material use, energy consumption and water consumption of the reference house. It turns out that the environmental impacts of material use amounts more than a half on depletion of raw materials, ozone depletion, photo-oxidant formation, human toxicity, eco-toxicity, acidification and euthrophication. Furthermore, the environmental impacts of energy consumption amounts more than a half on depletion of fuels and global warming. Finally, the environmental impacts of water consumption are of importance on ozone depletion only.

6.4 Role of life spans

6.4.1 Life spans of houses

Increasing life spans go together with decreasing environmental benefits
The longer the life span of a house, the higher the environmental impacts of materials, energy and water are, due to replacements and maintenance of house components and energy and water consumption during the occupancy phase of the house. Nonetheless, the environmental impacts per year decrease, because some house components only cause environmental impacts during construction. For instance, the load-bearing structure needs neither replacement nor maintenance in the occupancy phase, so the environmental impacts of construction are the same for all life spans, whether it is 30 or 120 years. Apart from that, there are some house components, which have a remaining life span if the life span of the house is shorter than the life span of the house components. In that case, the environmental impacts per year of a house increase, because these are provoked for a shorter period than the technical life span. Therefore, houses with relatively long life spans yield environmental benefits, while houses with relatively short life spans have to be rebuild once or more in the same period. However, these environmental benefits diminish, because more and more house components need replacement and maintenance anyway. This trend is shown in Figure 6.5 for seven different life spans of houses with respect to depletion of raw materials. The horizontal axis shows the years. The vertical axis contains the indexes of the scores on depletion of raw materials, in which the initial environmental burden during construction was set at 100. Over a long period, i.e. thousands of years, the environmental burden of the houses with relatively short life spans is considerably higher than the other ones. However, as life spans increase, differences in environmental burden decrease. At 75 years, the house with a life span of 120 years has a negligible lower burden and the house with a life span of 30 years a 40% higher environmental burden on depletion of raw materials than the house with a life span of 75 years. The same orders of magnitude apply to the other environmental impacts.

Figure 6.5 Trends in indexes of scores on depletion of raw materials during the years for different life spans of houses



Increasing life spans not always mean decreasing environmental impacts
Over a very long period there is a matter of unambiguous raise of environmental benefits, as life spans become longer. Yet, zooming in on the actual path of environmental impacts during the period from 0 to 180 years demonstrates a more complex image. It can very well be that in a given year in this period the environmental impacts of a house with a longer life span is higher than the environmental impacts of a house with a shorter life span. This is caused by different phases related to construction of new houses at the end of different life spans, as exemplified by Figure 6.6. In this figure the indexes of scores on depletion of raw materials during the years are reproduced for life spans of 30, 40, 75 and 90 years. The straight-up lines represent construction of new houses. The inclining lines represent occupancy phases. Actually, these should not be linear lines, because replacements and maintenance should cause peaks at certain years. However, Eco-Quantum accounts last times replacements in proportion to the remaining life span of the house. Therefore, it is not really justified to compare the houses at any given year. For example, at 180 years the house with a life span of 75 years scores higher on depletion of raw materials than the house with a life span of 45 years. However, the latter then has to be built again, while the first has not even reached half of its life span. In the case of environmental impacts on which energy and water consumption has a very large share (see Figure 6.4), it appears that the environmental burden features an almost linear raise during the years. In that case, houses with relatively short life spans distance itself fairly soon from houses with relatively long life spans, irrespective of the re-

Figure 6.6 Indexes of scores on depletion of raw materials during the years for different life spans of houses

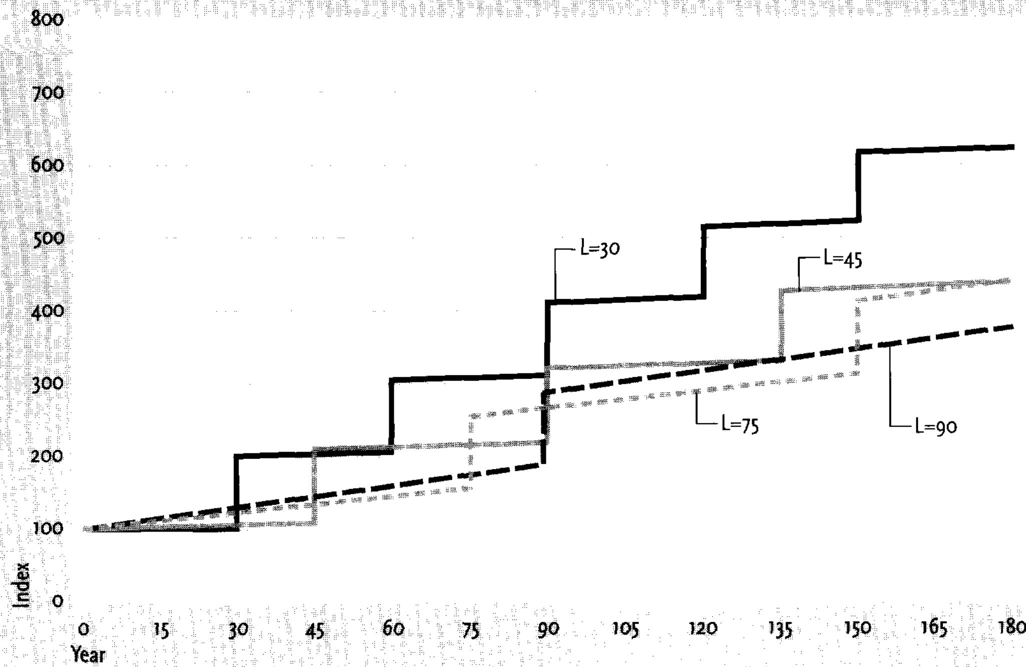


Figure 6.7 Indexes of scores on all environmental impacts for different alterations of life spans of house components

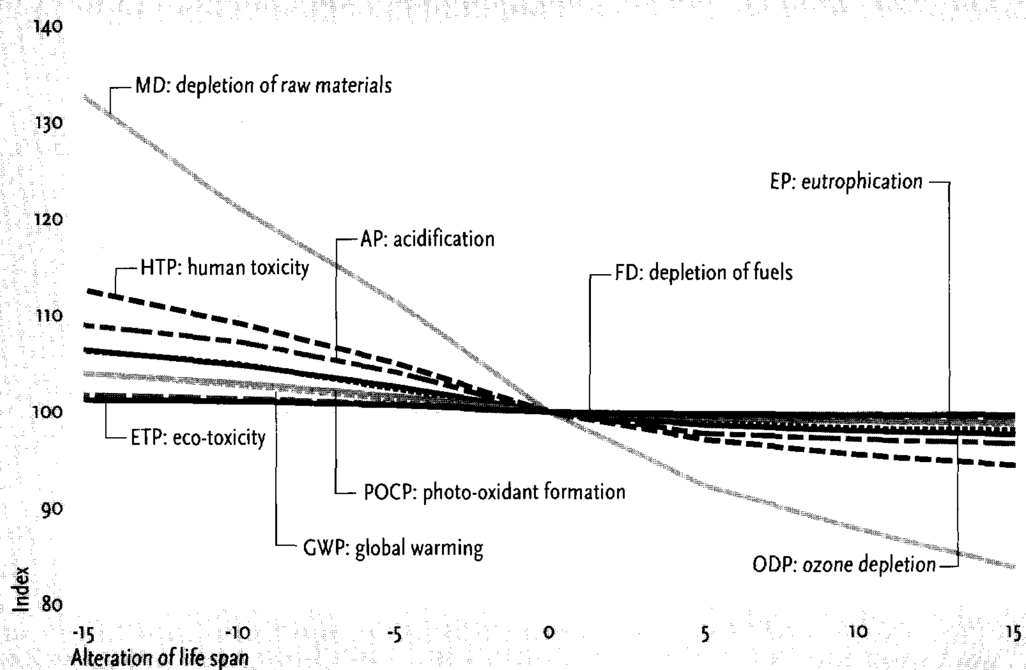
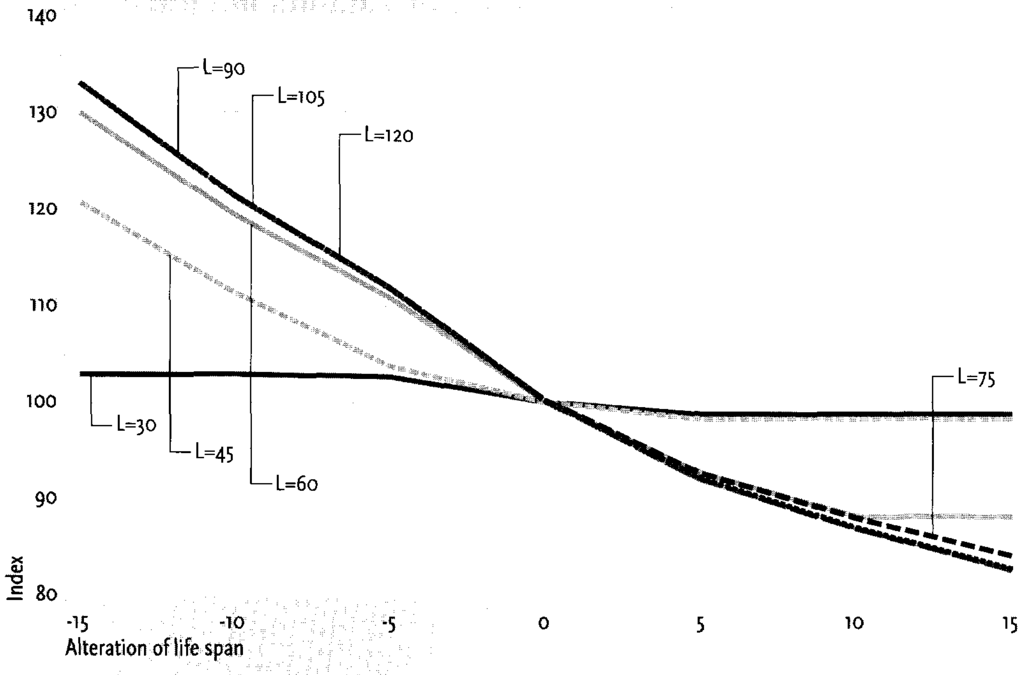


Figure 6.8 Indexes of scores on depletion of raw materials for different alterations of life spans of house components and for different life spans of houses



viewed period. This means that house components, which have to be replaced relatively soon, prevail with respect to the environmental burden.

6.4.2 Life spans of house components

Increasing life spans go together with decreasing environmental benefits
Besides life spans of houses, life spans of house components could have a significant influence on the environmental impacts of houses. Therefore, life spans of a number of house components were varied, namely the outer leave, the window frames, the glazing, the rain proofing, the parting walls, the combined boiler for heating and hot water, the floor coverings and the roof construction. These are components, which exert considerable influence on the environmental impacts of houses (Klunder, 2000a). Load-bearing components were left out of consideration, because their life spans equal the life spans of the houses. The life spans of all components were decreased and increased by 5, 10 and 15 years. Because of the relatively short life spans of the glazing and the combined boiler, these components were only varied between -10 and +10 and -5 and +5 years respectively. Figure 6.7 shows on the horizontal axis the alterations of life spans of house components and on the vertical axis the indexes of scores on all environmental impacts of a house with a life span of 75 years. The reference, i.e. an alteration of 0, was set at 100. It can be seen that fluctuations differ enormously. Depletion of raw materials shows the largest variations, whereas depletion of fuels shows the smallest variations. Moreover, shorter life spans of house components have more conse-

quences than longer life spans. The environmental benefits of an increase of the life spans of important house components by 15 years in a house with a life span of 75 years amount to an average of 4% over all environmental impacts. The environmental drawbacks of a decrease of the life spans of house components by 15 years amount to an average of 9%. The highest raise is 33%, while the highest decline is 16%.

Increasing life spans of house components are particularly useful in houses with long life spans

Figure 6.8 displays the indexes of the scores on depletion of raw materials for seven different life spans of houses. It appears that the alterations of life spans entail minor differences in environmental burden with respect to houses with relatively short life spans. In that case, longer life spans of house components are of no importance, because the life span of the house is shorter for almost all house components then. The longer the life spans of the houses, the lesser are differences between the environmental consequences of alterations of the life spans of the house components.

6.4.3 Environmental benefits of durability against other strategies

Durability is just one of the strategies to improve the environmental performance of houses. Other strategies are, for example, energy saving and renewable energy, dematerialisation, use of renewable materials, use of less environmentally damaging materials, reuse and decrease in maintenance (Blaauw, 2001). Klunder (2001) accounted the environmental benefits of some measures, which belong to three themes: energy saving, flexibility and use of renewable materials. The order of magnitude of environmental benefits, as average percentages over all environmental impacts, vary between a raise by 10% (regarding energy saving by means of installation technology), a decline by 5% (with respect to energy saving through constructional measures and flexibility) and a reduction by 15% (pertaining to the use of renewable materials). However, this fluctuates tremendously per environmental impact, namely from a raise by a factor of 2 to a decline by a factor of 5.

6.5 Role of recycling and reuse

Prolongation of life spans of house components and materials can also be realised through recycling and reuse. It is generally known that life spans of houses and house components as well as recycling and reuse have major consequences for the environmental impacts of houses. However, the environmental benefits of recycling and reuse are very hard to quantify for the time being. As yet, an unresolved difficulty in LCA is allocation. Often it is impossible to link processes in the product system by single material and energy flows. Most processes yield multiple inputs and outputs. These arise out of co-production of a number of products, combined waste treatment processes, production of recyclable material and use of recycled material. Therefore, inputs and outputs as well as associated environmental releases should be subdivided or allocated to the different products (ISO, 1998; Guinée, 2002). Several procedures are applicable for this purpose, such as partitioning on the basis of physical relationships, e.g. mass, or economic value, e.g. scrap value.

Dealing with allocation of recycling and reuse in LCA is even more complex.

- First of all, recycling and reuse may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system.
- Secondly, recycling and reuse may change the inherent properties in subsequent uses. In open loops, which means that building components and materials end up with transformed properties in another product system, the number of subsequent uses of the recycled material belongs to the allocation parameters, besides physical properties and economic value (ISO, 1998). For instance, the environmental benefits of recycling and reuse of house components and materials can be ascribed to the house from where these materials come from, but also to the house in where these materials will be used again. Besides, house components and materials can be recycled in product systems with lower-grade properties, such as concrete granulates in road constructions. Finally, upgrading and recycling processes also cause environmental impacts, which diminish the environmental benefits.

Hendriks *et al.* (1999a) distinguish the following four kinds of allocation procedures:

- Cut-off method: the environmental impacts of all processes in the product system are allocated to product A, with the exception of the environmental impacts of upgrading processes, which are allocated to product B.
- Co-production and upgrading method: the environmental impacts of a whole product system are distributed over product A and B in case of co-production, but in case of upgrading only the upgrading processes are distributed over product A and B.
- Subtraction method: the environmental benefits of recycling are allocated to product A by means of subtraction of a process, which would have taken place otherwise.
- Environmental impacts of primary production: the environmental impacts of primary production are distributed over product A and product B on the basis of the extent of recycling and quality losses.

Eco-Quantum handles allocation according to the most simple, but rough, cut-off method. The basic principle behind this choice is that no allocation of environmental benefits takes place now, while these benefits have to be realised in the distant future (Mak *et al.*, 1999). Nevertheless, it underestimates the environmental benefits of recycling and reuse, because for the use of secondary materials and products general figures are applied, in which no special design methods, such as design for recycling or design for disassembly, are taken into account. Durability is better off in this context than sustainability, because not the whole life cycle is considered. It is of great importance to gain more insight in the environmental benefits of recycling and reuse, notwithstanding allocation problems. Thormark (2000) subscribes to the viewpoint that future environmental benefits should not be allocated to the original product, like the subtraction method, but establishes that due to allocation problems the phases after demolition of buildings are either excluded or handled in a rather limited way. Therefore, Thormark argues for considering the potential of recycling next to the total environmental impacts. This definitely is an interesting approach to reflect the environmental benefits of recycling and reuse, as well as to compare different scenarios, so future conditions and uncertainties can be assessed. This kind of information is indispensable for optimisation of life spans.

6.6 Conclusions and recommendations

This chapter addressed two fields of tension between durable and sustainable.

1. Houses, house components and materials with long life spans, but with high environmental burdens, against houses, house components and materials with short life spans, but with low environmental burdens.
2. Houses, house components and materials with high environmental burdens, but suitable for recycling and reuse, against houses, house components and materials with low environmental burdens, but unsuitable for recycling and reuse.

Concerning the first field of tension, this paper presented calculations on the influence of life spans of houses and house components on the environmental impacts of houses, making use of Eco-Quantum and comparing to a reference house. This led to three main findings:

- Prolongation of life spans yields incontestable environmental benefits, because the environmental burden diminishes on all environmental impacts. Thus, a house with a life span of 30 years scores 33% worse and a house with a life span of 120 years negligibly better than an house with a life span of 75 years. However, in a certain period, this has not to be this way, because differences in phases occur with respect to new construction of houses, which produces a leap upwards of the environmental impacts.

- Furthermore, prolongation of life spans with 15 years of some important house components leads to a decrease of environmental impacts by 4% with regard to a house with a life span of 75 years, while shortening in the same way leads to an increase of environmental impacts by 9%. Longer life spans of house components are not useful in houses with relatively short life spans. With regard to houses with relatively long life spans the environmental benefits of alterations of life spans of house components are almost the same for every house, whether these have a life span of 75 years or 120 years.
- The results on other strategies, such as energy saving, flexibility and use of renewable materials are much more ambiguous due to improvements on some environmental impacts, while others are getting worse. The investigated strategies result in orders of magnitude of environmental benefits between 5 and 15%, although in one case studied a drawback by 10% was observed. Nevertheless, these figures differ greatly per environmental impact.

This results in the conclusion that durability is not a decisive factor in sustainability, although it remains an important aspect of it. Although a Dutch terraced house was used as a reference, this conclusion is expected to be generally valid.

Regarding the second field of tension, this paper discussed the problem of allocation of recycling and reuse, which obstructs gaining knowledge on the environmental benefits of recycling and reuse. The cut-off method in Eco-Quantum disadvantages designs, which anticipate on future recycling and reuse. Therefore, the environmental benefits of durable houses and house components should be seen in a broader perspective. Until now, methodological difficulties in LCA overshadow discussions on the potential of recycling and reuse, while this can put a much more positive view on houses with relatively short life spans.

Further investigation on the items mentioned above is needed to answer the question whether to build for eternity or temporality. Within this framework it should be regarded to what extent the XX philosophy offers starting points in housing. The XX philosophy is based on the continuing shortening of economic life spans of office buildings in particular. Nonetheless, also construction of houses has to contend with heightening consumer's wishes and fastening technological developments. Therefore, maybe this thought will provoke an impulse for innovative house designs, in which the right balance between durable and sustainable will be found.

7 The factor of time in Life Cycle Assessment of housing

Source: Klunder, G., and H. van Nunen, 2003, The factor of time in life cycle assessment of housing, in: Open House International, *28 (1), pp. 20-27.*

7.1 Introduction

Life Cycle Assessment, or LCA, is a widely accepted method to assess the environmental burden of products from cradle to grave, including the extraction of raw materials, the production of materials, product parts and products, and discard, either by recycling, reuse or final disposal. A framework for LCA has been internationally agreed upon (ISO, 1997). LCA-based calculation models are available to determine the environmental impacts (i.e. global warming, human toxicity and acidification) caused by houses. With the exception of service life predictions the factor of time has not been dealt with in LCA until now. Changes over time, being changes in the house and changes in technology, are not mentioned. In the case of simple products with a service life below 10 or 15 years incorporating the factor of time makes LCA an unnecessarily complex task. However, as a particular characteristic of houses is that they have a long service life, neglecting the factor of time in environmental assessment of housing introduces major shortcomings and inaccuracies. The aim of this article is to identify and classify the aspects comprising the factor of time and to seek solutions to handle these aspects in LCAs. This should improve the accuracy of calculations on the environmental impacts of housing.

The article is structured as follows. Section 7.2 gives an introduction to environmental problems and presents LCA as a tool to measure environmental impacts. Some general gaps in the LCA methodology are indicated, and the factor of time is introduced. In Section 7.3 specific characteristics of the construction industry are addressed which have implications for carrying out building-related LCAs. The differences between a house and a consumer product are explained. Section 7.4 divides the factor of time into six aspects. How to handle these aspects is the subject of Section 7.5. Finally, conclusions are drawn in Section 7.6.

7.2 Development of the LCA methodology

7.2.1 Knowing the environment

A growing awareness of the environment is a development of the last decade. Although the first serious signs became known several decades ago, the awareness of the need to take real action appeared later. Environmental problems were first mentioned in 1972, in a report called *The limits to growth*

(Meadows *et al.*, 1972) written under the authority of the 'Club of Rome'. It gave a picture of the world within thirty years, if nothing changed. This is the first study that indicates the future of the environment. In this report, the world economy plays an important role in the increase of the environmental burden.

In 1987 the World Commission on the Environment and Development (WCED) published the report Our Common Future (WCED, 1987). This report, the so-called 'Brundtland-report', again mentioned economic aspects, but also introduced social (UN, 1982) and ecological aspects. The Brundtland-report anticipated economic growth, but for the first time a disconnection between the growing economy and the decline of the environment was seen as a possibility. According to Brundtland, economic growth did not automatically have to involve environmental decline, but that new techniques and increased responsibility for the existing techniques was required.

All sectors of the economy have to contribute to improving the environment. The need for a global environmental policy is obvious. Because of the conflicting interests of some countries this has not yet come into being. The construction industry is cooperating at an international level, for instance in the PRESCO project (Practical Recommendations for Sustainable Construction), which seeks to facilitate the exchange of experience and the transfer of knowledge (PRESCO, 2002). Currently, buildings and their inhabitants are estimated to consume approximately 40% of the total energy, to be responsible for about 30% of CO_2 emissions and to generate around 40% of all man-made waste (Bourdeau, 1999). Due to the constant need for buildings eco-efficiency within the construction industry could have a huge impact, but it needs the environment to be brought out of obscurity and defined in measurable terms.

7.2.2 Making environmental impacts measurable

In 1996 SETAC (Society of Environmental Toxicity and Chemistry) formed a working group on Life Cycle Assessment (LCA). This term had already existed for a long time, but became well known in about 1990. It stands for the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 1997). The complete field of LCA is described in the ISO 14000 series, so the methods to produce environmental figures are defined. However, different assessment methods are available, the guides of CML (Leiden Centre for Environmental Studies) (Heijungs, 1992; Guinée, 2002), Eco-indicator 95 and 99 and EDIP are all examples of widely-used methods (Goedkoop *et al.*, 2001), each of which has been initiated independently. With the ISO standards, aspects like functional units, processes and boundaries are taken into account in every method. However, as the ISO standards are still open-ended regarding standardisation, there are differences in methods dealing with certain issues. This has consequences for the outcomes of LCA.

Further research has to be conducted to address these shortcomings in the LCA methodology, which include allocation, weighting, data reliability, bio-diversity and nuisance. Firstly, there are different opinions about allocating energy and material flows to a process, especially in processes that are sequential. Do materials that come out of a product have any value, economic or otherwise, and if so, does the environmental burden shift from the original product to the next (Vögtlander *et al.*, 2001; Borg *et al.*, 2001)? Secondly, weighting remains a widely discussed issue. The advantages of putting everything into a single score are opposed by the discussions of defining the weighting factors or losing information within an eco-profile (Schmidt and Sullivan, 2002). Thirdly, data collection for Life Cycle Inventories (LCI) is still a critical factor for successful work in the area of LCA (Huijbregts *et al.*, 2001). Without reliable data there is no possibility of achieving a reliable assessment. Then there is the discussion about bio-diversity and nuisance. The aspects that are implemented in LCA can be measured, but how is it possible to measure bio-diversity or nuisance and make it part of LCA? All these aspects are currently being researched. They might be called general problems of LCA, because they occur in a wide range of assessments, whether it is a coffee machine, aeroplane or a building. Besides these general issues still to be solved in the LCA methodology, some problems relate specifically to the use of LCA in the building industry, and these are discussed in the next section.

7.3 Use of LCA in the building industry

LCA studies of building components are comparable to LCA studies of many other products. In the building industry LCA studies were carried out on, amongst others, window frames (Hoefnagels *et al.*, 1992), insulation products (Seijdel, 1995) and concrete floors (Fluitman and De Lange, 1996). However, application of LCA on whole buildings entails major difficulties. There are three important reasons for this.

Firstly, each building has its own characteristics and contains a very large number of components and materials. Stuip (1993) compares buildings to consumer electronics. The latter concerns mainly mass-produced products, while buildings are, to a much larger extent, unique. This makes it rather complicated to draw general conclusions on building design and construction and their environmental consequences.

Secondly, buildings have extremely large service lives in comparison with, for example, electronic equipment such as computers. Differences in the order of magnitude of a factor of ten are no exception (Stuip, 1993). As a result of the longevity of buildings one of the problems is that the end-of-life stage is hardly predictable, as this will take place in the distant future. Kortman *et al.* (1996) conducted a study to estimate the environmental impacts of the end-of-life stage of long-cyclic products, namely water pipes, crash barriers and gutters. These are relatively simple products. Whole building assessment introduces an accumulation of uncertainties regarding end-of-life scenarios.

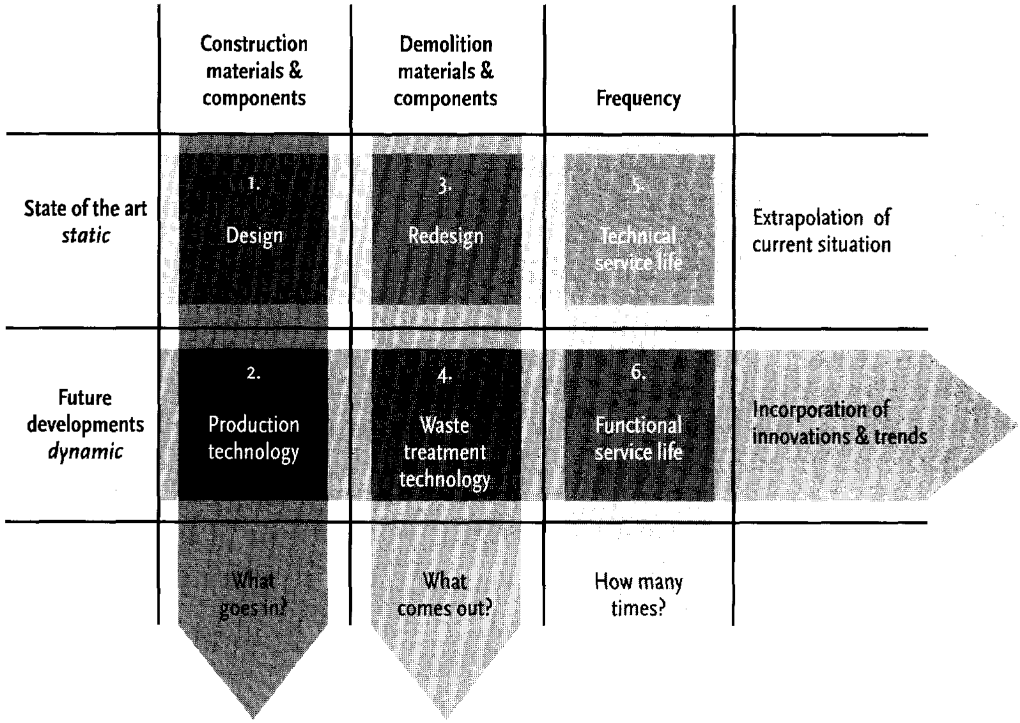
Thirdly, incremental changes feature in the building industry. The building industry mostly follows technologies developed in other branches of industry. Thus, it is not so much the building industry itself that directs new developments and innovations, but, for instance, the synthetic materials industry and the computer industry (Stuip, 1993). This implies that there are many influences on the development of the building and construction industry, and it is difficult to predict what will be adopted and how they will be implemented.

Environmental information on construction products and tools for the environmental assessment of buildings is available. In many countries whole-building environmental assessment tools have been developed or are being developed, including Eco-Quantum in the Netherlands, Envest in the United Kingdom, EcoPro in Germany and ESCALE in France. These tools have been designed for use in the determination, analysis and improvement of the environmental performance of buildings (Knapen and Boonstra, 1999a). Furthermore, the amount of environmental information on construction products is growing. Various countries have introduced LCA-based environmental declaration systems, such as Environmentally Relevant Product Information (MRPI) in the Netherlands and Environmental Profiles of Construction Products in the United Kingdom (CEPMC, 2001). This enhances the uniformity in the methodology of data collection and provision, making environmental information more unambiguous, reliable, accurate, transparent and harmonised. The Netherlands is even preparing to include environmental performance requirements for materials used in buildings in the Dutch Building Decree (Scholten *et al.*, 2000a). This strengthens the need for making the factor of time manageable.

7.4 Classification of aspects of the factor of time

For identifying and classifying the various aspects of the factor of time a single house is taken as a starting-point. Many changes occur in the features of the house over time, due to maintenance, replacements and renovation. In the operational phase new construction materials and components will be added and demolition materials and components will be discarded. Over time technological developments continue, which has consequences for the environmental efficiency of products and processes. These changes in the house as well as in

Figure 7.1 Classification of the aspects of the factor of time



technology introduce uncertainties when considering the factor of time.

Looking at changes in the house the factor of time has three kinds of uncertainty:

1. in-going materials and components;
2. out-going materials and components;
3. number of times materials and components will be going in or going out as a result of the end of service lives.

Looking at changes in technology we discern two kinds of uncertainty:

1. static approach, which means that assessment of a house is based upon extrapolating the current situation for the period of its service life;
2. dynamic approach, which takes into account innovations, changes and trends.

Figure 7.1 classifies the various aspects of the factor of time, according to the type of uncertainty. The columns represent the kind of uncertainty, related to three central questions: What goes in?, What comes out?, How many times? The rows reflect the distinction between a static and a dynamic approach. In this way six different aspects of the factor of time can be distinguished. Each of them will be explained below, taking window frames as an example:

1. Design

   The first aspect of the factor of time is design. This concerns in-going construction materials and components from a static point of view, which means that maintenance, replacements and refurbishment take place with current construction materials and techniques (extrapolation of present day techniques). Taking wooden frames as a starting-point, new frames can also be of wood, but there are two other possibilities, introducing uncertainties to this aspect of the factor of time. Firstly, new frames may be made of a material other than wood, such as synthetic material or steel. Secondly, refurbishment may result in new or adjusted components, for example the enlargement of window openings in the facade of a house. These uncertainties are concerned with changes in the housing design.

2. Production technology
   The dynamic point of view takes into account future developments in production technologies. Components do not keep the same characteristics during their service life, even though components are fabricated from the same materials. A wooden window frame today will be different from a wooden window frame tomorrow, due to modifications in material compositions and production processes (innovations). This is also the case if synthetic window frames or a newly developed alloy replace the wooden window frames.
3. Redesign
   The third aspect of the factor of time is redesign. This implies recycling and reuse of materials and components in a new house after their end-of-life in the original house or after the end-of-life of the whole house. A static point of view means that waste treatment scenarios, which is the division between dumping, incineration, recycling and reuse, are fixed during the service life of the house. Especially recycling and reuse cause uncertainties, because there are many reasons not to profit from technological possibilities. Amongst others, wooden window frames might not be appreciated any more in fifty years' time because they are considered too old-fashioned.
4. Waste treatment technology
   From a dynamic point of view there are uncertainties regarding waste treatment technologies. Recycling and reuse have not reached their highest level yet, including the recycling and reuse of window frames, but it is expected that these ways of waste treatment will grow to the detriment of dumping and incineration. Waste treatment processes and repairing processes to make components and materials suitable for redesign also belong to this factor of time. So, waste treatment technology comprehends waste treatment scenarios as well as processes.
5. Technical service life
   The technical service life indicates the period over which a certain product can fulfil its function. Service lives of products in practice can differ from theoretical values, due to house-specific conditions. For example, window frames last longer when protected by overhangs or when fitted in a house situated in a friendly climate zone. Besides, when the service life of window

frames is over but the remaining service life of the house is limited, the frames will often no longer be replaced. These are uncertainties in technical service lives.

6. Functional service life
   The functional service life is the period over which a certain product can fulfil expectations. Often products are replaced before there is a technical necessity to do so. In the case of window frames, aesthetic or convenience reasons may influence the need for replacing wooden frames with synthetic ones. The uncertainties of functional service lives concern the moment when people turn to technically unnecessary replacements.

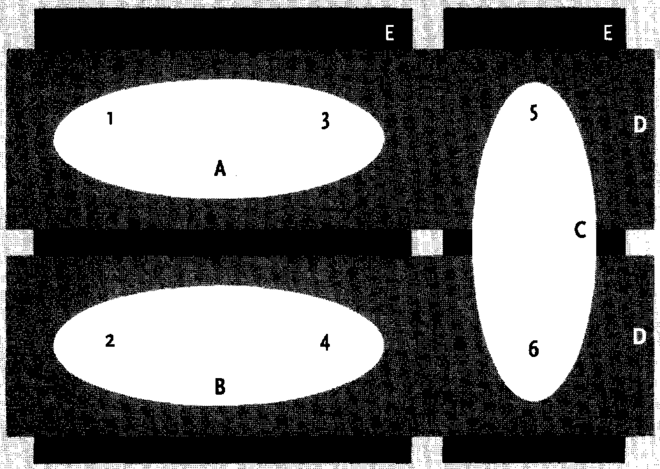
These six aspects of the factor of time have to be dealt with in LCA. As we already know much about the aspects, which in their turn influence technical service lives, we are therefore considerably able to predict technical service lives. However, exogenous factors, including legislation and economic growth, are also important and also change over time, though independently of the six aspects included in the classification. Although some aspects, in particular static uncertainties, are to some extent predictable, future developments as well as exogenous developments cannot be completely foreseen. The important question, however, is not the exact causes, but how to deal with the different aspects of the factor of time in LCA of housing?

7.5 Dealing with the factor of time in LCA of housing

7.5.1 Relations between the aspects of the factor of time

Each of the aspects of the factor of time states a significant aspect in which time can influence the environmental performance of a house and its components. To come to solutions for dealing with these aspects in LCA, we first describe several relations between these. We have identified the following as pairs which can be handled in a similar way: the aspects design (1) and redesign (3), production technology (2) and waste treatment technology (4), and technical service life (5) and functional service life (6). On the other hand, the aspects design (1), redesign (3) and technical service life (5) have to be treated in a different way to the aspects production technology (2), waste treatment technology (4) and functional service life (6). This can also be said for the aspects design (1), production technology (2), redesign (3) and waste treatment technology (4) against technical service life (5) and functional service life (6). The relations, indicated by A through E, are illustrated in Figure 7.2 and explained below.

Figure 7.2 Relations between the aspects of the factor of time



A. Design (1) and redesign (3) both handle materials, one constructing them, the other demolishing them. Currently, these factors are for a large part being taken into account, but aspects like refurbishment and use are not. Furthermore, new ideas, like adding flexibility to a building, cannot easily be calculated with the current tools. The result is a building that provides flexibility, but the environmental assessment shows a higher environmental burden because of specific material and design choices. The fact that this building can more easily be adapted is often not considered.

B. Contrary to design and redesign the aspects production technology (2) and waste treatment technology (4) are often not mentioned at all. These two factors indicate an advance in technology. The way these advances will develop over time depends on different aspects (i.e. economy, wealth, knowledge), and so the impact on the performances these products achieve cannot be predicted easily. These aspects are often not accounted for when performing environmental assessments. Within a larger time span, common in the building industry, the developments can make a significant difference to the environmental burden.

C. Finally, technical service life (5) and functional service life (6) are comparable aspects. There are two reasons why working with standard service lives, which tools generally do, does not reflect the actual situation. Firstly, theoretical values on technical service lives do not often correspond to practical values. Secondly, the functional service life may be of greater importance than the technical service life.

D. Within the six aspects of the factor of time contrasting groups can also be examined. Until now, LCAs dealt with a static cradle-to-grave approach (aspects 1, 3 and 5), which means that assessment of a house is based upon extrapolation of the current situation for the period of its service life. Innovations and trends are not taken into account (aspects 2, 4 and 6).

E. Another difference within the factors of time can be found between the material related aspects (1, 2, 3 and 4) and the service life aspects (5, 6). The issue of uncertainties about service lives has already been recognised, while knowledge about the causes for differences in material related aspects is limited.

7.5.2 Solutions for including the aspects of the factor of time in building LCAs

Splitting the factor of time into aspects and grouping them together again helps to explore which solutions suit which aspects best. Possible solutions are working with scenarios, turning points, sensitivity analyses and potentials.

Scenarios reflect possible futures, so they are a possibility to take changes over time into account. Working with scenarios seems especially appropriate when taking refurbishments into account. Refurbishments concern changes in time aspects 1 and 3 as well as 5 and 6. The scenarios define time, extent and quality of the changes. Although these elements are hard to predict, the choice of scenarios is important. After all, accurate scenarios make for accurate assumptions and form accurate input data for LCA.

Turning points can also support environmentally sound decision-making. This can be seen as a specific form of scenario analysis. For instance, bringing more materials into a building to achieve a certain level of flexibility will increase the environmental burden. When the materials used and the materials saved during the adaptation have come to an equilibrium the turning point is reached. This turning point can be assessed using probability. Turning points are related to all aspects of the factor of time.

Another way of interpreting the result of an environmental assessment is by using sensitivity analyses. When changes cannot be predicted easily it is more accurate to vary input data and important assumptions and calculate the consequences for the outcomes of the LCA. Varying input data is useful when considering unknown technological developments, identified by time aspects 2 and 4. Varying important assumptions includes service lives (time aspects 5 and 6). Sensitivity analyses give insight into the environmental consequences of deviations of the assumed service life.

The last method for dealing with the factor of time is working with potentials. This is important mainly within time aspects 1 and 3. The existing building stock can provide reused materials, but there is no guarantee that materials will be used again or if enough materials will be released at the right time. For instance, at this moment the available amount of recycled steel is less than the demand, so despite the technological possibilities for recycling steel, virgin resources have to be added (Ley *et al.*, 2002). So instead of incorporating the impacts of recycling and reuse, it might be a better idea to separate the potential impacts (Thormark, 2000), because of the allocation problem mentioned in Section 7.2. The choice of the allocation procedure clearly contributes significantly to the outcome of calculations on the environmental burden.

7.6 Conclusions

This study of the factor of time in Life Cycle Assessment leads to the following conclusions:

- LCA is a suitable tool to make environmental issues regarding building measurable. Research is being carried out into several general kinds of uncertainty in LCA, which are independent of the products assessed. However, there is hardly any attention on the factor of time.
- Using LCA in the building industry is complicated, because each building has its own characteristics, buildings have extremely large service lives and incremental changes are a feature of the building industry. Therefore, the factor of time is of major importance in whole-building environmental assessment.
- Six aspects of the factor of time have been identified, which cause uncertainties in the environmental assessment of housing. These aspects are design, production technology, redesign, waste-treatment technology, technical service life and functional service life.
- Current LCAs comprise the assessment of design, redesign and technical service life. This assessment is not complete, while assessment of production technology, waste treatment technology and functional service life is not taken into account at all. For dealing with the factor of time in LCA the aspects have been grouped regarding solutions, which are working with scenarios (time aspects 1 and 3 and time aspects 5 and 6), turning points (time aspects 1 to 6), sensitivity analyses (time aspects 2 and 4 and time aspects 5 and 6) or potentials (time aspects 1 and 3).

Further research on this subject will concentrate on estimates of the influence of the six aspects of the factor of time on the environmental burden of housing. Developing knowledge about the six time aspects will make designing an environmentally sound house an easier task, because more can be understood about the environmental consequences of design options, which are not addressed in current LCAs of houses. For this further research on all the time aspects will be necessary. In the end, more accurate and complete assessments of housing should become possible.

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8 Discussion on the state of the art in quantifying environmental impacts

8.1 Introduction

In the PhD research programme two versions of Eco-Quantum were applied, as were the latest scientific insights into LCA. However, the question as to how these versions of Eco-Quantum relate to each other still needs to be adequately addressed. The results presented in Chapter 3 (The search for the most eco-efficient strategies for sustainable housing construction; Dutch lessons) will be calculated with both versions and compared with each other to gaining some answers. The outcome of this comparison will point the way for further debate about the state of the art in quantifying environmental impacts, especially with regard to LCAs for buildings with exceptionally long life cycles. This issue is explored in Chapter 7 (The factor of time in Life Cycle Assessment of housing).

This chapter will attempt to establish how we have actually made progress in the quantification of environmental impacts. Section 8.2 explains the original idea behind the concept of environmental performance. Section 8.3 offers a broad view of developments in LCA. Section 8.4 presents the results of the comparison between Eco-Quantum 1.01 and Eco-Quantum 2.00 and Section 8.5 sets out the conclusions.

8.2 Introduction of LCA in the construction industry

Since the late 1980s, researchers in the Netherlands have been looking for an 'environmental quantification system' to measure the environmental aspects of building materials. Indeed, the issue is explicitly addressed in the National Environmental Policy Plan of the Dutch Ministry of Housing, Spatial Planning and the Environment (1989). The government and the building sector need quantification systems which enable contractors and builders to gauge the environmental impact of certain building materials. The policy plan defines this 'environmental quantification system' as: "key figure(s) for a raw material, a production process, a product or a waste substance, which expresses the (potential) environmental impact of production, consumption and waste-processing in such a way that environmental factors can be easily weighted in decision-making." The environmental Life Cycle Assessment would serve as a basis for this system.

However, the government plans were overtaken by events, for methods became available which worked with categorisation. Though most of these methods are subjective and can only be used for materials, they do enable fast and simple choices to be made for specific products. Out of all the publications which have appeared on this subject in the Netherlands the most well-known is *Handleiding duurzame woningbouw* (Guide to Sustainable House-

Figure 8.1 Environmental Preference Method

	preference 1	preference 2	preference 3	avoid
Pre-treatment wall	none	natural impregnated	water-based	synthetic dispersion
Wall-paint (interior)	whitewash	mineral paint	natural paint	alkyd paint
Wall-paint (exterior)	mineral paint	water-based paint	vinyl latex	alkyd paint

Source: Anink & Mak, 1993

Building, Anink and Mak, 1993), which applies the Environmental Preference (*Milieuvoorkeur*) Method: materials are subdivided into three preference categories and an 'avoid' category (see Figure 8.1) on the basis of a score for eight types of environmental impact, such as damage to eco-systems, scarcity, emissions, energy consumption, health, sustainability, waste and reuse. Though the eventual preference was poorly underpinned, this system was widely used for several years and is sort of the predecessor of the National Package for Sustainable House-Building (SBR, 1997).

The supply sector was particularly vociferous in its criticism of the Guide to Sustainable House-Building (Van Deelen, 1995), maintaining that it made far too many claims and assumptions on the basis of uncertainties, as LCAs had not been carried out yet on many materials. Furthermore, choices were made even more difficult, because each method applied different criteria and the results were sometimes contradictory. Hendriks (1995) pointed out that cellular glass gets a 'preference 2' in the Guide to Sustainable Building (only as facade insulation, roof insulation is not mentioned), a 'not recommended' in the NIBE (Dutch Institute for Building Biology and Ecology) environmental classification systems and 'the most realistic option' (as facade insulation; for roof insulation it gets a 'C') in the DCBA system. These bizarre differences apply to almost all building materials. For that matter, they have to do with, for example, the valuing of health effects.

However, the strongest argument in favour of scrapping preference lists is that products need to be considered in terms of application and life cycle. Ultimately, we also need insight into the environmental impact at building level. This is one of the reasons why Eco-Quantum was developed in the Netherlands. Similar initiatives were launched in many other countries. Eco-Quantum dispenses with the need to prescribe some products and ban other. In fact, Eco-Quantum is a performance-measuring tool which offers plenty of scope for interpretation. What is more, it can also cover energy consumption, water consumption, maintenance, etc. The development of Eco-Quantum is in line with the development of the LCA methodology.

8.3 Developments in LCA

Eco-Quantum 1.01 is based on the manual for the Environmental Life Cycle Assessment of Products (*Milieugerichte levenscyclusanalyses van producten*; Heijungs, 1992). This publication, further referred to as CML I, presents a step-by-step plan for performing LCAs and explains the calculation procedures for all environmental impact categories, but it still leaves a lot of choices open. In 1993 a code of practice was brought out as the first step towards improving the quality, transparency and credibility of LCAs (Consoli *et al.*, 1993). It was developed first by the SETAC (Society of Environmental Toxicology) and then by the ISO (International Organization for Standardization), which worked hard to standardise the LCA and further refine it. Meantime, a string of LCA standards have been published:

- ISO 14040: principles and framework (ISO, 1997);
- ISO 14041: definition of the objective and the scope and execution of the analysis (ISO, 1998);
- ISO 14042: life cycle-effect analysis (ISO, 2000a);
- ISO 14043: life cycle interpretation (ISO, 2000b).

In 2002 a new LCA manual (Guineé, 2002) – otherwise known as CML II – appeared. It was based on the ISO standards and contained an accurate account of the progress in LCA on a national and international scale in the past ten years. This manual formed the basis for Eco-Quantum 2.00, which provides a good impression of the current state of affairs in LCA. Though considerable strides have been made since 1992, many more developments are expected in the future. It should be borne in mind, however, that neither the LCA methodology nor the ISO standards were designed for buildings, but for far less complex products, like coffee-makers, which additionally have much shorter lifetime expectancies. Hence, the LCA methodology and the accompanying calculation programmes such as Eco-Quantum, are not really suited for the much longer and differing life expectancies of the materials used for construction and installation. To complicate things further, these life expectancies are inter-related. The ISO Technical Committee, Sustainability in Building Construction, is, however, devising a framework for assessing the environmental performance of buildings. The CEN (European Committee for Standardization) is also involved in the project and developing the standard further in the European context.

Close attention needs to be paid to the data as well as the methodology. A lot of energy is being invested internationally in environmental declaration systems for products. Initiatives have been launched in diverse countries, not least Environmentally Relevant Product Information (MRPI, *Milieurelevante Productinformatie*) in the Netherlands (CEPMC, 2001), where the ISO also plays a role. The fore-mentioned committee is also developing a standard for the environmental declaration of building products. In the Netherlands a standard has already been drafted for environmental data on the building materials, building products and building elements which is to be included in an environmental declaration (NEN, 2004). It seems that the step towards a material-specific environmental profile, which was to be incorporated in the Dutch regulations, was a step too far.

8.4 Eco-Quantum 1.01 compared with Eco-Quantum 2.00

8.4.1 Differences

In the report How Environmentally Friendly is Sustainable Construction? (*Hoe milieuvriendelijk is duurzaam bouwen?*; Klunder, 2002) nine sets of measures and three housing concepts are worked out. The sets belong to four strategies for the sustainable use of materials (dematerialisation (M1), material substitution (M2a and M2b), prolongation of service lives (M3a and M3b) and improvement of reusability (M4), and three strategies for the sustainable use of energy (avoiding unnecessary energy consumption (E1), use of infinite energy sources (E2) and clean and efficient use of finite energy sources (E3). The three housing concepts consist of an overall concept (C1), a flexible concept (C2) and an energy concept (C3).

The environmental benefits from all the sets of measures and housing concepts were calculated with Eco-Quantum 1.01 for nine environmental impacts: depletion of raw materials, depletion of fuels, global warming, ozone depletion, photo-oxidant formation, human toxicity, eco-toxicity, acidification and eutrophication. The environmental impacts of energy consumption and hazardous and non-hazardous waste are excluded, as they are, in fact, quantities (MJ and kg), which would lead to duplicate counts when the environmental benefits are being calculated. The reference dwellings of the Netherlands Agency for Energy and the Environment (Novem, 1999 a and b) served as a touchstone. The measures and the housing concepts were implemented in these dwellings. The comparison which is discussed here relates only to the terraced house. The same sets of measures and housing concepts were then also calculated with Eco-Quantum 2.00, this time for ten environmental impacts. Depletion of raw materials and depletion of fuels were combined and eco-toxicity was split into aquatic, sediment and terrestrial.

Table 8.1 shows the environmental benefits for each impact in Eco-Quantum 1.01 and Eco-Quantum 2.00. The percentages represent the environmental benefits and drawbacks from each variant in relation to the reference value for the twelve impact categories. The scores registered with Eco-Quantum 1.01 are shown first, followed by the scores registered with Eco-Quantum

Table 8.1a Environmental benefits per environmental impact in Eco-Quantum 1.01 as a percentage of the reference value

Variant	MD	FD	ADP	GWP	ODP	POCP	HTP	AETP	SETP	TETP	AP	EP
M1	1	0	-	1	2	2	2	1	-	-	2	2
M2a	1	1	-	6	9	2	-3	3	-	-	-5	-6
M2b	52	0	-	0	1	0	14	45	-	-	1	1
M3a	17	17	-	18	20	19	19	18	-	-	19	19
M3b	8	0	-	1	1	1	3	0	-	-	2	1
M4	8	1	-	5	5	8	5	1	-	-	5	5
E1	0	10	-	8	1	-2	0	0	-	-	0	1
E2	-55	10	-	11	-25	-5	-9	-1	-	-	-8	0
E3	0	5	-	5	3	-1	6	4	-	-	6	5
C1	17	35	-	38	29	24	21	36	-	-	21	23
C2	8	5	-	11	23	19	9	8	-	-	8	9
C3	-105	43	-	34	-74	-21	-33	-19	-	-	-37	-17

MD: depletion of raw materials; FD: depletion of fuels; ADP: depletion of a-biotic resources; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity; AETP: aquatic eco-toxicity; SETP: sediment eco-toxicity; TETP: terrestrial eco-toxicity; AP: acidification; EP: eutrophication.

Table 8.1b Environmental benefits per environmental impact in Eco-Quantum 2.00 as a percentage of the reference value

Variant	MD	FD	ADP	GWP	ODP	POCP	HTP	AETP	SETP	TETP	AP	EP
M1	-	-	2	1	2	2	2	1	1	1	2	2
M2a	-	-	0	2	6	1	0	1	1	-2	-5	-6
M2b	-	-	0	0	1	0	15	8	11	5	1	0
M3a	-	-	17	18	19	20	19	18	18	18	19	19
M3b	-	-	2	1	1	1	2	1	1	2	1	1
M4	-	-	16	5	5	6	3	3	2	5	6	5
E1	-	-	6	7	0	-4	1	0	0	1	0	3
E2	-	-	8	12	-1	-1	2	3	1	3	0	6
E3	-	-	3	6	4	-3	6	7	6	8	7	5
C1	-	-	41	36	29	20	26	29	30	27	22	25
C2	-	-	11	8	21	21	12	9	8	10	8	8
C3	-	-	34	33	-19	-17	-17	-25	-26	-24	-27	3

MD: depletion of raw materials; FD: depletion of fuels; ADP: depletion of a-biotic resources; GWP: global warming; ODP: ozone depletion; POCP: photo-oxidant formation; HTP: human toxicity; AETP: aquatic eco-toxicity; SETP: sediment eco-toxicity; TETP: terrestrial eco-toxicity; AP: acidification; EP: eutrophication.

2.00. The environmental impact categories sediment eco-toxicity (SETP) and terrestrial eco-toxicity (TETP) do not feature in Eco-Quantum 1.01. In addition, depletion of raw materials (MD) and depletion of fuels (FD) in Eco-Quantum 1.01 are combined in Eco-Quantum 2.00 to form depletion of a-biotic resources (ADP). A negative percentage indicates an environmental drawback. The figures in bold print indicate the strongest differences.

The differences between Table 8.1a and 8.1b are alarmingly large. In Eco-Quantum 1.01 it appears that considerable benefits can be realised in the environmental impact of depletion of raw materials (52%) and aquatic eco-toxicity (45%) by using synthetic alternatives instead of heavy metals (set M2b). In Eco-Quantum 2.00 these benefits disappear for depletion of raw materials and are a lot less for aquatic eco-toxicity (8%). The environmental benefits for depletion of raw materials in Eco-Quantum 2.00 (16%) are twice as high as for depletion of raw materials in Eco-Quantum 1.01 (8%) thanks to the reuse of foundation, window and door frames and roofs (set M4b). In Eco-Quantum 1.01 the environmental drawbacks from thermal and photo-voltaic solar energy are incorporated in depletion of raw materials (-55%), ozone depletion (-25%), human toxicity (-9%) and acidification (set E2). This is negligible in Eco-Quantum 2.00 and is even converted into an environmental benefit for depletion of a-biotic resources (8%), while eutrophication also shows a significant environmental benefit (6%). The same applies to the energy concept (set C3), but to a greater extent.

8.4.2 Causes

The differences between the two versions of Eco-Quantum are tied in with developments in LCA methodology and databases. Eco-Quantum 1.01 is based largely on the LCA methodology described in the Manual for the Environmental Life Cycle Assessment of Products, which was published in 1992. A revised version of this manual was published in 2002, and Eco-Quantum 2.00 was adapted accordingly. This is particularly evident in the list of environmental impacts. In Eco-Quantum 2.00 depletion of raw materials and depletion of fuels are combined under one category labelled depletion of a-biotic resources, and sediment eco-toxicity and terrestrial eco-toxicity have been added. As far as the databases are concerned, developments in environmental data have been integrated along with developments in product and process data. Together, the above factors account for the wide differences mentioned in Section 4.1. However, one major question which still needs to be answered is: to what extent is each factor responsible for these differences? Research findings have resulted in the following picture (Blom, 2004).

The differences between Eco-Quantum 1.01 and Eco-Quantum 2.00 relate only to data on the waste treatment scenarios and the materials for the components. Distinct differences are discernible, particularly in the waste treatment scenarios. These scenarios are therefore adapted in response to new information and new ideas about the treatment of products which have reached the end of their life expectancy or are left over from demolition. Separate environmental profiles are generated with the SimaPro program. It is not possible to see which products and processes are used to compile these environmental profiles. The composition of the environmental profiles is co-determined by the underlying CML II method.

The differences between CML I and CML II stem from the theory behind the impact categories of depletion of a-biotic resources, human toxicity and eco-toxicity and the calculation methods for the characterisation factors in other environmental impacts. The characterisation factors show how much a substance contributes to a specific environmental impact, usually in relation to a reference substance. Further, in CML II, various calculation methods are spelled out in which a standard is recommended for each category. The comparison presented here is based on the recommended methods. The following key differences emerged:

- In CML I the derived quantities of a-biotic and biotic raw materials are related to the available stock. The stock of a-biotic raw materials is finite; in the case of biotic raw materials the recyclable stock also plays a role. One new element in CML II is that the depletion of a-biotic raw materials is related to the exhaustion of the reference substance, antimonium. The depletion of biotic raw materials is not included, because, so far, the characterisation factor has been determined only for a limited number of types. The calculation method for the depletion of fuels is the same as the calculation method for the depletion of a-biotic raw materials.
- Revised lists of characterisation factors have been drawn up for global warming and photo-oxidant formation. The list is reviewed every time new substances or new values for already listed substances are announced. The characterisation factors for volatile organic substances which contribute to photo-oxidant formation are worked out with an adapted calculation method.
- The method for calculating the characterisation factors used for the human toxicity score has been completely changed. The characterisation factors in CML I do not take account of the migration of substances between compartments (water, air and soil) or the breakdown of substances in the environment. But migration plays an important role in relation to the degree to which and the way in which people can be exposed to a substance. The same applies to eco-toxicity. As all forms of eco-toxicity are related to the same substance, they can be aggregated.
- There are no significant changes in the other environmental impact categories.

Clearly, the characterisation factors and allocation methods used by Eco-Quantum 2.00 are different from those used by CML II. In addition, the environmental impact category eco-toxicity in Eco-Quantum 2.00 is split into aquatic, sediment and terrestrial, whereas these are aggregated in the CML II method. Finally, Eco-Quantum 1.01 and 2.00 have different normalisation and weighting factors. The different weighting factors are the result of the changes in the environmental impact categories. However, normalisation and weighting only play a role when environmental measurements and the environmental indicator are being calculated. They are excluded from the comparison in this section, with the result that there are no explanatory factors. It is interesting though that Eco-Quantum 2.00 uses different normalisation factors from the ones recommended in CML II. In addition, weighting is advised against, as the choice of weighting factors can have a huge influence on the results. The ISO standard (ISO, 2000b) goes even further, stating that weighting is not allowed when the LCA is intended for public purposes.

In short, the new methods for calculating environmental impacts are the main cause of the differences between the results of Eco-Quantum 1.01 and those of Eco-Quantum 2.00. This goes some way to explaining the differences in the depletion of a-biotic resources, human toxicity and eco-toxicity categories. Several differences have also been found in the data on the materials for components and waste treatment scenarios. For example, alterations to the data on solar panels (partly) explain the differences in the scores for the sets of measures and housing concepts in which these have been applied. The influence exerted on the differences by alterations to product and process data cannot, however, be determined. It was not possible to ascertain the degree to which each factor is responsible for the differences, because users of Eco-Quantum do not have enough insight into the used data or into what happens to it.

8.5 Conclusions

In the past ten years the LCA methodology has undergone strong developments, which have reverberated on Eco-Quantum. Further developments are anticipated in environmental impacts in the future which are still to be clearly defined. For example, characterisation factors are determined by scientific research, which is continuing unabated and is constantly discovering new substances, values and factors. Changes in the characterisation factors can be expected at present. Moreover, there are some environmental impacts, such as land use, which are not quantified at all.

Meantime, there is still no generally accepted weighting system at either regional or global level. Weighting is a social-economic-political affair which incorporates a value judgement. So, the use of aggregation to make an environmental profile easier to interpret is not scientifically sound.

Eco-Quantum 2.00 generates very different results from Eco-Quantum 1.01. This, in itself, is perfectly legitimate, as developments are, by definition, dynamic and results should always be applied with common sense. However, the fact that orders of magnitude cannot be maintained without compromising technological developments is more serious. It raises the question of whether we have sufficiently mastered the quantification of environmental impacts. At the same time, standards leave far too many choices open, so forecasts are often based on assumptions. A recent headline in the press read "Case for scrapping refillable bottles founded on quicksand" (Didde, 2004). LCAs for buildings – which have long life expectancies – are fraught with far more uncertainties than bottles. Standardisation could help to formulate universal principles that would increase the reliability of the calculations. But, it looks as if it could still take years to get this far.

9 Conclusions and recommendations

9.1 Introduction

The research described in this report was conducted to identify the environmental benefits offered by sustainable solutions in the construction and renovation of housing. The various stakeholders in these processes are then offered the opportunity to include environmental considerations in the planning process. The main research question is how the environmental performance of Dutch housing can be further improved. The Eco-Quantum method played an important role in quantifying environmental burden. Section 9.2 presents the main conclusions of the study. This is followed by a number of recommendations in Section 9.3.

9.2 Conclusions

Here, conclusions relating to each of the nine research questions presented in Section 1.2 are presented, together with a number of findings taken from the appendices (addressing research questions 1, 2, 4 and 7).

Which components of the house are the major contributors to environmental burden?

In order to identify the prime causes of environmental burden, the study first considered the quantities or flows of materials, energy and water over the total service life of 75 years. This led to the following conclusions:

- Some 80% to 90% of the *material flow* is accounted for by the foundation, facades, inner walls and floors. Only twelve of over forty materials commonly used account for almost the entire mass. Replacement and maintenance of components account for a fraction (less than 10%) of the overall material flow (i.e. including the construction phase).
- The gas consumption for heating and hot water has a major influence on the *energy flow*.
- The *water flow* is largely accounted for by use of the lavatory, shower and washing machine.

To understand the nature of the causes of environmental burden, the environmental impacts attributable to the three flows – materials, energy and water – were calculated. The conclusions of this process were:

- *Environmental burden of material use* is not in direct proportion to the size of the material flow. Alongside the contribution of those materials used in large quantities, there are some specific materials which make a major contribution to a limited number of environmental impacts.
- In terms of *environmental burden of energy consumption*, it may be stated that, while gas consumption is higher than that of electricity, both are of equal

importance at the level of environmental burden.
- *Environmental burden of water consumption* is of lesser importance than those attributable to material use and energy consumption.

The flows and environmental impact analyses were conducted for three types of housing: a terraced house, a semi-detached house and a gallery apartment. Logically, the flows and their environmental impacts are greater in proportion to the size of the house itself, whereby the gallery apartment is the smallest and the semi-detached house the largest. However, the semi-detached house and the gallery apartment each achieve the poorest scores in terms of a number of environmental impacts.

The main contributors to environmental burden identified by the analyses, the 'priorities', then formed the basis for approaches whereby the environmental impacts of new houses can be reduced. Although the type of house is important in terms of the absolute environmental impacts, the priorities are largely identical in each case:
- Fourteen priorities apply to the *material use*: the foundation beam, outer leaves, inner leaves, window and door frames, glazing, rain proofing in the facades, parting walls, load-bearing walls, ground floor, storey floors, floor overlays, roof construction, roof overlay and heat-generation installation.
- Five priorities apply to the *energy consumption*: space heating, hot tap water, lighting, ventilation and auxiliary energy.
- No priorities may be identified with regard to *water consumption*.

What environmental benefits do current sustainable houses present?
The environmental benefits represented by the current sustainable construction residential properties was calculated in two ways. First, a number of thematic concepts were considered, derived from four demonstration projects specifically addressing sustainable construction methods: the Energy balance dwellings in Amersfoort, the energy efficient dwellings in Bakel, the Respekt dwellings in Tilburg and the Ecosolar dwellings in Goes. The results were projected onto the reference terraced house. This process provided greater insight into the likely extent of environmental benefits of four sustainable construction approaches (whereby negative environmental benefits represent an increase in environmental burden rather than the desired decrease):
- 10% energy saving by means of installation technology;
- 5% for energy saving by means of constructional measures;
- 5% for reuse and increase of the life span;
- 15% for the use of renewable materials.

It should be noted that the scores for each environmental impact category vary greatly, from a 77% increase in environmental burden to an 81% decrease.

In the second step, attention shifted from specific projects to a more general, systematic approach. Seven strategies for sustainable construction were identified, each of which was further defined by means of a set of measures representing current practice and/or technological possibilities. The average environmental benefits for each strategy addressing sustainable material use are:

- 0% for dematerialisation;
- 13% for material substitution;
- 20% for prolongation of service lives;
- 5% for improvement of reusability.

The average environmental benefits for each strategy addressing sustainable energy consumption are:

- 0% for avoiding unnecessary energy consumption;
- 8% for the use of infinite energy sources;
- 0% for clean and efficient use of finite sources.

The environmental benefits offered by each strategy are broadly comparable regardless of the housing type.

Finally, the study looked at a number of housing concepts in which strategies for sustainable construction are combined. The average environmental benefits then become:

- 28% for an overall concept in which all measures are used;
- 0% for a flexible concept;
- -25% for an energy concept.

What strategies can best be pursued in order to further improve the environmental performance of houses?

The strategies for sustainable construction will provide a short-term improvement of environmental efficiency by a factor of 1.4. The many innovations in sustainable construction do not therefore represent any substantial reduction of the environmental impacts on the part of residential new construction. A factor of 1.1 applied to the post-war stock would provide comparable benefits and may be seen as a realistic level of ambition. However, it should be remembered that this factor was calculated without taking weighting factors into consideration. If agreement is reached with regard to the weighting factors to be applied in order to render environmental impacts directly comparable, the results are likely to be different. Moreover, the findings with regard to research question 2 do not indicate which strategies it will be most appropriate to follow in order to improve environmental efficiency. The following remarks are in place here:

- *Dematerialisation, avoiding unnecessary energy consumption and clean and efficient use of finite energy sources* will produce a reduction in the environmental impacts in all areas, but the benefits to be made are limited.

- In terms of *material substitution*, positive impacts in one area will frequently be offset by negative impacts in another.
- *Prolongation of service lives and improvement of reusability* are essential to provide any real advance in terms of environmental efficiency. However, these strategies have the disadvantage that the overall environmental benefits will only be achieved in the (distant) future. Flexibility, which in practice entails over-dimensioning, will not necessarily lead to greater environmental efficiency.
- The environmental impacts attributable to material use in installations must be reduced in order to render the *use of infinite energy sources* a more promising approach.

What is the current status of methods and tools for sustainable housing management?

The improvement of the post-war housing stock is a major challenge which must be taken up in the years ahead. Tools for sustainable housing management may serve to encourage a sustainable approach. In order to determine the current status of methods and tools for sustainable housing management, the study examined tools in two countries, the Netherlands and Finland. In the Netherlands, such tools are largely geared towards the quantifiable aspects. In Finland, they have a somewhat broader scope, providing considerably more qualitative information. Notably, the type of tool in use is not in keeping with the restructuring ambitions of either country. In the Netherlands, which seeks large-scale restructuring, a broad focus would be more appropriate, while the Finnish renovation would benefit more from a quantitative approach.

In general, it may be said that a sufficient number of process-support tools is available to address sustainability within the housing stock, but that there are no tools which offer more than an initial indication of the environmental impacts. The current calculation methods used to quantify environmental impacts is of limited practical applicability in supporting environmental decisions relating to the housing stock. Eco-Quantum can be used for this purpose, but it is not ideal. At the strategic level, it will not be enough to extend the applicability of existing tools: new tools are required. When developing these tools, the intended users must be consulted in order to encourage their actual use.

How can the environmental impacts of the various interventions in the housing stock be compared?

To date, tools for sustainable housing management have focused on new construction, whereby it is difficult to assess and compare the environmental impacts of interventions addressing the housing stock. The method applied in this study is based on the following principles:

- The environmental burden of a renovated house is represented by two construction phases, two occupancy phases and two demolition phases.
- The environmental burden attributable to the components being removed, where the full service life of these components has not yet expired, will be attributed to the intervention.
- The basis for comparison are the average annual environmental impacts.
- Comparison with new construction is based on the reconstruction of the houses as part of the improvement process.

What are the environmental impacts of interventions in the housing stock?
In order to identify the environmental impacts of interventions in the housing stock, two case studies were conducted: the transformation of the Hengelolaan apartment block in the Morgenstond Midden district of The Hague, and the transformation of the high-rise apartment buildings of Poptahof in Delft. The following remarks may be made with regard to the flows in Morgenstond Midden:

- The average annual *material use* of the transformation process is 11% lower than the zero situation (i.e. when no intervention is made, also referred to as consolidation), while that of new construction would be 59% higher. In either case, energy consumption falls by 20% and water consumption rises by 12%.
- The foundation, facades, inner walls and floors account for some 90% of the *material use*. There is little difference between transformation and new construction in terms of the use attributable to each building component. The components which have to be replaced regardless of the approach adopted contribute little to the flow of materials.
- The amount of *demolition waste* produced by the transformation process is 14% of that produced by new construction, i.e. 657 ton against 4,621 ton.

The environmental impacts analysis produces the following picture:

- The *environmental impacts* of transformation are between 0% and 17% lower than in the zero situation (no intervention). The environmental impacts of new construction vary from 12% lower and 30% higher than in the zero situation. The overall environmental benefits represented by the transformation process are mostly attributable to the reduction in energy consumption. The facades have the greatest influence on the majority of environmental impacts, while in the case of new construction, the floors also have a significant influence.
- The *environmental measurements* are 0% to 18% lower for transformation than in the zero situation. The environmental impacts for new construction are between 14% lower and 24% higher than when no intervention is made.

In the case of Poptahof, the flow analysis revealed the following:

- The average annual *material use* when undertaking transformation is 41%

lower than in the zero situation and 55% higher in the case of new construction. In both *energy consumption* falls by 13%, while *water consumption* remains largely unaltered.
- The foundation, facades, inner walls and floors account for approximately 90% of the *material use*. The facades contribute somewhat more to the overall flow of materials in the transformation process than in the case of new construction.
- The amount of *demolition waste* in the transformation process is 9% of that of new construction, i.e. 1,047 ton compared to 11,622 ton.

The environmental impact analysis reveals:
- The *environmental impacts* of transformation are between 9% higher and 20% lower than in the zero situation. Those of new construction are between 0% and 25% higher. In general, material use accounts for a comparable or slightly proportion of the overall environmental benefits of the transformation process than does the energy consumption. The facades have the greatest effect in terms of most environmental impacts, while in the case of new construction the floors also have a major influence.
- The *environmental measurements* following transformation are between 13% lower and 9% higher than in the zero situation. Those of new construction are between 6% lower and 31% higher.

In both Morgenstond Midden and Poptahof, transformation leads to greater environmental performance than demolition and new construction. Moreover, transformation provides greater environmental performance than no intervention at all. The results for Morgenstond Midden and Poptahof are remarkably similar despite the differences in the type of intervention and in the material savings.

What is the role of the service life in terms of the sustainability of buildings and their components?

Sustainability in the sense of environmental friendliness is often set against durability in the sense of prolonged service life. These are both aspects of the same concept. Durability makes a significant contribution to sustainability. However, it must compete with other strategies intended to reduce the environmental burden of houses, such as energy saving, flexibility and the use of renewable materials. An analysis of the service life of both houses and the components used therein allows the following conclusions to be drawn:
- An increase in the service life of houses is accompanied by a decrease in environmental benefits, and will not necessarily result in less overall environmental burden. A house with a service life of 30 years scores 33% lower than one with a service life of 75 years, while a house with a service life 120 years scores only very slightly higher.

- An increase in the service life of building components is accompanied by a decrease in environmental benefits. However, prolonging the service life of components is appropriate in the case of houses which themselves have a particularly long intended service life. Extension of the service life of main components by 15 years will lead to a 4% reduction in environmental burden in a house with an intended service life of 75 years, while a concomitant decrease will lead to environmental burden some 9% greater.

Here, it is important to note that recycling and reuse can be included in the LCA in various ways. This is still the subject of discussions. An efficient inclusion of recycling and reuse can produce a more positive picture when applied to houses with a relatively short service life.

What role does the factor of time play in the LCA?
The LCA methodology is useful in rendering the environmental aspects of construction processes measurable. Research has been conducted into several types of uncertainty inherent to the LCA methodology, which are independent of the products assessed. However, little attention has been devoted to the factor of time itself. Using the LCA methodology in the building industry is complicated because each building has its own characteristics. Buildings generally have extremely long service lives and incremental changes are a feature of the construction industry. The factor of time must therefore be seen to be of major significance.

Six aspects of the factor of time which cause uncertainties in the environmental assessment of housing have been identified:
1. design
2. production technology
3. redesign
4. waste treatment technology
5. technical service life
6. functional service life.

Current LCAs involve the assessment of design, redesign and technical service life. This assessment itself is incomplete, while production technology, waste treatment technology and functional service life are not taken into account at all. In addressing the factor of time in the LCA, relevant aspects have been grouped by solutions concerned with the scenarios (time aspects 1, 3, 5 and 6), turning points (time aspects 1 to 6), sensitivity analyses (time aspects 2, 4, 5 and 6) or potentials (time aspects 1 and 3).

What is the current status of efforts to quantify environmental impacts?
The 'preference lists' popular in the Netherlands in the 1990s were often incompatible or even contradictory. This led to the development of the Eco-

Quantum system. There are major discrepancies between Eco-Quantum version 1.01 and Eco-Quantum version 2.00 in terms of several environmental impacts: depletion of a-biotic resources, ozone depletion, human toxicity, eco-toxicity, acidification and eutrophication. These differences are largely due to developments in the underlying LCA methodology. Both the method and the data output of the LCA system have been subject to close attention over the past ten years. Standardisation has played a significant role. The developments are likely to continue. Inadequate environmental knowledge, combined with the problem of the long service life of buildings, raises doubts as to whether the quantification of environmental impacts at building level is useful at this time.

Concluding remarks

It now becomes appropriate to address the question: how can the environmental performance of Dutch housing be further improved? In doing so, material use and energy consumption are of equal importance. In both cases, the flows themselves do not provide enough information. We must look at the environmental impacts themselves. It would seem that even the materials (e.g. lead and copper) and types of energy (e.g. electricity) which are used in small quantities can have major environmental impacts. Moreover, the differences between the impact categories themselves are large, whereby much information is lost when expressing the overall environmental burden as a single figure. In the case of new construction, one problem is that the short-term environmental benefits will be relatively modest, while the long-term benefits can be substantial. It is therefore imprudent to concentrate solely on the strategies with highest environmental benefits, since these involve too many uncertainties. It is preferable to adopt a broad view of all opportunities for improvement. This study has provided an indication of the potential available, and of the pros and cons of certain strategies, whereupon a reasoned choice of sustainable construction approach can be made. Transformation results in major reductions in material use and the amount of waste produced. However, here too the environmental impacts show a smaller improvement than the flows analysis would suggest. Significant opportunities will be missed if transformation is regarded as offering greater environmental benefits than new construction in every case.

The aspect of service life plays a special part in answering the question of how the environmental performance of housing can be improved. Where the prolongation of the service life is adopted as a strategy, it must be remembered that the environmental benefits will only become apparent in the (distant) future and are therefore subject to uncertainty. Moreover, prolongation is not always useful. For example, there is no point in striving for a long service life for components being used in a building which itself has a short (remaining) service life. Achieving an appropriate balance between the service life of components and their host building is therefore something of a challenge. It would seem that the greatest environmental benefits to be had from service life prolongation are those which derive from not having to build a completely new property. However, construction products, construction processes and the nature of the houses themselves are likely to change considerably over time. It is therefore not possible to make any firm conclusions regarding the long-term environmental benefits. A further complication is that the LCA system is not yet fully developed. It is appropriate to devote attention to the concept itself. Quantification of the environmental impacts of houses is useful, but it must be realised that major uncertainties remain. Although the collection of empirical data concerning service lives can increase our understanding of cause and effect, there will always be wide 'bandwidths'. Accordingly, we must not concentrate too much on attempting to remove the uncertainties.

9.3 Recommendations for policy, practice and further research

This section presents the lessons to be drawn from the current study in terms of policy (Section 9.3.1) and practice (Section 9.3.2), together with suggestions for further research (Section 9.3.3).

9.3.1 Recommendations for policy

The Dutch Ministry of Housing, Spatial Planning and the Environment last reviewed its policy on sustainable construction in 2002. The new programme includes three spearheads, i.e. points for special attention: reduction of energy consumption, responsible use of materials and improved interior climate. These priorities apply to the level of the individual building. In terms of material use, the intention was that efforts should be directed by means of the Building Decree, which would contain further performance requirements for the environmental profile of a building, related to material use. This intention is no longer to be pursued, whereby policy can be seen to be marking time. The further development of calculation tools has also reached an impasse. At European level, the adoption of 'Environmental Product Declaration' schemes by the construction industry is being encouraged, whereupon the developments will not reach a complete full stop (EU, 2004). At the level of development locations, the emphasis has been placed upon the integration of sustainable construction methods in the urban renewal programme. Here, we may note that, from 2005, sustainability will no longer be one of the performance indicators by which local authorities will be assessed when applying for funds from the Dutch policy instrument Urban Renewal Investment Budget. Only locally manifested environmental aspects will be taken into account. The following policy recommendations may be made on the basis of the current study.

Firstly, the inclusion of LCA-based performance requirements in the Building Decree is too complex an undertaking. Scholten *et al.* (2000b) see various advantages in doing so, such as rendering the local, often poorly substantiated environmental measures unnecessary, the introduction of uniform, national legislation, and the realisation of a minimum standard of sustainability. Nevertheless, there are so many different aspects to the LCA system that legislation as such is inappropriate. In its place, the national government should enable local authorities to make agreements (subject to civil law) in those areas not covered by the Building Decree, including sustainable construction. In the Life Equation trial project, eight local authorities experimented with performance agreements for sustainable construction based on the Eco-Quantum system (SEV and SBR, 2004). Support for such an approach appears to exist, although a number of obstacles must first be removed. These include the fact that local authorities are currently able to enter into private contractual agreements with contractors, whereby there is little recourse to law should those parties fail to meet the agreements. Enforcement is also a significant sticking point. The findings of the Life Equation project suggest that sustainable construction requirements should be embedded in national legislation. Greater support for this proposal is likely to be forthcoming if the requirements cover every aspect of environmental efficiency, rather than material use alone.

It would be a shameful waste of the efforts thus far if no further development of calculation tools is sought. Eco-Quantum is still rather too complex and its output too obscure to warrant broad adoption in practice. However, the Preliminary Design Tool (VO-tool), which can be applied in the earliest stages of the development process to provide an indication of the projected environmental efficiency of a new house using just a few basic specifications, proved successful during the trial project mentioned above. Its simplicity and speed are particularly appropriate to market requirements. Moreover, a single environmental indicator applied in the trial project, while not scientifically proven, is nevertheless usable. It falls to the government to determine how the environmental indicator is to be calculated regarding weighting. This is not a matter for the developers of the tool, but should be decided at least at the European level. After all, the environment does not stop at the national borders. Moreover, in that case the environmental indicator will have no impact on the international competitive position of construction materials and components.

Labelling will provide a means of making residents aware of the environmental efficiency of their house and of influencing demand for better efficiency. The United Kingdom has successfully introduced the sunflower label, based on the EcoHomes tool. By 2005, some 15,000 houses bearing the sunflower label will have been completed (SEV and SBR, 2004). Further development of a comprehensive calculation tool such as Eco-Quantum will be required to form the basis for simplified methods in such initiatives.

That sustainability is no longer a required performance field for urban renewal subsidies is a missed opportunity. Sustainability must be encouraged in the housing stock, not least because it is this sector which lacks knowledge, experience and tools. The current government policy drives sustainability into the background. The main focus is on local environmental aspects which rely not so much on sustainability (there and later) but on liveability (here and now). Local environmental problems must certainly be resolved, but the problem is much wider in its scope. Policy addresses only energy consumption and renewable energy. The government's concern with energy is understandable and indeed prudent, since the Kyoto Protocol will now be ratified in full following its acceptance by Russia. The Kyoto Protocol entails international agreements to reduce CO_2 emissions and the resultant climate change. If the reductions are to be achieved, it will be necessary to increase gas and oil prices substantially. This may be achieved through an increase in the regulatory energy tax that already applies to gas, oil and electricity. A restrictive pricing policy will serve to increase investments in energy efficiency, since the payback period will be shortened (ECN, 1998).

In sum, what can the government do in order to improve the environmental efficiency of the housing stock? Tools are important, provided they are appropriate to the requirements of the field. The connection between the various environmental themes and strategies must remain visible. It is still too early to leave the development of the tools to the market itself. Moreover, it is simply too complex to include performance requirements in legislation. When the time comes to do so, the legislation will only be useful if a single requirement is included to cover material use, energy consumption and water consumption in combination. Although something of a 'belt and braces' approach, it may be appropriate to allow the EPC to remain in place as the minimum energy efficiency requirement alongside an environmental efficiency requirement. The introduction of the latter would then address the five main aspects covered by the Building Decree: safety, usability, health, energy efficiency and the environment. Until such times as legislation is forthcoming, it is important that the Building Decree does not hinder the sustainability ambitions of local authorities and other stakeholders. The pioneers must not be held back. But neither must local authorities become too dependent on legislation alone. Performance agreements may well provide an opportunity to devote due attention to sustainability. It will also be necessary to seek alternative ways of improving the environmental performance of housing. The focus on the housing stock is important, given that it is here that the greatest environmental benefits are to be made. The housing stock represents significant environmental capital and the government should do everything in its power to ensure that that capital is used, rather than to pursue a policy of demolition and redevelopment. Urban renewal is essential, but creative solutions which achieve renewal without destroying the environmental capital are still too few and far between. The government might try to counter the preconceptions (regarding the supposedly high costs of transformation, etc.) by collecting and disseminating information and expertise. There are plenty of good examples: the mystery is why they are so rarely followed.

9.3.2 Recommendations for practice

Because the results of this study are subject to some serious reservations (see Chapter 8), the recommendations for practice are rather less concrete than had been expected when commencing the research. Nevertheless, a few general lessons for the various stakeholders in the construction process can be presented.

Local authorities – It is important that local authorities are not overly constricted by the requirements imposed by central government. Legislation is not the only means by which they can achieve their sustainability ambitions. An increasing number of developments are now subject to performance agreements between the local authorities and the contractors or developers. Such agreements serve to underpin the changing role of the local authority, which is becoming more of an equal partner with the other stakeholders in the process. Sustainability will benefit if it is given a permanent place in the agreements which set out certain firm objectives, including the financial conditions (Boon and Klunder, 2004).

Project developers – Project developers are key figures in the realisation of sustainable residential properties and other buildings. They can exert influence in all aspects of contracting and construction. While developers are unlikely to consider environmental efficiency a compelling selling point, neither is it something that will discourage buyers. Project developers can create greater support for sustainability by drawing attention to the future benefits residents will derive: lower energy bills, more comfort and better health. Similarly, real estate agents have to inform house buyers.

Architects – It remains difficult to devise simple guidelines for the design of houses with low environmental impacts. It is a question of applying a cohesive set of measures. All measures, concepts and strategies have pros and cons in terms of overall environmental efficiency. Accordingly, it is very important not to rely on just one strategy, such as attempting to prolong the service life of the house. Various strategies should be applied in combination with each other. The exact number and form of these strategies will not be so important to the overall picture.

Contractors – Contractors responsible for the building and its installations must ensure that everyone on the building site is aware of the importance of sustainable construction. Even minor construction faults can result in the potential environmental benefits being lost. For example, careless application of insulation material can greatly affect heat loss and the energy required to counter this loss. Similarly, installations must be properly adjusted to ensure maximum energy efficiency.

Housing managers – From the environmental point of view, housing managers are too quick to opt for demolition and new construction. They assume that improvement of the existing property is too difficult or too expensive. However, this option should be thoroughly investigated in every situation. The challenge is to arrive at creative solutions representing the 'golden mean' between retention and replacement of the housing stock. There are many opportunities to achieve greater sustainability while retaining the housing stock. Great benefits may be had if an environmentally friendly approach to the improvement process is adopted.

Residents – Residents, the end users of the dwelling, are also an important stakeholder in the construction process. They too will have a major influence on environmental burden (see suggestions for further research, below). However, residents should not be expected to adapt their behaviour drastically. It falls to the designers, product developers and legislators to address resident behaviour more closely. For example, installations should not encourage inappropriate use. It used to be quite common for residents to strip out brand new kitchens from their brand new properties, in order to replace them with something more attractive and practical. This was the fault of legislators. Residents can only be held to account for the environmental impact caused by maintenance and renovations. It is therefore appropriate to find more environmentally friendly methods in this area.

9.3.3 Recommendations for further research

The realisation of the potential environmental benefits will depend entirely on people. On the one hand, it is a question of resident behaviour, while on the other the management practices of housing managers will determine the progress made. It is now known that the occupants of sustainable dwellings are, in general, satisfied with their housing situation and that some environmental measures do require behavioural shifts (see for example Silvester and De Vries, 1999; Van der Reijden *et al.*, 2002; De Vries, 2004). However, very little research has been conducted into the effect of resident behaviour on environmental performance. Hertz (1996) reports that certain measures already put in place are not having maximum effect because resident behaviour is not in line with expectations. This is the case when, for example, a porch is used as a heated area rather than a buffer zone. Enormous differences have been noted in the energy consumption of identical houses (Haas *et al.*, 1998). There are also certain rebound effects': greater energy efficiency leads to lower energy bills, whereby the demand once again rises (Greening *et al.*, 2000). Knowledge concerning resident behaviour is essential to the realisation of the environmental benefits offered by sustainable construction measures. Besides, little is yet known about the influence of management behaviour: How often do managers make any interventions?, What is the nature of those interventions?, What methods are used?

In this study, houses were considered in isolation from their physical location. Nevertheless, the location can have a major influence on environmental burden if we consider the environmental impacts of use, rather than those of construction alone. In itself, the residential setting causes neither more nor less environmental impact, but location may render it easier or more difficult for residents to use a car rather than a bicycle or public transport. Another consideration is the availability of recreational facilities close to the house. Here too, little research has been conducted to date.

This study asks how useful the current LCA approach is when applied to buildings. An interesting question for follow-up research is whether any other possibilities exist for the quantification of the environmental impacts of buildings. The LCA principle need not be abandoned in its entirety. Moreover, it may well be unnecessary to identify and measure all environmental impacts. Perhaps some impacts can be used as indicators for others. It may also be enough to concentrate (for the time being at least) on a limited number of construction-related environmental problems, such as energy consumption and waste production. It seems appropriate to subject the use of the LCA on residential and other buildings to critical scrutiny and to reformulate the system if necessary. Sensitivity analyses can be used to measure the bandwidths of certain assumptions. The application of different allocation methods for recycling, for example, will produce minimum and maximum values for the environmental benefits to be had. This could well lead to useful guidelines without the need for extensive and detailed calculations. In any case, some of the current uncertainties would be resolved. Attention should focus on the housing stock, about which there is currently very little scientific knowledge available.

Finally, when focusing on environmental impacts, it must be remembered that they do not yet form the basis for decisions in the planning process. In order to incorporate consideration for the impacts into the decision-making, it is important to develop further knowledge. This thesis attempts to do just that. However, the next step will be to give that knowledge a place in the overall planning process for both new-build property and restructuring projects. The development of a model is called for. Only then will the cycle be complete.

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Samenvatting

Duurzame oplossingen voor de Nederlandse woningbouw; het verminderen van de milieueffecten van nieuwe en bestaande woningen

Inleiding

Er zijn talloze maatregelen bekend voor duurzaam bouwen, maar nauwelijks bekend is hoeveel milieuwinst die maatregelen opleveren en welke maatregelen het beste kunnen worden getroffen om verder te komen. In veel landen zijn instrumenten ontwikkeld voor het kwantificeren van de milieubelasting van gebouwen. De resultaten van verschillende instrumenten zijn echter moeilijk vergelijkbaar. Van systematisch inzicht in de milieuwinst van duurzaam bouwen is geen sprake. Bovendien ontbreken methoden en instrumenten gericht op de woningvoorraad. Duurzaam bouwen en beheren is tot nu toe dan ook vooral gebaseerd op een intuïtieve benadering. Dit promotieonderzoek richt zich daarom op het kwantitatief onderbouwen van duurzame maatregelen, concepten en strategieën voor nieuwbouw en renovatie van woningen. Doelstelling van het onderzoek is het verkrijgen van inzicht in de milieuwinst van duurzame oplossingen daarvoor. Daarmee worden alle partijen in de bouw, waaronder projectontwikkelaars, bouwbedrijven, gemeenten en architecten, in staat gesteld milieuafwegingen objectief mee te nemen in het planvormingsproces. De algemene probleemstelling luidt als volgt: *hoe kan de milieukwaliteit van de Nederlandse woningen verder worden verbeterd?*

Eerst zijn de grote veroorzakers van de milieubelasting van nieuwbouwwoningen bepaald met behulp van een milieuanalyse van een tuinkamerwoning, een twee-onder-een-kapwoning en een galerijwoning. Dat heeft geleid tot het identificeren speerpunten, ofwel 'grote vissen', voor duurzaam bouwen. Vervolgens is de milieuwinst van duurzaam bouwen bepaald. Enerzijds is gekeken naar de milieuwinst van de maatregelen getroffen in vier voorhoedeprojecten. Anderzijds zijn maatregelpakketten samengesteld en doorgerekend voor zeven strategieën voor duurzaam bouwen. Daaruit is afgeleid welke strategieën de beste perspectieven bieden voor het verlagen van de milieubelasting van woningen. Voor renovatie zijn geen specifieke instrumenten beschikbaar. Daarom is een methode ontwikkeld om ingrepen in de woningvoorraad te kunnen kwantificeren en vergelijken, met de LCA-methode als uitgangpunt. Daarmee zijn twee casestudies verricht naar herdifferentiatie van de woningvoorraad: Morgenstond Midden in Den Haag en Poptahof in Delft. Ten slotte vormt een literatuurstudie de basis voor het in kaart brengen van de rol van de tijdfactor in LCA en zijn alle onderzoekservaringen gebundeld in een discussie over de stand van zaken in het kwantificeren van milieueffecten. Het blijkt namelijk dat bij de gemaakte analyses serieuze

Tabel 1 Hoeveelheden materialen, energie en water in de referentiewoningen over de totale levensduur

Stroom	Tuinkamerwoning		Twee-onder-een-kapwoning		Galerijwoning	
	Totaal	Per m^2	Totaal	Per m^2	Totaal	Per m^2
Materialen	205 ton	1,9 ton	254 ton	1,9 ton	153 ton	2,0 ton
Energie	4.157 GJ	37,4 GJ	5.252 GJ	39,2 GJ	2.680 GJ	35,7 GJ
Water	6.772 m^3	61,0 m^3	10.847 m^3	81,0 m^3	4.110 m^3	54,8 m^3

kanttekeningen moeten worden geplaatst. Het Nederlandse, LCA-gebaseerde rekeninstrument Eco-Quantum is ingezet als milieubeoordelingsmethode. Eco-Quantum berekent de milieueffecten van het materiaalgebruik tijdens de bouw en voor vervangingen en onderhoud, en van het energie- en watergebruik tijdens bewoning. Aangezien het instrument nog in ontwikkeling was, is eerst Eco-Quantum 1.01 gebruikt en later Eco-Quantum 2.00.

Milieubelasting van Nederlandse woningen; speerpunten voor vermindering van de milieubelasting en de milieuwinst van duurzaam bouwen

'Factor 20' staat voor een zeer ambitieuze toename van de *milieuefficiëntie* om in de maatschappelijke behoeften te voorzien. Dat is nodig om een halvering van de mondiale milieubelasting te bereiken, bij een verdubbeling van de wereldbevolking en een vervijfvoudiging van de welvaart. Een dergelijke doelstelling vergroot de behoefte aan kwantitatieve informatie over de milieuwinst van duurzaam bouwen. Om te beginnen is de milieubelasting van de drie referentiewoningen bepaald. Deze drie woningen zijn typerend voor de huidige Nederlandse traditionele woningbouw. In tabel 1 zijn de hoeveelheden materialen, energie en water voor de drie woningen op een rij gezet. Het blijkt dat de galerijwoning relatief materiaalintensief is, terwijl de twee-onder-een-kapwoning relatief veel energie gebruikt.

Bij negen milieueffecten draagt het materiaalgebruik meer dan 50% bij aan de milieubelasting, bij drie milieueffecten is dat het energiegebruik. Terwijl de milieubelasting groter is, naarmate de woning groter is, blijkt de verdeling van de milieubelasting over het materiaal-, energie- en watergebruik ongeveer gelijk te zijn. Ook de grote veroorzakers zijn voor elk woningtype nagenoeg hetzelfde. Veertien speerpunten zijn van toepassing op het materiaalgebruik: funderingsbalken, buitenbladen, binnenbladen (alleen bij de twee-onder-een-kapwoning), buitenkozijnen, beglazing, waterkeringen in de gevel, niet-dragende binnenwanden, dragende binnenwanden (bij de tuinkamer- en galerijwoning), beganegrondvloer, verdiepingsvloeren, dekvloeren (bij de tuinkamer- en twee-onder-een-kapwoning), dakconstructie (hellend bij de tuinkamer- en twee-onder-een-kapwoning, plat bij de galerijwoning), dakbedekking (alleen bij de galerijwoning) en warmteopwekkingsinstallatie. Hierbij gaat het niet alleen om materialen die in grote hoeveelheden voorkomen, maar ook om een aantal materialen die slechts in kleine hoeveelheden zijn gebruikt. Vijf speerpunten zijn van toepassing op het energiegebruik: ruimteverwarming, warmtapwater, hulpenergie, verlichting en ventilatoren. Dat zijn alle energiefuncties. Hoewel het gasverbruik driekwart uitmaakt van het totale energiegebruik, is het elektraverbruik op een aantal milieueffecten doorslaggevend voor de milieubelasting. Het watergebruik behoort niet tot de speerpunten, omdat het van ondergeschikt belang is ten opzichte van het materiaal- en energiegebruik.

Om te kijken of we op de goede weg zijn met duurzaam bouwen, zijn voor drie thema's enkele in het oog springende maatregelen uit een aantal voorhoedeprojecten geprojecteerd op de tuinkamerwoning. Het gaat om 1) energiebesparing, opgesplitst in een installatietechnische aanpak (Energiebalanswoningen in Amersfoort) en een bouwkundige aanpak (energiezuinige woningen in Bakel), 2) hergebruik en levensduurverlenging ('Respekt'-woningen in Tilburg), en 3) het gebruik van vernieuwbare materialen ('Ecosolar' in Goes). Het leidt tot een orde van grootte van de milieuwinst van -10% voor de installatietechnische aanpak en 5% voor de bouwkundige aanpak van energiebesparing, 5% voor hergebruik en levensduurverlenging en 15% voor het gebruik van vernieuwbare materialen. Een negatief percentage betekent een verhoging van de milieubelasting in plaats van een verlaging, dus per saldo een verslechtering van de situatie. Bij de genoemde ordes van grootte moet worden bedacht dat de verschillen per milieueffect zeer groot zijn, variërend van een toename van de milieubelasting met 77% tot een afname van de milieubelasting met 81%.

De zoektocht naar de meest eco-efficiënte strategieën; Nederlandse lessen voor duurzame woningbouw

Een meer systematische aanpak is gehanteerd om de meest eco-efficiënte strategieën voor nieuwe woningen te bepalen. Het gaat om vier strategieën voor een duurzaam materiaalgebruik: dematerialisatie (M1), materiaalkeuze (M2), verlengen van de levensduur van gebouwen en bouwdelen (M3), en bevorderen van de herbruikbaarheid van bouwdelen en bouwmaterialen (M4). Er zijn drie strategieën voor een duurzaam energiegebruik gehanteerd: voorkom onnodig gebruik (E1), gebruik eindeloze bronnen (E2) en gebruik eindige bronnen verstandig (E3). Per strategie zijn een of meer maatregelpakketten opgesteld en doorgerekend, refererend aan de huidige praktijk c.q. de huidige stand van de technologie. De resultaten daarvan zijn te vinden in de tabellen 2 en 3.

De strategieën dematerialisatie, het voorkomen van onnodig energiegebruik en het verstandig gebruiken van eindige bronnen leiden tot een vermindering van de milieubelasting bij alle milieueffecten, maar deze milieuwinst is in de toekomst begrensd. Voor materiaalkeuze geldt dat verbeteringen en verslechteringen bij de verschillende milieueffecten bijna altijd hand in hand gaan. Ten slotte is er meer aandacht nodig voor het materiaalgebruik van zonne-energiesystemen. De milieuwinst van het verminderde energiegebruik wordt namelijk voor een groot deel tenietgedaan door het materiaalgebruik. Levensduurverlenging en hergebruik zijn nodig voor een sprong voorwaarts, maar daarbij moet wel worden bedacht dat de milieuwinst daarvan

Tabel 2 Milieuwinst van maatregelpakketten voor een duurzaam materiaalgebruik in de tuinkamerwoning

Maatregelpakket	Milieuwinst in procenten								
	MD	FD	GWP	ODP	POCP	HTP	ETP	AP	EP
M1 draagconstructie 10% kleiner gedimensioneerd									
M2a vernieuwbare materialen: houtskeletbouw			5	8				-5	-6
M2b kunststoffen in plaats van lood en koper	54					14	47		
M3a levensduur van woning 90 in plaats van 75 jaar	17	17	18	20	19	19	18	19	19
M3b levensduur van componenten van woning 5 jaar langer	8								
M4 hergebruik van fundering en binnenwanden	8		5		8	4		5	5

MD: uitputting van grondstoffen voor materialen; FD: uitputting van brandstoffen; GWP: broeikaseffect; ODP: ozonlaagaantasting; POCP: fotochemische smogvorming; HTP: humane toxiciteit; ETP: ecotoxiciteit; AP: verzuring; EP: vermesting.

Tabel 3 Milieuwinst van maatregelpakketten voor een duurzaam energiegebruik in de tuinkamerwoning

Maatregelpakket	Milieuwinst in procenten								
	MD	FD	GWP	ODP	POCP	HTP	ETP	AP	EP
E1 $R_c = 4.0$ in plaats van 3.0 m^2K/W, $U_{window} = 1.2$ in plaats van 1.7 W/m^2K		11	8						
E2 thermische en fotovoltaïsche zonne-energiesystemen	-45	7	8	-20		-6		-7	
E3 lagetemperatuurverwarming en hoogrendementventilatie		5	5			6		6	5

MD: uitputting van grondstoffen voor materialen; FD: uitputting van brandstoffen; GWP: broeikaseffect; ODP: ozonlaagaantasting; POCP: fotochemische smogvorming; HTP: humane toxiciteit; ETP: ecotoxiciteit; AP: verzuring; EP: vermesting; R_c: warmteweerstand; U: warmtedoorgang.

onzeker is, omdat die winst in de verre toekomst moet worden behaald. Deze twee strategieën kunnen dan ook het beste in combinatie met andere worden ingezet.

Instrumenten voor duurzaam woningbeheer: de casus Nederland en Finland

Nederland kent drie instrumenten voor duurzaam woningbeheer, te weten Duwon, het Nationaal pakket duurzaam bouwen woningbouw – Beheer en Groene financiering. Deze instrumenten geven slechts indicaties van de milieuwinst van de te nemen beheermaatregelen. In Nederland ligt de nadruk op de kwantificeerbare aspecten van duurzaam bouwen. De huidige instrumenten voorzien echter niet in kwantificering van de milieueffecten van duurzaam woningbeheer. De kwantitatieve benadering past ook niet goed bij de beheeropgave, die herstructurering van vooral naoorlogse woonwijken omvat. Dat vraagt om een meer strategisch instrumentarium. In Finland is slechts één instrument in ontwikkeling dat duurzaam woningbeheer ondersteund en uitspraak doet over de milieuwinst, te weten de Milieugids voor vastgoedbeheer. Ook dit instrument benadert de milieuwinst kwalitatief. De Finse beheeropgave bestaat vooral uit renovatie. Daarbij past juist een kwantitatieve benadering. LCA-gebaseerde instrumenten zijn in beginsel geschikt om te worden aangepast voor renovatievraagstukken. Voor strategische afwegingen voldoet het bestaande instrumentarium ook in beginsel niet.

Milieueffecten van ingrepen in de Nederlandse woningvoorraad
Transformatie kan het gat vullen tussen niet-ingrijpen (regulier onderhoud) en sloop met vervangende nieuwbouw (herontwikkeling), omdat noodzakelijke vernieuwingen worden gerealiseerd met zo veel mogelijk behoud van bestaande structuren. Het omvat namelijk woningverbetering van een woonblok of wooncomplex, dat over de grenzen van individuele woningen heengaat, zoals het geval is bij het samenvoegen van woningen. Transformatie wordt vaak als milieuvriendelijker beschouwd dan sloop. Aangezien het ontbreekt aan methoden en instrumenten om de milieueffecten van ingrepen in de woningvoorraad te kwantificeren en te vergelijken, is hiertoe een methode ontwikkeld. Voor het berekenen van de milieubelasting van een verbeterde woning worden twee bouwfasen, twee gebruiksfasen en twee sloopfasen bij elkaar opgeteld, namelijk de fase vóór verbetering en de fase na verbetering. De milieubelasting van de componenten die bij de verbetering worden gesloopt, maar nog een resterende levensduur hebben, wordt toegerekend aan de ingreep. Om ingrepen met verschillende levensduren te kunnen vergelijken, vormen de gemiddelde jaarlijkse milieueffecten de vergelijkingsbasis. Ten slotte geschiedt de vergelijking van woningverbetering met sloop en nieuwbouw op basis van het herbouwen van dezelfde woningen na de verbeteringreep.

De methode is toegepast op de casestudies Morgenstond Midden in Den Haag, een jarenvijftigwijk met drie- en vierlaagse portiekflats, en Poptahof in Delft, een jarenzestigwijk met (middel)hoogbouwflats. Beide bestudeerde woonblokken bieden goede mogelijkheden voor transformatie. Dat leidt niet alleen tot nieuwe woningplattegronden, maar ook tot andere verbetermaatregelen, zoals thermische en geluidsisolatie, en vernieuwing van de installaties. Ondanks dat dus sprake is van omvangrijke ingrepen, zijn met transformatie ten opzichte van nieuwbouw enorme besparingen op het materiaalgebruik en het sloopafval te realiseren. Voor Morgenstond Midden gaat het om 41% respectievelijk 86%; voor Poptahof om 62% respectievelijk 91%. De fundering, gevels, binnenwanden en vloeren veroorzaken in beide gevallen 90% van het materiaalgebruik. Transformatie leidt verder tot minder materiaal- en energiegebruik dan niet-ingrijpen.

De milieuwinst van transformatie bedraagt in Morgenstond Midden ten opzichte van de referentie, dat wil zeggen niet-ingrijpen, 0% tot 17%. De resultaten bij nieuwbouw variëren van een 30% hogere tot een 9% lagere score. De milieuwinst van transformatie ten opzichte van nieuwbouw komt voornamelijk door het energiegebruik. De milieuwinst is kleiner dan op grond van de besparingen op de hoeveelheden materialen en energie zou mogen worden verwacht. Dat betekent dat relatief milieubelastende bouwdelen worden aangepakt. In Poptahof wordt een vergelijkbare milieuwinst geboekt van 0% tot 20%, met uitzondering van uitputting. Bij uitputting neemt de score met 9% toe. Nieuwbouw scoort op alle milieueffecten tot 25% hoger. Zowel het materiaalgebruik als het energiegebruik leveren een bijdrage aan de uiteindelijke milieuwinst. Ook hier geldt dat de milieuwinst kleiner is dan op grond van de besparingen op de hoeveelheden materialen en energie zou mogen worden verwacht. In Poptahof moeten de gevels echter ook geheel worden vernieuwd. Dat is het bouwdeel met de grootste bijdrage aan de meeste milieueffecten. Voor zowel Morgenstond Midden als Poptahof geldt dat transformatie van de woningvoorraad leidt tot meer milieukwaliteit dan slopen en nieuw bouwen, en dat transformatie tot meer milieukwaliteit leidt dan niet-ingrijpen.

Tussen 'duurzaam' en 'duurzaam': optimalisatie van levensduren

Duurzaam in de zin van lange levensduur en duurzaam in de zin van milieuvriendelijk worden vaak als twee aparte benaderingen gezien. Er liggen dan ook twee spanningsvelden in besloten. Ten eerste kunnen materialen met een lange levensduur meer milieubelasting veroorzaken dan materialen met een korte levensduur. Ten tweede kunnen materialen relatief milieubelastend zijn, maar goed herbruikbaar, tegenover materialen die minder milieubelastend zijn, maar ook minder goed herbruikbaar. Optimalisatie van levensduren, waarbij 'duurzaam' in de zin van lange levensduur en 'duurzaam' in de zin van milieuvriendelijk met elkaar worden verenigd, lost deze paradox op. Daartoe is een analyse gemaakt van de rol van levensduren van woningen en componenten in de uiteindelijke milieubelasting van de tuinkamerwoning. Hieruit blijkt dat de milieuwinst van een langere levensduur van woningen afneemt naarmate de levensduur langer wordt. Een kortere levensduur heeft een negatiever effect dan een langere levensduur een positief effect heeft. Bovendien betekent een toename van de levensduur niet altijd een afname van de milieubelasting. Dat heeft te maken met het moment dat een nieuwe woning moet worden gebouwd. Dat veroorzaakt een grote sprong in de milieubelasting. Ten aanzien van levensduurverlenging van componenten geldt logischerwijs ook dat een langere levensduur minder bepalend is dan een kortere levensduur. Het toepassen van componenten met lange levensduren heeft vooral zin in woningen met lange levensduren. Recycling en hergebruik hebben ook te maken met optimalisatie van levensduren. Korte levensduren kunnen bijvoorbeeld gecompenseerd worden door een goede herbruikbaarheid. Hoewel hierin nog onvoldoende inzicht is, is dit in principe voordelig voor 'duurzaam' in de zin van milieuvriendelijk. Levensduurverlenging leidt in ieder geval tot milieuwinst, maar het is geen doorslaggevende factor.

De tijdfactor in levenscyclusanalyse van woningen
LCA kent nog diverse onvolkomenheden, zoals allocatie, weging, databetrouwbaarheid, biodiversiteit en hinder. Deze onvolkomenheden gelden ongeacht de toepassing. Voor de bouw komt daar bij dat de lange levensduur van gebouwen LCA complex maakt. Dat leidt ertoe dat LCA van gebouwen met veel onzekerheden is omgeven. De factor tijd komt hierbij om de hoek kijken. In de loop der tijd verandert er veel aan een woning. Een aantal malen gaan bouwmaterialen en -componenten de woning in en gaan sloopmaterialen en -componenten de woning uit. Bovendien hoeft er niet hetzelfde in te gaan als bij de bouw, maar ook als dat wel het geval is, zorgen innovaties en trends voor veranderingen ten opzichte van de oorspronkelijke woning. Dat wordt nu niet meegenomen in LCA. We komen zo tot zes aspecten van de tijdfactor. Drie daarvan zijn statisch: ontwerp, herontwerp en technische levensduur. De andere drie zijn dynamisch en hebben betrekking op toekomstige ontwikkelingen: productietechnologie, afvaltechnologie en functionele levensduur. Om een compleet beeld te krijgen van de milieueffecten van duurzaam bouwen, moeten alle aspecten in de berekening worden betrokken. De reeds opgedane kennis heeft vooral betrekking op de statische aspecten. Meer inzicht in de rol van de andere aspecten van de tijdfactor kan worden verkregen met behulp van scenario's, omslagpunten, gevoeligheidsanalyses en potentiëlen.

Discussie over de stand van zaken in het kwantificeren van milieueffecten
LCA is geïntroduceerd in de bouwsector als reactie op de onvolkomenheden van de lijsten die materialen voor bepaalde toepassingen in categorieën plaatste, van eerste voorkeur tot vermijden. Deze lijsten waren vaak onderling tegenstrijdig. Bovendien kwam de gedachte op dat materialen in hun toepassing en over hun gehele levensduur moeten worden beschouwd. De stap naar gebouwniveau werd vervolgens snel gemaakt. Een van de instrumenten die werden ontwikkeld is Eco-Quantum. Eco-Quantum 1.01 is gebaseerd op de zogenoemde CML I-methode; Eco-Quantum 2.00 op de tien jaar later gepubliceerde CML II-methode. CML II sluit aan op de LCA-normen die in de tussentijd zijn ontwikkeld. Doorrekening van dezelfde maatregelen met Eco-Quantum 1.01 en Eco-Quantum 2.00 leidt tot verontrustende verschillen in uitkomsten. Zo is een milieuwinst in Eco-Quantum 1.01 van 52% bij de uitputting van grondstoffen niet meer terug te zien in Eco-Quantum 2.00. Verder is een milieuwinst van 45% bij aquatische ecotoxiciteit verminderd tot 8%. Forse verhogingen van de milieubelasting van 55% bij de uitputting van grondstoffen voor materialen, 25% bij de ozonlaagaantasting, 9% bij de humane toxiciteit en 8% bij verzuring zijn zelfs omgezet in een verlaging van de milieubelasting van 8% bij de uitputting en 6% bij de vermesting.

Het blijkt dat de verschillen voornamelijk voortkomen uit de ontwikkelingen in LCA. Uitputting van grondstoffen enerzijds en brandstoffen anderzijds worden niet meer onderscheiden. Voor uitputting, humane toxiciteit en ecotoxiciteit zijn geheel andere berekeningsmethoden gehanteerd. Verder zijn de karakterisatiefactoren voor het broeikaseffect en de fotochemische smogvorming bijgesteld. Deze factoren relateren de bijdrage van een stof aan een milieueffect aan een referentiestof. Wijzigingen in Eco-Quantum, waaronder materiaal- en afvaldata en normalisatie- en weegfactoren, spelen waarschijnlijk een veel kleinere rol. Eco-Quantum is echter niet transparant genoeg om het effect te achterhalen van alle factoren die verantwoordelijk zijn voor de verschillen tussen Eco-Quantum 1.01 en 2.00. Hoewel LCA de afgelopen tien jaar behoorlijk verder is ontwikkeld, worden nog steeds nieuwe ontwikkelingen voorzien. Deze constatering leidt, in combinatie met de lange levensduur van gebouwen, tot aanzienlijke twijfels over het huidige nut van het kwantificeren van de milieueffecten op gebouwniveau. Kennelijk zijn de toegepaste hulpmiddelen (nog) niet robuust genoeg.

Conclusies en aanbevelingen

Voor het verbeteren van de milieukwaliteit van de Nederlandse woningen zijn het materiaalgebruik en het energiegebruik van even groot belang. Voor beide geldt dat stromen materialen, energie en water niet genoeg zeggen. We zullen ook moeten kijken naar de milieueffecten daarvan. Het blijkt namelijk dat materialen (lood, koper) en energiedragers (elektrisch) die in kleine hoeveelheden worden gebruikt toch grote milieueffecten kunnen veroorzaken. Verder zijn de verschillen tussen de milieueffecten groot, waardoor veel informatie verloren gaat bij het uitdrukken van de milieubelasting in één getal. Bij nieuwbouw speelt het dilemma dat de milieuwinst die op de korte termijn kan worden behaald relatief klein is, terwijl de milieuwinst die op de lange termijn kan worden behaald relatief groot is. Het is dan ook onverstandig om uitsluitend in te zetten op de 'grote vissen', omdat die met teveel onzekerheden gepaard gaan. Beter is het om een brede kijk te blijven houden op de verbetermogelijkheden. Dit onderzoek heeft inzicht gegeven in de potenties en haken en ogen van bepaalde strategieën, waarmee een meer gefundeerde keuze kan worden gemaakt uit de maatregelen voor duurzaam bouwen. Transformatie leidt tot grote besparingen op het materiaalgebruik en het sloopafval. De milieueffecten laten echter ook hier een kleinere verbetering van de milieukwaliteit zien, dan op grond van de stromenanalyse zou kunnen worden verwacht. Een groot potentieel blijft onbenut wanneer transformatie op zich als het grootste milieuvoordeel wordt gezien ten opzichte van nieuwbouw.

Het thema levensduur neemt een bijzondere positie in bij de vraag hoe de milieukwaliteit van woningen verder kan worden verbeterd. Bij levensduurverlenging als strategie is al als kanttekening geplaatst dat de milieuwinst daarvan in de verre toekomst moet worden gerealiseerd en dus onzeker is. Bovendien heeft levensduurverlenging lang niet altijd zin. Het is bijvoorbeeld niet zinvol om in te zetten op een lange levensduur van componenten in een woning die een korte (resterende) levensduur heeft. Het is een grote uitdaging om levensduren van zowel componenten onderling als componenten en de woning op elkaar af te stemmen. Het blijkt verder dat de grootste milieuwinst van levensduurverlenging voortkomt uit het niet hoeven bouwen van een nieuwe woning. In de loop der tijd verandert er echter nogal wat aan zowel de woning als de bouwproducten en -processen. We zeggen daarom uiteindelijk niet veel over de uiteindelijke milieuwinst. Die ligt namelijk ver af van de werkelijkheid. Daarnaast is de LCA-theorie nog lang niet volledig uitgekristalliseerd. Dit pleit ervoor de grote lijnen in ogenschouw te nemen. Het kwantificeren van de milieueffecten van woningen is nuttig, maar men moet zich realiseren dat dat met grote onzekerheden gepaard gaat. Hoewel het verzamelen van empirische gegevens over levensduren het inzicht daarin sterk kan vergroten, zal er voorlopig sprake zijn van grote bandbreedtes. We moeten daarom onze inspanningen niet richten op het wegnemen van alle onzekerheden.

Het onderzoek leidt tot diverse aanbevelingen voor het beleid. Ten eerste zitten aan LCA te veel haken en ogen om daarop gebaseerde eisen aan het materiaalgebruik op te nemen in het Nederlandse Bouwbesluit. Het blijkt echter dat gemeenten wel uit de voeten kunnen met prestatieafspraken op basis van Eco-Quantum, hoewel nationale regelgeving hun voorkeur heeft. Met Eco-Quantum worden dan ook niet alleen eisen gesteld aan het materiaalgebruik, maar worden ook het energie- en watergebruik meegenomen. Nu het hoofdstuk milieu in het Bouwbesluit vooralsnog leeg blijft, zou de overheid gemeentelijke eisen op dat gebied moeten toestaan. Het stimuleren van de ontwikkeling van rekeninstrumenten is nog steeds aan de orde. Wel moet de nadruk liggen op de praktische toepasbaarheid. Een belangrijke omissie is het ontbreken van weegfactoren. Bij voorkeur wordt dat niet politiek bepaald op nationaal niveau, maar op Europees of internationaal niveau. Het rekeninstrumentarium kan ook de grondslag vormen voor een labelsysteem, waarmee bewoners meer milieubewust kunnen worden gemaakt. Ten slotte moet duurzaamheid afrekenbaar zijn in het kader van het Nederlandse beleidsinstrument Investeringsbudget Stedelijke Vernieuwing. Anders blijft alleen het beleid voor energiebesparing en duurzame energie over met betrekking tot de woningvoorraad. Om het Kyoto Protocol na te kunnen leven, is er veel potentieel aanwezig in de woningvoorraad. Het zal echter hoe dan ook nodig zijn de gas- en olieprijzen te verhogen om duurzaam bouwen en renoveren te stimuleren.

Voor de bouwpraktijk zijn de aanbevelingen beperkter, aangezien bij de resultaten van het onderzoek belangrijke vraagtekens kunnen worden gezet. Gemeenten kunnen proberen hun duurzaamheidsambities waar te maken door middel van prestatieafspraken over woonprogramma's. Projectontwikkelaars kunnen de verkoop van duurzame woningen stimuleren door de voordelen van duurzaam bouwen te vatten in een lagere energierekening, meer comfort en een betere gezondheidskwaliteit. De uitdaging voor architecten is om verschillende strategieën voor duurzaam bouwen met elkaar te verenigen. Het inzetten op één strategie is niet aan te bevelen, omdat aan elke strategie niet alleen milieuvoordelen, maar ook milieunadelen kleven. Bouwers en installateurs moeten alert zijn op uitvoeringsfouten. Het realiseren van het grote potentieel aan milieuwinst die ligt in de woningvoorraad, is een primaire verantwoordelijkheid van woningbeheerders. Woningbeheerders moeten meer energie steken in de afweging tussen woningverbetering en sloop met vervangende nieuwbouw. Bovendien is meer milieuwinst te behalen dan uitsluitend het behoud van woningen. Bewoners kan niet veel worden gevraagd als het gaat om duurzaam bouwen. Het bewonersgedrag zou leidend moeten zijn bij de keuze van duurzaambouwenmaatregelen.

Ten slotte volgen vier aanbevelingen voor vervolgonderzoek. Ten eerste is er weinig bekend over de invloed van het bewoners- en het beheergedrag op de milieuwinst van duurzaam bouwen. Daarnaar zou meer onderzoek moeten worden gedaan. Ten tweede geldt iets dergelijks ook voor de milieueffecten die samenhangen met de locatie van woningen, zoals het autogebruik. Ten derde geven de ervaringen met LCA van gebouwen aanleiding om te zoeken naar alternatieve manieren voor het kwantificeren van de milieubelasting van woningen. Ten vierde is LCA ontwikkeld voor consumentengoederen en niet voor woningen. Daarbij moet uitdrukkelijk de woningvoorraad worden betrokken. De kennis over de milieueffecten van ingrepen in de woningvoorraad staat nog in de kinderschoenen. Ten derde is het aan te bevelen een afwegingsmodel te ontwikkelen voor het integreren van milieukennis in het planvormingsproces van zowel nieuwbouw als herstructurering.

Curriculum Vitae

Gerda Klunder was born in Lemmer, the Netherlands, on 12 November 1973. She attended school in Veendam and Breukelen before going on to study Building and Architecture at the Eindhoven University of Technology, graduating in Technology and Society. Her undergraduate research into the sustainable renovation of residential properties was conducted at TNO Building and Construction Research in Delft. In 1997, Gerda Klunder joined the OTB Research Institute for Housing, Urban and Mobility Studies, part of Delft University of Technology, as a researcher specialising in sustainable housing construction and sustainable housing management. She has been involved in several research projects, including The Ecological City, a pioneering and innovative project conducted by the Delft Interfaculty Research Centre on the Sustainable Built Environment. In 2002 she became team leader of the research group focusing on Sustainable and Healthy Housing. In 2004, she left the OTB to take up a new position as standardisation consultant with the Netherlands Standardization Institute (NEN).

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