Evaluating Office Buildings with MOLCA
(Model for Office Life Cycle Assessment)

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ABSTRACT

MOLCA (Model for Office Life Cycle Assessment) is a project that aims to develop a tool that enables designers and builders to evaluate the environmental impact of their designs (of office buildings) from a environmental point of view. The model used is based on guidelines given by ISO 14000, using the so-called Life Cycle Assessment (LCA) method.
The MOLCA project started in 1997 and will be finished in 2001 resulting in the aforementioned tool.
MOLCA is a module within broader research conducted at the Eindhoven University of Technology aiming to reduce design risks to a minimum in the early design stages.

Since the MOLCA project started two major case-studies have been carried out. One into the difference in environmental load caused by using concrete and steel roof systems respectively and the role of recycling. The second study focused on biases in LCA data and how to handle them. For the simulations a computer-model named SimaPro was used, using the world-wide accepted method developed by CML (Centre for the Environment, Leiden, the Netherlands). With this model different life-cycle scenarios were studied and evaluated.
Based on those two case studies and a third one into an office area, a first model has been developed.

Bottle-neck in this field of study is estimating average recycling and re-use percentages of the total flow of material waste in the building sector and collecting reliable process data. Another problem within LCA studies is estimating the reliability of the input data and modelling uncertainties. All these topics will be subject of further analysis.

1. INTRODUCTION

It becomes more and more clear that by recycling and re-using building materials one can pay a significant contribution to lowering the amount of polluting and hazardous emissions to the (global) environment.

To quantify and thereby putting more weight on this statement, research has started at several different research groups around the world to develop design and evaluation tools to help designers and builders analysing their buildings from an environmental point of view. In almost al cases one, internationally accepted, method has been used. This concerns the so-called LCA (Life-Cycle Assessment) method, developed by CML (Centre for the Environment, Leiden, The Netherlands). This method currently runs on the computer program SimaPro developed by Pré Consultants (Amersfoort, The Netherlands), which is broadly used to evaluate products.

The MOLCA-project aims to develop a model which has to result in a computermodule to evaluate buildings from an environmental point of view in the early design stages. In these stages all major decisions regarding use of materials and architectural design have to be made and the influence of the results from these stages is a very important one.

2. PREVIOUS WORK

In recent years, approximately from 1992, studies into the possibilities for LCA studies start to appear. The most important ones are exploring the possibilities of LCA for all different kinds of purposes (mainly strictly defined products). Those studies could be classified as case-studies[1,2].
Also more general publications are produced in which possibilities for a more consistent LCA-method and a more general use of LCA are explored[3,4].
Last year De Haas published his Ph.D. thesis at the Eindhoven University of Technology, in which he tries to develop a single indicator method (so-called TWIN-model) to estimate the total environmental impact of (building) materials[5].

Coming into the present and the future, efforts are now being undertaken by IVAM Amsterdam, TNO MEP, Intron BV and the Eindhoven University of Technology to reach general agreement on how to perform LCA studies following a standardised format.
This standard format will be used in the MOLCA-project (Model for Office Life Cycle Assessment)[6]. With this model it should be possible to assess the environmental impact of offices.

Recently, two pilot-studies were carried out to show the impact of respectively recycling/re-use and the bias in available data regarding production of materials and processes[7,8]. These studies can be seen as exercises, trying to optimise the MOLCA-model and to prepare a larger study concerning a complete (existing) office room. The results of this study will be presented at the Green Building Conference 1998, to be held in Vancouver, Canada starting October 26 until 28, 1998.
The MOLCA-project is due to last until the year 2001.

3. METHODOLOGY

LCA is the scientific method to determine the environmental impact of all kinds of different products, processes and waste scenarios. The method is based on the fact that all the relevant (production) processes use (raw) materials and energy and produce (next to the products) emissions and waste. But it is of course impossible to compare the literally thousand different emissions from, for instance, two different production processes.
Therefore, so-called environmental classes are introduced and computer-programs have been developed to cope with this huge amount of calculations that have to be done.
The environmental classes used in the CML-method are: eutrophication, ozone depletion potential, ecotoxicity (aquatic), ecotoxicity (terrestrial), energy consumption, greenhouse effect, acidification, solid emissions (waste), summer smog, human toxicity and exhaustion of earth's resources.
So, products and/or processes are compared with each other on a total of eleven different environmental effects.
The CML methods exists of 2 important steps: classification and normalisation.

3.1 Classification

The first feature, the classification step, is necessary to allocate the "right" airborne, waterborne or soil/solid emission to the right environmental "category". An example: CO_2 contributes to the greenhouse effect so in the classification step it is allocated there.

Classification factors are scientifically based figures, because in a laboratory environment it is possible to measure the "harmfulness" on the greenhouse effect for every possible substance. Most classification-factors are empirically determined and therefore scientifically based values.

3.2 Normalisation

In the normalisation step environmental impacts are related to the average contribution of each individual inhabitant in a certain region. This region could be the whole world, one country, or a large group of countries, like Europe.

Normalised effectscore (jr) = effectscore (kg) / yearly emission per inhabitant ($kg \cdot jr^{-1}$)

Normalised effect scores must be used with great care, in case of comparison, because all sorts of different sets of Normalisation factors are being used. The CML-method uses World Normalisation scores.

3.3 Evaluation

Evaluation factors are not scientifically based numbers, that is they are not empirically determined. By implementing evaluation factors, it is possible to compare completely different environmental "categories" or "issues" like for instance the greenhouse effect and the ozone depletion potential by giving them a weighting factor. These weighting factors or evaluation factors are more or less dependent on "political" views and international agreements on decreasing all kinds of emissions. They are not based scientific research. The CML method does not use evaluation factors.

4. THE MOLCA MODEL: SCOPE, ASSUMPTIONS, DEFINITIONS

4.1 Scope

The scope of the MOLCA-project is to evaluate office buildings from an environmental point of view in the early design stages, so that the relevant design decisions in these stages can be studied and, if necessary, be changed. For this purpose, the office buildings are split up in five different levels, each one having their own specific requirements.

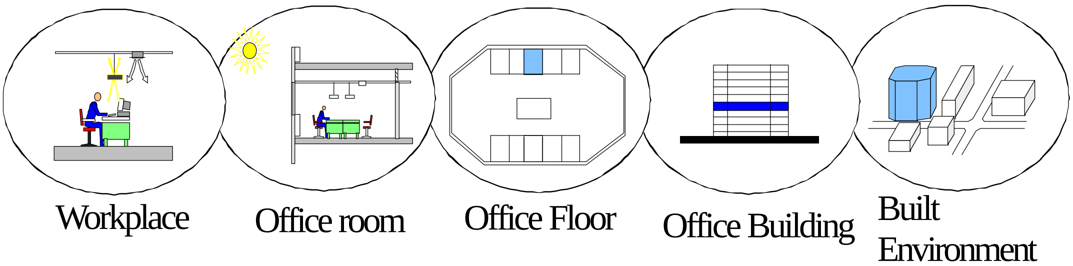

Figure 1: **Five different levels in office buildings evaluation, (Hill and Rutten, 1997).**

These five different levels concern:

a) individual workplace area, will not exceed a few square meters;
b) office room, in the third case study: 6 by 5 meters, 4 people working in it
c) office floor, a workfloor existing of about 30 offices, including elevators and stairs;
d) office building, complete building of about 10-20 office floors including facilities on a building level, like a restaurant.
e) built environment; highest level, including activities like transport, infrastructure, etc.
All these different levels must be thoroughly studied by different case-studies before MOLCA can be effectuated.

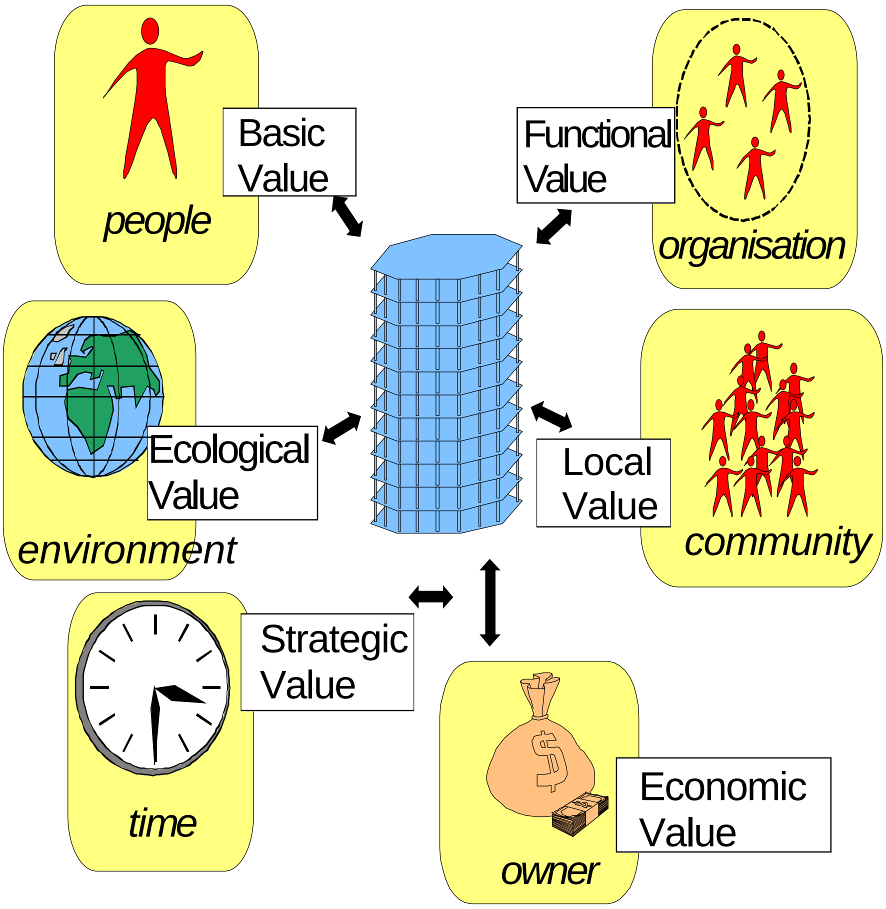

Figure 2: **Different building evaluation values, Ecological value being one of them (Hill and Rutten, 1997).**

4.2 Assumptions and Definitions

As was mentioned earlier, most tools that are being developed to analyse buildings on their environmental impact use the so-called LCA method. This method is subject of ISO 14040 series.
LCA is defined in ISO 14040 as follows.

"LCA is a technique for assessing the environmental impact aspects and potential impacts associated with a product, by

- compiling an inventory of relevant inputs and outputs of a system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory and impact assessment phases in relation to the objectives of the study."

For all other definitions I would like to refer to ISO 14040 and the definition study for the MOLCA project, to be published in July 1998.

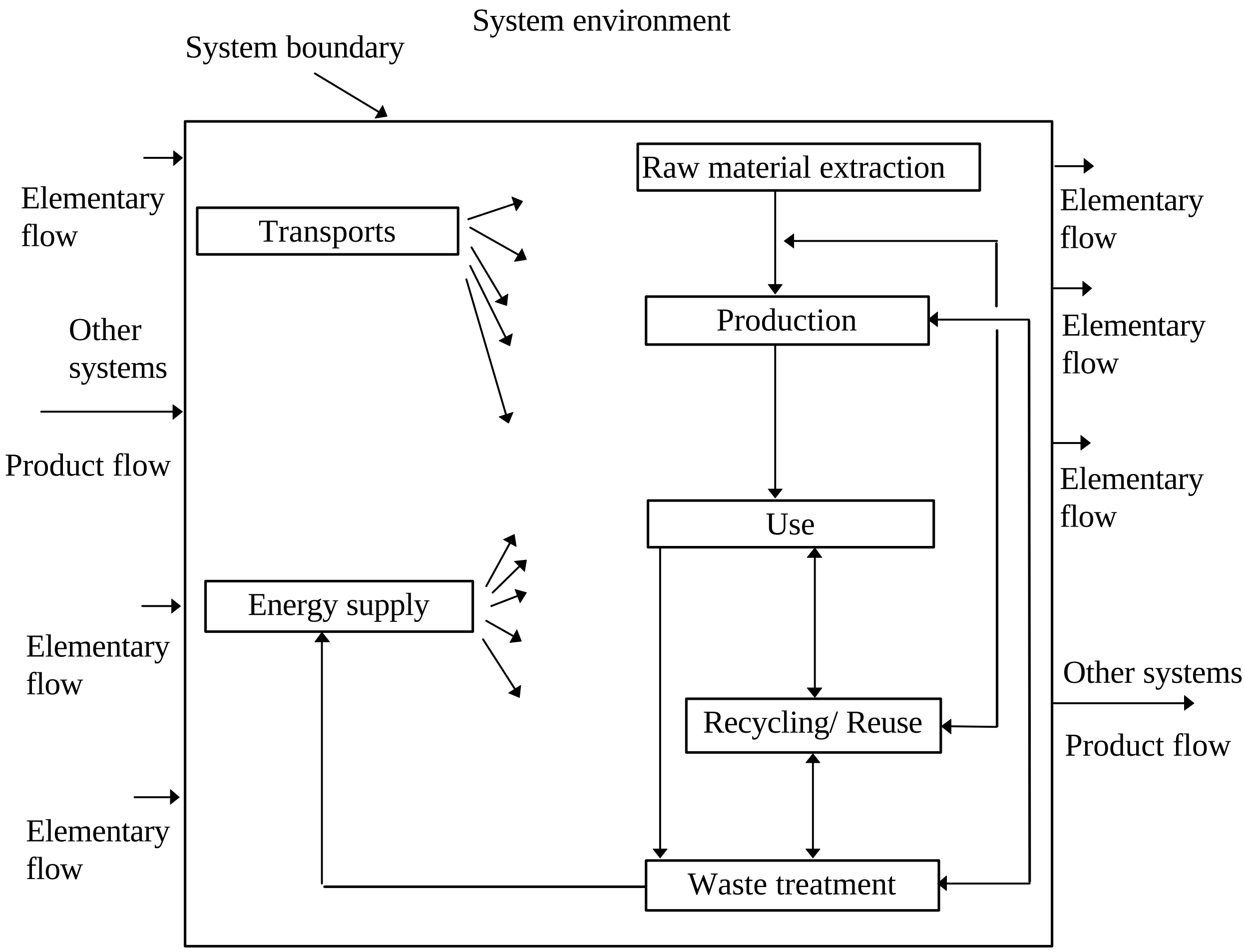

Figure 3: **A product system for LCA (ISO 14041: Environmental management - Life Cycle Assessment - Goal and scope definition and inventory analysis).**

Of course, assumptions had to be made to keep the case-studies relatively simple. The main assumptions that were made are:

a) for the moment only the workplace and the office room level will be subject of case-studies, in the future also higher levels will be taken into account;
b) certain allocation rules had to be set; sometimes this was disputable. The definitions study of MOLCA contains a complete overview of all allocation rules applied;
c) the life span of the office buildings is set at an arbitrary age of 50 years.
d) demolishing the building then - in 50 years time - is mainly based on figures for demolition waste for now. This assumption is based on the fact that it is

impossible to predict what will happen with building waste over that period of time. However, some possible future scenarios will be calculated with when the development of MOLCA is making further progress.
e) Since MOLCA is being developed as a sort of "early warning system" for designers and builders, new office buildings will be of greater importance for the model than already existing offices.

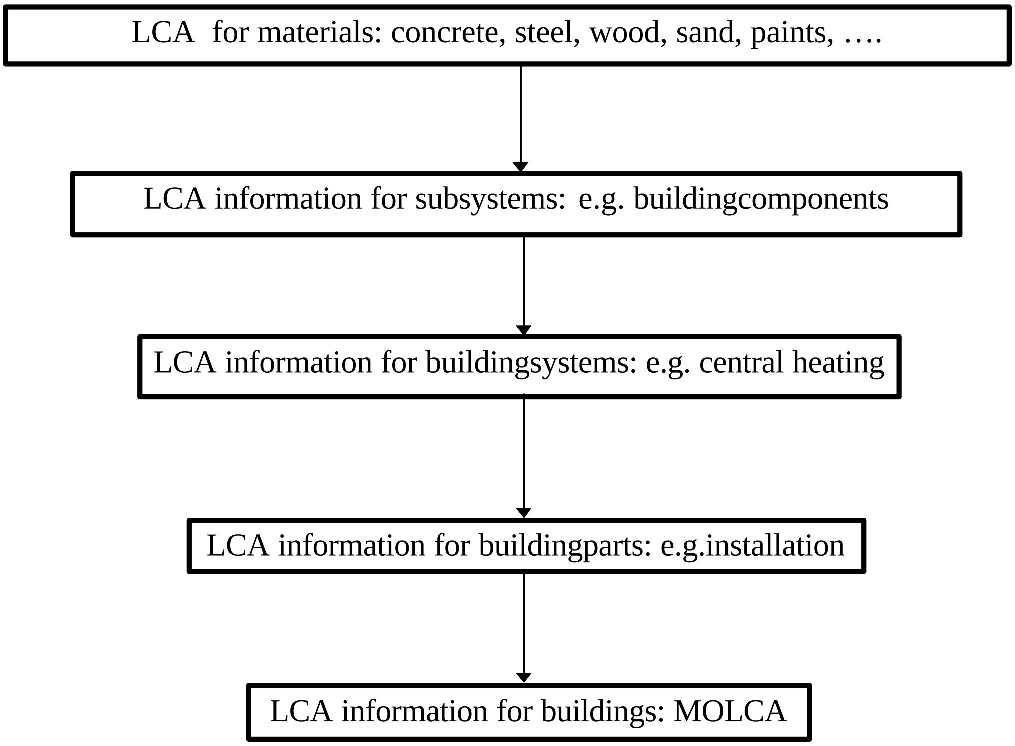

Figure 4: **Simplified structure of the MOLCA module; again working from a low level (materials) to the complete building (De Hoog, 1997).**

5. MODEL FOR UNCERTAINTIES WITHIN LCA CALCULATIONS

Handling uncertainties when performing LCA studies is essential. When comparing two or more products on environmental criteria, the biases in emission data should be more or less known. Some preliminary studies have been undertaken to establish a formula to incorporate biases in data[8], but this has never been done for a more complex product like for instance a complete roof construction or a complete building.

In the aforementioned study the so-called method of "successive estimating" has been applied for a study concerning the CO_2-emission of 10 different wall types. This study showed that for instance the results for CO_2-emissions of 5 out of 10 wall types overlapped. In this particular case it was not possible to

"rank" most walltypes on a scale ranging from "good" through "bad" for the environment.
However, this simple example shows that when dealing with thousands of different processes and products in a more complex product, like a building, biases could determine the final results completely.
Therefore it is necessary to develop a method which allows an analysis that pinpoints "the centre of uncertainty" within a LCA. To this purpose the following formula can be used:

$$\sum_{\substack{i=1\\l=1}}^{n,\,m} \mathbf{U}_{(L,\,C,\,N,\,E)} = \sum (U_{L,i,l}^2 + U_{C,i,l}^2 + U_{N,l}^{\ 2} + U_{E,l}^2) + \alpha + \beta \qquad \textbf{(1)}$$

where:

$\sum_{\substack{i=1\\l=1}}^{n,\,m} \mathbf{U}_{(L,\,C,\,N,\,E)}$ = the total **relative** uncertainty in a characterised, normalised and evaluated product's LCA.

n = number of emissions occurring during the complete life-cycle of the observed system.

m = number of environmental classes observed.

$U_{L,i,l}$ = relative uncertainty in amount of emission i during the complete life-cycle of a product for environmental class l.

$U_{C,i,l}$ = relative uncertainty in the value of the classification factor for emission i for environmental class l.

$U_{N,i,l}$ = relative uncertainty in the value of the used normalisation factors.

$U_{E,l}$ = relative uncertainty for evaluation factors (supposed to equal zero because evaluation factors are not taken into account for this study).

α = correctionfactor for uncertainties due to differences in used waste treatments, recyclingspercentages, transportdistances, etc.

β = correctionfactor for uncertainties due to differences in used technologies (future, modern, backdated).

Because of the preliminary state of this study a few assumptions have to be made:

1. Only the most important environmental class of a product will be taken into account, so l = 1.
2. The determination of classification and normalisation factors is not supposed to be the scope of this kind of LCA studies, these values are mainly determined by both practical and theoretical toxicological research. Preliminary results from this research, when available, will be implemented in LCA studies at a later stage.
3. The evaluation step will not be performed in this study, so this factor will also be eliminated.
4. All production processes are using the same level of technology, so β equals zero.
5. Because no reliable information concerning α was available, the two different waste scenarios were assumed to be the "extreme values" of one average waste scenario, therefore α equals zero in this study.

When taken these assumptions into account formula 1 can be rewritten as follows:

$$\sum_{i=1}^{n} U_{(L)} = U_{L,i,l} \qquad (2)$$

Now, only uncertainties in emissiondata have to be calculated according to the method of **successive estimating** proposed by Petersen[9].
The example shown below is based on results from a case-study carried out earlier to determine the influence of the bias of one of the main products in a roof construction. The covering of two different roof systems was APP and PVC respectively. All other components were exactly the same.

5.1 Results comparing APP and PVC roof covering with bias in data

Since there is no alternative process data available for producing APP, it was only possible to make an estimate about the bias in PVC production. This was done based on four different sources for the production of PVC. Most of these sources were again based on averages on two or more production processes for PVC. This, of course, diminishes the bias in emission data for the production of PVC.
Firstly, the bias in the summer smog environmental class was calculated. The bias (mean value minus two times the standard deviation and plus two times the standard deviation) was about 33% for the emission of C_xH_y, which is responsible for more than 95 % of the summer smog caused by the production

of PVC. The production of PVC alone is responsible for 10,6% and 11,8% for the low and high recycling ratio scenario respectively. On this basis the bias caused by uncertainties in the emission data for summer smog caused by the production of PVC would be 3,5% and 3,9% for the low and high recycling ratio scenario respectively. The results are shown in Table 1.

Table 1: Normalisation score for different roofs including biases for PVC.

APP low	**APP high**	**PVC low**	**PVC high**
130	72,2	134,1 - 143,9	73,0 - 84,0

It is demonstrated that the scores for APP and PVC almost overlap. This would certainly be the case when the bias in the APP production emission data is known. A bias of only 2% would be enough to establish this (also considering the fact that relatively more APP is needed per square meter of roof).

6. DISCUSSION

Three major limitations of LCA will be shortly outlined.
First, the reliability of the process data which was entered into the computer. Different data will of course result in different outcomes. The emission data used were based on average production data in Western Europe. Production processes at other production plants of, for instance, APP and PVC might be more polluting or less polluting. Often it is not known where products come from exactly. Another problem concerning process-data is the fact that some factories or producers do not give exact, detailed emission data. All sorts of motives could be responsible for this. It could well be possible that not every company wants everybody to know what kind of production processes or methods they are applying.
Secondly, and this is related to the first limitation, in actual fact, there will be a bias in production emissions.
This bias will result in a bias in the final outcome of the total environmental impact and based on this bias a comparison between two or more products is sometimes questionable.
Thirdly, the results of any LCA calculation are strongly dependent on the normalisation and evaluation method used. In this study the CML-method was used, which from a scientific point of view is the most reliable one. The CML method does not use so-called evaluation factors which give every single environmental class a specific weighting factor to make comparison possible. Eventually this method produces one "environmental mark". Evaluating in this way is at this moment scientifically not sound.
Based on these three limitations, one should always be very cautious when reading LCA studies, certainly when comparing results with each other.

7. CONCLUSIONS

Based on the pilot-studies the following conclusions can be drawn:

1. With MOLCA it becomes possible to evaluate buildings from an environmental point of view and hereby decrease the risks in the early design stages dramatically.
2. Recycling should not be the main objective. The real goal must be diminishing the environmental impact of buildings products or processes. Recycling can be very important in diminishing environmental impacts.
3. Further research into developing better, more reliable models to describe biases is essential.

8. LITERATURE

[1] Hoefnagels, F. and De Lange, V.P.A.: "De milieubelasting van vier verfsystemen", CREM/Akzo coatings, Deventer, 1994

[2] De Hoog, J: "Milieugerichte LevensCyclusAnalyse (LCA) van de productgroep dakgootsystemen met behulp van Simapro 3.0", Eindhoven University of Technology, 1996

[3] Guinée J.B. et al: "Milieugerichte levenscyclusanalyses van producten. Deel I: handleiding. Deel II: achtergronden", NOH rapport 9253/54, 1992

[4] Kortman, J.G.M., Lindeijer, E.W. et al,: "Towards a single indicator for emissions - An exercise in aggregating environmental effects", IDES, CE, Inforplan, 1994

[5] De Haas, M.: Milieu Classificatiemodel Bouw, TWIN-model, Ph.D-thesis Eindhoven University of Technology, 1997

[6] Hendriks, N.A. and Rutten, P.G.S.: "STW-aanvraag MOLCA project", Eindhoven University of Technology, 1997

[7] Hendriks, N.A. and de Hoog, J. : The Importance of Recycling in Life Cycle Assessment of Roof Systems", Eindhoven University of Technology, The Netherlands, 1998, to be presented at the Steel in Green Building Conference, March 18-21 1998, Orlando, Florida (USA)

[8] Hendriks, N.A. and de Hoog, J. : The Importance of Recycling in Life Cycle Assessment of Roof Systems", Eindhoven University of Technology, The Netherlands, 1998, to be presented at the International Waterproofing Association Conference, June 10-12 1998, Copenhagen, Denmark

[9] Petersen, E.H.: "Life-cycle assessment of building components - Handling uncertainty in LCA's, Danish Building Research Institute (SBI), Horsholm, Denmark, 1997