The MaSe decision support system:

Development of an integrated information system for the selection of environmentally preferable materials and products in the building process

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September 03

URN:NBN:no-6424

PREFACE

"Art and science has their meetingpoint in method".

Edward Bulwer-Lytton

I don't think I knew what I was starting, when I responded positively to Frank Henning Holms proposal to write a thesis in a meeting at Statsbygg in May 1997. I liked the idea, and an application to NFR with support from Stein Rognlien at Statsbygg, and in October 1997 I started out at the Norwegian Building Research Institute with the work that hopefully would lead me to the dr. ing. degree. There has been many ups and downs, but as my main tutor at the Norwegian university and Science en Technology, Kai Nielsen, always says: "at least you are confused at a higher level".

Some times, as I suppose most dr. students have, I thought that the most sensible thing to do would be to "throw in the towel". However, with the support of my husband, Bjørn Erik, I always found reasons to go on. He deserves the gold medal in patience. In 2001, we had a wonderful son, Elias, who brings sunshine in to our lives, and always takes my mind of work when I come home. I want to thank my family and my friends, who have encouraged me throughout these years. I hope I will have better time also for them now that this is over!

I am grateful to my main tutor Kai Nielsen at NTNU, who has been an important pillar of support in my most desperate moments. Thanks are also sent to Stein Rognlien at Statsbygg and Frank Henning Holm, my tutor at NBI. My good colleges at NBI have meant a lot to me the last years. Especially the Environmental group with Guri Krigsvoll, Kristin Holthe, Svein Erik Haagenrud, Sverre Fossdal, and Trine Dyrstad Pettersen as an enthusiastic ad hock member of the group. I am also very grateful to Lars Myhre, who has suffered through many pages of this thesis, providing important comments and corrections, and Jørn Brunsell, leader of my department at NBI, for the valuable practical support during my engagement at NBI.

I also thank those who willingly shared their experience with me in my survey, for me very unknown landscape, of the building process. Finally, I thank those who provided all kinds of information about their own work, for example Bobbie Lippiatt with the BEES system and Petersen at SBI, with the BEAT2000 system.

ABSTRACT

New building regulations and increased focus on building related environmental burdens have created a need for guidance to design more sustainable buildings. The main objective in this thesis is to develop a decision support system, to guide decision-makers to a better selection of building materials and products, based on environmental prioritisation. The system is focused on building materials and products, but the structure of the system can be adapted to other types of decision problems. No tool is found that satisfy the identified needs for a material selection system. By studying existing methods, however important information and possible solutions are gathered, that partly could be used in a new tool.

Key decision makers with respect to material and product selection are the client, the architects, the technical consultants, and the contractors when they decide on specific brands. The user of the MaSe system first identifies the materials acceptable in the specific project, based on the technical requirements. These pre-selected materials are then scored and ranked through the procedures in the MaSe system. The alternative ranking is then the basis for the selection of construction elements, materials or products.

Seeing the building and real estate industry as a part of our society, it is clear that the use of material resources and pollution are areas that need improvement. The MaSe system includes environmental aspects under the headlines Resources, Ecology and Human health. When selecting building materials, factors like recycling and reuse needs to be considered. Renewability, energy and waste are other aspects included in the Resource area. Toxic substances are clearly important when it comes to building materials. Factors to be included under the headline Ecology are global warming, acidification, and photochemical oxidant formation. The emissions of toxics to air, water and soil will have effect on human health. Aspects that should be included in the assessment of the indoor environmental influence of a material includes emissions of substances and fibres, cleaning methods, cleaning chemicals, cleaning friendliness and dust adhering properties. The results from each sub area are weighted into one index, referred to as the Environmental index. Each material is characterised with this index and a judgement. All costs related to the production, use and disposal of a material are included in the MaSe system evaluation.

The MaSe system is suited for use in the relevant phases of the building process. It is possible to use the system on different levels and with different input, from client priorities to details of the different products studied by the contractor. Economy is included in the system, and this one important aspect that separates the MaSe system from many of the existing systems. Many different products and materials can be handled within the system as long as the functional unit (FU) of the data are carefully defined. The structure of the scorecards and the aggregation of information into one index using Analytical Hierarchical Process (AHP) and pair wise comparison, makes it possible to include new information as it is made available.

URN:NBN:no-6424

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1 Introduction

The development of a material and product selection system requires input from many professional areas. The basis has been knowledge about environmental and resource related problems. In addition, this work has required knowledge about building material and construction aspects, the building process, indoor environment and other health related aspects, decision analysis and economy. This has made it necessary with extensive contact and discussions with persons representing these fields of knowledge.

1.1 Background

New building regulations and increased focus on the building related environmental burdens have created a need for guidance to design more sustainable buildings. The objective of this work is the development of an information and selection system. The system is focused on building materials and products, but the structure of the system can be adapted to other types of decision problems.

Several tools exist that can be used to assess materials, but few are developed with the building process in mind. Some attempts have been made to use guides in the form of handbooks in building projects, but this is not found to be completely satisfying, and none is implemented on a regular basis.

Life**c**ycle **A**nalysis (LCA) is today seen as the method that gives the most correct environmental evaluations. Several problems are related to the practical use of LCA, primarily the time needed to perform an assessment, but also the lack of agreed methods for the final assessment steps. Because of the lack of direct guidance within the LCA standards, for example for system boundaries and allocation, the results from different LCA studies are rarely comparable. The possibility for using LCA for building material comparison and selection is therefore limited. The interest and needs in the industry, and the failing of existing tools to meet these needs have lead to the development of the MaSe system (**Ma**terial **Se**lection system).

1.2 Objectives

The main objective in this thesis is to develop a decision support system to guide decision-makers to a better selection of building materials and products, based on environmental prioritisation.

The system covers the total lifecycle of the building, and is designed to fit well within the framework of the building process. The system is aimed at relevant actors involved in material selection. This includes the process from the client setting the initial priorities, to the contractor making the final adjustments. The system is primarily aimed at the professional market. Further simplification is needed for the system to be used by private persons planning their own homes.

Building materials and the impact they make on the environment, through emissions, resource use and waste production have not been the topic of any scientific studies in Norway. As the knowledge of the environmental consequences of our actions is increasing, the framework should be able to implement this knowledge successively.

For a tool to be implemented in the building process, the time aspect is very important. Therefore, it must not be too work intensive and time demanding. Another aspect is that every project is unique, and the materials and products must be assessed and selected in every new project. An assessment procedure must therefore be performed repeatedly. In addition, there are large material quantities involved, and a large number of products. This makes it necessary to provide large amounts of data before a tool satisfy the needs of a user. The users are not environmental specialists, so the results from the evaluation must therefore be easy to understand without in depth technical or environmental skills.

1.3 Limitations

The focus of the present study has been on larger buildings, mainly office buildings. However, the current system can be easily adapted to other types of buildings, including dwellings. The focus in this work is on developing the framework, not to make a fully operable system. Making an operable system would require large efforts in collecting data, programming, loading data into the program and testing. This will be a natural continuation of the work presented in this thesis. The result of the development work is a spreadsheet operable by an expert, following the instructions provided through this thesis. A paper copy of this spreadsheet is included in Appendix A.

It must be underlined that the intention is not that the MaSe system shall be 100 per cent scientifically correct. To reach a practical solution that covers the areas found important to be included in the system, some simplifications are made. Considering the time constraint at all stages in the building process, exact science has been sacrificed, to a limited extent, for the sake of reaching a practical solution.

1.4 Contents and scientific method

The main structure of the thesis is separated in three parts:

1. The identification of needs:
    a. Environmentally.
    b. In the industry.
2. To what extent can existing tools and methods be used to satisfy the identified needs?
3. Development of a new tool.

The thesis covers several areas, and will have readers with different backgrounds, it is therefore important to include enough information to ensure a common basis and understanding of the different topics. This is especially important for the part that covers the building process. Here it is made celar that different parts of the industry see the process differently and there is no common framework valid for all participants. No attempt is made to find the perfect definition and systematisation of the process, but an attempt is made to create a common understanding of the process and its elements. The result is also used to place the different steps in the MaSe system where they belong.

The structure and the work in this thesis are illustrated in Figure 1-1. It is considered important to identify the most significant environmental consequences related to building materials and products, in order to define the parameters that should be included in a material selection system. A practical tool is the target, and therefore it is important to include political guidelines and regulations, since this is an important part of the reality, the participants in a building project must relate to. The third chapter in the thesis is therefore describing the environmental impact of building materials, as well as relevant political requirements, rules and regulations.

The development of a decision system is of no use if a system already exists that fulfils the identified needs in Chapter 2 and 3. Existing systems has therefore been systematically evaluated according to a set of identified requirements. These systems also form important input to the design of the material selection system.

Chapter 5 constitutes the core of the MaSe system development. **M**ultiple **C**riteria **D**ecision **M**aking methods (MCDM), existing material evaluation tools, LCA and various other methods are used in the development of the system. Focus is also set on the input data situation. Concern has been expressed about the availability and quality of environmental data. This is the reason why Chapter 6 has been dedicated to these aspects. To better explain the system, three examples on how to use the MaSe system are included in Chapter 7. For readers not interested in the details of the evaluation procedure, this is a simple guide to how the system is intended to function.

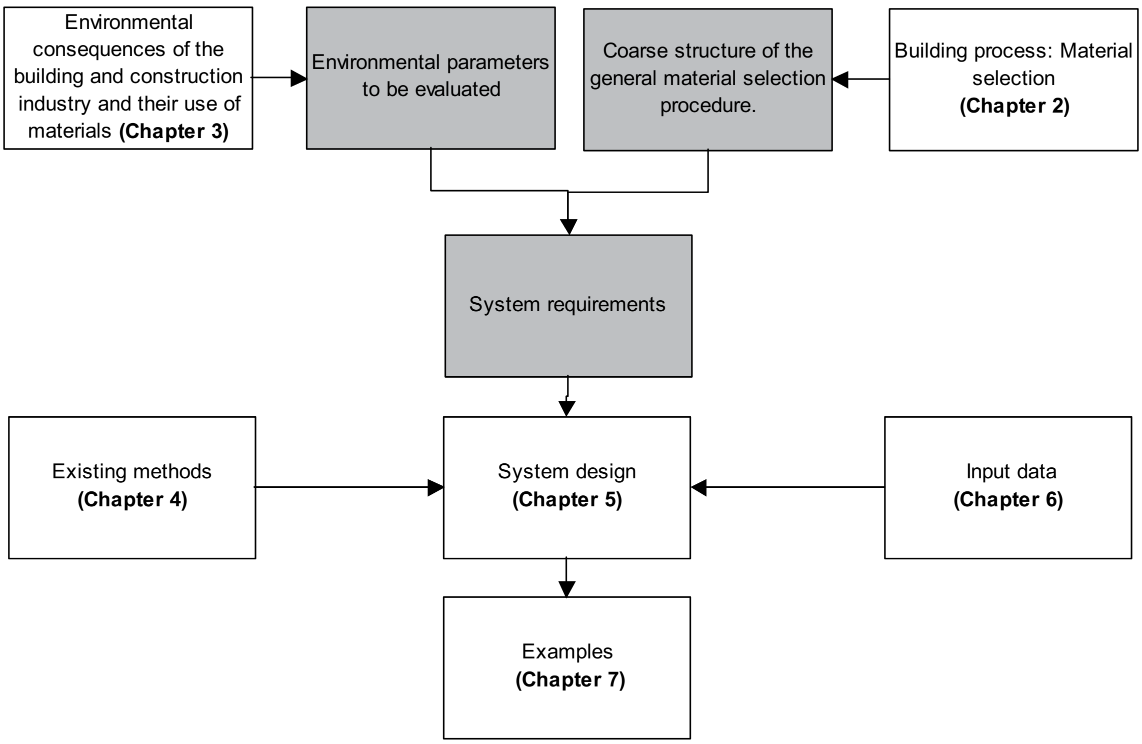


Figure 1-1: Structure of the thesis, the work and the different chapters.

2 The material and product selection procedure

The building process includes all processes that lead to, or are conditions for, a finished building. The material and product selection procedure (herafter named only materil selection procedure) is a part of the building process, but also includes stakeholders that are not traditionally regarded as a part of the process. Without knowing who needs information, at which stage of the process the information is needed, and the type of information required, it is difficult to develop a useful system for selecting environmentally benign building materials and products. This is especially important for the often complex organisations in larger building projects.

This chapter first presents a model of the building process and the material selection procedure. The study of the material selection procedure is further supported by interviews with selected key participants. Based on these studies, the factors and the processes determining the material selection will be outlined. This again forms the basis for the further development of a material selection system.

2.1 Participants in a building project and their role in material selection

In broad outline, the building process includes mainly the following participants (after Samspill i Byggeprosessen, 1996, Eikeland, 1998):

- User.
- Client.
- Project manager.
- Designer manager.
- Design supervision.
- Designers (architects, construction, technical subjects and special consultants)
- Site manager (co-ordinating the construction).
- Clerk of work (construction manager).
- Responsible co-ordinator for the construction.
- Contractors.
- Suppliers of products.

One participant may fill two or more of these roles. Some participants are not included in the list, such as finance institutions, real-estate agents, lawyers, educational institutions, information suppliers, suppliers of control systems, research organisations, consultants on superior levels, public institutions like ministries, directorates etc..

The following description of the different roles in the process, their involvement in material selection and in a material selection system, is based on both process descriptions and interviews with central actors in the industry. A brief discussion of the environmental motivation and responsibility for the different actors is also included.

2.1.1 The interviews

The interviews were made in order to find out if there was a need for a material selection system among potential users, and the type of information they would want. The interviews were also used as an opportunity to investigate the material selection procedure, the criteria that are dominating today, and what criteria the parties see as becoming more important in the future.

Interviewing demands resources, as it requires a large range of interviews, a random selection of objects etc. After discussing the aim of this investigation with professionals on the subject, it was concluded that a selection of about ten key persons with known backgrounds would be just as useful.

The questions asked concerned the development in the industry the last five to ten years with respect to environmental considerations, how they were involved in material selection, what they saw as important criteria for materials selection, and what they would need of support in order to include environmental considerations in material selection. The questions are included in Appendix B, and the list of respondents is presented in Table 2-1.

Table 2-1: The respondents and their role in the building process:

Name	**Company**	**Role**
Eriksson, Mads	OPAK	Project manager
Holm, Harald	F. Holm	Project manager/clerk of work
Lindquist, Per Håvard	Lindstow Eiendom A	Client
Rellsve, Tom	RIF	Consultant
Ryjord, Morten	Statsbygg	Client
Salvesen, Henriette	DIVA arkitekter	Architect
Stormoen, Halvard	Statsbygg	Client
Strand, Harald	Multiconsult	Consultant
Strøm, Asle	Arkitektskap	Architect
Venold, Terje	Veidekke	Contractor

In general, the feedback from the respondents was positive. They were all familiar with the problems of including environmental considerations in their work, but at different stages in the building process.

Only Statsbygg had tried to include systematic environmental considerations in the selection of building materials. When asked what he thought was the most important obstacle against environmental material selection Ryjord answered (translated from Norwegian by the author): "*The problem is that it is difficult to concretise the requirements. What is it we shall measure? If the requirements are difficult to define, the architect will not manage it either, oralternatively it will be reflected in the prices.*"

Only a few of the companies had been involved in projects that included environmental considerations, beyond plans for waste and contaminated ground. The respondents had been involved in research projects that had made them consider the problems that the business in general is facing. Nevertheless, few had considered what the consequence would be on a practical level. However, they are all experienced participants in the building and real estate industry, and their answers and attitude are valuable, and also important to whether or not such a system will be used.

2.1.2 Client

The client is legally responsible for the project, and carries the initial risk for the costs of the project. The client is the central employer for the development and execution of the project. Client responsibility, client rights and project risk are some of the key words. Bearing the total responsibility for the project also involves financing and organising (Eikeland, 1998).

The client is vital for whether or not environmental goals are included in the project. Further, he/she is responsible for setting priorities and evaluating the actions throughout the production process. The programme/clients brief, is one of the means that the client uses to communicate these requirements. The environmental goals can be set according to company environmental policy, or by hiring a consultant to formulate an environmental programme (Byggecentrum, 1999).

The responsibilities for the client in the early stags regarding environmental considerations include (NBI, 1996):

- Decisions to take special environmental considerations into the project.
- To appoint an environmentally responsible engineer.
- To engage co-workers with knowledge about environmental problems.
- To accumulate and utilise experience from previous projects.
- To consider what kind of regulations that will apply.
- To consider further environmental considerations.
- To get the overall view of possible actions.

In the interviews, it was confirmed that both the public and the private owners realise that environmental considerations must be included in the projects. In theory, the client has quite a degree of freedom within the existing framework, but as stated in an interview, the client's decisions are made in co-operation with the architect. Other clients see themselves as involved to a very small degree in direct material or product selection. This indicates that the client involvement vary from one project to another. The most likely situation is that the owners will make the decision about using a material selection system, like for example the MaSe system, and make the principal priorities.

2.1.3 Project manager

The trade term project manager includes the client's project manager, together with all other persons assisting the manager.

The project manager is responsible for organising, arranging and co-ordinating the total project. In addition, administrative procedures like procurement procedures and control with progress, economy and quality are included in the tasks of a project manager (Eikeland, 1998). He/she can be employed or engaged in the client's organisation. The responsibility of the project managers in material selection is to insure that the prescribed qualities are fulfilled. This will also involve ensuring that a system like the MaSe system is used.

2.1.4 Architects and technical consultants

Designers include both architects and technical consultants of different disciplines. Design is about documenting and illustrating the physical result of the project, which serves as information for the contractors and craftsmen, concerning how the product shall be erected (Eikeland, 1998).

Consultants on construction, electricity, HVAC, sanitation, fire safety etc. are also participants in the preliminary design stage. The consultants have to develop and provide requirements concerning documentation of the given recommendations. This is partly done in control plans, and includes requirements for design execution, operation and control.

The responsibility of the consultants is explained as optimising requirements from the client. The degree of involvement in material selection is depending on the organisation of the project. In a main enterprise, the consultant can specify for the contractor the materials types to be used, including quantities, and then the contractor selects the brand.

Especially the structural consulting engineer has responsibilities when it comes to environmental considerations related to material selection. NBI (1996) has recommended that he/she in preliminary design stage should collect data, consider technical solutions and assess the consequences for the different alternatives. In the main project phase, he/she decides the detailed solutions, document the chosen alternatives and set requirements for the site execution work. During the formation of the contract, the consulting engineer must ensure that the environmental considerations are included in the basis for tendering, and that they are included in the contract.

The architect plays an important part in the building process. There is normally a group of architects involved, often from the same bureau. NBI (1996), has made recommendations that the architect (or the environmental engineer) should have the following tasks in the programming phase:

- To develop preliminary environmental plans together with the client.
- To describe possible environmental effects.
- To describe exterior and interior areas and functions.
- To assess necessary permits.
- To set environmental requirements during the construction period.
- To set superior environmental requirements for materials and structures.
- To pre-qualify consultants and contractors.

The architects in the interviews see themselves as deeply involved in material selection, but seldom on a product level. In the interviews, they seemed very interested and engaged in including environmental considerations in their line of work. At the same time, it left an impression that this did not reflect the architects as a profession in general. As Strøm stated: "*The architects in NAL (the Norwegian Association of Architects) in general are on the move, but falls short. A part of the organisation is in the front, as for example NABU (Norwegian Architects for a Sustainable Development).*" He also thinks that "*the architects is in danger of falling behind, except from groups with top competence*" (translated from Norwegian by the author).

The architects felt that it is the client's task both to set priorities and to take care of the economic effort in order to include environmental considerations in a project. In addition, they were in need of a method enabling them to satisfy such requirements from the client, and optimising the building to the best possible total performance.

The consultants had, in the interviews much the same focus and needs as the architect, but they may have different roles regarding material selection. In some cases, the only consultant responsibility is engineering and construction tasks, but he/she also forward recommendations to the client.

2.1.5 Design manager

The design manager co-ordinates the designers in the building project, and normally report to the project manager. Traditionally the architect has had this role. However, increasing specialisation has lead to other professions taking over the role, usually the construction engineer (Eikeland, 1998).

2.1.6 Contractor

The assignment of the contractor does not only include the physical work on the site, but also administrative functions, planning, organising and leadership linked to the execution (Eikeland, 1998). In the construction phase, the contractor or the work execution manager, is responsible for the control of the materials, the work execution, and updating according to the environmental plan (NBI, 1996).

The contractor's influence on material selection is also depending on the organisation of the project. A total package builder is involved in almost all the decisions. He/she then collects all information about costs and the technical properties, and makes a decision on basis of this information.

2.1.7 Craftsmen

The quality of the work of the craftsmen is decisive for the quality of the building, and the function of the materials, throughout its lifetime.

Environmental requirements may involve changes in the working methods of the craftsmen. Such as the sorting of waste fractions, clean building site, construction for deconstruction etc. In order to get these types of changes to be a success, effort is needed in educating and informing the craftsmen.

2.1.8 Building material producer and supplier

The materials producers have several clients to attend to, and these clients have different needs and information requirements. Documentation problems for the supplier turn up when (De Paoli, 1999):

- The materials are used for different purposes.
- The raw material suppliers are changing.
- The chain of producers and suppliers can be hard to keep track of.
- There are no standardised system for collection and presentation of the environmental data.
- The documentation requirements may represent a barrier for local and small material suppliers.

At the Norwegian Building Research Institute (NBI), there is work ongoing to develop a framework for self-declaration of building materials. Other countries are also developing similar systems, like UMIP in Denmark and Building Material Declarations in Sweden.

The building material suppliers in Norway have developed a database for a more advanced form of building product information, Norsk Byggevarebase (NOBB). This is a database that handles information about the products, prices, technical and commercial information etc. This will help secure that the product described by the contractor, is the product actually selected for the building (The Organization of Timber and Building Materials Merchants, TBF, 1996).

2.1.9 Aspects that affect the material selection

An important task when trying to see where and how the process of change in material selection has to take place is to investigate the reasons for selecting a particular material. In this work, an attempt has been made to uncover some of the controlling aspects of material selection for the different parties involved.

Most of the statements in this work are a result from the interviews performed in the spring of 1999. The respondents must have the author excused if the interpretation of their answers is not correct.

In these interviews, it was seen that the most common factors affecting material selection today were:

- Price.
- Aesthetics.
- Indoor environment.
- Technical quality.
- Image.
- Tradition.
- Functionality.

All the parties agreed that environmental qualities will be considered more important in the years to come. How these changes will occur was however a point of dispute.

The obvious conclusion after performing the interviews was that all the parties showed most interest in what happens after the material was installed in the building. The areas of interest included emissions of gases from materials, indoor environment in general, and energy use. In addition, the focus was set on traditional aspects like aesthetics and price.

When asked how to change the process so that material use will be sustainable, there where different responses from "*It will come off by itself*" to "*Development of standards*". A part of the blame for the lack of change so far, is also put on "environmentalists" and others with responsibility to get clear messages forward, on what is environmentally friendly and what is not. Up until now, there has been a lack of credibility, because "*what is said to be environmentally friendly changes in a couple of years*". The lack of agreement within the area of environmental science seems to reduce the credibility of the solutions presented. In addition, a point made from Holm: "*It is often a market gimmick to claim that something is environmentally friendly, therefore there is no willingness to pay for it either"*, introduces another credibility problem.

When asked what reasons they saw for the necessary evaluations not being included today, the response can be grouped in the following categories:

- Lack of knowledge by the professionals in the building and real estate industry.
- Attitude of all involved parties.
- Lack of concrete specifications and documentation in all parts of the process.

Between the respondents, there was little agreement on what parameters to include when selecting environmentally preferable materials. This indicates that assistance is needed to make the necessary changes due to lack of knowledge and competence.

2.1.10 Summary of the material and product selection procedure

Key decision makers with respect to materials and product selection can, with basis in the previous chapters, be listed as:

- The client.
- The architects.
- The technical consultants.
- The contractors when they decide on specific brands.

In some cases, the user might also have influence on the selection. In addition, the producers and suppliers of building materials have indirect influence through the type of information they present.

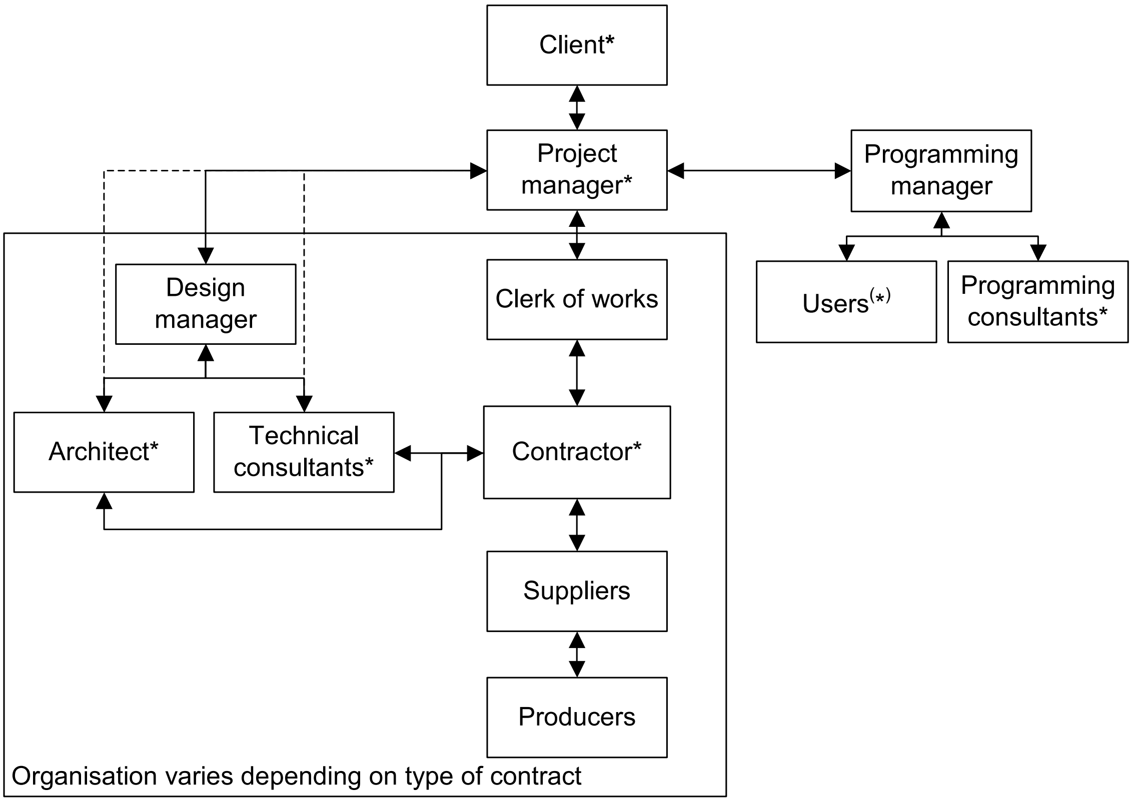
The designers need to break down the requirements from the client into materials and solutions that meets these requirements. The contractor and supplier share the responsibility of documenting the selection of materials. A suggested procedure illustrated in Figure 2-1, involves that:

– The designers and contractors use the goals and prioritisation from the client to define the specifications for the products. The contractor also in the end has to make sure that this documentation is provided.

– The material supplier must document that his/hers products fulfil the functional requirements

– The contractor is responsible for the documentation that the product he/she specifies in his/hers bid fulfils the functional requirements in the description, for example for emissions.

The communication channels are however hard to track, and it may not be possible to get the full picture.



* Key decision makers for material and product selection.

Figure 2-1: Different communication channels for material selection in the building process.

2.1.11 Identified needs for a material selection tool

The respondents in the interview all agreed that environmental considerations must be included when selecting materials. On the other hand, only one of them had made any plans for how to start this work. It was also a tendency to put responsibility on other participants in the building process, usually the client, for not implementing the relevant aspects in the early phases. It is also a problem that there exist no methods to satisfy such requirements adequately.

All the respondents also agreed that they needed some kind of help when including environmental considerations in material selections. There were different views on the type of support that would be best, depending on their role in the building process.

The clients see their role as ordering the use of a system. The private client had a specific idea about a "catalogue". This catalogue should contain the properties of the materials presented systematically after a standard. He also agreed that there had to be some weighting and important key words were documentation, neutral, specific and simplified.

The public client asked for increased focus on the user phase of the product. He thought that it had been too much focus on the producers. He supports the value-chain thinking, and wanted more focus on the part of the chain that the building owner can influence. A classification of the building materials on a scale was seen as interesting. Requirements could then be set to which class the building should satisfy. Both clients agreed that there must be a set of weights according to priorities, but they also want influence on these priorities, to unsure that they are in accordance with their objectives.

The architects agreed about wanting a simple system, like for example a handbook. They had a perception of a guide, on Internet or as a book, with popular texts for non-specialists. They wanted a qualitative description together with categories (not labelling). The system should also allow the user to go into details, but the information must be as simple as possible. Regarding the use of weights, the architects were a bit sceptical, and said that in any case it is important that the prioritisation is visible.

The contractor also saw an Internet based tool as the right way to go. He wanted a quantitative system that includes the economic consequences. The documentation must be simplified, not presented as CO_2, NOx etc., and it should be open for the user to decide what to prioritise.

Another contractor is very clear on not wanting lists of what is good and what is bad; "*it is not as simple as that*", he responded. He wanted a simple, predefined set of weighted parameters, but these weights had to be set by the client, for example after priority from the ordering part. Weighting should be based on what he calls "mathematical or physical facts".

The consultants were very enthusiastic about a database, for example linked to DAK. Elements stressed by this group were that they did not want some kind of labelling system, or raw data, like for example material declarations. They wanted to be able to follow design criteria, and see the reasoning behind the results of a material evaluation.

The clerk of work also wanted a database with environmental data for the products, and a calculation model showing the environmental qualities of the materials. He did not se a list of good and bad materials, but a set of criteria allowing the person selecting the materials to decide what criteria to include.

2.2 The building process

As a basis for understanding the building process, one can use general project theory. However, a complicated set of trade terms and communication channels has evolved specially for the building and real estate industry. Different actors in the industry have developed special trade terms for their type of work, and different parts of the industry may place different meaning into one single trade term.

This confusion has lead Eikeland (1998) to develop a common theoretical basis, as a part of the research project "Interactions in the building process" (Samspill i Byggeprosessen, SiB). The definitions agreed upon in the report will, as far as possible, also be used in this work. Specific examples are provided from Statsbygg where this is found useful. It must be noted that this is valid only for Norwegian conditions, and that other countries may have a different structuring of the process, and different trade terms.

According to Eikeland, the building process consists of three main elements, administrative, core and public processes. Focus in this work is mainly on the core processes, described in Chapter 2.2.1, 2.2.2, 2.2.3 and 2.2.4. All the phases within the core process are discussed briefly, with the aim to identify the critical stages for material selection. A short description of public requirements affecting the material selection procedure is also presented. The administrative processes are important as they include the procurement process. Procurement encompasses contracts, entering contracts and follow up on contracts. These are vital aspects, but are not seen as directly relevant to material selection, and are therefore not discussed as a separate issue in this thesis.

The core processes are related directly to the production of a building. The core building processes are divided in phases to give a superior and general control and organisation of the project. The approval of one phase often forms the basis for signing contracts for the following phase, and engaging new participants in the project. However, the phases often proceed more or less overlapping in time.

Eikeland (1998), reached the conclusion, after studying various approaches, that the processes typical for building projects can be divided in four phases common for most projects; Idea, Development, Execution and Use. He also provides an illustration of the generic phases of the building process, as seen in Figure 2-2.

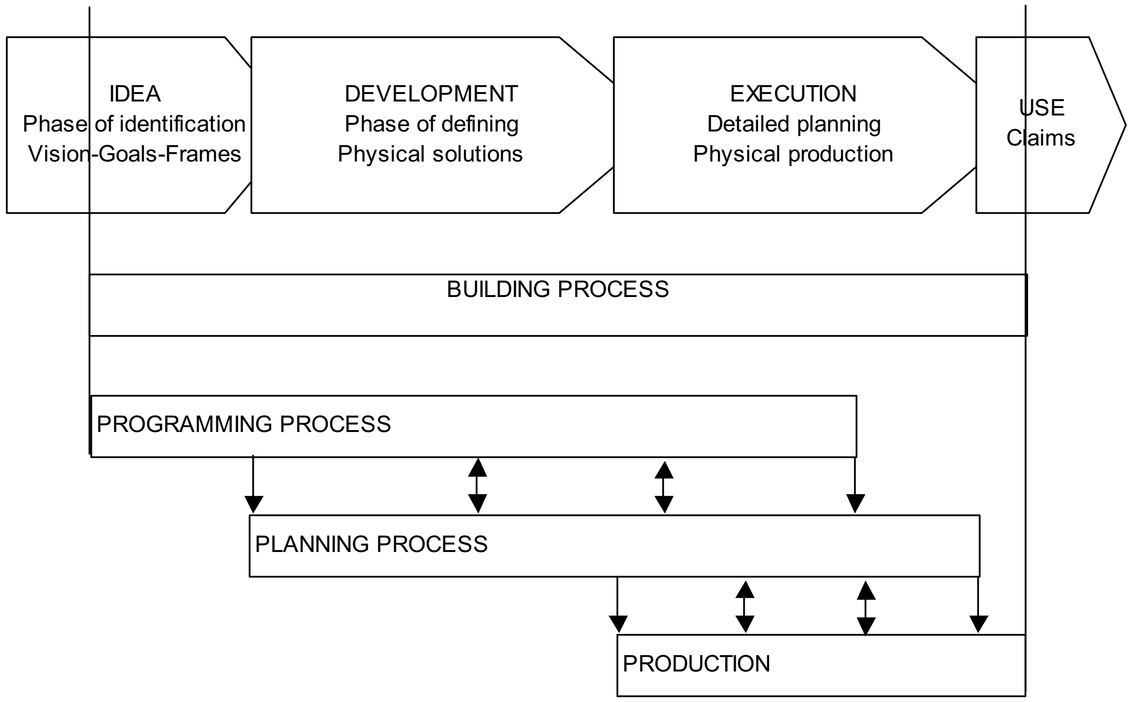


Figure 2-2: The generic phases of the building process (after Eikeland, 1998).

The division in phases may vary between different organisations. Statsbygg has their structure, so do other companies and organisations. A systematic and short overview of the different phases is given in Table 2-2. The User phase is not included in Table 2-2, but this is recognised as the fourth phase in a project. In the further work in this thesis, four phases is considered: Idea, Development, Execution and Use. The different phases will be discussed in detail in the following chapters.

Table 2-2: Division of the building process.

SiB-terms (Eikeland, 1998)	Statsbygg (1996) trade terms		Actions
	Development	**Phases**	
Idea	Programming/briefing	Deliberations	Functions and needs.
		Floor space programme	Specification of the floor spaces, project plan.
		Programme/clients brief	Initial cost estimate, statements of the owner's requirement for the building.
Development	Design	Conceptual design	Contracts with designers. Spatial plans, facades. New cost estimate.
		Preliminary design	The work from the preceding phases is worked out in more detail, and technical solutions are presented. Drawings and descriptions.
		Detailed design	The detailed decisions.
Execution	Construction	Contract and construction	Tendering of contractors.
		Commissioning	Construction and supplement of detailed design-plan. Follow up of contract budgets. The contracts are completed.
Termination	Termination	Finishing	Handling over the building.

2.2.1 Phase 1: Idea

The idea phase is dominated by the definition of the conditions, objectives and framework for the project. This phase is important, as the decisions made here will have a major effect on the rest of the project (Eikeland, 1998). In addition, this is the phase with the high degree of freedom. The spatial plans and the building programme are important results from this phase.

At this stage in the building process, it is often required that the first estimate of annual costs is made. This estimate is based on the locality, building category/functional requirements, size, interest rate and time horizon for the use of the building, and gives important signals to the following phases of the process.

Regarding environmental qualities, it is important that priorities are set already at this stage. It has, at least for larger projects, become a usual practice to formulate an Environmental Programme (EP). An EP may also contain environmental requirements for the materials to be used in the project. The formulation of these requirements vary, from general statements as (translated from Norwegian by the author): *"In the selection of building materials consideration for environmental and resource effects must be included"* (University Hospital in Trondheim, 1999), to more specific requirement like (translated from Norwegian by the author): *"The Handbook of sustainable building", using the Environmental Preference Method (EPM), must be used as a basis for material selection. Materials that fall into the Category of "Not recommended" must not be used. 80 per cent of the selected materials must be in Category 2 or better"* (Statsbygg, 1999).

Through the **programming** process, the client's needs are translated into specific requirements for the building. The weighting is balanced between goals for functions, costs and time schedule. This process should also include the following environmental related activities (Byggecentrum, 1999):

– Survey of environmental effects related to the project.
– Ranking of different environmental effects.
– The formulation of environmental goals to be reached in the project.

The **programme** is the documentation from the programming process, including the floor space program. The main goal of the programme is to document all the conditions like framework requirements and user requirements for the finished building. The programme forms the basis for design and execution of the construction work, and it should:

– Contain all requirements and framework conditions.
– Form a basis for the spatial structure of the building.
– Function as the administration document of the client.
– Form the basis for the decision of realising the project, and constitute the information basis for all other participants in the process.

The client formulates the programme. The description form has changed from a physical description to a functional description. Environmental requirements should form a separate chapter as well as being incorporated in the other chapters. Environment and health are also mentioned in the framework, in the same way as public regulations, neighbourhood considerations, and connection to infrastructure.

In Statsbygg, the programme is completed by what is called design instructions. The purpose of these instructions is to separate the "general part" of the programme, which applies to all projects, from the specific programme. The programme will then state what to include in the specific project, and the Design instructions how this must be incorporated together with the required results (Statsbygg, 1997).

Statsbygg has many design instructions, one of them deals with the building itself, others include ventilation and electrical installations etc. In the instructions for construction, the material selection is described in a separate chapter, so is building elements and special installations like windows, doors etc. (Statsbygg, 1997). Typical instructions are technical requirements like U-value, windshield details, jointing details etc. One can also find that surface material descriptions are included, such as: "*for flooring in general, 2 mm vinyl or 2.5 mm linoleum with welded joints is to be used*." More common are technical performance descriptions like for example: "*the facade shall largely be maintenance free*". Moreover: "*In the evaluation of exterior wall materials there must in addition be evaluations regarding security of the building, for example regarding burglary*"(translated from Norwegian by the author).

From the theoretical study and examples of programmes from Statsbygg, it is clear that the programme is central also for the description of the environmental requirements of the materials. The architects and the technical designers are then compelled to include these requirements in the subsequent phases.

2.2.2 Phase 2: Development

Development involves the developing the physical solutions, based on the specifications from Phase 1. Design, conceptual design, preliminary design and detailed design are a common sub-division of the development phase.

Design includes the task of further specification of the requirements from the client. The functional requirements set in the program are successively detailed, and developed into specifications that are more precise.

The **design** phase also includes processes like entering contracts with designers, conceptual design and preliminary design. The result is a model where geometry and standards are specified, so that the solution fulfils the functional requirements.

In the **conceptual design**, different solutions and related costs are described, and more details about material selection are included. As an example from Statsbygg, the following is said in general about exterior walls (translated from Norwegian by the author): *"The material use is adapted to the existing buildings in the area. The materials shall be durable and promote low service and maintenance costs, and be as environmentally friendly as possible*."

Specifications that are more concrete may for exterior walls include the following (translated from Norwegian by the author): *"Insulated 150 mm timber frame wall, with brick lining, plaster boards with fibreglass wall covering. In the lecture rooms, the walls are of concrete, with exterior insulation and brick lining. The windows are aluminium covered coupled wooden windows with 3 layers of glass and an intermediate layer of blinds…"*

The **conceptual design** includes a further specification of the costs on level two in the annual cost system (Norwegian Standard, NS 3454). In addition to the information from level one, the estimates at this stage are based on floor space plans, programme with specifications, technical standards and suggested selection of main materials. Main materials include facades, windows, roofing, both interior and exterior.

In the **preliminary design**, the major lines of the project and related costs are determined. The result is a description of the physical framework of the project, main floor space plans, intersections and facades, together with the main principles for load carrying systems, and technical solutions (Rasmussen et al., 1997).

The documentation of the **preliminary design** stage is, of course, more comprehensive than the documentation from the conceptual design. The level of detail for building material selection compared with the results from earlier phases varies; it can be the same or increased. The material types are often specified as far as possible without going into producers or labels. It is decided for example that the facade should have ½ stone red bricks, that the roof should have concrete tiles, that the floor in the lobby should have granite etc.

In addition, there are technical requirements like for example (translated from Norwegian by the author): *"The concrete structures suppose the following material qualities: Concrete C35, Environmental class Na, Normal control, Tolerance 2, reinforcement with re-bars K 500 TE."*

In the **preliminary design**, the costs are calculated on the third level in the annual costs method (NS 3454). The selected material influence several elements (Bjørberg, 1993) including project cost, insurance cost, and user costs, like energy, cleaning and maintenance. **Detailed design** involves further specification based on the preliminary design.

2.2.3 Phase 3: Execution

Execution involves the construction of the building based on the decisions made in earlier phases. Important activities are logistics, co-ordination, production technology and supervision (Eikeland, 1998). The execution phase is subdivided in the main tasks: main project, contracts and construction.

Detailed design forms the basis for the complete production description of a building, and the basis for the tendering process. Planning for production includes specifications of materials, manpower, equipment, transport and waste handling. Production plans are developed describing these factors.

Contracts are normally established through tendering. The contractor does his/her own calculation before he/she makes a bid. This calculation is often performed using a computer tool with built-in prices and/or own experience. The client then selects what he/she thinks will give the best result. The criteria for selection may be total costs, reputation of a contractor and/or special qualifications.

In the tendering documents, the materials are listed sometimes with specific brands, but normally with a general description, see Figure 2-3. The specific product selected in the building is therefore very much up to the contractor. A large contractor can often have agreements with producers or importers of materials, which give them better prices. This may be the decisive factor for the product selection.

Post	Description	Mass	Kr.
….	….	…..	……
.02	H73.100 MINERAL WOOL ALONGSIDE FOUNDATION WALL		
	On finished concrete- or Leca, Rockwool foundation board overlapping, thickness 75 mm. Rockwool brochure "Insulation of shallow foundations" m^2	270	
…..	……	…….	……

Figure 2-3: Example of an item in a calculation of an office building.

Several firms often participate in the work of constructing a building. The organisation of these firms is controlled using different types of contract models. The contract model regulates the relationship between the client and the contractor. The most common contract types include shared contract, main contract, general contract and package builder, but combinations of these types also occur.

In the case of **shared contracts**, the client enters contracts with several contractors. These contractors are equal, and there is no administration contractor. Each contractor has his/her own contract with the client (Skjønhals, 1998). Administration of these contracts is often handled by administrating side-contractors. Using shared contracts allows parallel design and construction, which has become increasingly common.

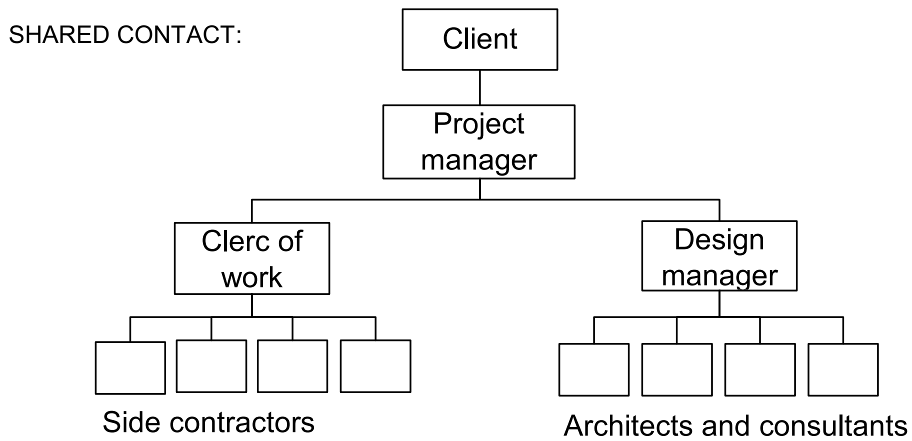


Figure 2-4: Illustration of the organisation in shared contracts (after Byggfagrådet, 1996).

In **main contracts**, the client engages architects and consultants, but the client is responsible for the design. The contractor is responsible for major parts of the building, but the client may organise the technical contract. In addition, it is usual that the building contractor administers the other contracts, thereby the trade term main contract (Skjønhals, 1998). An important feature of this organisation is that the design must be complete before advertising for bids (Byggfagrådet, 1986). It must be noted that the main contract model is not a usual way of organising building project contracts (Skjønhals, 1998).

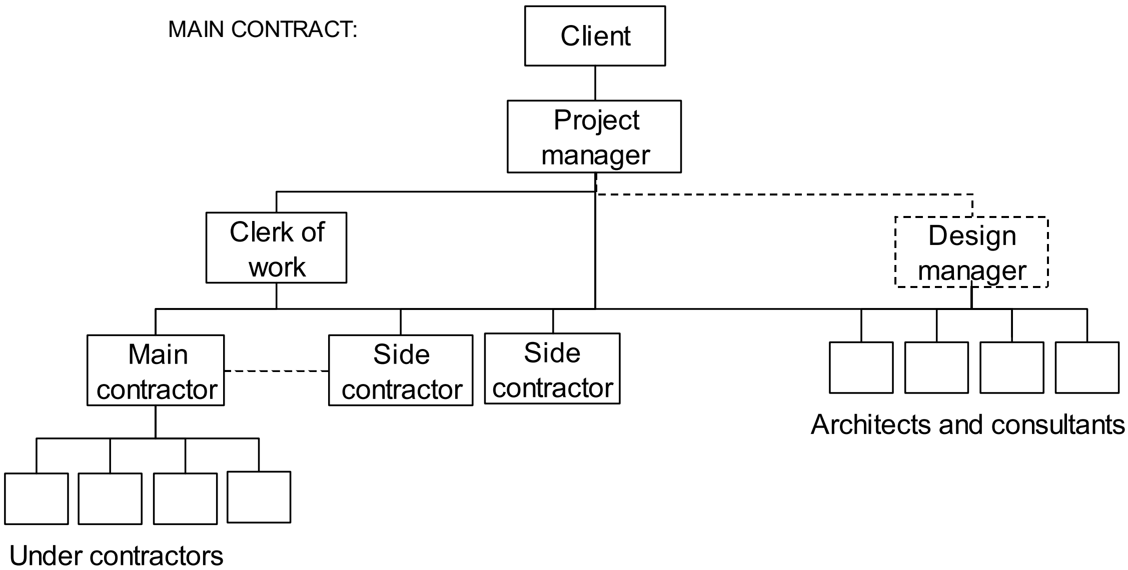


Figure 2-5: Illustration of the organisation in main contracts (after Byggfagrådet, 1996).

In **general contracts**, design is completely separated from the construction process. The client engages architects and consultants, but only one contractor. In a strict general contract, there can be no parallel design and construction. However, if the contract is a **managed general contract**, the design and construction can be performed in parallel. The client then collects bids for work and part deliveries, shifted in time related to the planned progress. The contractor then organises both building and the technical installations etc.

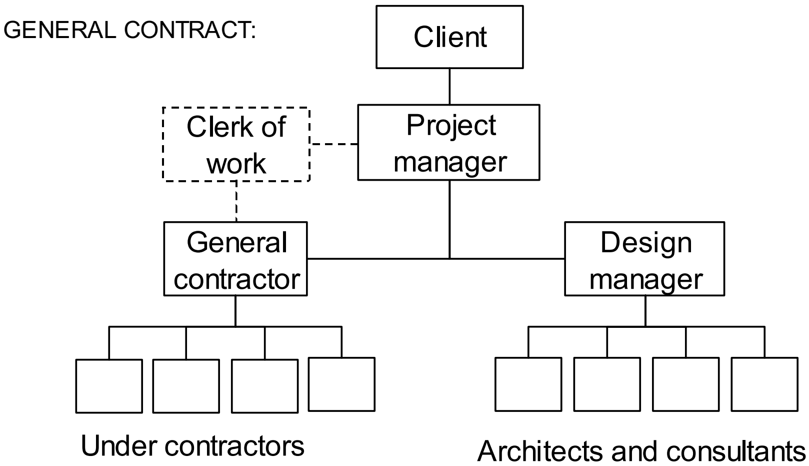


Figure 2-6: Illustration of the organisation in general contracts (after Byggfagrådet, 1996).

A variant of General contract is **construction management**, which means that the administration job is set out to others. Both in main and general contracts, the design follows the programming phase, and production starts after the design is completed (Berntsen, 1994).

In **total package contracts**, the client only forms a contract with one contractor. The single contractor then engages architects, consultants and other contractors. The contractor is then responsible for both design and construction. The basis for these contracts is the functional requirements from the client. Both for total package and shared contracts the design and production overlaps in time, reducing the project period (Berntsen, 1994).

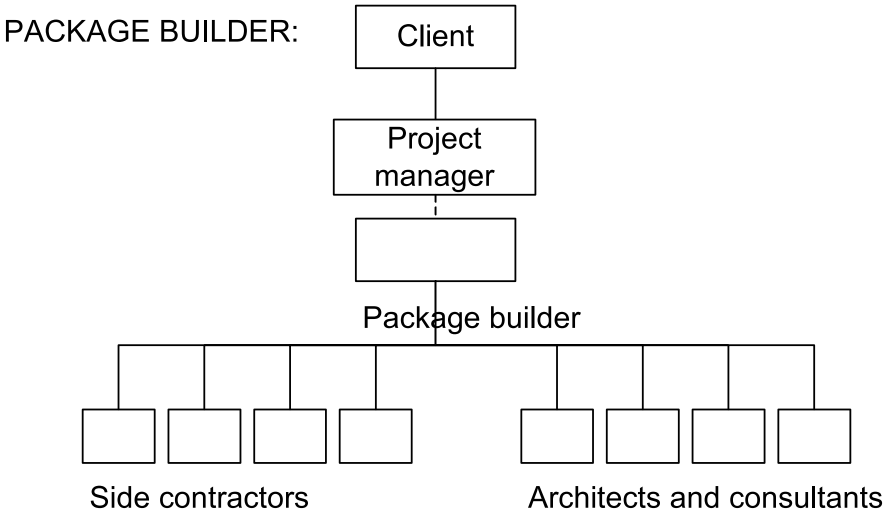


Figure 2-7: Illustration of the organisation in a package builder contract (after Byggfagrådet, 1996).

It is seldom a strict total package contract. Often specific solutions and material selections, references to other buildings etc. are included in the basis for the bidding. This is then a "partly controlled" shared contract.

The organisation of the process will also affect the material selection process. The degree of freedom for each contractor depends on the type of contract. For example, a package builder will have larger influence than would be the case in a project with shared contracts.

In **construction**, all requirements set in the preceding phases are followed through, including the environmental goals. The construction phase includes several tasks and instructions, like site administration with daily journals, safety procedures, machine lists, work plans, delivery plans, environmental and waste plans, instructions for surveys, instructions for delivery and handling of warranties (Erlandsen, 1997).

In construction, situations may also occur that changes the material producer. For example, that the product is not available from stock at the time, or that some importer of a product as ended a contract with one material producer and now receives materials from another producer.

2.2.4 Phase 4: Use

The commissioning of the project marks the beginning of the user phase. However, to dissolve the project organisation, handling of claims and solving of conflicts may take many years (Eikeland, 1998).

Energy and cleaning is traditionally the most cost demanding elements. Environmental requirements may also be included as a checkpoint in the control and verification plans.

In the user phase the management staff and the user are responsible for the supervision of the environmental plan, for example reuse when remodelling and refurbishing (Norwegian Building Research Institute, NBI, 1996). This includes using correct cleaning methods for the materials, performing maintenance to optimise service life of a product etc.

At the end of the service life of a building, the company demolishing the building should be responsible for selective deconstruction and separation of the materials. There are strict rules on waste handling and waste treatment today through local regulations, as for example in Oslo municipality (1996).

2.2.5 Public requirements relevant for the building process

Public requirements that affect a building project includes both planning and approval processes. Traditional planning includes aspects like planning on local community level, and will not affect the material selection procedure to any degree. The approval process related to each project however, can have some implication on the material selection, but this is assumed minimal.

The Planning and Building Act is on top of the hierarchy of the set of laws relevant to buildings. The act encompasses the following regulations:

- Technical Regulations under the Planning and Building Act, 1997.
- Regulations on procedures and control in construction.
- Regulation on approval of enterprises with liability rights.
- Regulation of the organisation of the central approval system for enterprises with liability rights.
- Regulation of environmental impact assessment after the Planning and Building Act chapter VII-a.

The Technical regulation under the Planning and Building Act includes functional requirements on different levels. These functional requirements are decisive for defining the appropriate performance requirements for the materials and products in buildings. To define the appropriate performance one can use the regulation guide. Performance in the regulation instructions is the government's interpretation of what to understand as the acceptable risk level. Alternatively, one can use analyses and/or calculations to establish necessary performance. One of the advantages related to performance based regulations, is that they do not prescribe use of certain technical solutions, but leave the designers and/or other involved parties to find good and optimal solutions based on their frame of reference.

The building authorities also have supervision of the building products. The Building regulations §77, states that the products used in buildings must satisfy certain quality requirements given pursuant to this law. The local authorities have the supervising responsibility through the approval of each building project. In addition, The National Office of Building Technology and Administration (BE) carries out market controls.

The producers are responsible for providing documentation that their products satisfy the requirements set in the regulations. Some organisations have been appointed to do the appropriate testing and documentation, like for example The **N**orwegian **B**uilding **R**esearch **I**nstitute (NBI) and the Norwegian Certification System.

Public actors have additional requirements through the Public procurment act (Ministry of trade and industry, 1999). Here it is stated that public agencies must include considerations for the investments lifecycle costs and environmental consequences in investment planning.

There is also legislation that prohibits manufacturing and use of products that can cause health damage or constitute environmental risk, for example the Product Control Act. This act also opens for setting maximum limits for the energy use of a product, but this is not done today.

2.3 Implications for the development of a material selection system

It is clear that a material selection system must be adapted to the different phases of a building project, and that there are several persons involved in material selection. A conflict of interest occurs when it is a requirement for the system to be flexible, but also adapted to the process. In addition, different organisations use different partitions between phases on a detailed level, and to some extent different trade terms.

The best solution is to use the coarse division in phases defined by for example Eikeland (1998), which seems to reflect what is agreed upon in the industry:

- Idea.
- Development.
- Execution.
- Use.

The material selection system will not be linked to one specific company's organisation, but be designed so it may be used within different organisation models. An organisation putting the system into use, must invest some effort initially in defining where in their system they will include the different considerations.

The alternative would be to develop a system closely adapted to one type of organisation, but this might involve a higher user threshold for others interested in using the system. In addition, the organisation selected to be the "correct answer" in this work could develop a type of "ownership" of the system, and thereby impede the spreading of the system.

There is no doubt that all the participants in the process are decision-makers, although at different levels. To summarise, the client set the requirements, and the consultants and the architect suggest materials to the client, who makes the final decisions. The contractor orders the products according to specifications from the designers and building owner. The clerk of work is responsible that the materials are installed correctly in the building.

Based on the research done in this study, it is possible to draw some conclusions regarding what type of system that is best suited as a decision support system for material selection.

An important source of information is the performed interviews. One of the first aspects noticed, is that the interviewed persons do not mention the same parameters/criteria for what they want to include, when moving towards including more environmental considerations. This could be because they where not aware of what to include in the term environmental evaluation. For the system, this result means two things: First, there needs to be a standard for what parameters that are evaluated for all materials or groups of materials. Second, it must be left up to the user which parameters he/she wants to include in a project.

Another evident result is that actors on different levels in the building process have different needs. The client needs help to set clear requirements for the materials, and documentation of the results to show for the finished building. The consultants and the architect are in need of a method to satisfy the requirements from the client, and optimising the building to the best possible total performance. They also need a way to communicate these requirements to the contractors. An important requirement from this group is that they want to go into the details if they are interested in the reason for a material or a product being evaluated as good or bad. This concerns the consultants in particular, as they are responsible for the quality of the finished product.

The contractor buying the materials and installing the products in the building needs to comply with the requirements, when purchasing the materials. In addition, the quality of the site work is important for the performance of the materials during their service life.

An important aspect is that few want a system that only represents the properties of a material with one number. They do not want to be alienated from the evaluation, and they want to be able to affect the results of the evaluation.

Further, the examination of the studies in this chapter, leads to the following recommendations for the development of the MaSe system:

– In the Idea phase, a framework is needed for the client to set clear environmental requirements. This is not only needed for the selection of materials, but also for priorities between areas like energy use in relation to indoor environment.

– All clients cannot go trough the process of developing a detailed environmental programme. Standard procedures have to be developed that guides the client through all the environmental problems and prioritisations needed in a building project.

– In the Development phase, the building details are worked out successively. It is common that the materials are included in the specifications, not the specific products. In the material selection system, this also has to be separated in a two-step process: First the selection of best preferable material and then requirements for the contractors to select the optimal product to be used in the building, with respect to environmental properties. Some exceptions then have to be made, but this should be possible to incorporate in the system. Figure 2-8 shows how the material or product details are worked out during the process.

– The contractor making the final product selection also needs guidance. The earlier phases provide the necessary input to make the necessary evaluation.

– The contractor also has the important responsibility of installing the product correctly. This critical stage could change the environmental profile of a material dramatically.

– When the building is completed, the process of maintaining its environmental quality is an important task. Buildings do not come with a clear user's guide on how these qualities are maintained through the service life. For technical systems, there is a follow up, but for the materials that constitute the building, only a short description is made when the building is completed. One solution may be to develop a user guide that also needs follow-up, as the materials are maintained or replaced. This is to ensure that the building maintain the environmental qualities it had when it was new.

– The development of a material guide/declaration of the building that is updated throughout the service life of the building, will also simplify the work when demolishing the building.

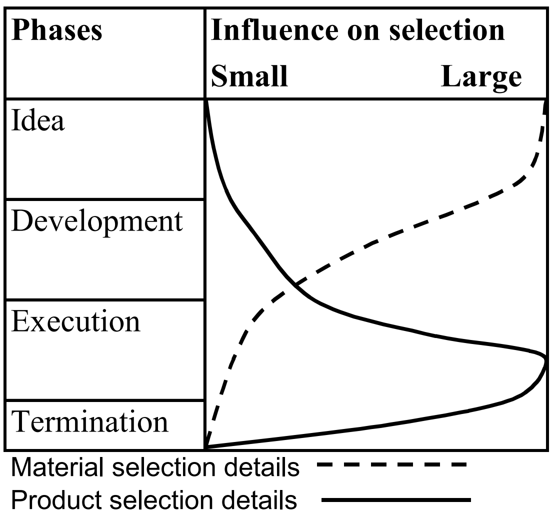


Figure 2-8: Illustration of the influence on material selection in the different phases of the building process.

What type of system satisfies these requirements? It has to be a system where the user can decide the level of detail, as in a hierarchic system. The result also needs to be presented on different levels, and in different constellations like a relation database. A relation database can satisfy most needs:

– It can form the basis for the preparation of a handbook.

- It can be attached to various computer tools used in the design phase as a reference work or as an integrated part of the tools.
- It is possible to add new information in the system, and this information can be assessed and presented in several ways.
- It can be programmed in a way that it is easily updated.

When developing a system for material selection the public process must be included. It is important that a system at any time is updated on regulations affecting material use.

Rules and regulations will also impose limitations on a material selection system. For government services like Statsbygg, the EEC-regulation states that in the documents for tendering there can be no specific requirements of products or a specific producer. However, the specification can go as far as describing a product in such detail that there is little doubt about which product it is. This is obviously in conflict with the requirement of selecting the best product with respect to environmental considerations, and what specifications that may be included.

Seeing the barriers of material selection based on environmental considerations and the need for help (see for example chapter 2.1.9), it is clear that a material selection system must give clear recommendations, based on visible assumptions. The system must also allow the users of the system to set their own priorities.

Figure 2-9, presents a simplified, general illustration for how the system could work when selecting materials for an exterior wall. On the left side are the user's requirements for the different alternatives. The box to the right illustrates the input to the MaSe system, the different products and their environmental data sets. In the middle is the MaSe system. The user of the MaSe system first selects the acceptable materials based on the technical requirements in the specific project. These pre-selected materials are then scored and ranked through the procedures in the MaSe system. The alternative ranking is then the basis for the selection of construction elements, materials or products.

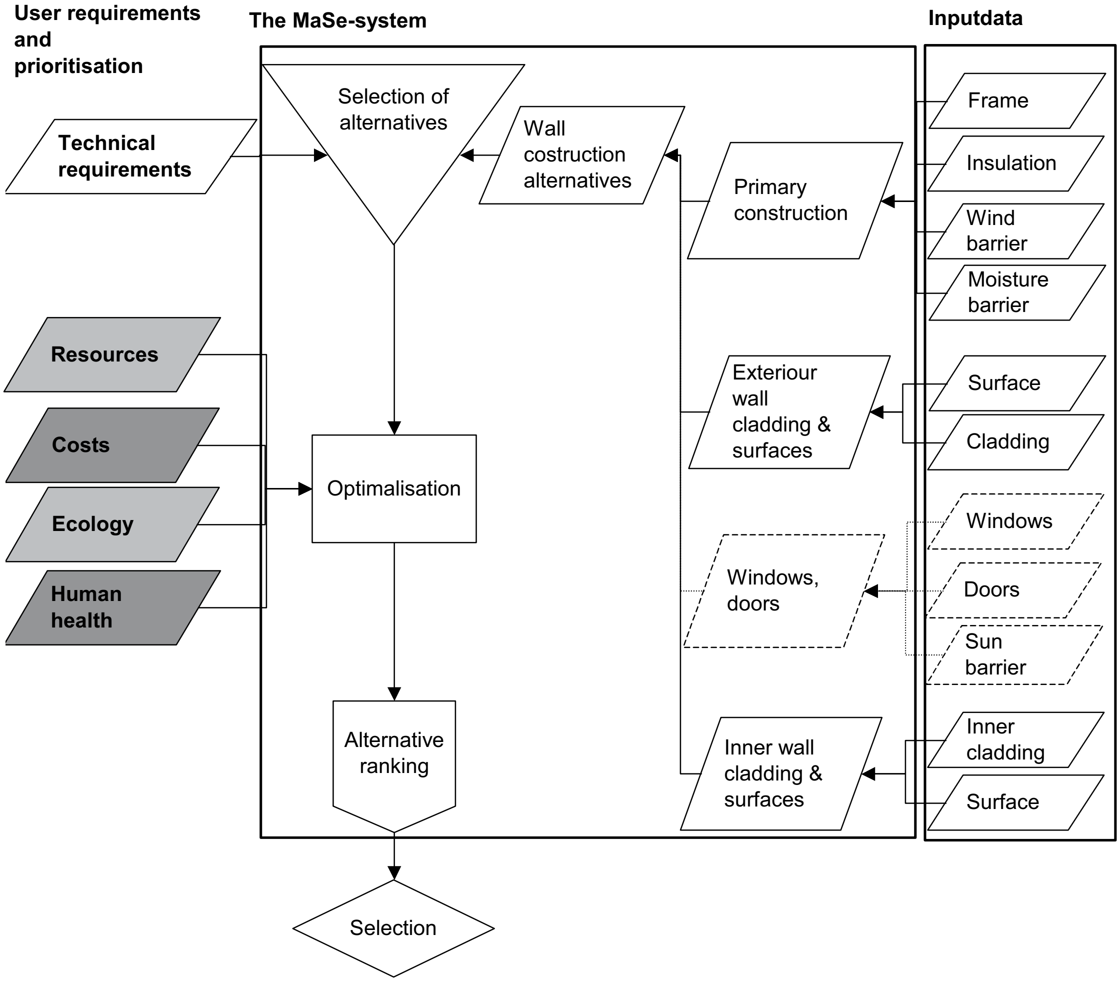


Figure 2-9: Optimisation and selection of exterior wall construction. The dash line illustrates elements that is not included, but regarded as a part of the function of a wall.

3 Building materials and the environment

The objective of this chapter is to describe the environmental loads related to the building and real estate industry, with a focus on the production, use and disposal of building materials and products. The work is based on available estimates of for example amounts of materials used in the building industry, and also on information from the government about what areas that, in their view, are seen as important for improvement. The concept of sustainability is also studied in order to see if this might help in the task of defining the effect categories to be included in the evaluation of building materials. The goal is to single out the most relevant areas to include in the environmental evaluation of building materials in the MaSe system.

3.1 The environmental loads from the building and real estate industry in general

The building and real estate industry is by the Norwegian authorities regarded as a heavy sector in the environmental context. When the construction activities and materials are included, the sector is responsible of about 45 per cent of the energy use and 40 per cent of the waste that are deposited nationally. According to the World Watch Institute (Brown, 1995), buildings consume between 17 and 50 per cent of the worlds physical resources. In the few months the construction period lasts, the consumption of resources and creation of pollutions represents 10 years use of the building. The ministry also recognise that the industry affects most areas of environmental policy (Ministry of Local Government and Regional Development, 1999).

GRIP is a governmental organisation set up to ensure that the goals set for sustainable production and consumption is fulfilled. Construction is one of the defined working areas for GRIP, and in November 2000, they published a report describing the environmental effects related to the building end real estate industry. The report confirms the “40 per cent industry” term, and lists some of the environmental potential for the industry regarding energy, area efficiency, waste and recycling.

In general, the industry is aware of the environmental consequences related to their activities. However, the transition from understanding, to accepting the responsibility for action is not straightforward. The industry is characterised by having many participants, small margins and many responsible parties. It is relatively easy to convince oneself that nothing can be done because of for example contractual or economical conditions. During the past few years, some central actors in the industry have recognised their responsibility. They have also seen that environmental aspects need to be included as early as possible in order to get the best effect. To ensure this, they have developed environmental action plans.

Development of standards together with methods and tools for assessment of environmental consequences of material use and technical solutions is listed as one of the main priority areas in a report regarding the government’s environmental policy and the environmental state of the country (Ministry of Environment, 2000).

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Many studies have been performed internationally of the building industry and its environmental consequences. It is not considered relevant to present an overview of all the work that is done. A selection of studies is included based on what is published in conferences or has received attention in other ways. The only study of any detail of the Norwegian building industry and its environmental consequences, in addition to the GRIP study, was performed in 1997, after the initiative of Åke Larson Construction (Raadhuus, 1997).

3.2 The concept of sustainable development

The term sustainable development is disputed and complex, and with few specific agreed strategies. First, there are the different definitions of sustainable development, where Murcott (1997a), has collected 57 definitions of economical, social and ecological sustainability. On this level, it is found to be mainly agreement between the different definitions. The most frequently quoted definition is from the World Commission on Environment and development (Langhelle, 2001): "*…development that meets the needs of the present without compromising the ability for future generations to meet their own needs*". When it comes to the development of this definition into perspectives and concepts of sustainability, however there are larger differences. Langhelle (2001), has developed a typology to distinguish the different perspectives of sustainability. First, he uses the terms known from the economic approach to sustainability, namely "Weak" and "Strong" sustainability. These principles involve "rules" for how sustainable development could, or should, be attained. Strong sustainability implies:

"…that environmental resources and ecological services that are essential for human welfare and cannot be easily substituted by human and physical capital should be protected and not depleted. Maintaining or increasing the value of the total capital stock over time in turn requires keeping the non-substitutable and essential components of natural stock constant over time".

Whereas "strong sustainability" requires that manmade and natural capital each must be maintained separate, "weak sustainability" only requires that the aggregate value of the total capital stock is maintained. Manmade and natural capitals are considered to be perfect substitutes in the "weak" sustainability perspective. For those who support this perspective, material scarcity is not a problem, only the environment's capacity to deal with waste and emissions (Ekeli, 1999). The difference between the perspectives of sustainability is mainly the explicit or implicit view on scarcity. This is also the conclusion reached by Langhelle (2001).

In addition to the "weak" and "strong" perspective, intra and inter generational justice is also an area of discussion. This brings in the ethical perspectives on sustainability, widely discussed by Ekeli (1999), who presents three different ethical perspectives that forms the basis for the views on sustainable production and consumption. This is the "Anti materialistic", the "Ecospace" and the "Needs based" perspective. The "Anti materialistic" view is based on religion or deep ecology. "Limits to growth" and the over-consumption thesis fit well within this category. This view criticises the modern consumer society, and the unjust distribution between North and South. Acting upon this view will involve a complete paradigm shift to reach sustainable development, including a total transformation of current consumer societies and their underlying values.

The "Ecospace" view is shared by the "Friends of the Earth", and form the basis for their project "Towards a Sustainable Europe". Advocates of this perspective claims that all individuals have the same right to use an equal amount of natural resources, and to pollute the global commons, in other words an egalitarian distribution of access to natural resources. The last perspective, the "Needs based" perspective, is shared by the Rio declaration, Agenda 21 and "Our Common Future". The necessary social change involves the countries in the north to promote development strategies that provide for present and future basic needs. This view does not require equal distribution of social and natural resources.

The different ethical views are by Ekeli (1999) linked to different policy implications. The "Anti materialistic" perspective would advocate development strategies promoting a very strong sustainability. It is argued that this form of sustainable consumption and production is not compatible with further economical growth. The "Ecospace" perspective is seen as an advocate for strong sustainability. This means that the global consumption must not deplete the quality of the environment or the availability of resources for any future generations. This is considered as a radical view on intergenerational justice. The last perspective, the "Needs based" perspective, is linked to weak sustainability. This perspective considers sustainable development as compatible with further economic growth.

No final answer exists to which perspective that gives the right strategies, but common for all three perspectives is that they propose large-scale policy reforms. In addition, most advocates for the different perspectives are uncertain about the conclusion. Langhelle (2001) has identified the points of agreement between the different perspectives of sustainable production and consumption. First, he states, none of the perspectives are "business as usual" perspectives.

A third aspect identified by Langhelle (2001) is that there is agreement that global warming is the first ecological limit we (most likely) will reach or have reached. He also lists what he calls a baseline of environmental policies based on "Our Common Future":

1. The satisfaction of human needs, in particular the essential needs of the worlds poor to which overriding priority should be given.
2. Climate change (and thus the energy use issue).
3. Loss of biological diversity.
4. Pollution (**P**oly**c**hlorinated **b**iphenyls (PCB), radioactive pollution, acid rain etc.).
5. Food security.

OECD has identified the following potential limits:

– The degradation of renewable resources, particularly agricultural land.
– The accelerating rate of species loss.

- The accumulation of emissions and wastes in the environment whose effects, particularly on combination, represent a largely unknown risk (e.g. toxicity and climate change).

3.2.1 The scarcity discussion

It has been argued that scarcity of materials does not impose a limiting factor (Pearce, 1993, Sagoff, 2000 and OECD, 1995). Others again recognise that it will be some sort of scarcity, but see other environmental factors as more pressing (Langhelle, 2001, Langhelle, 2002). A third group argues that scarcity is, and will be a problem, and that we must reduce the load on our natural resources (Meadows et al. (1992) Weizacker et al. (1998), Wackernagel et al. (1996) Schmidt–Bleek (2000) and Hille (1996))

The fact that the prices of raw materials, adjusted for inflation, are steadily declining, together with the increased amount of available resources, is presented as evidence that scarcity will not impose a problem. There is no doubt that the amount of reserves discovered has increased, as seen in Figure 3-1. The Figure shows how the reserves of copper, lead and zinc have increased in the period 1940 to 1993. Nevertheless, this increase in discovered reserves cannot be sustained forever. As seen in Figure 3-1, the rate of new discoveries has been decreasing since the seventies. Recycling and reuse of materials will therefore become increasingly important as a material resources, this is also recognised by Pearce (1993).

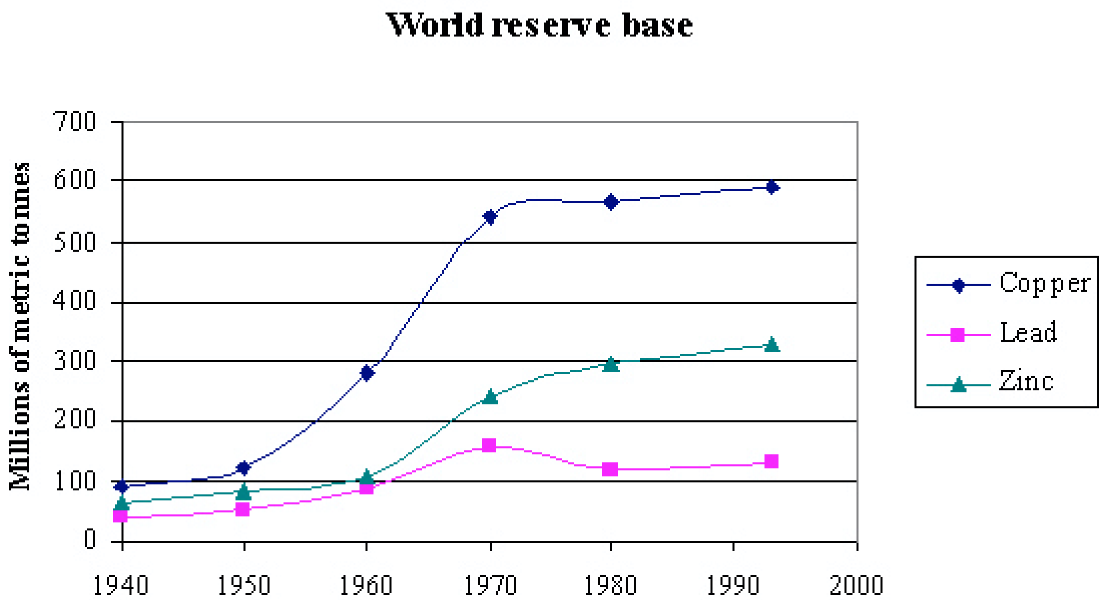


Figure 3-1: The development in the world's reserve base for copper lead and zinc. The illustration is based on numbers from Hodges (1995).

Another common statement is that when a material gets scarcer, the price will increase and substitutes and new technology will solve our problems (Vogtländer, 2000). It is not obvious that the predicted rise in prices will affect the price of the final products. According to Goeller (1984), the material costs for many final products only constitute a small part of the total costs. The prediction that material scarcity, expressed only in market prices, will affect the selection of e.g. building materials might not be enough. This is a theory also supported by Messner (2002).

Messner (2002) states that substitution is the most important way of preventing or delaying increasing resource scarcity and rising resource prices caused by depletion. He argues that substitution and the cost advantages it represents, often is negligible compared to the total production costs. The term he calls the "path dependence[1]" is seen as dependent on five factors; knowledge advantage, the existence of cooperation networks, costly rearrangements of capital goods, the risk of adverse product quality changes and fluctuating material prices. It is seen in for example the copper-aluminium substitution in the production of electrical conductors that other factors than price has affected the substitution rate, mainly quality differences or technological trajectories. Messner (2002) concluded that relative material prices drive material substitution, but these factors seem to work with a delay of several years or decades, rather than being effective immediately. Material substitution is dependent on processes of learning, using and adjusting. These are processes that take time, capital, research and experience in order to take place.

Reynolds (1999), from a resource extraction point of view, strongly argues that prices and costs falsely can signal decreasing scarcity. His theory is based upon the fact that a prospector never exactly knows the size of the resource base, but gains information about the potential location of new reserves as discoveries proceed. This information causes the exploration costs to fall, and that again can cause the price to fall over time until an eventual scarcity of the resource again cause the price to rise. Only at the end of the exhaustion, the true scarcity is revealed in the price. This theory is confirmed, performing a "mineral market" simulation. The results are shown in Figure 3-2. It is seen in the figure that the price decline for many years before the price finally increases. During this time span quantities of resources extracted also increases. It is not until late in the cycle that the power of technology to overcome the scarcity is known.

[1] Path dependency is the tendency to maintain the material composition of established products or technologies. "Path dependence defines the set of dynamic processes where small events have long-lasting consequences that economic action at each moment can modify, yet only to limited extent" (Messner, 2002)

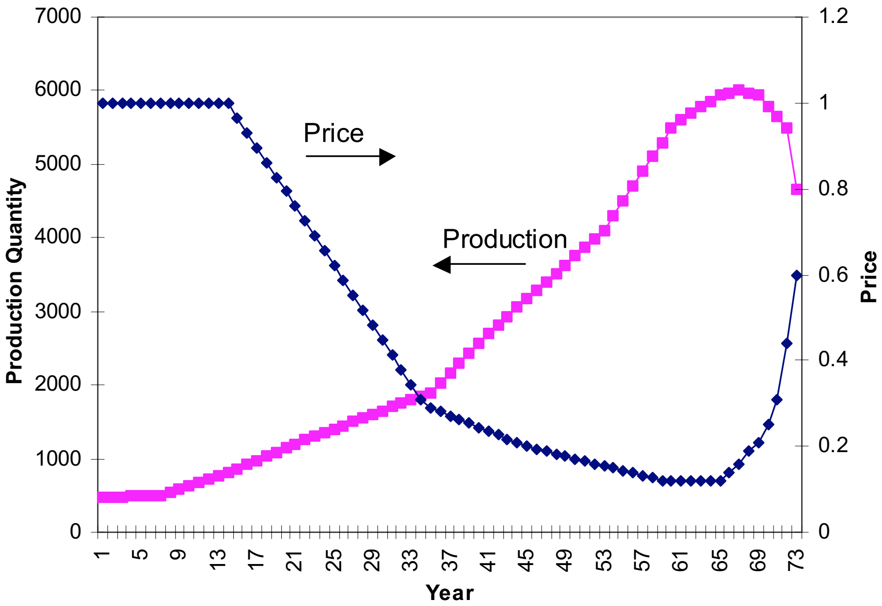


Figure 3-2: Price and production as a function of time (after Reynolds, 1999).

Another advocate for the "no scarcity" view is Crowson (1993). He states, "*it is highly improbable that society will run out of minerals over the long run*". However, he opens up to short-term disruptions of supply caused e.g. by political situations. He also argues the higher prices is seen as the most important factor that have an impact on reserves by encouraging new discoveries, greater recovery and increasing recycling, and bringing into production previously uneconomic deposits. He also concludes that substitutes will evolve to cover the extent that the supplies are not increased. Recycling allow metals to be considered as renewable, as they can be recycled indefinitely with little or no loss in their technical attributes.

Scarcity or not, our living standards in the North and the development in the South, requires increasing amounts of raw materials. Reuse and recycling are important, and will be increasingly important as future raw material base. In addition, it is agreed that renewable materials are threatened (Our common future, OECD, Wackernagel et al.). The weak sustainability principle also opens up to regard some resources as critical. The advocates of weak sustainability and "efficiency approach sufficient" do not share this perspective. Pearce (1993) e.g. says: "*if non-renewable resources such as coal and oil are available, why not use them?*" But he also states that "*They should be used in such a way that their environmental effects are fully accounted for. So, sustainability means making sure that substitutes resources are made available as non-renewable resources become physically scarce, …*" It is therefore concluded that for all perspectives widely discussed in Langhelle (2001), Ekeli (1999) and Pearce (1993), some evaluation of resource use of the various building materials should be included in the MaSe system. It seems to be a general agreement that recycling, reuse and sustainable use of renewable resources are important aspects, and these will therefore be include in the MaSe system.

3.2.2 Concepts that reflects sustainability

Different conceptual frameworks are developed to reflect the sustainability of a person, a nation, a household or a product. The different concepts may be divided in four main groups (after Murcott, 1997b), "Human/Environmental interaction conceptual frameworks", "Economy/Environmental interaction conceptual frameworks", Human/Economy interaction conceptual frameworks" and Environmental/Human/Economy interaction conceptual frameworks". Known examples within these concepts are Eco-efficiency, Ecological footprint and Ecological space. Most of these concepts are developed to be used on a national level, and will not be very useful in the evaluation of building materials for a specific project.

Rees et al. (1996), introduced the Ecological Footprint as the key to sustainability. The Ecological Footprint is defined, as "*the area of productive land and water required continuously to produce all resources consumed and to assimilate all the wastes produced by a defined population, wherever on earth the land is located. The Ecological Footprint is a land based surrogate measure of the population's demands on natural capital*." This sustainability measure ignores many other factors incorporated in the term sustainability. The Ecological Footprint is only an index of biophysical impacts, and does not include either the technological or the cultural aspects of sustainability. The Ecological Footprint is also considered too general to be used as a measure for building materials. It is a more appropriate measure on the level of political discussions.

Another attempt to define a set of requirements for sustainability is presented by Robèrt (1998). He developed **T**he **N**atural **S**tep (TNS), which is a set of four system conditions for a sustainable society. In a sustainable society the nature's functions and diversity will not be disturbed through:

1. A systematic increase of concentrations of substances in the earth's crust.
2. A systematic increase in the concentrations of substances from the production of the society.
3. A systematic over-exploitation, displacement or manipulation.
4. In a sustainable society the user of recourses are so effective abs fair that human needs are met everywhere.

The primary limiting factor seen by TNS is the waste generated. This is based on the view that the earth is like a petri dish; a closed system where the wastes are threatening to poison us (DuBose et al., 1997).

The Environmental Utilisation Space, also called Ecospace, is another framework for achieving more equitable distribution of access to global environmental services. Ecospace is defined as:

"The Environmental Space for a given resource is the maximum amount that the world may sustainably consume per year, given the constraints imposed by long term availability as well as by the environmental effects of its extraction and use. Once the environmental space for a given resource has been defined at the global level, environmental space per capita is given by the assumption that each world citizen has a equal right to consume" (Langhelle, 2001)

Quantitative limits are set based on scientific analysis and political evaluation of the risk associated with exceeding these limits. Ecospace is then established on a national, regional and a per capita level. "Environmental utilisation space" has no meaning as a purely biophysical concept, but may be used as a political tool (Murcott, 1997b). Hille, who has worked with the concept in Norway, describes the concept as a simplified tool for getting the grips on "equitable global resource distribution" (Langhelle, 2001).

Eco-efficiency is yet another concept, and has for business corporations described as "*to produce ever more useful goods and services while continuously reducing resource consumption and pollution*" (Graedel et al., 1995). OECD uses the following definition of eco-efficiency (Nordic Council of Ministers, 1999):

"*Eco-efficiency expresses the efficiency with which ecological resources are used to meet human needs. It can be considered as a ratio of an output divided by an input; the "output" being the value of products and services produced by a firm, a sector, or the economy as a whole, and the "input" being the sum of environmental pressures generated by the firm, sector or economy. Measuring eco-efficiency depends on identifying indicators of both input and output*".

The **W**orld **B**usiness **C**ouncil for **S**ustainable **D**evelopment (WBCSD, 2000) also presents a definition of eco-efficiency:

"*Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity.*"

WBCSD has been working to find a common approach for companies to measure their environmental performance, and for stakeholders to assess the progress they are making. They have defined a set of generally applicable indicators that may be used for all businesses. The indicators fall into two groups according to the eco-efficiency formula, showed in Equation 3-1. The eco-efficiency ratio used in many businesses expresses a product's functional use related to its impacts.

$$Ecoefficiency = \frac{Max \sum_{t=1}^{n} Utilities}{Min \sum_{j=1}^{m} EnvironmentalBurdens}$$

Equation 3-1

Indicators for the utility may be volume (e.g. volumes sold), mass (e.g. kg sold), monetary (e.g. net sales), function (e.g. product durability), or other relevant information like product prices, market share etc. The environmental burden includes:

- Energy consumption.
- Material consumption.
- Natural resource consumption.
- Non-product output as e.g. air emissions.
- Unintended events as for example accidental discharges and spill.

Eco-efficiency has been criticised for not being an adequate measure of the environmental quality of a system. From **Equation 3-1** it is seen that the efficiency only describes the product utility. Hanssen (1999) provides a good example of the problem: The efficiency of cars, dishwashers etc. have increased significantly the last 5-10 years, as the consumption of energy per unit of utilisation of these products has been reduced. The absolute energy use for most of these systems has however increased, due to increased and more widespread use. The result is therefore increased eco-efficiency and increased environmental burdens at the same time.

Eco-effectiveness is by Hanssen (1999) suggested as a better measurement of the environmental qualities of a system. Eco-effectiveness takes the demand side of the utility function **Equation 3-1** into consideration, as shown in Equation 3-2.

$$Ecoeffctiveness = \frac{\frac{1}{\sum_{i=1}^{n} SufficientUtilities}}{Min \sum_{j=1}^{n} EnvironmentalBurdens}$$

Equation 3-2

Hanssen (1999) introduces a new aspect, sufficient utility. This nominator is included in order to introduce a deeper discussion of what is needed for instance in an office building (Hanssen, 1999):

1. Are the functions as such essential for the user?
2. How much of the functions are really needed by a given user, and can these needs be adjusted to a lower level?
3. Is it possible to segregate users into different groups of requirements, and is it possible to change the user requirement or to fulfil requirements with more flexible solutions (not use one given standard of solutions, but to fulfil the really needed demand by each user group).

Eco-efficiency is considered as a mean of translating sustainability into operational targets (Murcott, 1997 b). This is also a concept considered as useful in the evaluation of building materials. However, the problem is not only finding an expression of the environmental burden, but also to find an expression for the utility of a building material.

3.2.3 Perspective and concepts of sustainable development in the MaSe system

It is shown later in this chapter that building materials represents significant impacts on several environmental aspects. Key words are material and energy resources, global warming, toxic chemicals and pollution of the indoor environment. The goal of the MaSe system is to be an aid in selecting materials that are more sustainable than the alternatives. Because of the disagreements and confusions regarding the term sustainable development, it was considered necessary to study the different perspectives and concepts to identify the key areas that should be included. It is not possible to reach a conclusion as to which of the different perspectives of sustainable development described earlier in this chapter that is correct, with regard to building materials.

As no conclusion is drawn regarding the different perspectives on sustainable development, a solution is to see if there are some points of agreements between them. These agreements will then form the basis for the MaSe system. It is concluded from the discussion of weak and strong sustainability, that it is possible to identify some points of agreement. For building materials, relevant aspects include climatic change, degradation of renewable resources, accumulation of emissions and wastes.

Turning to the ISO standard under development for sustainability in building construction, resource consumption is included as one of the performance issues (ISO/TC 59/SC3 N468, 2002). This factor being included in the ISO standard does not prove that resource scarcity should be regarded as a problem, but it illustrates that it is difficult to reach any conclusion.

A conclusion about scarcity, whether it will be a problem or not, is a value judgement. It is also a question of accepting the precautionary principle or not. As argued by both Messner (2002) and Reynolds (1999) the degree of scarcity, and the technical possibilities we have to solve it, is not known until we are very close to depletion. The precautionary principle must then be used to increase recycling and substitution. The prices and costs cannot be relied upon resolving this development alone, thus other means are needed.

It is fair to say that most parties in the discussion, for various reasons, agree that recycling is necessary. As Reynolds (1999), Messner (1999), the advocates of strong sustainability, see scarcity as a problem, Crowson (1993), Langhelle (2001) and the advocates of weak sustainability, claims it will not impose a problem. In fact, Crowson (1993) claims that "*any argument that international policies should reflect the need to protect or conserve its mineral resources on the basis that the world is running out of them may not only be misguided, but costly for society. It would be more correct to stress policies in support of the more economically and environmentally efficient methods of exploration, production, use, recycling and disposal of mineral resources*". Pearce et al. (2000) on his part claims that the advocates of strong sustainability have been "*strongest in assertion and weakest in offering empirical substance to their views*". Studying available information from both sides, it seems like this statement could be used also the other way around.

It is concluded in Chapter 3.2.1 that some evaluation of resource use should be included, but that this should not involve a detailed evaluation of scarcity. This is also in accordance with the new ISO-standard under development for sustainability in building and construction. This view is not enough to place the MaSe system in the strong sustainability frameworks, it is closer to a weak sustainability framework, but with the recognition that material input is important.

Another question to be answered is if the eco-efficiency approach is sufficient to solve the challenges we face in achieving sustainable development. To achieve sustainable development on a global scale it might not be enough. For the MaSe system, there is "limited room for action", as it is already decided that the function of a building material is needed. Therefore, the MaSe system perspective leans towards weak sustainability, regarding the efficiency approach to be necessary, but not sufficient, also shared by the OECD. OECD has adopted the eco-efficiency concept also with the argument that this strategy does not inhabit the same "ideological baggage" as other concepts ("Ecological footprint" and "Ecospace").

One challenge with both eco-efficiency and eco-effectiveness is to define the quantitative measures for utilities and the sufficient utilities. For buildings, several measures could be considered dependent of the use of the building:

- A factory: Unit produced.
- An office: Number of full time employees.
- A hospital: Number of patients.

For a building material, it is difficult to find a measure for the utility. For an insulation material the utility is the reduced energy use in the building, for paint it is the protection of the underlying surface and the aesthetics. Different materials will have different utilities, and the utilities are difficult to quantify.

To avoid the uncertainties and difficulties related to the quantification of the utility of the different building materials the environmental qualities can be compared directly. A requirement for being able to do this is that the materials compared fulfil the same utility. The utility of a building material is then replaced by the functional unit (functional unit is also discussed in Chapter 6.3). If two wall elements is to be compared they must for instance have the same heat and sound insulating values, alternatively the designer selects the wall alternatives that lies within an acceptable quality range. The utility in Equation 3-1 is then the same, and the environmental burdens can be compared directly. How this environmental load is calculated is described in Chapter 5.

3.3 Material and energy resources

More and more countries are aiming for the materials intensive economy, and this will increase the environmental loads in the same manner. In some cases the environmental loads will increase more than the material growth, as for instance when the quality of the ores decline thereby increasing the amount of waste and slag generated per tonne extracted metal (Brown, 1999). This trend is also seen in Norway, where manufacturing and mining has increased from 1995 to 1999 (Statistics Norway, 1999c). While the ore grade that is found to be profitable is reduced (Strand, 2000).

The increasing consumption and the population development globally, has lead to research into what the earth can support of further increase. Some researchers have come to the conclusion that the industrialised countries must reduce their material use by 90 per cent the next 50 years, in order for the developing countries to increase their material standards. In contrast, an American estimate shows that between the year 2000 and 2020 we will need just as much building materials as we did during the whole twentieth century (Brown, 1999).

The use of energy is an area with detailed knowledge regarding consumption etc. because of the value of energy and that it is easily quantified. The energy sector in Norway represents about 30 per cent of the CO_2 emissions and 60 per cent of the VOC emissions. Per capita energy use in Norway is 20 per cent above average in OECD, and

4 times the world average. Energy is also seen as an important field where the environmental load related to the building and real estate industry can be reduced.

3.3.1 Use of material and energy resources in buildings

The most common building materials in Norway are concrete, sand, wood, brick and steel, but the total amount of materials used in Norwegian buildings each year is not known with any accuracy. In 1997, Raadhuus AS performed an analysis for Åke Larson Construction, regarding the building industry in Norway (Raadhuus, 1997). This study included an analysis of the use of 7 selected building materials: concrete, steel, painting, wood, glass, plaster and brick. The use of these materials was estimated to about 5.000.000 tonnes in 1996.

In Sweden, the same fractions represent about 85 per cent of the materials used in buildings (Naturvårdsvärket, 1996, Tolstoy et al., 1998). If assumed that this is correct also for Norway, the total amount of building material used in 1996 would be about 6.5 million tonnes. In comparison, Denmark used about 10 million tonnes in 1997 and Sweden about 8 million tonnes in 1995 (Dinesen et al., 1999, Tolstoy et al., 1998). The Swedish population is about twice the number in Norway, and this makes the estimates for Norwegian consumption seam to be rather on the high side.

Naturvårdsvärket (1996) have calculated the total flow of materials in construction of new buildings and maintenance of existing buildings in Sweden in 1995. These figures have been converted to Norwegian conditions; using the 6.4 million tonne estimate of materials and the same material distribution. The result is presented in Table 3-1. The numbers in the table are hampered with a +/-40 per cent uncertainty for turnover quantities. In the table, it is seen that concrete represents the largest fraction, but sand/stone and wood also represent important fractions. Textiles and joint-fillers represent the smallest fractions. Compared to the use in new buildings, materials for rebuilding and renovation in average represents about 30 per cent of the amounts used for construction of new buildings.

Table 3-1: Total quantities for material used in buildings, including renovation and rebuilding (based on Raadhuus, 1997, and Naturvårdsvärket, 1996).

Material	Ktonnes	Material	Ktonnes
Total	6 407	Brick And Ceramics	64
Concrete	3 848	Building Stone	61
Plaster Board	314	Sand And Gravel	717
Mineral Wool	99	Lightweight Concrete	264
Plastics	14	Roofing Paper	9
Jointfillers	2	Levelling Masses	66
Glass	50	Linoleum	5
Wood	664	Paint	30
Metal	199	Textiles	1

Because of the increasing consumption of materials, reuse and recycling have received increased attention in the last years. In Sweden, 90 per cent of natural stone, sand and gravel from demolition are reused or recycled in the construction and heavy engineering sector. Sixty per cent of the asphalt is recycled, and 80 per cent of the wood is converted to energy. At the same time, only 20 per cent of the concrete waste is recycled (Naturvårdsverket, 1996). In Norway, the introduction of recycling and reuse of materials has been very slow. Only about 31 per cent of the materials are reused, recycled or used to produce energy (see chapter 3.4.1).

Land is rarely a topic in the resource discussion, at least in Norway, but the fact is that land is also a resource with a varying degree of scarcity. In the near future, agricultural land for food production will be a critical factor in many areas. Large areas are lost yearly because of erosion and nutrient depletion, and housing will in countries like India, occupy substantial agricultural areas in 50 years time. But compared to areas covered by roads, housing and other infrastructure, extraction of raw materials for building is considered not to have significant effect.

Energy consumption is in many environmental studies of materials and structures found to be the dominant problem. The use of energy itself is however not the problem, it is the source of this energy that is the critical issue. The environmental effects related to the use of energy are dependent on the energy mix used. In older Norwegian studies, it was common to regard electricity in buildings as 100 per cent hydropower based. Today it is known that electricity is imported in peak-demand periods from both coal and nuclear based power plants. For example, the import of electricity exceeded the export by 3.8 TWh in 1997 (Statistics Norway, 1999). During the winter 2002/2003, there was shortage of energy in Norway, and the prices of energy rose to about 1 NOK/kWh for private consumers. Energy is therefore one of the few environmental areas where savings give direct economic results.

The operation of buildings in Norway required 80 TWh in 2000, while the production of materials required 5 TWh and construction 3 TWh, in 1997 (The Norwegian Water Resources and Energy Directorate, 2003, Ministry of Local Government and Regional Development, 1998). In total this is 88 TWh, representing 40 per cent of all energy use Norway.

Manufacturing of building materials is often rated as the second most important environmental factor. In several studies, the energy mix chosen is crucial for the result (Adalberth et al., 2001, Pears, 2000, Strand et al. 2000b). There are different ways of calculating this energy mix. In Norway, there are mainly three "directions":

- Fossil fuel or "marginal energy"; use the emissions related to one extra unit of produced energy.
- Energy mix in a geographical area, for example Norway or EU.
- Hydropower based.

One additional problem related to buildings is the long service life. A service life period of 50-100 years is used in environmental studies, even if most building can last longer. This time span means that assumptions about the development of alternative energy sources must be made.

It is likely that renewable energy sources will be the choice in the future. The time perspective for this is however uncertain, so reducing energy use is highly relevant (Ofori, 1992). As the energy use in the operation of a building is reduced, embodied energy will become increasingly important. The influence of the choice of building materials on the energy use in the building's lifecycle is therefore an important factor.

Compared to the energy consumption in the user phase of the building, material processing has not had the same attention. In USA, material working represents 14 per cent of the energy use (the per cent related to building material is not known). Most of this energy is produced of fossil fuels. This also means that the material working industry is a major contributor to emissions of greenhouse gasses. In addition, it is found that about 5 per cent of the carbon emissions in USA come from the cement industry (Brown, 1999).

In a study for the British Cement Association, it was concluded that no single materials dominated with respect to energy use (Parrot, 1997). As concrete (because of the cement) is a fairly energy intensive material, and represents 60 to 70 weight per cent of the material use in construction, rebuilding and refurbishing, this might seem strange.

Mitchell (1996), claims that the material industry accounts for in excess of 20 per cent of the world's fuel consumption alone.[2] He also estimates that the "embodied energy" can be equivalent to the operating costs of a building over a ten-year period.[3]

Table 3-2: Energy use in the production of building materials in UK (after Parrot, 1997).

Materials	**Delivered energy (GWh)**
Aggregate stone	12
Portland cements	16
Clay bricks	8
Ferrous metals	19
Non-ferrous metals	8
Timber and panels	18
Other materials	26
Total (per cent of UK)	107 (6.1)

3.3.2 Resource factors to be included in the evaluation of building materials

The data presented in Chapter 3.3.1 make it clear that the building and real estate industry is one of the main consumers of raw materials. It is also clear that the industry needs to change, and increase the material efficiency. To build less m^2 may be a

[2] Refers to Habitat News (April 1991). "Use of energy by Households and Construction and in Production of Building Materials: Report of the Executive Director". Vol. 13. No. 1, p. 8-12-

[3] Refers to Crosbie, M. J. (1992) "Towards a Greener Architecture" Architecture: The AIA Journal. Vol 81. No. 1. pp. 99-101.

possible target, but for a specific building, the target is to increase the material efficiency. How this material efficiency is measured may vary, but for offices, a relevant parameter would be materials/full time employee. The material efficiency factor can also be linked to what the businesses consider their success factor, for example materials/net profit or materials/produced unit. However, this is a factor to be included on the building level, and not on the material selection level, which is in focus in the MaSe system. Material efficiency is therefore not considered a relevant factor to include.

Another important factor is that the building is constructed so that resources put into the building may be reused after the building is demolished. Reuse of the different materials in a building after its service life is an important sustainability aspect, and must be included in a material selection system.

The government encourages the use of resources that are renewable and abundant. Availability assessments are often used as evaluation criteria for resources, but the degree of scarcity of these resources is a difficult and disputed issue. This issue is discussed in Strand (2000), and this study showed that fossil fuels are the only reserves commonly agreed upon as scarce. Considering this, and the conclusion of the scarcity problem discussion in Chapter 3.2.1, a detailed scarcity evaluation is not included in the MaSe system. Aspects like non-renewable or renewable resources should still be included in a material evaluation.

The energy used in the production of building materials is not very important compared to the energy use during operation of the building, but as stated before this ratio might change. The amount of energy resources used in the production should therefore be included, based on the importance of this area.

Factors to be considered in the aspect of materials and energy resources are summarised as:

- Material sources: non-renewable or renewable.
- Energy sources and energy amount.
- Sustainable use of renewable recourses.
- Recycling and reuse.

Further details about the parameters and the evaluation procedures are found in Chapter 5 and 6.

3.4 Waste

Waste from the building industry represents about 40 per cent of the total amount of waste from our society. A relatively large portion is deposited on landfills and generates methane, contributing to global warming and toxic emissions to soil and water. The negative environmental consequences of waste are now recognised also in the building and real estate industry. The generation of waste has very visual effects, and there is less room for discussion of the effects than for some other environmental aspects. Increased focus has also lead to increased resources spent on studies of the generation, sources and effects. The economical resources put into this area by the government has made companies see profit in waste and reuse or recycling. People are beginning to look at waste as a resource that can provide economical benefits.

3.4.1 Waste related to building materials

According to a study performed by Myhre (1998), the building and construction industry in Norway produces about 14.2 million tonnes of waste annually, including excavation masses that are often used as landfill. The waste from construction, reconstruction and tearing down of buildings represent 1.2 million tonnes. Waste from the production of the materials is not included. The corresponding volumes calculated by the Statistics of Norway are 1.5 million tonnes waste from the building and real estate industry (also 1998 figures) (Rønningen, 2000).

Building waste includes waste from new building projects, maintenance, refurbishing and demolition, as seen in Table 3-3. Most of this waste is deposited, only 0.1 million tonne are reused or recycled and 0.1 million tonne is used for energy production (Myhre, 1998). In Oslo and Akershus, the numbers are higher, it is assumed that 25-50 per cent of the waste is reused or recovered in this area (The Ministry of Local Government and Regional Development, 2000). In Denmark, 10 per cent of the building- and construction waste is deposited.

Table 3-3: Waste from construction, refurbishing and demolition of buildings, sorted by type of waste (after Rønningen, 2000).

Fraction	**Total (kt)**	**%**	**Const-ruction (kt)**	**%**	**Refur-bishing (kt)**	**%**	**Demo-lition (kt)**	**%**
Total	*1 543*	*100 %*	*210*	*100 %*	*372*	*100 %*	*961*	*100 %*
Concrete and brick	1 057	68.5 %	77	36.7 %	181	48.7 %	799	83.1 %
Wood	214	13.9 %	42	20.0 %	123	33.1 %	77	8.0 %
Metal	43	2.8 %	3	1.4 %	9	2.4 %	31	3.2 %
Plaster	37	2.4 %	14	6.7 %	21	5.6 %	2	0.2 %
Cardboard, paper and plastics	17	1.1 %	8	3.8 %	2	0.6 %	7	0.7 %
Hazardous waste	8	0.5 %	0.2	0.1 %	3	0.8 %	5	0.5 %
Insulating materials	6	0.4 %	3.5	1.7 %	2	0.5 %	2	0.2 %
Glass	5	0.3 %	1	0.5 %	2.	0.6 %	2	0.2 %
Waste of unknown composition	130	8.4 %	61	29.0 %	29	7.8 %	40	4.2 %

Waste from the construction of new buildings represents 14 per cent of the waste generated annually in the building and real estate industry. The demolition of buildings clearly generates the major amounts of waste.

3.4.2 Waste factors to be included in the evaluation of building materials

The first action is to reduce the amount of waste created in the production, use and disposal of the materials. In the material selection system, it is possible to determine the waste created in the production of the material. However, production of waste on the construction site or in the future is connected with larger uncertainties.

The waste that arises during construction can be based on estimates from the material producer and on experience. The amounts may also vary depending on the practise of the contractor or the producer. Some producers take back the waste from the installation of the products for recycling. This is the case for the Swedish PVC-flooring producer, Tarkett, who recycle the waste from the building site (Bramslev, 2000). Eight per cent of the retained spill is recycled into new PVC tiles. The remaining per cent is used in energy production. Some large contractors have also seen the necessity of recycling, and developed systems for recovering and treatment of building waste.

In the future, it will be increasingly difficult to reclaim building materials because of today's use of composite materials. The increasing number of different types of materials also complicates future reuse or recycling. But the regulations of the Planning and Building Act in Norway include requirements of assessing the potential for future reuse and recycling when selecting building materials (Ministry of Local Government and Regional Development, 1997).

To conclude on the waste area, the potential for future reuse or recycling is an important factor to include when selecting building materials. The MaSe system should therefore consider both the type and amount of waste produced in the different lifecycle phases of a product. Focus should be set on how the material is disposed of in the different phases. Further details about the parameters and the evaluation procedure are found in Chapter 5and Chapter 6.

3.5 Emissions

Emissions should preferably include emissions to air, water and soil. However, emissions to soil are hardly discussed in any LCA literature, and the data available are very limited. In the building and real estate industry, soil pollution is mainly a problem at the construction site. It may also be a problem in the extraction of some minerals, when the waste is deposited, especially hazardous waste. This should be included in the MaSe system, but until more information is available, emission to soil is left out, except from toxic emission discussed in Chapter 3.6. Emissions to air and water include substances that lead to:

- Global warming.
- Ozone depletion.
- Creation of photochemical oxidants.
- Acidification.
- Eutrophication.

Emission of toxic substances is dealt with in a separate chapter.

Little quantified information is found regarding the emissions that can be directly related to the production, use or disposal of buildings in Norway. Studies from other countries like England, Sweden and Denmark will therefore be used to estimate the emissions in Norway.

3.5.1 Global warming

Gases like carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (N_2O), have different ability to affect the radiation of energy from the earth and the atmosphere. Simply stated, the consequences for all of them, however, might be increasing temperatures and changes in climatic conditions on the earth.

Industrial processes are the largest sector in terms of CO_2 emissions. Metal production, with the production of ferroalloys, is very dominant, followed by the chemical industry and the production of mineral products. Within mineral production, the cement industry is responsible for about 95 per cent of the greenhouse gas emissions (State Pollution Agency, 2001). The emissions of CO_2 are mostly related to the use of energy in the different processes. The exemption is the production of cement, where the major part of the emissions origin from the production processes itself (Howard, 2000).

Emissions related to the production and use of building materials

The emissions of CO_2 from production of building materials are in a study by Myhre (1998) found to represent about 8 per cent of the Norwegian CO_2 emissions. This is consistent with a study by Howard (2000), which found that the manufacture and transport of construction material represent about 10 per cent of UK emissions. In a study performed by Gielen (1997), the emissions related to building materials for Western Europe range from 275 to 410 Mt of CO_2 per year, representing 8-12 per cent of the total CO_2 emissions in this region. In a study from the British cement industry, the emissions related to the manufacture of construction materials ranged from 4 to 13 per cent of the total emissions in the UK. The emissions are significant enough to be included in the assessments of UK sustainability.

The most important materials from a CO_2 point of view are cement, timber products, steel, bricks and aluminium (Gielen, 1997). In a study from Parrot (1997), the major environmental effects were linked to a group of six materials, which were aggregates, cement, bricks, ferrous metals, non-ferrous metals and timber, see Table 3-4.

Table 3-4: Emission of CO_2 from different material groups on UK construction (after Parrot, 1997).

Materials	Carbon dioxide (Mt)
Aggregates	4
Portland cement	10
Bricks	3
Ferrous metals	8
Non-ferrous metals	2
Timer and panels	6
Other materials	4
Total (% of UK)	37 (7)

A study by Howard (2000) shows that a dominant part of the CO_2 emissions from the production of the different materials stems from the use of energy, cement being an exemption. Transport has earlier been regarded as a decisive factor for the environmental load. It has been estimated that the transport only accounts for 16 per cent of the environmental effects that can be related to the production of building materials (Byggesktorns kretsloppsråd, 2001). It must be noted that transport is a significant source of pollution nationally, especially the transport of heavy materials like minerals and aggregates.

Howard (2000), also included an aspect that up until know has received little attention. The large amounts of construction waste deposited on landfills are suspected to contribute significantly to the emission of methane emission over time. This is relevant for materials with organic components. The best estimate shows that bout 16 per cent of the CH_4 emission from landfills stems from construction and demolition waste, the uncertainty of this estimate is however high.

3.5.2 Depletion of the ozone layer

The ozone layer protects humans, animals and plants from ultraviolet radiation. Ultra violet radiation can lead to skin cancer, eye damages and deterioration of the immune system of humans and animals. The growth of plankton in the sea and plants on the earth may also be reduced because of increased radiation. The emission of gases like **c**hloro**f**luoro**c**arbons (CFC) and **h**ydro**c**hloro**f**luoro**c**arbons (HCFC) reduces the stratospheric ozone layer. This ability is expressed as the **O**zone **D**epletion **P**otential (ODP). In addition, ozone depleting substances also tend to have a global warming potential.

Emissions related to the production and use of building materials

Production and use of building materials is an insignificant source of ozone depleting substances. As a simple check of this statement, 41 common building materials was studied, none of which was reported to include any ozone depleting substances in any stage of the production. Other relevant products in buildings are cooling agent in larger cooling systems (2/3 of HCFC), and polyurethane insulation foam (1/3 of HFC). These uses are now restricted through the new regulations that entered into force in January 2003. Because of this regulations and the success seen in reducing the emissions, the evaluation of ozone depleting substances is not included in the MaSe system.

3.5.3 Formation of photochemical oxidants

The combination of **V**olatile **O**rganic **C**ompounds (VOC) and NOx forms photochemical oxidants in the presence of Ultra Violet radiation. Photochemical oxidants are strong oxidants that are irritating, damage vegetation, reduce soil fertility, and attack building materials. NOx emissions also cause acidification, which according to the government is one of the biggest threats against biological diversity in Norway (State Pollution Agency, 2002a).

Emissions related to the production and use of building materials

About 3 per cent of the total emissions of NOx are directly related to the operation buildings (State Pollution Agency, 2002a). This 3 per cent, however, does not include emissions from production, use and disposal of building materials. As seen in Table 3-5, the study by Parrot (1997) showed that aggregates and timber products cause the dominating emissions of both VOC and NOx.

Table 3-5: Emissions of NOx and VOC from different material groups in the UK construction industry (after Parrot, 1997).

Materials	**NOx (kt)**	**VOC (kt)**
Aggregates	64	19
Portland cements	31	1
Bricks	6	3
Ferrous metals	34	10
Non-ferrous metals	8	9
Timber and panels	66	33
Other materials	21	19
Total (per cent of UK)	*231 (10)*	*93.5 (4)*

The industrial sector in Norway represents about 9 per cent of the NOx emissions. These emissions are mostly a result of combustion, only a part is related directly to the industrial processes. Reductions of the emissions in the wood-processing industry, oil refineries and cement production are recommended in the action analysis performed by the State Pollution Agency (Ministry of Environment, 2000).

The dominating emissions of **N**on-**M**ethane **V**olatile **O**rganic **C**ompounds (NMVOC) from construction are related to the use of white spirit, paint and varnish. In 1993, the Norwegian emissions from paint and varnish reached 4 650 tonnes, impregnating substances contributed with 650 tonnes and white sprite 2 200 tonnes. The main initiative for reducing these emissions is to replace the products with products not based on solvents (State Pollution Agency, 1997).

Some building materials are listed as potential targets for reduction in order to fulfil the reduction requirements set in the Gothenburg Protocol. In addition, Norway has far from fulfilled the stated reduction targets. Together, these two factors leads to the conclusion that the **P**hotochemical **O**xidant **C**reation **P**otential (POCP) should be included in the MaSe system.

3.5.4 Acidification

Emission of sulphur dioxide (SO_2) causes acid rain, which again can reduce the biological diversity in lakes and on land. Acid rain also leads to increased weathering of buildings and monuments of cultural value.

Emissions related to the production and use of building materials

Industry and mineral extraction are responsible for major parts of the SO_2 emissions in Norway (above 80 per cent) (Statistics Norway, 1999). Howard (2000), found that 8 per cent of the total SO_2 emissions is related to the production and transport of building materials in the UK. The study from Parrot (1997) shows that the production of ferrous materials is responsible for the dominating emissions in the UK construction industry. This is illustrated in Table 3-6.

Table 3-6: Emission of SO_2 from different material groups in UK construction (after Parrot, 1997).

Materials	**SO_2 (kt)**
Aggregates	16
Portland cements	19
Bricks	8
Ferrous metals	52
Non-ferrous metals	16
Timber and panels	20
Other materials	22
Total (per cent of UK)	*151 (6)*

Norway has fulfilled the emission reduction target set in the Gothenburg Protocol. However, acid rain is a regional problem, and other countries have not succeeded in achieving their reduction goals, therefore SO_2 must be included in the MaSe system.

3.5.5 Eutrophication

Eutrophication is the process that is initiated when fertilizing compounds in seas, lakes or rivers, increase the amount of organic and biologic material in the water. Eutrophication leads to a decline in water quality both in freshwater and marine areas. This again can cause fish death, loss of biological diversity, reduced recreational value and reduction of the water's suitability for drinking etc. Emission of nitrogen and phosphor are the most important factors in this process.

Emissions related to the production and use of building materials

Studying Norwegian emission reports and action plans, the production and use of building materials does not seem to be responsible for any substantial emissions of eutrophicating substances (Miljøstatus Norge, 2003, Ministry of Environment, 2002c and Ministry of Local Government and Regional Development, 2000). From available data (Miljøstatus Norge, 2003), it is seen that in 1999, the industry in total represents 3 per cent of the national nitrogen and phosphor emissions. Agriculture, aquaculture and public discharge are the dominating sources. Due to the small contribution of nitrogen and phosphorous emissions from building materials, these emissions are excluded from the MaSe system.

3.5.6 Emission factors to be included in the evaluation of building materials

Conscious selection and use of building materials are seen as important by the government to reduce the impacts our society causes on the environment. In a report to the Norwegian Parliament, the use and development of less environmentally damaging products is encouraged to reduce the emissions in production (Ministry of Environment, 1997). In Agenda21 (Agenda 21, 1992), it is seen as important to promote the use of economic instruments, such as product charges, to discourage the use of construction materials and products that causes pollution during their lifecycle.

The Swedish study of the important environmental aspects linked to the building and real estate industry shows that the production and use of building materials is relatively small compared to the effects linked to energy use in the operation of the building (Byggsektorns kretsloppsråd, 2001). Still, the industry is responsible for large portions of the material resource use, and it is in these chapters shown that the environmental aspects linked to the production and use of these materials are important. In the MaSe system, the following emission factors will be included in the evaluation:

- Global warming.
- Photochemical Oxidant Formation.
- Acidification.

All stages in the lifecycle of a product must be included, but the major contributions from most materials stems from the production phase. Testing of the system may in future determine if further simplification can be justified in the MaSe system.

3.6 Hazardous chemical substances

There is no precise definition of hazardous chemical substances. It is common to separate between toxic substances and substances that endanger human health and the environment. Toxic substances is harmful even in small amounts, they are almost non degradable and accumulate in organisms. Heavy metals like lead and cadmium and organic compounds like PCB, DDT and dioxin, are considered toxic substances. The term health and environmentally damaging chemicals involve substances that are for example carcinogenic, but not heavy degradable or bio accumulative, and thus not toxic.

The Ministry of Environment sees the spreading of toxics substances (together with climatic change and the reduction of biologic diversity) as the most serious threat against sustainable development. It is stated that pollution of water, soil and air, gradually increasing the amount of toxic substances in the food chains is a threat to the basis for existence on earth, the supply of food, and the health of the coming generations (Ministry of the Environment, 1999d). Unwanted effects of chemicals include many aspects from acute toxicity to allergy inducing effects (Ministry of the Environment, 1999b).

3.6.1 Toxics substances related to building materials

There are emissions of chemicals both during production and transport of materials, during construction and use of buildings, and in waste handling. It is estimated that the construction industry generates 30 000 tonnes of hazardous waste annually (Myhre, 1998). Waste defined as special waste amounts to 7 500 tonnes (Bramslev, 2000), representing 25 per cent of what is regarded as hazardous waste.

The State Pollution Agency publishes a report annually on toxic substances in products. From these reports, it is clear that several building materials contain substances that are under observation (State Pollution Agency, 1999). A study by the Danish Building Research Institute presents a survey of problematic substances in building materials (Krogh, 1998). A list of materials containing substances that in the future may give health and environmental problems is presented in Table 3-7. It is seen that a range of products contain these problematic substances, but it is found mainly in products that resents small amounts of the total mass of product in a building.

Table 3-7: Substances in building materials, that has given or in the future can give health and environmental problems (Krogh, 1998).

Type	Substances/groups of substances	Building materials
Metals	Arsenic. Lead and lead compounds. Cadmium. Chromium compounds. Pewter compounds. Nickel. Copper compounds.	Impregnated wood. Fittings, cables, PVC. Pigments, in soldering paste. Impregnated wood. Impregnated wood. Locks. Impregnated wood.
Slow deterioration	Polychlorinated biphenyls. Phthalates. Chlorinated paraffin's.	Joint-filler. Jointfillers, plastics. Glue.
Solvents		Paints, impregnation oils.
Dispersants	Nonylphenoletoxylates.	Paints.
Biocides	Fungicides. Conservation agents.	Joint filler, paints. Joint filler, paints.
Monomers	Isocyanides. Epoxy compounds. Phenol. Formaldehyde.	Foam joint-filler. Epoxy glue. Two components glue. Two component glue.

For the new University Hospital in Trondheim, Wærner (2001) made a list of materials that may contain unwanted components. Listed materials are: Accelerators, corrosion inhibitors, wood stains, building profiles, electrical cables, pipes, gutters, ceiling light globes, windows, roofing materials, moulding oils, formwork waxes, antifreeze solutions, Jointfillers, flooring materials, impregnated wood, glues, paints, varnishes, primers and fungus remedies.

The difficulty when making such a list is that future problems are difficult to foresee. Today the industry strives to repair old sins in buildings, like for example the use of PCB and mercury. The last few years, bromated flame retardants have drawn increased attention because of their slow degradation in nature and bio accumulating properties. Emissions can occur from production, use of the product or from waste. Long transported air currents are also a source of pollution. State Pollution Agency (2002c) estimated that about 50 tonnes bromated flame retardants are used in Norwegian domestic production. However, the total turnover in products was in 1998 estimated to between 300 and 600 tonne. These substances are most common in computer equipment and electronic equipment, but paint and varnishes, together with building materials and furniture are also product groups that may contain bromated flame retardants. It is likely that as we in the future gain more knowledge about the substances that are used today, and more will be discovered that must be removed from our buildings to avoid health damages.

Paint and varnishes often contain harmful substances. In the Product Register for chemical products in Scandinavia, there are 11 800 registered paint and varnish products that contain harmful substances. In total, these products amount to approximately 81 000 tonnes each year (Nordic Council of Ministers, 1999). In addition, in the cleaning of buildings chemical substances are used that can cause unwanted effects. About 1 700 substances used in detergents are listed in the production register as hazardous to health or the environment, and the consumption amounts to 250 000 tonnes each year.

Plastic is also an important source of emissions of hazardous chemicals, including e.g. phthalates and lead, which could leak during use. However, the major environmental problem related to plastics is waste. In Table 3-1, it is seen that in the use of plastic materials in buildings amounts to about 14 000 tonnes annually.

3.6.2 Toxic substances to be included in the evaluation of building materials

Substances that are harmful to the health and the environment in a new building may not be present in large amounts, but the risk may still be significant:

Risk = Probability x Consequence

This means that even if there is little probability that toxic substances are present, the risk could be quite large depending on the toxicity (consequence) of the substance. In addition, the building and real estate industry is important in the bigger picture, as the industry is the fourth largest user of these substances.

As there are large gaps in current knowledge, the precautionary principle will be used in the evaluation of undesirable effects in the MaSe system. This is also the government policy. The evaluation of a product must be based on the A list, B list, the Obs list and the Substance list. These lists are by no means complete, so other substances must therefore be included based on specific studies (for example on PVC or Linoleum), or news and reports from for example the State Pollution Agency or European Chemical Bureau. Details on the evaluation procedure are described in Chapter 5.

3.7 Indoor environment

Indoor environment includes the health of the occupants of a building. Indoor environment by definition a result of seven elements: thermal environment, the atmospheric environment, the acoustic environment, the actinic environment, the mechanical environment, the aesthetic environment and the psychosocial environment. Building materials will directly or indirectly affect all these seven elements.

The working environment of the material producers and the construction workers are not usually included in the material evaluation procedures. This is mainly due to two factors. First, the area is not included in traditional LCA, which constitutes the foundation for most of the environmental building material evaluation systems. Second, for both working environment and indoor environment it is difficult to establish the same type of parameters and evaluation methods as it is done for traditional environmental effects.

A relevant factor to include is the accident frequencies. However, there are several problems linked to such use. Not all countries have such reporting systems, and the control in the countries that actually do have such a system may vary. Using accident frequencies also as a factor to decide whether to buy one product or not, might also increase the tendency of underreporting.

Working environment is not included in the MaSe system because the workers in a production facility or on a building site generally are aware of, or at least should be aware of, problems related to for example the use of various chemicals. They are in a better position when it comes to protect himself/herself from potential hazards. A user of a building is not familiar with the possible health effects related to the indoor environment, and cannot protect him/herself. This is an argument for focusing on the occupant of the building, rather than the workers in the construction process. No attempt will therefore be made to include other working environment aspects than the use of chemicals and their potential health hazard in the production, construction and demolition of a product.

3.7.1 Indoor environmental problems related to building materials

Material selection is only one of the aspects that must be included to improve the indoor environment in a building. Ventilation and cleaning are other important aspects, but the choice of materials is, as mentioned, relevant for the atmospheric environment in a building. Emissions from building materials originate from solvent residuals, raw material residuals (e.g. rest monomers), detrimental products, additives or finishing treatment of a product like for example polishing (Bakke, 1993). These emissions can cause health problems, odour and reduced comfort. It is confirmed that the right selection and treatment of building materials could reduce the risk of allergies and health damages, increase the comfort in the first years of the buildings service life, and reduce the need for ventilation (Norwegian Building Research Institute, 1993).

Substances emitted to the indoor environment in buildings include inorganic gases like SO_2, NOx, CO_2, CO, O_3, water vapour and radon, organic gasses like VOC and formaldehyde, organic particles like bacteria and pollen, together with inorganic particles like dust and other mineral fibres (Norwegian Building Research Institute, 1992). Table 3-8 shows a summary of well-known materials and their possible indoor environmental risks. It is important to notice that materials from different producers may have different properties, as for example particleboards, which shows large variations in formaldehyde emissions. Some boards have emissions that satisfy the P1[4] requirements, and others have such high emissions that they should not be used.

[4] The Norwegian Council for Building Standardization has set quality characteristics that give particleboards with less than 10 mg free formaldehyde per. 100 g material the characteristic "P1". Particleboards with less than 25 mg per 100 g of material have the quality characteristic "P2".

Table 3-8: Well known building materials, and possible indoor environmental risks, based on NBI (1992) and other sources (Malvik et al. 1993, Aas, 2002).

Material	**Possible indoor environmental factors**	**Comments and conditions**
Concrete	Cement dust. Emissions depending on the surface material. Moisture and organic substances may cause problems.	If untreated.
Bricks and tiles	None	If low emitting glue and mortars are used.
Wood	Formaldehyde if untreated Rot if exposed to moisture.	Emissions depending on surface treatment. Depends on wood type.
Particle boards	Formaldehyde	Large variations in emissions. Emissions often caused by maltreatment.
Fibreboards	Trace emissions.	
Plywood	Emissions on the level of untreated wood	
Plaster plates	Organic trace emissions.	
Mineral wool	Micro organisms. Particles.	If in contact with water. If not well sealed.
Plastic floorings	Large variations in emissions. Organic emissions, smell and irritation if reaction with underlying surfaces. Simple cleaning procedures.	Requires the presence of water.
Linoleum and laminate	Emissions may occur from the cleaning and maintenance procedures. Organic emissions, smell and irritation from reaction with underlying surfaces.	
Textile flooring	Organic emissions, smell and irritation if reaction with underlying surfaces. Dust binding.	Requires contact with water. Correct cleaning is resource demanding.
Levelling paste	Odour	If high moisture content, reaction between levelling compound, moist concrete and the glue under the flooring material.

Cont. Table 3-15.

Material	Possible indoor environmental factors	Comments and conditions
Jointfillers	Large emissions of organic solvents.	From non-tempered materials.
Paints Water based. Solvent based. Mineral based paints Varnish	 Low emissions. Emissions from white spirit and rest products. Cleaning difficulties. High VOC emissions.	 The emissions will continue over a long period. Emissions only a short time after applying. Reduces rapidly with time.
Glues Synthetic "Natural"	 Emissions of formaldehyde (urea glue), epoxy (epoxy glue), VOC, residual monomers from acrylate glue. Production of nitrogen compounds.	 The health effects are mostly related to the production and construction phase. If in contact with moisture in the underlying surface.

Often, it is assumed that natural products are healthier than synthetic products. This is, according to for example Aas (2002), not always correct, especially when the materials are sealed within the tight shell that modern buildings represent. Allergy is often linked to natural substances, e.g. natural latex in paint. Natural products also constitute a perfect growth media for microorganisms.

Aesthetics is also included as one of the seven indoor environment elements. Relevant aesthetic requirements of materials include colour, surface structure, radiance etc. (Aas, 2002).

3.7.2 Indoor environmental issues to be included in the evaluation of building materials

Aesthetics is always important when building materials are selected. None of the existing material evaluation systems includes aesthetics as a criterion. The evaluation of these aesthetic qualities depends on the subjective aesthetical sense of the individual, as our sense of aesthetics depends on culture, upbringing, learning etc. At this stage, it is considered difficult to include an aesthetic evaluation of the material, so this factor is for the time being excluded from the MaSe system.

Factors to be included in the evaluation of indoor environmental problems should be:

– The emissions of gasses, particles and fibres in the user phase, related both to the material and the relevant surface treatments.

– Cleaning properties.

URN:NBN:no-6424

3.8 Discussion and summary of findings

In a report from the GRIP to the Nordic Council of Ministers some recommendations is made as to how the building and real estate industry may meet the needs for efficiency improvement. (GRIP, 2000):

- There should be a general reduction of materials input and output into the building and real estate industry. The dematerialization should also include replacement of non-renewable resources with renewable resources, increased recycling etc.
- There should be a reduction of consumption of eco-toxins with a factor depending on the type of eco-toxin.
- The energy efficiency can be increased with a factor of ten.

Studies show that major changes are needed to meet the growth seen in consumption and subsequent depletion of resources, damages to human health and the environment. It is difficult to see that one building material contribute in a significant way to one of the world's environmental problems. Nevertheless, the causes behind an environmental problem are complex, and the largest challenges are no longer linked to any single source, but to the effect of everyday acts of transport, housing and consumption. Seeing the building and real estate industry as a part of our society, it is clear that the use of material resources and pollution are areas that need improvement.

Reviewing the factors that need to be included in the material evaluation procedure the following summary can be made, also see Table 3-9:

Material and energy resources

All studies show that the building and real estate industry is a dominating consumer of both material and energy resources. When selecting building materials, factors like recycling and reuse need to be considered, and also the renewability of the material in various products.

Energy should be assessed as other resources, not as consumed kWh as is done in many methods. What is important is the amount and type of resources used to supply the energy. For example the amount of energy produced from one tonne of coal may vary, what is important is that one tonne of coal is extracted and used once and for all. A producer that exploits an energy source effectively will use fewer raw materials to supply the same amount of energy than another, less effective producer. The effective producer should be rewarded for this. Using kWh of primary energy would cover these aspects.

Large amounts of waste are generated in the building and real estate industry. In addition, waste is generated in the production of the building materials. Included in the waste problem area are the amount of waste that generated through a material lifecycle, and the type of waste.

The potential for reuse or recycling is an important aspect. If a selected wall plate is reusable, it is important that it is easy to dismantle after its service life is ended, without damaging the product. It is difficult to foresee the future utilisation of a material, but setting up a set of guidelines for evaluation, it is possible to say something about probable outcomes. If all conditions to increase the probability for future reuse are included, the wall plate should not be considered as a waste fraction, but rewarded for its reuse potential. It is important to notice that it is a potential for reuse, and not a stated fact that this material will be reused.

Ecology

Toxic substances are clearly important when it comes to building materials. This is recognised by the industry itself, the authorities and in several studies of the environmental consequences related to the building and real estate industry. Under the headline "Ecology", the effects of chemicals are only assessed according to their Eco-toxicological effects.

Other factors to be included under the headline Ecology are global warming, acidification, and Photochemical Oxidant Formation.

Human health

The emissions of toxics to air, water and soil will have effect on human health. An evaluation of the human toxicity should be included in the MaSe system assessment. Effects on human health from global warming, eutrophication, acidification and ozone depletion are aspects not included in the MaSe system. In the future, methods to include these aspects may be developed to such an extent, that they could be included in material selection systems like the MaSe system.

Aspects that should be included in the assessment of the indoor environment influence of a certain material are emissions of substances and fibres, cleaning methods, cleaning chemicals, cleaning friendliness and dust adhering properties.

Table 3-9: Summary of the environmental aspects that should be included in the MaSe system. All the factors listed are further elaborated in Chapter 5and 6.

Main area	**Production**	**Transport, construction and use**	**Transport and demolition**
Material and energy resources	Energy use and energy sources. Recycling, reuse. Renewable and non-renewable materials. Sustainable use of renewable material resources. Amount and type of waste.	Energy use and energy sources. Recycling, reuse. Renewable and non-renewable materials. Sustainable use of renewable material resources. Amount and type of waste.	Energy use and energy sources. Recycling, reuse. Renewable and non-renewable materials. Sustainable use of renewable material resources. Amount and type of waste.
Ecology	Global warming, Acidification, formation of Photochemical oxidants. Eco toxicity	Global warming, Acidification, formation of Photochemical oxidants. Eco toxicity	Global warming, Acidification, formation of Photochemical oxidants. Eco toxicity
Human health	Human toxicity.	Human toxicity. Emissions of gasses, particles and fibres, cleaning methods cleaning friendliness and dust adherence properties.	Human toxicity.

4 Existing systems and tools for environmental evaluation of building materials

The focus in this chapter is to study some of the systems developed for the environmental evaluation of building materials. Material evaluation systems included are listed in Table 4-1. In this table, it is seen what type of help the systems provide, whether it is a database, if the system give advice or guidance to the user and/or allow comparison of alternatives.

Table 4-1: The different material evaluation and selection systems and tools.

Tool	**Database**	**Advice/ guidance**	**Comparisons and alternatives**
BEES	Yes	No	Yes
ATHENA	Yes	No	(Yes)*
Guide for material selection	No	Yes	Yes
ERG	No	Yes	Yes
EPM	No	Yes	Yes
BEAT2001	Yes	No	Yes
ENVEST	Yes	No	Yes
The Folksam-guide	No	Yes	Yes

* Comparison only on the building level, direct comparison of materials is not possible.

Several handbook types of guides are excluded from this study. This is because they are not considered as very interesting for this discussion. Methods that evaluate the building in total are also of interest, but will only be included to the extent that they include evaluation of building materials. It must be noted that the tools included only represents a selection; it is not intended as a total overview of existing tools. There exists no complete survey of tools internationally. Many tools may be under development that has not been presented on conferences, in literature or on the Internet. In addition, it is a lot of activity on the area, which is also revealed through a simple search on the Internet. Searching with the following key words: environmental, materials, products, evaluation, building, selection and tool, resulted in 103.000 hits using Google Search.

A detailed study of how to present the assessment information is included because this is an important aspect of a decision tool. The goal of the study presented in this chapter is to find solutions that it may be possible to use in the MaSe system.

4.1 Existing material evaluation systems

The importance of including environmental considerations when selecting building materials, and the complicated issue this represents, has lead to many initiatives to develop systems that support this need. The purpose of studying existing methods is to see if there are solutions that can be adapted to a Norwegian system, and also to avoid some of the weaknesses of the earlier methods.

Reviewing the existing systems, there are many important aspects to study. A basic requirement is whether a system is capable of recommending one material alternative as better than another material. The properties of the existing systems and how these fit with the defined requirements of the MaSe system is discussed under the headlines Environmental aspects, Economy, Building process and User functionality:

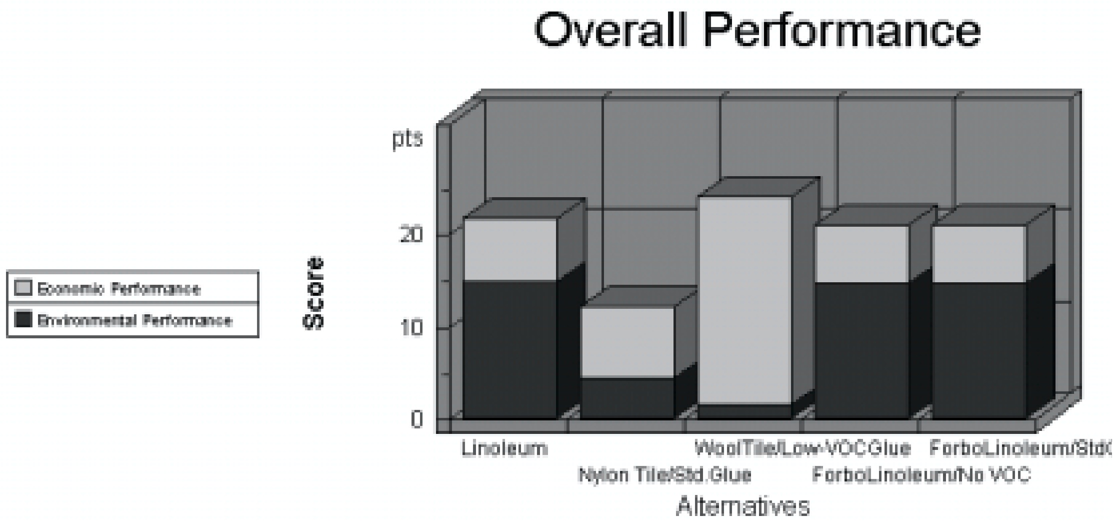
1. Environmental aspects:
    a. What parameters are included in the evaluation? Does the parameters cover the identified aspects from Chapter 3? What type of endpoints is used in the evaluation?
    b. Is the evaluation based on a lifecycle view?
    c. On what basis does the system make the comparison of the parameters included?
    d. Can the environment in which the material is used, together with the maintenance procedure affect the rating of the material? How site specific is the evaluation?
2. Economy:
    a. Is economy included in the evaluation?
    b. How is economy included? Is it based on a lifecycle view?
3. Building process:
    a. For whom is the system developed, and is it clear who the target group is?
    b. In which phase of the building process is it suited?
4. User functionality:
    a. How is the ability of the system to differ between materials or products?
    b. Does it require special knowledge from the user?
    c. To which degree can the user affect the result of the evaluation?
    d. Is eth system general, flexible and transparent?
    e. Does the system require massive data input?
    f. Is the system sensitive to miscalculations?

No complete descriptions of the different systems are included, only when this is necessary to explain some of the points on the list presented above.

4.1.1 BEES, USA

BEES (**B**uilding for **E**nvironmental and **E**conomic **S**ustainability), is a computerised tool for choosing environmentally preferable building materials. The BEES project started at NIST (**N**ational **I**nstitute of **S**tandards and **T**echnology in US) in 1994, and the third version was released in October 2002.

The purpose of the BEES has been to "*develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance based on the decision makers* *values"*. For a full description of the methodology, the reader is referred to the methodology report (Lipiatt, 2002). Figure 4-1, shows an example of how the result may be presented. Figure 4-1 presents the total result of the evaluation; where ecology and economy are weighted together, using preferences set by the user (here 50-50). In addition, the results can be presented by the different impacts, by lifecycle stage or embodied energy.



ɔwer values are better

Category	Linoleum	Nylon Tile	WoolTilLow	ForboNoVOC	ForboStd
Economic Perform.--50%	6.8	7.8	22.5	6.4	6.4
Environ. Perform.--50%	14.8	4.4	1.6	14.6	14.6
Sum	21.6	12.2	24.1	21.0	21.0

Figure 4-1: Presentation of the result as "overall performance" of floor covering alternatives: generic linoleum, generic nylon tile carpet, generic wool tile carpet with low VOC glue, Forbo linoleum with no VOC glue and with standard glue.

The BEES environmental performance assessment is based on the LCA standards, including categorising in impact categories, normalising by dividing by the U.S. emission per year per capita, and weighing by relative importance. Available weights includes EPA (United States Environmental Protection Agency) Science Advisory Board list of relative importance of various environmental impacts, Harvard University study, equal weights and self defined weights.

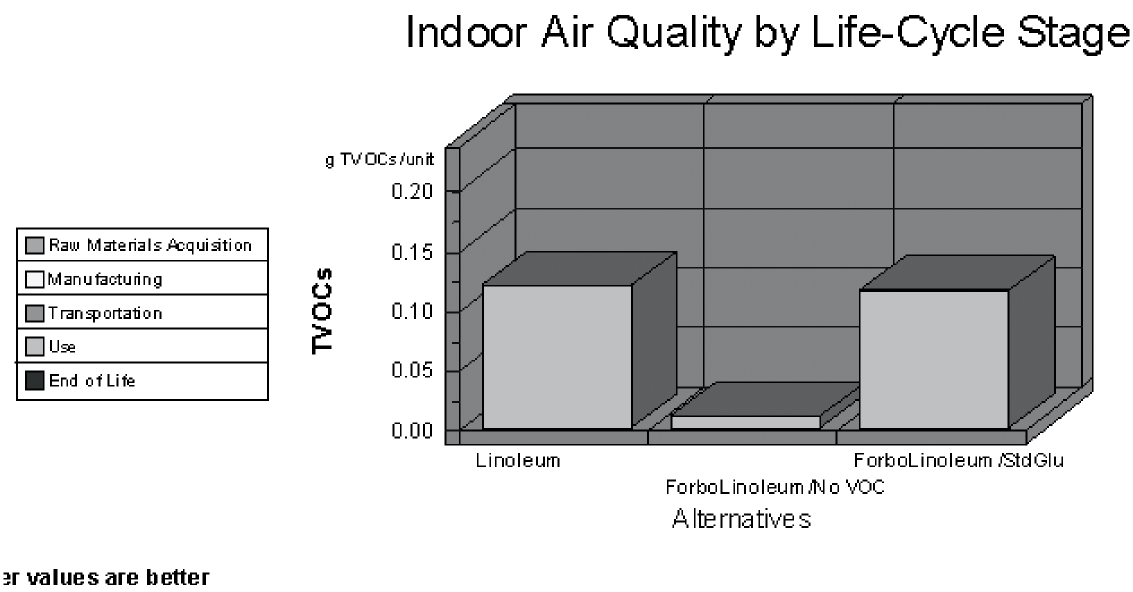
The economic performance is based on LCC calculation, and normalised by dividing by the highest life cycle cost, thereby ranking the materials from 0 to 100. Finally, an overall evaluation involves the environmental score and the economic score being weighted together using relative importance decided by the user.

Costs are included as LCC, but studying the database, it is only the initial and the replacement costs that are included. Studying for example flooring materials, no costs for cleaning and maintenance are included.

The system can be site specific for some aspects. For example, the chosen transport distances can affect the result. The different environmental effects, and the different service lives obtained with different scenarios of maintenance and use are not included. Some of the environmental effect assessments are more or less site specific (smog formation, acidification, eutrophication, eco toxicity, human health and air pollutants), this is not considered in the assessment.

The method was initially aimed at designers, builders and product designers. In addition, the use of the BEES system requires no knowledge of environmental science or the different material properties. A user that is familiar with the terms of environmental effects, indoor air quality etc. would however find the method more useful.

The system was not product specific in the first two versions, but in the third version, data are presented both for specific products and for generic materials. Testing the system, it seems like it is capable of separating different material groups. Studying products however it seems like the differences might be harder to discover. For floor coverings, evaluation results were compared for linoleum with no VOC glue, Forbo linoleum with standard glue and Generic linoleum with standard glue. Eutrophication was found to dominate the environmental performance totally. However, for this situation, it is likely that there might be some difference in IAQ. This is also correct, as seen in Figure 4-2. The alternative with no VOC glue is the best alternative, but this disappears in the total picture where no difference is seen in the environmental performance score.



Category	Linoleum	ForboNoVOC	ForboStd
1. Raw Materials	0.0000	0.0000	0.0000
2. Manufacturing	0.0000	0.0000	0.0000
3. Transportation	0.0000	0.0000	0.0000
4. Use	0.1200	0.0110	0.1160
5. End of Life	0.0000	0.0000	0.0000
Sum	0.1200	0.0110	0.1160

Figure 4-2: Indoor air quality in BEES for generic linoleum, Forbo linoleum no VOC glue, and Forbo linoleum standard glue.

The transparency of the system can be characterised as relatively high. The users can se if it is global warming, nitrification or other aspects that causes a high score, or he/she can choose a presentation where he/she can see to which life cycle stage the high score is connected.

It seems like the system is based on a relation database, which implies that it will be quite flexible to changes in any type of information. For the same reason, and because of the way information is presented, the system is regarded as generic.

The BEES system is structurally based on a lifecycle view. To which extent this is realised depends on to which degree data for cleaning and maintenance are available. Studying the program and the underlying data, it does not seem like cleaning and maintenance are included to any extent. What data that are actually included in the evaluation are also limited by the equivalency factors (Se Appendix C for the complete list for factors). Note that the evaluation is performed only with quantitative parameters.

The risk of placing a material the wrong category is difficult to determine for this system. The parameter where the result is assumed to vary the most is indoor environmental effects. However, in the BEES system the assessment of indoor air quality is unusual. For the product in question an estimate of TVOC is used, and the total VOC emission over an initial number of hours is multiplied by the number of times over the 50 year period those "initial hours" will occur. This results in an estimate of total VOC per FU for product. This estimate is again normalised to 30 per cent of the U.S. VOC emissions/year/capita. Using 30 per cent of the emissions is based on the information that this is the share of VOC emissions related to consumer products. Consumer products include surface coatings, personal care products, household articles etc. This normalised number is then weighted together with the rest of the normalised effects.

From this calculation procedure, two assumptions can be made: first, the consequence of using 30 per cent of U.S. emission/year/capita as a normalisation value probably yields an underestimation of the importance of the VOC emissions. Second, it reduces the possibility to establish the difference between products.

Another factor increasing the danger of misevaluation of a product is that the necessary input is limited by available potentials for the different effects, especially eco toxicity. Because of this inherent limitation, it is a chance that materials having effects not included in the system are favoured over materials that would be the best selection if all effects where included. However, this is a problem for all methods using effect potentials. In addition, other indoor environmental aspects than VOC, eco toxicity, and formation of photochemical smog are not included in BEES. The use of average data may also result in a product evaluation being misleading. This was, however, not investigated in any detail.

To study the success of a system, it is interesting to see the extent to which the tool has been used. For BEES, this is an easy task, because an extensive user survey has been carried out. The survey shows many interesting results, but it will not be discussed in detail.

In July 2001, 4500 people had downloaded BEES 2.0 from the Internet. The user survey was sent out to 3177 people and NIST received 566 submitted surveys (Hofstetter et al, 2002). Only 6 per cent of the respondents reported to have used BEES in a specific project, and of these 9 per cent (equal to three persons) had actually used BEES in a specific decision situation. This is not impressive, considering the number of people that has downloaded the tool.

It is interesting to identify the reasons for the modest results for the number of people actually using the tool for decisions. The user survey does not discuss this matter explicitly, and the reasons for the results could of course be many, but the following aspects are probably relevant:

- The product of interest was not available.
- There is no information on how to use BEES in the building process. Various directions for material and product use are included in different stages of the building process, and there is seldom one designer or consultant that decides upon which product to be used. The decision to include environmental considerations must be made from the top and concretised further as the process moves on. These aspects seem to be underestimated.
- BEES are easily available, with software and user manual, free from the Internet. Perhaps the success story would have been different if the users also were offered a course in the method and how to use it?

- Certain weaknesses in the evaluation method might cause some people to be sceptical of using the method.

Further development of the system

In order to improve the BEES system both with respect to quality of the data and the usefulness of the system, the IAQ evaluation should be improved. The presentation of the material evaluation results is good, but a systematic way of presenting data for the different lifecycles stages and effect is lacking. It would also be an improvement if the data behind the evaluation could be accessed more easily.

The actual use of the system might improve if a user course was established, including infoamtion regarding how environmental considerations should be included throughout the building process.

4.1.2 ATHENA

ATHENA™, is an LCA tool developed at the ATHENA™ Sustainable Materials Institute in Ontario, Canada (1999). The ultimate goal of this system is to "*encourage the selection of material mixes and other design options that will minimise a buildings potential life-cycle environmental impact and foster sustainable development*" (Trusty et al. 1998). This evaluation of the ATHENA tool is based on the tutorial version of the newest software version (2.0) and an earlier beta version of the software (1.2 Beta). For a more detailed description of the methodology, the reader is referred to the ATHENA website (http://www.athenasmi.ca). The results for the assessment can be presented in terms of:

- Absolute totals of selected measures of the complete design.
- Absolute values on a per unit area basis.
- Values normalised to a selected design that may be one of the alternatives designated as a base case or some previously design of a similar building, see Figure 4-3.

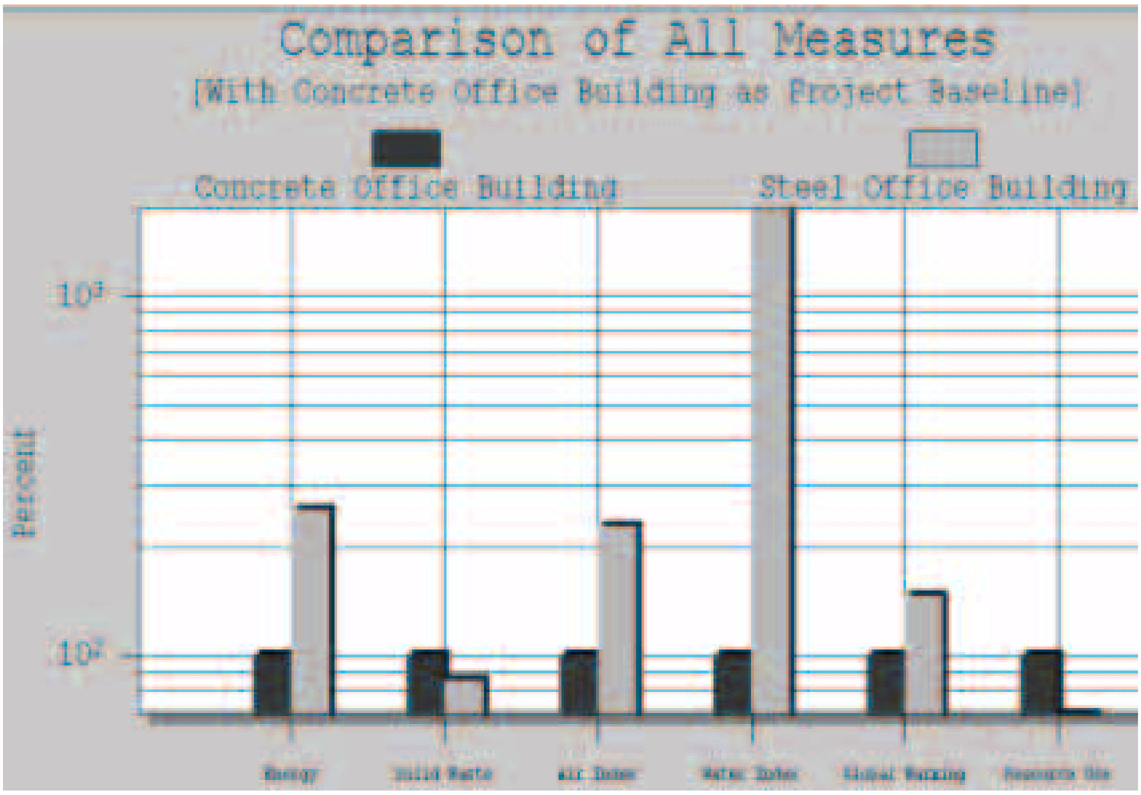


Figure 4-3: Example of presentation of results from calculation with the ATHENA tool values normalised to a selected design (Sustainable materials institute, 1999)

Available endpoints are as seen in Figure 4-3, energy consumption, solid waste, air pollution index, water pollution index, global warming potential and weighted resource use. Studying the different results, it reveals that the user phase and demolition is excluded from the evaluation. Economy is not included in the assessment either.

The objects of comparison in ATHENA are specific designs of a building. With the background of an LCI (**L**ife **C**ycle **I**nventory) database, the tool automatically breaks down the elements into products that are available in the database. From data in the LCI database, the program assesses the environmental properties of the design alternative. It is possible to compare five design alternatives in the system.

The LCI database contains data for several materials, mainly from producers. They are not producer specific, but represent the industrial average. The information from this database is not accessible for the user of the system, who only sees the results presented for the building in total.

The system is mainly addressed at architects and designers. The detailed level of the input to the system suggests that it might be used in the detailed design phase. The interpretation of the results requires that the designer understand the environmental end-points of the tool, and the consequences of the different effects in practise. All in all the knowledge requirement of the user of this tool is quite high.

It seems that the transparency of the ATHENA tool is low. It is not a complicated evaluation procedure, but it is hard to see what materials cause the largest effects in a design alternative, in order to improve the design. It is altogether difficult to see what practical help the tool provides for the designer in order to improve the environmental quality of a design.

It is not possible to test the tool's ability to distinguish between materials, but it is assumed that it is low. This is because a comparison is made on the total building level. On this level of aggregation, it is difficult to see the differences when changing one product or a material.

Input to the system from the user includes a general description of the project, like location and floor area. The user also specifies the design by selecting typical assemblies or by entering specific quantities of the individual products like floor, wall areas, openings, related materials, spacing, dimensions, working loads or spans. As seen in Figure 4-4, this is quite detailed information. This makes the system quite demanding when it comes to input from the user.

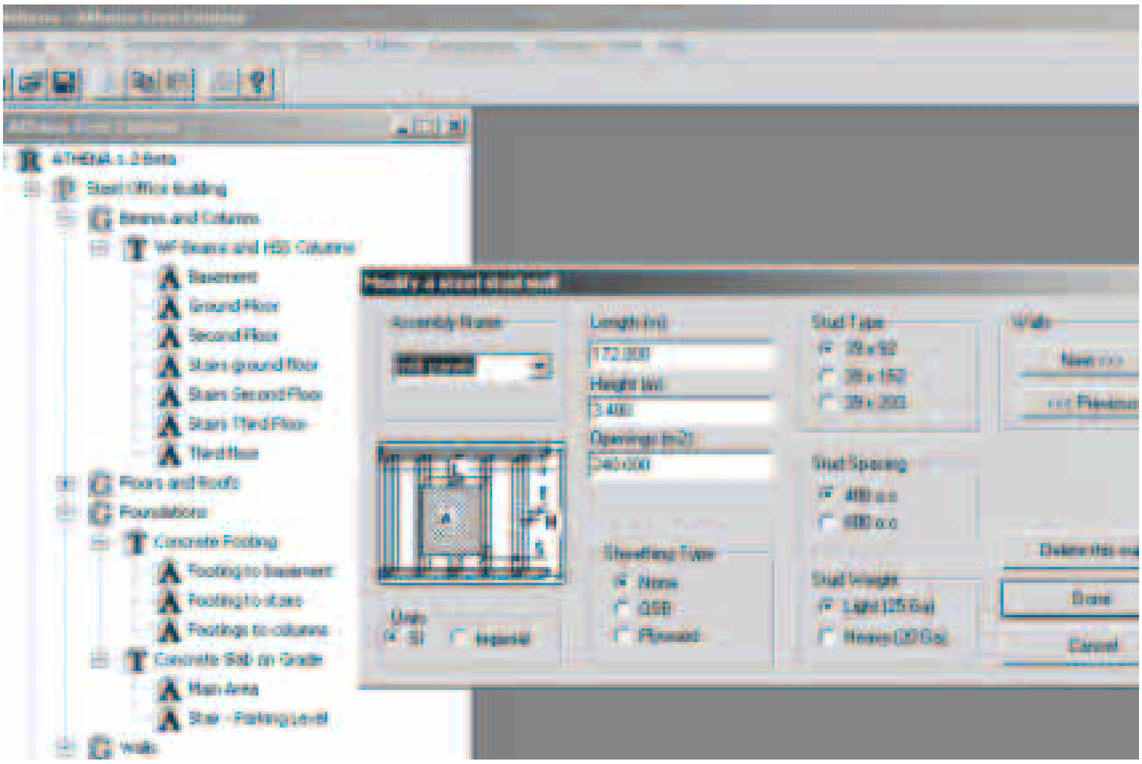


Figure 4-4: The data entry of a wood stud wall in the ATHENA tool.

<u>Further development of the system</u>

In the development of the ATHENA tool a lot of work has been put down in structuring the information of the special building design. It is also required that the user enters quite detailed information before he/she is able to perform any assessments. This information is not taken fully advantage of in today's version. Included in the input data fields for the elements, seen in Figure 4-4, environmental information could be included. Direct comparison of elements and materials or products is then possible, and improving the design of the building would become easier. Having entered all the information about a building, this could also form the basis for an environmental building label.

However, to be able to make material and product comparisons the assessment procedure must be improved. First, it is important to include the total lifecycle of the building. The selected endpoints should then be reconsidered, and the assessment carefully developed to better reflect the real environmental consequences of a material or a product. This also includes the development of a weighting procedure.

4.1.3 Guide for material selection

The "Guide for material selection" is developed at the Institute of Building Ecology in Sweden. The Guide includes 220 building materials in 20 different material groups. All the materials are evaluated on a scale from 1 to 5 where (Institute for Building Ecology, 1997):

1. Recommended first hand.
2. Recommended second hand.
3. Accepted.
4. To be avoided.
5. Unaccepted.

Figure 4-5 presents the ranking of inner wall alternatives. Lightweight concrete and wood is presented as the choice recommended first hand, aluminium, lightweight concrete blocks, steel and brick is recommended second hand, and plastic is placed in the "accepted" category. The different alternatives are also followed by a qualitative description of some of the aspects related to raw material extraction, manufacturing process, environmental consequences etc.

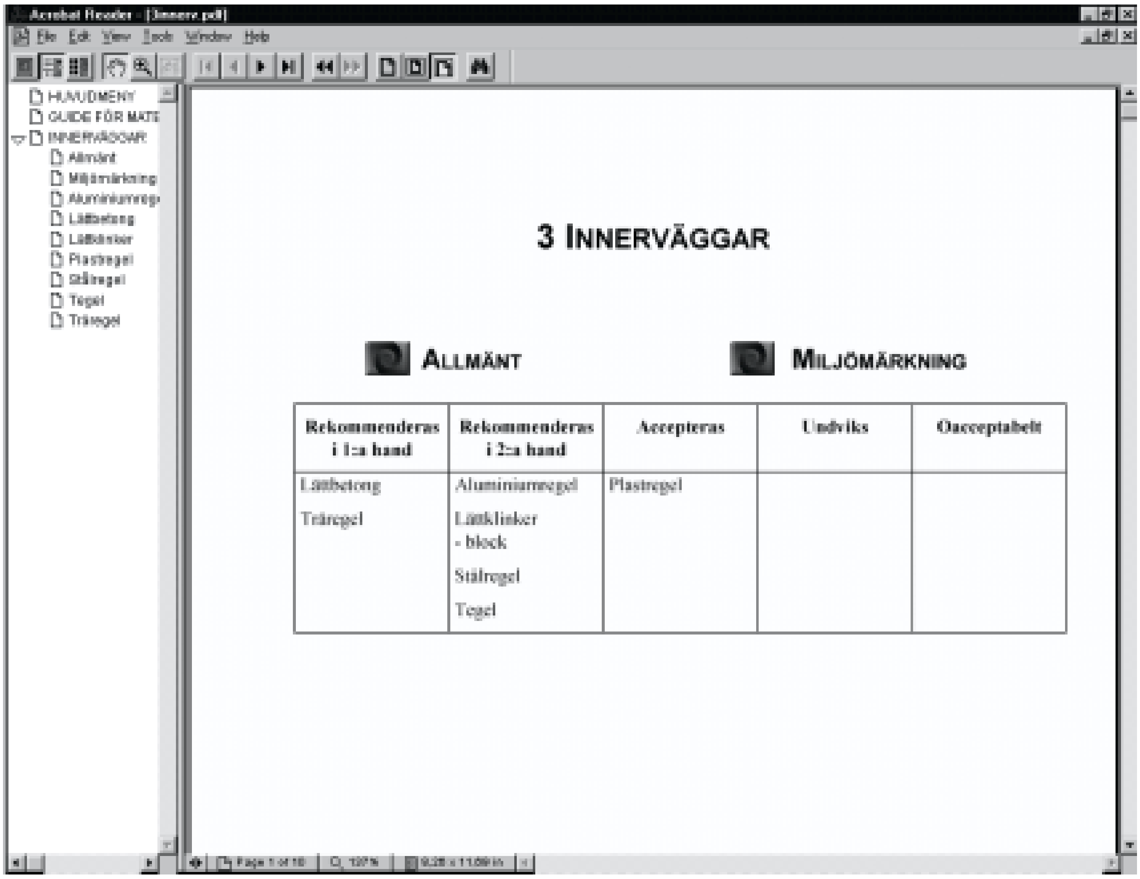


Figure 4-5: Example from the Guide for material selection: classification of inner wall framings (Institute for Building Ecology, 1997). (Rekommenderas i 1:a hand = Recommended first hand; Rekommenderas i 2:a hand = Recommended second hand; Accepteras = Accepted; Undviks = Avoid; Oacceptabelt = Unacceptable)

The environmental aspects included in the guide are raw materials, energy use, chemicals, emissions that can cause health effects, treatment after use and toxic waste. The criteria for the parameter evaluation are described in Table 4-2.

Table 4-2: The evaluation criteria of the materials in the Swedish Guide for material selection (translated from Swedish by the author).

Requirements: **Rating:**	**Raw material**	**Energy use**	**Waste treatment**	**Emissions**	**Chemical compounds**	**Toxic waste**
1. Recommended first hand	Large share of renewable raw materials, materials included must be infinite and available in large amount as reused materials.	Energy use in the production must be low.	Re-use or recycling must be possible	Possible emissions must not lead to known health risks	Substances on the National Chemicals Inspectorate list shall in principle not occur. Trace amounts can in some cases be accepted for certain substances.	Toxic waste cannot occur.
2. Recommended second hand	------"------	Has not affected the evaluation	Reuse, recycling or energy recovery must be possible	----"---	Substances on the National Chemicals Inspectorate list can occur. Certain substances on the Obs- and limitation list can occur in small amounts, e.g. zinc oxide and formaldehyde	Toxic waste can occur in small amounts for uncured products, like paint, varnish, glue and joint-fillers with low values (<5%) of solvents
3. Accepted	If large share of finite materials with limited availability is included, that material cannot be considered better than 3. Some exemptions are included, like the placement of latex-based colour in powder form is recommended in Recommendation 2, because it does not contain conservation agents.	------"------	Reuse, recycling or energy recovery must be possible	Emissions with known health risks can occur if the risks are reasonable, like e.g. isothiazolones.	Substances on the Obs- and limitation list from the National Chemicals Inspectorate that today are hard to replace but for which use should be outfaced in 2-6 years can occur, like e.g. isothiazolones, amines, cobalt compounds, HFC and most dense metals.	---"---
4. Avoid	Has not affected the evaluation	------"------	Materials that only can be deposited	Emissions with known health risks involves, like e.g. isocyanides and toluene	Content of isocyanates in large concentrations, phthalates, chlorparaffines, bromated lame retardants (type hexabromocyclododecane), methylethylketoxime, nonylphenol ethoxylates, xylene and toluene.	Materials that are sources of toxic waste
5. Unacceptable	------"------	------"------	Has not affected the evaluation	Emission of formaldehyde from wood based board that exceeds 0.13 mg/m^3 air. It is forbidden to sell boards that exceed the limits in ref. KIFS 1989:5.	Content of emissions that are forbidden by law. Examples of substances forbidden for certain use are: lead, cadmium, creosote, arsenic, chromium, mercury, nickel, zinc chromate, styrene oxide, tinorganic compounds, formaldehyde etc.	Has not affected the evaluation

A qualitative evaluation of the materials represents the basis of the guide. The parameters are developed in accordance with the philosophy of "The Natural Step" in Sweden. In addition to the guidelines in "The Natural Step", the guide includes emissions to the indoor environment. The evaluation of emissions is based on the Obs list over substances that require special attention and the "Begränsingslistan" (the Limitation list) from 1996, a list of substances that are forbidden, or whose use is limited, by the National Chemicals Inspectorate in Sweden. Economical considerations are not included.

In the introduction to the guide, it is stated that it covers the phases from production, construction, use and disposal. The information is mostly based on information from producers. If the criteria are studied, it is clear that the classification only includes emissions in the user phase, and how the materials are treated after use. Maintenance, repair, durability etc are not included to any extent.

The target group of the guide is not defined, but reviewing the information, it seems like it can be something architects can utilise, when deciding what materials they are going to use in a building during the early design phase.

Further it seems like the category "Unacceptable" is assigned to products that are forbidden or about to be forbidden by law. A larger part of the materials is placed in class 2 and 3, 36 per cent and 33 per cent respectively, 20 per cent are placed in class 4. It seems like the system separates the different materials well between the different categories.

Assumed that the user accepts the evaluation principles of the system, the guide requires little or no knowledge about ecology. An architect deciding on for instance inner wall framing may find it easy to use, and see that he/she should prefer light concrete or wood to a steel frame. He/she should then see if his/her requirements could be satisfied with a material as far left in the table as possible, see Figure 4-5. Problems arise however, when the compared materials are not functionally equivalent, this is up to the user to determine.

The user of the system has no influence on the classification of the materials. The guide supplies the user with information about the different materials, like cleaning method for linoleum, emissions from laminate flooring etc. Nevertheless, how the materials behave during use is not one of the assessment criteria, see list in **Table 4-2**.

Information about the criteria supporting the classification is described in the guide. There are 6 criteria in each class, which the material must satisfy to be placed in the respective class. The criteria are mostly qualitative, it is for example not stated what "*low energy use in production*" means. Still, the information on why a material is placed in a category is easy accessible, and easy to understand.

A wide range of materials is evaluated after the same criteria. This is possible because the criteria are qualitative, and the system can therefore be described as quite general. The flexibility to handle new information must however be characterised as low. The guide must be rewritten if new information is to be included.

The data requirements to evaluate the materials must be characterised as minimal. There are some quantified requirements, as emissions and waste, but this is not information that is difficult to obtain. The other inputs are qualitative criteria that the different producers can supply without any extensive investigations.

Because of the qualitative nature of the evaluation, and the broad classes, the likelihood of placing a material tin the wrong category is considered small. The routines for collecting information from producers are not known. It can therefore be some room of misleading information. The use of industrial average(s) may lead to materials being misplaced, but this possibility is not investigated.

Further development

Further development of the guide may involve:

- Testing and maybe improvement of the evaluation criteria.
- Including more materials.
- Increased focus on the needs of the decision-makers, and how he/she can use the guide.
- A closer connection to the database the guide is based upon is also of interest.

This last point can enable the user of the system of performing an in-depth study of materials of special interest. The database could be included as a part of a package where the contractor finds his/hers role when choosing the specific products. Requirements and needs posted by the contractor may also be included in such a system.

4.1.4 Environmental resource guide

The **E**nvironmental **R**esource **G**uide (ERG) is developed at the **A**merican **I**nstitute of **A**rchitects (AIA) with co-operative funding from the U.S. Environmental Protection Agency (American Institute of Architects, 1996). The ERG is a printed guide, primarily aimed at architects and designers.

The guide consists of application reports for the different products groups. The core of an application report is shown in Figure 4-6. In addition, the user is presented with a summary table with the main reasons for the scoring. In addition, in a separate part of the guide, extensive information about the lifecycle of each material is found. This is not quantified information, but a qualitative description the material including material acquisition and preparation, manufacturing and fabrication, construction, use and maintenance and waste treatment. This is very useful information for those interested in going into details of the different materials.

In Figure 4-6, three different framing systems are compared. They are all evaluated from good to poor for the 14 parameters included in the system. With equal weighting of the parameters, steel framing is found to be the best of the alternative. This is mainly because of its properties in building operation is better compared to wood, except from energy use, where steel may have negative consequences because of possible thermal bridges. Wood is considered as inferior in virgin resource depletion because it needs to be produced from virgin material. It also has negative effects with regard to biodiversity. In realty, this will vary from producer to producer, and this provides a good example of a product specific property.

Atmospheric impacts are evaluated as reasonably good for both steel and wood. As this seemed a little strange, this was compared to steel and wood framing data in the Danish BEAT2001 system. Here steel was found to result in a 50 per cent higher global warming potential than wood. The reason for the difference between the BEAT2001 and the ERG might be that in US they include the reduction of CO_2 sink capacity when trees are cut down. The system is not producer specific, therefore the performance categories is labelled as for example “varying from good to poor”. This is meant to make the user of the system aware that there are significant differences within the product group.

	Environment and ecosystems					**Health and welfare**			**Energy**			**Building operation**		
	Air quality/atmospheric impact	Water quality/availability	Land and soil quality/availability	Virgin resource depletion	Biodiversity/habitat loss	Workers/installers health	Building occupant health – IAQ	Community health and welfare	Production/manufacturing	Transportation	Impacts on operational energy use	Life expectancy/durability	Maintenance requirements	Reusability/recycleability
Wood framing	ậ	ậ	ǎ	ǎ	ǎ	Ẫ	Ẫ	Ǎ	Ẫ	Ǎ	Ẫ	Ǎ	ậ	ậ
Steel framing	ậ	ậ	ậ	ậ	ậ	ậ	Ẫ	ậ	ậ	Ǎ	Ǎ	Ẫ	Ẫ	Ẫ
Steel with exterior XPS foam insulation	ậ	ậ	ậ	Ǎ	ậ	ậ	Ẫ	ậ	ậ	Ǎ	ậ	Ẫ	Ẫ	ậ

Performance

Ẫ good
Ǎ varies from good to reasonably good
ậ reasonably good
Ǎ varies from reasonably good to poor
ǎ varies from good to poor
ậ poor

Figure 4-6: Example of comparative environmental performance of light frame systems in ERG (after American Institute of Architects, 1996).

Studying for example flooring materials, linoleum is evaluated as better than PVC, mainly within the area of air quality/atmospheric impacts and water quality/availability, but also for health and welfare issues.

Studying the different application and material reports in the ERG, it is clear that the materials are subjected to an extensive evaluation. The results however require some effort of interpretation. There is no overall ranking of the materials, and if there are several possible choices, it can be difficult to decide which choice is the best.

The ability of the system to distinguish between materials is difficult to assess, as the documentation of the underlying evaluation procedures are missing. It seems like the ranking of the different parameters is distinguished, but the as a total the materials are not distinguished.

It seems obvious that architects are the main target group for the guide. Other groups however, like clients, facility managers, manufacturers, private organisations and public agencies concerned with for example pollution prevention, and researchers are mentioned as users of the guide.

The user of the application reports must have knowledge that enables him to determine what is most important among the different performance categories, like atmospheric impact, resource depletion and IAQ, and make a ranking between these categories. The first time the guide is used this will be quite work intensive. The user will probably find that the process will become easier each time the guide is used.

To evaluate the transparency of the system, the score for vinyl has been studied. It is seen that vinyl is given a poor score for the category water quality/availability. The cause of this is found in the illustration describing the environmental impacts for vinyl flooring. The conclusion regarding transparency must therefore be that this is quite good for some materials, but that it may require some knowledge about the different materials in question.

The evaluation procedure is not transparent as it is based on subjective expert evaluation. The underlying information is available, but no information about the experts and their methods are included.

The system is general as it is based upon subjective evaluation. This makes it up to the experts evaluating the materials to determine what can be included and how. New knowledge may however lead to a re-assessment of one or several of the materials. The system must therefore be characterised as having low flexibility.

The assessment is based on information from all lifecycle stages of a material, covering extraction of raw materials, production, construction, use and end use. Impact categories in the building operation phase include:

- Durability: Theoretical useful life and average age at replacement.
- Maintenance: Frequency of cleaning, type of cleaning, frequency of re-coating or refurbishing, and type of re-coating or refurbishing.
- Reusability/recycleability: Ease of recovery, reusability and recycleability.

The impacts from the cleaning agents etc. and economy are not included.

The ERG is based upon existing analyses, data from producers, published work etc. and it does not require a new inventory. The collected data are evaluated according to some data quality criteria, like incomparability, inconsistency, incompleteness, bias and proprietary.

The 47 impact categories are included in the evaluation of the different materials. The selection of these criteria is based on suggested impact categories from the LCA methodology of both EPA and SETAC. The correct assessment of the materials depends on the quality of the data gathered from the different sources, and the ability of the experts to consider eventual flaws in these data. If there are major variations in the data, this is also displayed in the comparative performance of the materials. As there are large subjective elements, with no stated guidelines in the assessment, the danger of misjudging a material is present.

Further development

Further development of the system may include the development of a web-based system that can ease the search for relevant information as the amount of information increases. A paper version could maybe include a simple ranking of the materials that are easy accessible, similar to the application reports.

A clearer statement of the priorities of the assessors (experts) will make it easier to accept the valuations. In addition, developing a more consistent set of evaluation criteria may reduce the possibilities of variations due to different assessors.

Finally, including more materials will increase the usefulness of the system.

4.1.5 Environmental Preference Method

The **E**nvironmental **P**reference **M**ethod (EPM) is developed by Woon/Energy, in the Netherlands in 1991, within the program on Sustainable living at the Dutch Steering Committee on Experiments in Housing. The main goal of the handbook was to construct a ranking of building materials according to their environmental preference. The method concentrates on consequences of selecting building materials and components, which in turn can be used to complement other environmental schemes like for example BREEAM (**BRE** **E**nvironmental **A**ssessment **M**ethod) (Anink et al., 1996). An example of material ranking after the EPM handbook is shown in Figure 4-7.

Figure 4-7 presents the ranking of wall and ceiling frame systems. European wood is here Preference 1, steel preference 2 and aluminium Preference 3. European wood is preferred because the EPM system values use of renewable resources and does not include the loss of sink-effect for CO_2 (ref. the U.S. ERG). Turning to for example flooring materials, linoleum is preferred before ceramic tiles, and vinyl is labelled “Not recommended”.

Preference 1	Preference 2	Preference 3	Not recommended
European wood	Steel	Aluminum	-

environmetal preference	Wood is a renewable material and does not cause problems for waste disposal because it degrades well. The extraction and production of aluminium pollutes more than that of steel. Aluminium and steel can be reused, therefore the difference between them and the native softwood becomes less significant. See Part 4 for a more detaild description of the environmental impact of the materials mentioned.
basic selection	Wood is included in the basic selection asa material for wall and celing framing systems.
comments	A panelled frame for a celing system has the adventage that a sound-insulating layer can eb applied between the panels and the ceiling. Another advantage is improved acoustics.

Figure 4-7: Relative ranking of wall and ceiling frames systems in the EPM method (Anink, et al., 1996)

In the introduction of the book, it is explained that the system is based on a pragmatic approach. This means that the material ranking is based on information available at that stage. LCI data are therefore used when available, but this is not a requirement. The main issues included in the evaluation are:

- Shortage of raw materials.
- Ecological damage caused by extraction of raw materials.
- Energy consumption at all stages (including transport).
- Water consumption.
- Noise.
- Odour pollution.
- Harmful emissions, such as those leading to ozone depletion.
- Global warming.
- Acid rain.
- Health aspects.
- Risk of disasters.
- Reparability.
- Reusability.
- Waste.

Costs and aesthetics are not included in the evaluation. The economical aspect is included in the outlining of the “basic selection”. It is stated that the basic selection can be selected before the “Preference 1” alternative if the material in question is economically preferable today, and is a more technically suited or tested material.

There is no detailed information on how the method compares the different parameters. It is explained that a matrix is constructed that compare the different aspects by assigning +, 0, ÷ or x if the effect is harmful. There are no fixed weights, but a subjective decision for those reviewing the data in order to decide what are the most serious effects.

The total lifecycle of a material is included, from extraction, production, erection and occupancy to decomposition. The parameters listed in the description of the methodology seem to cover these phases. However, there is no producer specific evaluation of the materials, and the ranking is produced based on information from different sources, like for example LCA or producers data.

The ranking is static, and does not change with the localisation of the project or maintenance procedures. The user is presented to the ranking and some justification of the ranking. This user may be architect, engineers and contractors, who can refer to the EPM, preferred material, in early design phases. The environmental evaluation of the materials is fully completed, little or no environmental knowledge is therefore required from the user.

The method sufficiently ranks the materials in the different categories. Nevertheless, it must be commented that a subjective evaluation and weighting by those reviewing the data may also be the reason the materials are well separated in all the groups.

The transparency of the system must be characterised as medium to low. The users of the system are presented with some justifications of why the materials are ranked the way they are, as seen in see Figure 4-7. However, the prioritisation behind the evaluation is not known.

The system can be used on many different materials and components, because of its qualitative and subjective character. The flexibility however is low because a handbook is static, and represents the current situation. The system must be updated periodically by rewriting the book.

It is hard to determine whether a material can be misjudged in a category in the EPM. It is however assumed that it is a chance for this happening, both due to possible variations in the data and due to the subjectivity of the evaluation.

Further development

Further development of the method may involve the development of a set of minimal requirements for the material data, and a known set of evaluation rules that lead to a reduction of subjectivity. Including the possibility of an in-depth analysis of the reasoning behind the ranking of the materials will increase the acceptance of the system.

4.1.6 *BEAT2001: Database and inventory tool for environmental parameters of buildings and building elements*

The Danish Building and Urban Research has developed a database system to be used as an environmental evaluation tool for buildings. The tool includes a database and an evaluation tool as an integrated part of the database. The database can perform evaluations on three different levels; the building, building elements and building products (Petersen, 1997).

The results after simulation can be presented in three ways: as input and output from the processes, as environmental effects, or as normalised and weighted environmental profiles. Figure 4-8 illustrates the results of a comparison of the steel frame inner wall and a wood frame inner wall. No additional materials are included in this comparison. A wood frame wall is, according to BEAT2001, by no doubt better than a steel frame wall. This was a straightforward conclusion because steel totally dominates wood for all parameters. For other materials, the ranking might change dependent on which parameter that is used as a rank base. It is difficult to understand why an aggregation of the environmental profile into one index is impossible in the database, as long as the parameters are weighted against each other and therefore, in theory, can be summarised to ease the interpretation.

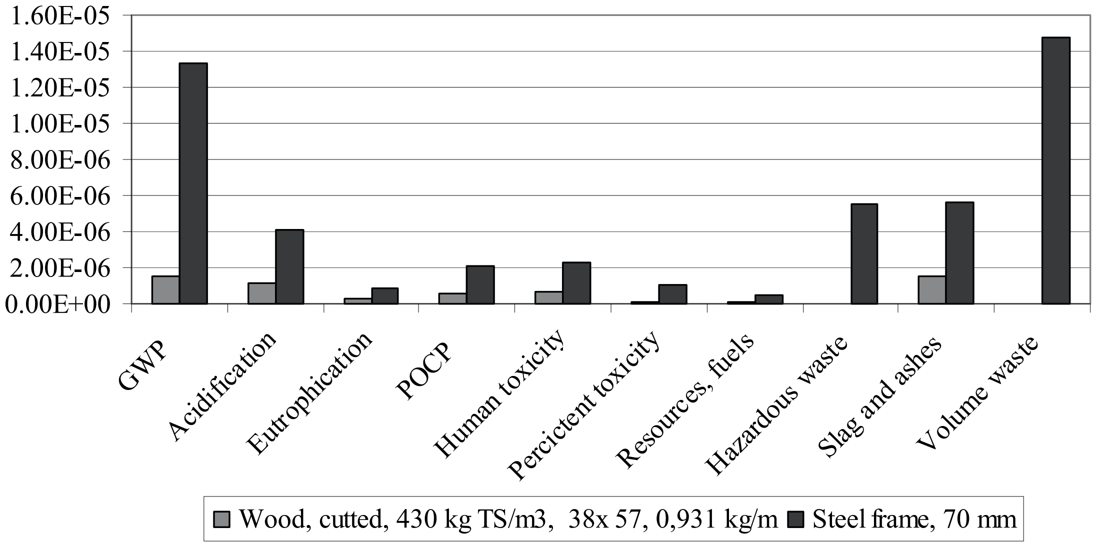


Figure 4-8: The evaluation results in BEAT2001 for two 1m^2 inner wall frames (wood and steel). Data are exported to Excel and the parameter "Resources, metal" are removed from the illustration.

Turning to the details in the database, extensive data are needed for a material to be included in the BEAT2001 system. Not all data have Effect factors assigned to them at this stage. The BEAT2001 database makes the evaluation based on equivalence factors, but the references are not included. Economy is not included in the BEAT2001 system either.

It is stated in the BEAT2000 report, that the calculation should be based on a lifecycle view, but activities during the user phase of the building are not included (Petersen, 1997). These are factors like cleaning, refurbishing, energy use etc. The one thing that can be included is the durability of the materials or elements. If, in the calculation of the effects from a whole building, one element has a shorter durability than the building, replacement of the element must be included.

The system is not aimed at any particular user group. It is stated in the report describing the system that a wide group of people in the building and construction industry can use the system. By reviewing the database, it seems like the system is most suitable for researchers, this is also confirmed by Petersen, the main author of the system (Petersen, 1999).

In addition to calculating the amounts of material used, the user must be capable of handling information about the different environmental effects. The aggregated results are presented as environmental profiles. To compare alternative materials, elements or buildings, the user has to perform simulations of the different alternatives, and then compare the profiles. If there are more than two solutions, it may be difficult to decide which one is the most environmentally friendly alternative.

There where 200 listed products in the 2000 version of the database, but the real number of products that has been subjected to an LCI is probably lower as there is a separate analysis for every available dimension of a material. For example, porous concrete block is registered as five products with different dimensions and one data set presented per tonne, in total this counts as six products.

The tool's ability to differentiate between the products is not evaluated in detail. However, from the evaluation procedure and studying some selected materials assessments it seems like the BEAT system differentiate the materials. With some effort, it is also possible to get some information about the reason behind a material's environmental profile. The transparency must therefore be characterised as medium good.

The system can handle most types of materials, as long as it is possible to calculate the masses, the related resources and the emissions. The data are only put in once, as it is a relation database. Both generality and flexibility can therefore be characterised as good.

There are nine parameters included in the system. Today about 80 effect factors are included in the system, which means that many chemicals are left out of the evaluation. There are 22 effect factors for persistent toxicity and 9 for human toxicity. Data gaps or missing out of important parameters can cause the system to be sensitive with regard to computing misleading profiles for the materials, but this is not investigated in detail.

This also introduces a last aspect, namely the accuracy of the data. In BEAT2001, the input/output data table includes a column for the deviation of the data. This column is not yet in use. As it stands today, some astonishing data are presented. As for example for the earlier discussed inner wall with wood frame, the emissions are listed in µg, with two to eight decimals and zero deviation. These numbers is to be normalised against the total emission in Denmark of that particular substance before weighting. It is clear that these data should have been excluded using a cut off rule to make it more manageable. This indicates that there has been no testing for the deviation. It is also meaningless to operate on this level of accuracy in a system like this.

Further development of the system

The focus in the further development of the BEAT2001 should be on increasing the user friendliness of the system. Improving the possibility the user has for comparing elements and products should be the first focus area. In addition, the structure of the application where a total building is entered, with all its elements, products and related emissions could be improved, and perhaps can ATHENA (presented in Chapter 4.1.2) be used as a model.

The input/output tables are presented with deviations. This is important information that is missing in most other evaluation tools. This function is not used at present, but it should be implemented. It is considered important that deviations are reflected in the total evaluation of the results.

Aspects worth considering in the assessment method are to include indoor environment and economy. In addition, the user phase of the building should receive more attention.

4.1.7 ENVEST

ENVironmental Impact **EST**timating Design Software (ENVEST), is a computerised tool to estimate the environmental impacts of construction, developed at the Building Research Establishment in England (BRE, 2001). It includes impacts related to materials, energy and water, but in this case focus will only be on the material part. This evaluation of the tool is based on the demo version and additional information provided from the BRE.

The working procedure of the ENVEST tool is first to enter basic information about the building, including gross area, number of storeys, storey height, maximum length, building type, if it is air conditioned and location of the building. This information forms the basis for the “Shapes menu”. The “Shapes menu” is a menu of different main shapes of the buildings presented with different Eco points. Eco points are what constitute the core of the environmental assessments in ENVEST. One hundred Eco points is equal to the environmental impact from 1 UK citizen in one year (Eco points is described in Howard, 1998). The functional unit are the elements typical as-built elemental form (m^2) over a service life of 60 years.

In the “Shapes menu”, the user selects a shape, enters actual building data (glazing area, occupancy, floor areas, external wall area etc.) and then moves on to study either Fabric and structure or Services. The interface where various fabrics and structures are selected is presented in Figure 4-9.

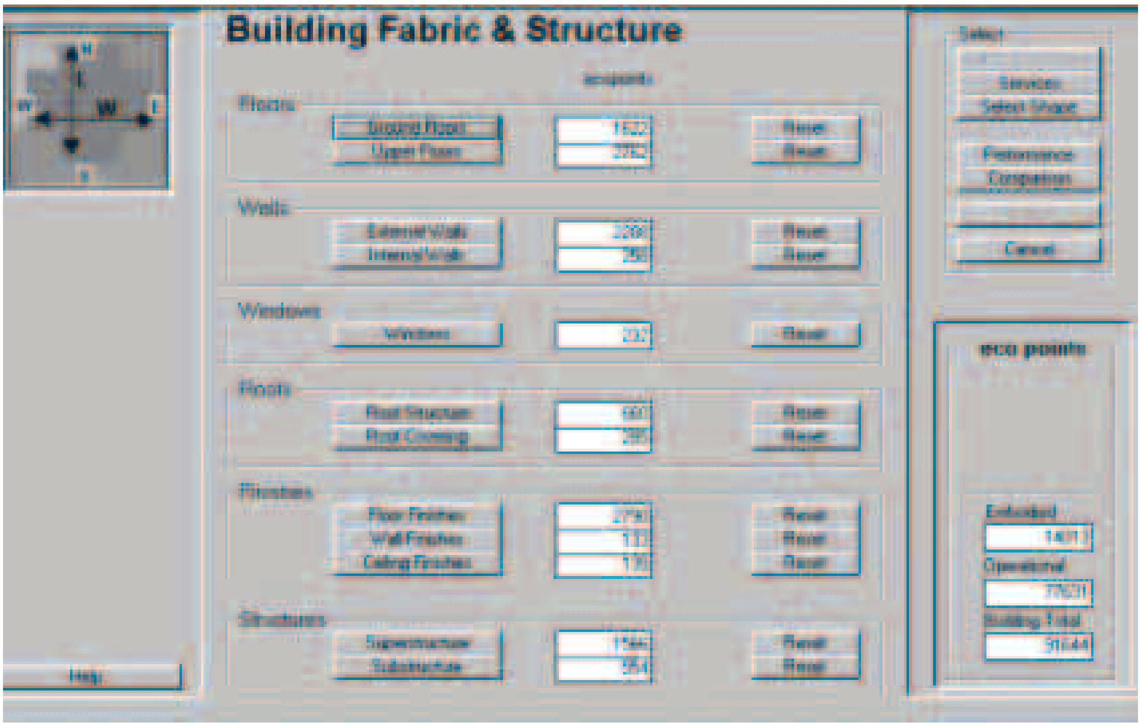


Figure 4-9: The interface where the user selects the various structures in ENVEST.

For the different elements, the materials are then selected to minimise the total Eco points. The total score of Eco points is always included at the bottom right of the screen. “Embodied eco points” are the Eco points caused by the materials and structures in the building. The user interface for the selection of roofing structure is presented in Figure 4-10. After going through the total building, selecting structures and materials, the corrected Eco points may be calculated.

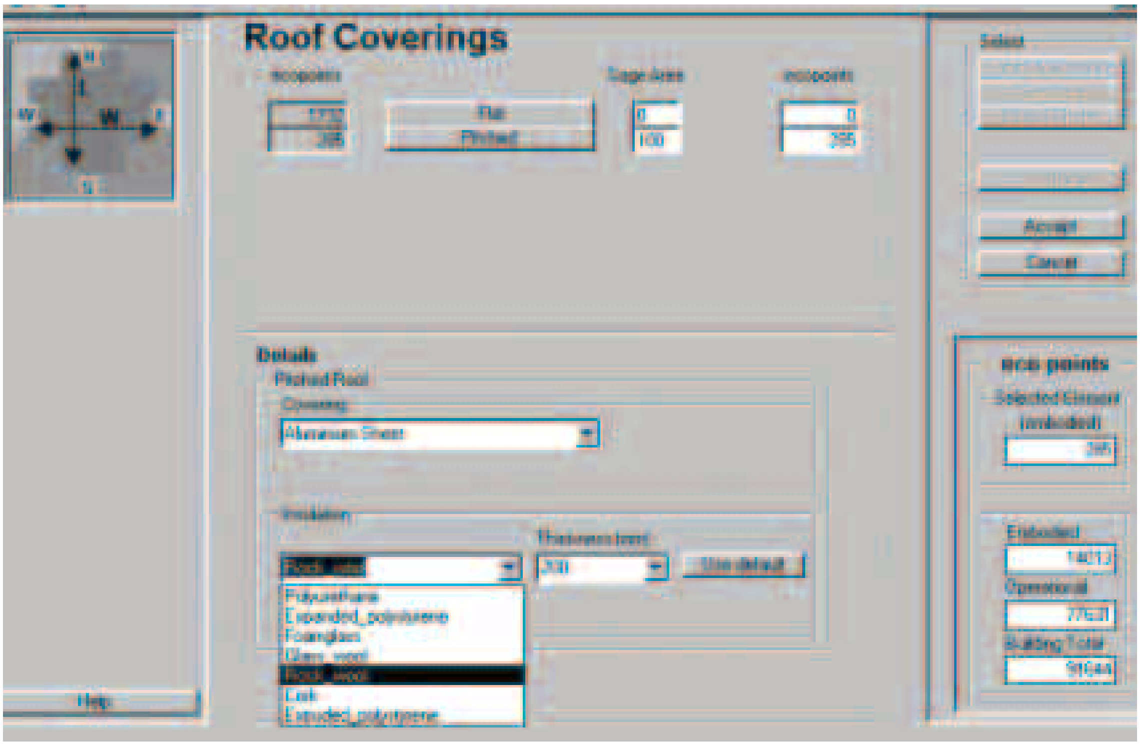


Figure 4-10: The user interface for selecting the detailed roof structure in ENVEST.

The result may be presented as pie charts of operational vs. embodied Eco points, or as Eco points distributed between the different building elements and service elements. It is also possible to compare the current building with a saved building, then in bar graphs. The diagram illustrates the balance between operational and the embodied energy, and the Eco point distribution between the different building elements. This last presentation is illustrated in Figure 4-11. It is seen that the floors would be an obvious area of interest in re-evaluating the materials selected in this particular case.

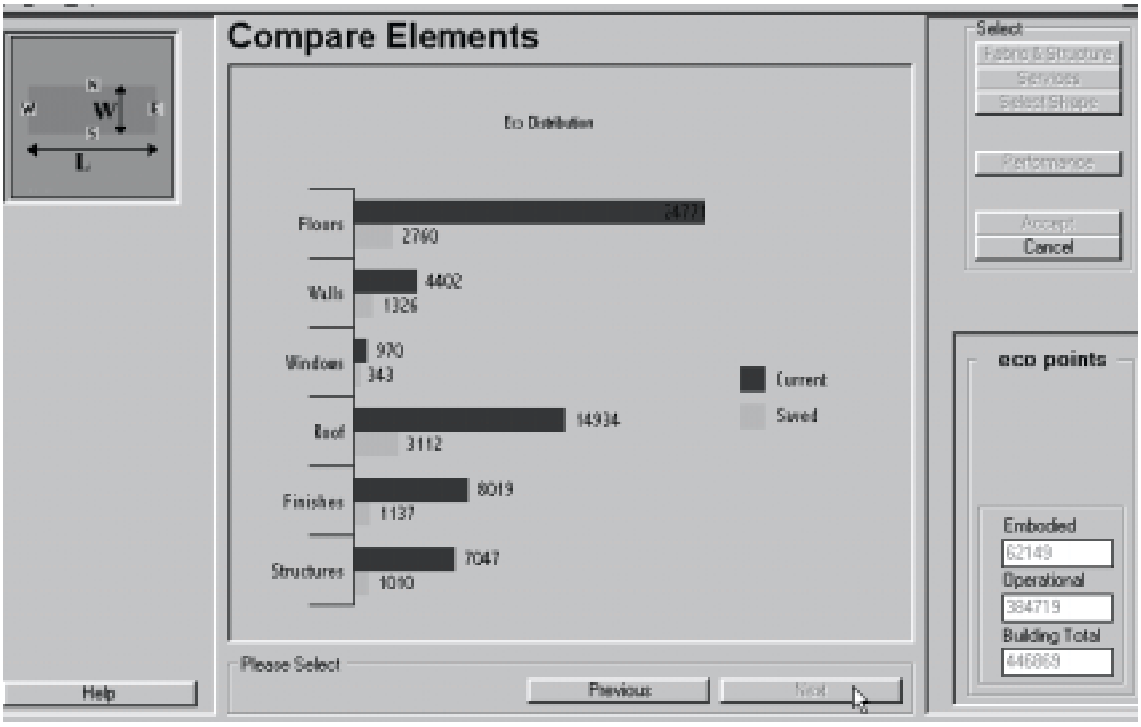


Figure 4-11: Example of presentation of the results in the ENVEST tool. The Eco pints are divided between the different building elements for both the current building and a saved building.

It is stated that the embodied impacts includes construction, maintenance and repair, but this is difficult to test, as the there is no access to the data input. In addition, the results are presented only as total data, and not per lifecycle phase. It is found in the Eco point description report that the impacts during erection of the building are not included in the first version of the Eco points (Howard, 1998). Painting and varnishing is included, but others operations like maintenance or cleaning are not included. Replacements are included based on a set of replacements factors. The contribution to the energy use in the building is not included for the different building elements. All the elements are designed to meet the minimum U-value requirements in the building regulations. This first edition of the methodology includes neither demolition impacts nor removal impacts. From demolition, it is only possible to include the CO_2 and methane emission from incineration and landfill. Economy is not included in any of the lifecycle phases.

The ENVEST tool is aimed at the early design phase. Some references must be made in the programming phase, but the tool is best fit to be used in the conceptual design/preliminary design stage. It does not contain enough information to be used in the detailed design phase. The users are therefore primarily designers.

Only having access to the demo version of the ENVEST tool, it is difficult to assess the degree to which the tool is able to separate the different materials. Instead, available Eco point calculations of different materials are studied. It seems like this assessment system is able to separate the materials quite good.

It is easy to get started using ENVEST, and very easy to get some results. There are no special knowledge requirements to use the system. For interpretation of the results however, and the optimising of the environmental load, knowledge about design and environmental aspect is an advantage. The user is not able to affect the result by changing the weights, excluding parameters etc.

The system only handles data per as-built elemental form. As long as the products fit in one of the defined elements, it may be included in the system. To be able to handle other types of materials, new elements and FU needs to be defined, the system is this way able to handle all types of materials.

The system is based on LCI data, 12 parameters are included, and this makes the system quite demanding on data input. However, these 12 parameters are not included for all lifecycle stages. In addition, indoor environment and economy is left out. The sensitivity of misjudging a material is therefore present. Accepting these limitations of the system however, the risk of misjudging a material is quite low.

Further development

Increasing the user's access to underlying data and preferences would increase the credibility of the tool. Today it is impossible even to find the weighting used to aggregate the environmental information. Some additional help could also be provided in the optimising process. As seen in Figure 4-10 the user must experiment with different materials and thicknesses to find better solutions. Pull down curtains is convenient, but a listing of the materials and their Eco points might ease the task of finding a better solution. Some guidance on how to carry the experience with ENVEST through the detailed design phase, and into a completed building would also be helpful.

Finally, the assessment procedure could be improved by including indoor environment and other operational aspects, together with economy.

4.1.8 The Folksam guide

The Folksam "Environmental building guide", is quite similar to the other Swedish guide, "Guide for material selection", described in 4.1.3. The Folksam guide is in contrast to many other tools and methods not developed by a research institute, but by an insurance company.

There is no written evaluation procedure for the Folksam guide. Two experts have performed an evaluation based on their experience and knowledge. An explanation key however presents some of the areas that have been taken into consideration. This key is illustrated in Table 4-3. The materials are judged according to these criteria and placed with a final judgement: Red which means "Not recommended", yellow, which means "Accepted until further" or green which means "Recommended". Green will be the best environmental choice.

Table 4-3: The Interpretation key to the Folksam guide (Folksam, 2002).

Area	●	◍	○
Natural resources	Non renewable resources – limited access	Non renewable resources – good access	Renewable resources Non renewable resources with very good access
Working environment in production	Open process – dangerous substances	Closed process – dangerous substances Open process – some dangerous substances	Closed process – some dangerous substances
Working environment in construction	Chemical exposure with known risks or chemical exposure and heavy lifting and/or ergonomic demanding positions.	Chemical exposure or heavy lifting or ergonomic demanding positions.	No known risks
Use	High emissions or high use of chemicals in maintenance or poor function, hard to clean.	Low emissions, use of chemicals in maintenance, good function, not so easily cleaned.	Low emissions, little use of chemicals in maintenance, easily cleaned.
Waste – construction	Deposit – questioned chemical contents Hazardous waste	Energy extraction Deposit - safe	Reuse Recycling
Waste – end of use	Deposit – questioned chemical contents Hazardous waste	Energy extraction Deposit - safe	Reuse Recycling
Obs! list and limitation lists	The product contains substances with defined time of out phasing or substances on the Obs! list with a total above 0.5 weight %.	The product contains substances on the limitation list with stated highest content or substances on the Obs! list with a total of maximum 0.5 weight %.	The products do not contain any of the substances on the list.
Health and environmental classification	The product is classified as health – or environmentally dangerous according to the Chemical inspectorate lists.	The product contains components that must be classified as health- or environmentally dangerous.	The product does not contain any components that are classified as health – or environmentally dangerous.
Final judgement	**Not recommended**	**Accepted until further**	**Recommended**

The material evaluation in the Folksam guide is based on a lifecycle view, as it includes aspects from several lifecycle stages. The basis of the comparison is materials that can replace each other in a building.

The user of this system could be anyone in the building process. It may be used in the programming to set requirements, in design and further specification of products in detailed design and tendering. It goes further than other guides of the same kind do, as it also includes specific product recommendations, not only materials. For instance, several products are listed as recommended insulation products, including Isover Gullfiber glass wool, Nordiska Ecofiber cellulose insulation and Rockwool stone wool.

The materials are classified in three categories. Of 61 materials, eight ends up in the "Not recommended" group, 27 in the "Recommended until further notice", and 26 ends up in the "Recommended" group. In practice it seems like the worst material are singled out and the rest distributed evenly between the other two classes.

Further development

For the purpose, the Folksam guide probably works well. One important aspect is that more material and products should be included in the guide.

To increase the value of the assessments several classes should be included, but this again would require a more defined evaluation procedure. It is manageable to separate the materials in three classes based on subjective assumptions, but it will be more difficult with 4-7 classes.

A simple introduction on how to use the guide in the building process would also be of use. The different actors could then easily see their role in the process of selecting more environmentally friendly building materials.

4.1.9 Experiences drawn from the existing systems and tools

An overview of the systems and tools discussed, and their most important advantages and disadvantages are presented in Table 4-4.

Table 4-4: Summary of the most important advantages and disadvantages of the different systems and tools.

System	Advantages	Disadvantages
BEES	Economy is included. The graphics and the result presentation are informative.	US specific. Generic data dominate. (Large amounts of data).
ATHENA	Tree structure of the building design	Evaluation method. Direct material comparison is missing.
Guide for material selection	Low user threshold	Coarse separation of product groups. Operational aspects missing.
ERG	Low user threshold. LCA product information.	No weighting. "Hidden" evaluation procedure.
EPM	Low user threshold.	Operations aspects. "Hidden" evaluation procedure.
BEAT2001	Detailed information available.	User phase. Final ranking.
ENVEST	User friendly. Information structure.	Missing aspects. Low transparency.
The Folksam-guide	Low user threshold.	"Hidden" evaluation procedure. Missing aspects.

Summary tables are presented for some of the central properties. These tables are included to keep better track of the systems, and their strong and weak aspects. Table 4-5 summarises the different systems suitability in the different phases of the building process. In addition to being suited to the information need in the different phases, this includes aspects like user friendliness, user influence and user-friendly presentation of the results. Chapter 2 forms the basis for the evaluation of the tools regarding this aspect.

Table 4-5: The suitability of the different systems in the different phases of the building process.

+++ very suitable
++ suited, but do not cover all needs
+ could be used, but does not cover all needs and is too time consuming
0 not suited
? unable to assess the tool for this aspect

System	Programm-ing	Design		Construct-ion	Term-ination
		Conceptual design	Detail project		
BEES	++	++	0	0	0
ATHENA	0	0	0	0	+
Guide for material selection	++	++	0	0	0
ERG	+	++	0	0	0
EPM	++	++	0	0	0
BEAT2000	0	0	+	0	0
ENVEST	++	+++	0	0	0
The Folksam-guide	++	++	++	++	0

In Chapter 2, it was found that including economy in an evaluation system was an important aspect. How this is included in the studied systems are summarized in Table 4-6. The coverage of the environmental properties of a product in the different lifecycle phases is the subject of Table 4-7.

Table 4-6: How the different systems include economy.

+++ very good
++ cover important needs on different levels of detail
+ cover only some needs on a superficial level
0 not included
? unable to assess the tool for this aspect

System	Investments costs	Operation costs	Lifecycle costs
BEES	++	++	++
ATHENA	0	0	0
Guide for material selection	0	0	0
ERG	0	0	0
EPM	0	0	0
BEAT2000	0	0	0
ENVEST	0	0	0
The Folksam-guide	0	0	0

Table 4-7: Does the systems cover all lifecycles of a material or a product?

+++ very good
++ cover important needs on different levels of detail
+ cover only some needs on a superficial level
0 not included
? unable to assess the tool for this aspect

System	Production	Use	Disposal	Total
BEES	+++	++	++	++
ATHENA	++	0	0	0
Guide for material selection	++	+	++	+
ERG	++	++	++	++
EPM	++	++	++	++
BEAT2000	+++	++	++	++
ENVEST	++	+	++	++
The Folksam-guide	+	+	+	+

Table 4-8 presents a summary of three other important properties of a material evaluation and selection system; generality, flexibility and differentiation. Generality reflects how the systems are able to include materials and products with different properties and different functional units, including whether it can handle information on different levels, from products to whole building. Flexibility means how the tool is able to include changes in material data, changes in weighting and new knowledge about environmental aspects to be excluded or included. Finally, the systems are assessed as to whether they are able to differentiate the different products included in an evaluation.

Table 4-8: Is the system able to handle many types of products and materials with different functional units? Is it flexible, in the respect that it can easily adopt new knowledge? Moreover, is it able to separate the materials or products assessed across the applied scale?

++ yes
+ yes, to some extent
0 no
? unable to assess the tool for this aspect

System	Generality	Flexibility	Differentiation
BEES	++	+	+
ATHENA	+	?	?
Guide for material selection	++	0	++
ERG	++	0	+
EPM	++	0	+
BEAT2000	++	+	+
ENVEST	+	?	?
The Folksam-guide	++	0	+

Another interesting aspect is if the different systems and the evaluations performed for similar materials are consistent; see Table 4-9 and Table 4-10. For flooring materials linoleum end ups second in two systems, and first in three. Ceramic tiles ends up third in BEES, second in the EPM system and first in the Folksam guide. BEES is the only tool of these three that covers all lifecycle phases according to the ISO standard for LCA, and economy. Ceramic tiles are energy intensive and expensive, and this is probably the reason for the bad score. The two Swedish guides do not agree on the scoring of ceramic tiles. The reason is perhaps that the "Guide for material selection" takes into consideration the joint-fillers that may contain harmful substances, in the Folksam guide Jointfillers are valued separately.

Table 4-9: Comparison of relative ranking after evaluation of different flooring materials in the discussed methods.

Method: Material	BEES	ERG	EPM	Swedish guide	The Folksam guide
Linoleum	2	1 [1)]	1	Recommended 2nd hand	Recommended
Ceramic tiles	3	Not included in the evaluation	2	Not included in the evaluation	Recommended
PVC	1 (Vinyl tiles)	2	Not recommended	Should be avoided	Not recommended

1) Linoleum is better than vinyl in 7 out of 14 parameters and equal in 5 of 14.
2) If no foam on the underside or no colophon

For wood framing and steel framing the ERG evaluation is inconsistent compared to the others. This is probably because of the way they value renewable recourses, this is also discussed in Chapter 4.1.4. Consequently, to be sure that the correct material is selected, more than one system should be checked. The reasons for eventual differences must also be investigated. Alternatively, the systems must be studied to find the one that corresponds exactly with the preferences for the project in question.

Table 4-10: Comparison of relative ranking after evaluation of different inner wall framing in the discussed methods.

Method: Material	Swedish guide	ERG[1)]	EPM	SBI [2)]
Wood framing	1	2	1 (European wood)	1
Steel framing	2	1	2	2

1) The ERG does not give a clear ranking of the materials, steel score better on 6 out of 14 parameters, and equal 4 out of 14

2) BYogBYG database does not give a clear ranking, but wood is almost ten times better than steel for all parameters. This analysis also covers the total wall element with insulation etc.

The inconsistency in the results is not surprising as the different systems uses different input and different evaluation procedures. This is also the first aspect to be studied, and it is important information with respect to the parameters included in the MaSe system, Table 6-1 shows the different systems and their respective endpoint calculations.

There are mainly two types of systems, qualitative and quantitative. Most of the computerised tools are quantitative, and the printed versions are qualitative. What is interesting to notice is that none of the quantitative system includes health issues like workers health or IAQ. This is because there are few quantitative methods to handle this type of information. The solution for the MaSe system is to include both qualitative and quantitative information. This is to be able to include all relevant aspects, independent of existing quantification methods.

Different types of information are needed at different decision levels, and for different users in the building process. It seems like the systems aimed at architects are of a more qualitative type than the other systems, this includes the ERG and the EPM guides. The quantified systems normally have a wider target group.

Studying another important aspect, namely weighting, many methods use some kind of expert panels. The expert is used either to develop a set of weights or to perform the actual evaluation stage, as for example Folksam, ERG and EPM. BEAT2001 uses political prioritisations as a basis for weighting, and ATHENA weights all the impacts equally.

The BEES system has a good way of solving a difficult problem like weighting. The user may select between two "expert panel derived" weight sets, equal weighting or individual weights. To be able to cover all areas of interest, this will also be the best solution for the MaSe system. This is also in coherence with on of the conclusions from Chapter 2, where it was concluded that the users of the system must be allowed to set their own prioritisations.

In the interviews performed and presented in Chapter 2.1, costs were one important factor affecting which products that was selected. BEES are the only system that systematically includes a cost evaluation procedure. This is an important source of information and inspiration for the development of the cost evaluation procedure in the MaSe system.

In the user survey of the BEES tool, it was found that many users did not use the total result presentation (a combination of the environmental and the economical scores). In the user survey report, they did not attempt to analyse the reason for this results, but this indicates that a different approach is needed in the MaSe system.

The user application of the systems varies from one presented index to a whole spreadsheet of information. The BEAT database may be used as a basis for a material selection system. However, apart from supplementary information, the data needs further treatment in order to be presented for a user in a selection situation. The data could be presented in a form like for instance the ERG guide for the architects, while the contractors would need information that is more detailed. All the systems also lack the possibility to present the results for a complete building.

The perfect system suited for all phases and all relevant actors in the building process would probably be a synthesis of the existing systems. In this relation, Table 4-4 presents a good summary of which element to include from which system. Beginning with the details, the BEAT2001 or the BEES 3.0 databases would be a good place to start. However, this should be adapted to Norwegian conditions, like for example the Ecodec system. The data must then be aggregated, but no completely satisfying system is found. It must be possible to aggregate information on the level of materials, elements and buildings.

The ENVEST system has a good way of structuring the data, as do ATHENA. The boxes where the user enters his/hers choices are quite similar, but the ATHENA user must be provided with more details regarding the concrete design of the building. The presentation of the evaluation results is important, the graphics, the nomenclature, the number of classes, amount of information etc., is all important aspects for the user of the system in order to accept the system and the results it provides. This is discussed in Chapter 4.2.

4.2 Alternatives for presentation of evaluation results

The interviews performed and presented in Chapter 2, provides some important knowledge on how the environmental properties should be presented. Almost all of the interview objects mentioned simple or simplified as an important criterion. But, it is also important to notice that the different participants have different wishes and needs. Classification and information presented like a handbook are requested solutions. Lists of good or bad, inventory data/declarations and labelling are on the "not wanted" list. The fact that individuals with varying backgrounds and varying needs will use the system, involves that the possibility to facilitate several ways of presenting the information must be included. Information must be presented so that non-experts find it satisfying, and it must provide opportunities for the expert to study the underlying evaluations leading to the result.

A potential user of a system like the MaSe system must also be convinced that the system is trustworthy. How to gain this trust is a difficult question, as trust is a feeling based on subjective criteria. Some relevant aspects might be that a recognised organisation or institution is responsible for developing the system, and that the user is convinced that the system is based on thorough work. If the system is open, the user is able to see all the evaluations and prioritisation in the system. It would also be an advantage if the industry itself participated in the development of the system, and a sense of ownership is developed. This might reduce the implementation barrier. It is also helpful if the user finds that the system is in coherence with the way he/she organize his/her work and that the terms are consistent with the terms used in the industry.

To summarise, for a system like the MaSe system to be used, two important criteria needs to be fulfilled:

- The results presented must be easy to understand.
- The system must be trustworthy.

In the following sections different evaluation methods and their results is studied to see of any of them might be used in the MaSe system.

A method must be found that can present the environmental properties of a building material in coherence with the requirements for the MaSe system. What can be described as traditional LCA and methods developed for building and building material evaluations is studied to find a suitable solution.

4.2.1 LCA methods in general

Life cycle Assessment (LCA) is a systematic methodology for assessing the environmental impacts related to a product, or a product system throughout its lifecycle. The assessment can be used for supporting strategic decision-making, product development, product comparison etc. According to the Code of Practise stated by SETAC (1998), LCA consist of the following steps:

1. Goal definition and scooping.
2. Inventory analysis.
3. Classification.
4. Characterisation.
5. Valuation.
6. Improvement analysis.

In this chapter, the focus is set on step 5 in LCA, valuation, or weighting, as it is called in the ISO methodology. Different groups have developed different methodologies for valuation, often adjusted to their needs in a specific study. Work has been done in order to reach a common understanding of a generic valuation method, but so far, there have been no success. Both SETAC and ISO classify the valuation methods in three categories (SETAC, 1998): Monetary methods, such as willingness to pay and shadow pricing, sustainability or target methods, such as in the "distance to target" procedure and third, social and expert methods. A summary of the methods is shown in Table 4-11. Further description of the different methods relevant to be included in this study is found in the following sections.

Table 4-11: Summary of the LCA weighting methods and their principles.

Category	Method	Weighting principle
Monetary	EPS	Willingness To Pay (WTP)
	Eco-cost/Value ratio	Marginal prevention cost + product value
	TELLUS	Willingness To Pay (WTP)
	DESC	Prevention costs
Sustainability and target methods	Ecopoint, BUWAL	Political priorities
	Environmental theme	Political priorities
	Ecoinidcator'99	Damage models
Social and expert methods	CML effect scores	Expert panel

4.2.2 Monetary methods

In monetary methods the different effects are valued according to for example people's **W**illingness **T**o **P**ay (WTP) for avoiding them, abatement cost, restoration costs or other economical aspects. One of the best-known examples is the EPS system, which is based on WTP studies of for example preserving lives. The Tellus valuation system, developed at the Tellus Institute, is based on society's willingness to pay. The Eco-cost/value ratio is on the other hand based on marginal prevention costs (Vogtlander, 2001).

The **D**ecision making **E**nvironmental **S**trategies for **C**orporations (DESC) method is developed in the Netherlands by Institute for Environmental Economics (TME) in cooperation with UNILEVER, and is very similar to the Tellus method (Hanssen et al., 1994). The DESC method uses costs of emissions reductions to a target level as the valuation factor (Finnveden, 1999).

The Swedish Environmental Research Institute (IVL) is responsible for the development of the **Environmental Priority Strategies in product design (EPS) system**, together with the Swedish Federation of Industries and Volvo Car Cooperation. The EPS system is more than a weighting method, but this is the only part of the method discussed here. The WTP estimates are based on a large set of studies performed by various institutions all over the world.

The EPS system has been exposed to some serious critics. Finnveden (1999), performed a thorough study of the system, and one of the major points of his criticism was the use of different types of monetisation measures for different problems. The method uses a mixture of market prices and other prices that cover larger parts of the economical value.

The use of discounting is also an aspect that is criticized. It is stated that the system do not use discounting, but the time aspect is some places included, for example by including a timeframe of 100 years for global warming. For resources on the other hand, future cost is used as a measure, regardless when this cost arises. Effects of global warming that arises 100 years from now are excluded. But other studies have shown that the marginal costs for CO_2 more that doubles in the time period 300 to 1000 years in the atmosphere.

A stated principle of the EPS system is that the future generations are as important as the present. This aim is not consistent with what is done in the calculations of the system, where future generations are not given any weight beyond a defined timeframe. Other remarks made about the system include data gaps, poor transparency, high threshold for including some toxic substances that consequently are excluded from the system, and little coherence with the societies understanding of the problems. One example is that the EPS system shows that the exploitation of osmium is the largest environmental problem we are facing today. For example to the ELU for hexaclorobenzene (4.46 ELU/kg) (on the B list), the use of osmium (59 400 000 ELU/kg) is about 13 000 000 times more important. In addition, the EPS system shows values several orders of magnitude lower for some effects compared to other calculations of cost of damage. In total Finnveden (1999), does not recommend that the EPS system be used today. Studying the objections to the system the EPS system is also excluded as method to be used in the MaSe system.

The **Eco-cost/Value ratio method** is based on the marginal prevention costs of measures. The idea is to link the "value chain" of Porter to the ecological "product chain". The model is developed at the Delft University of Technology. The purpose of the method is to provide designers and decision makers with a new tool to interpret the results from LCA (Vogtländer, 2000).

The direct and indirect eco-cost is described below. The Eco-cost/Value ratio is defined as the ecological costs divided by the value.

A low EVR indicates that the product is fit for use in a future sustainable society. The EVR is merged with the LiDS wheel presented by van Hemel, and the combination is called the "Eco-cost and Value wheel". The wheel is meant to provide a quantitative overview of the eco-efficiency of a product or a service, see Figure 4-12. It is seen that the value of the product is determined by the product quality, the service quality and the image and design. The cost structure of a product comprises the purchased material, required energy for production, depreciation and labour.

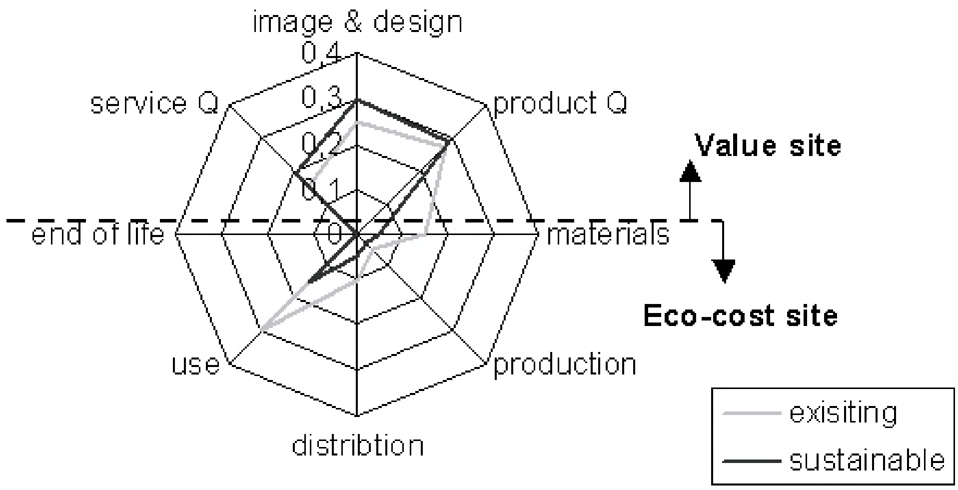


Figure 4-12: The Eco-costs & Value Wheel with value and eco-cost (Vogtländer, 2000).

The Eco-cost/Value ratio is not developed with building materials in special focus, but for designers of product services, government, citizens, strategic decision makers and business managers. The tool is very systematic and seems to present the user with valuable environmental information. Vogtländer (2001) found in the testing of the system, that potential users seem to accept results presented in monetary terms easier than traditional LCA results (in this case Ecoindcator'99). Expert users however did not accept the system, and did not change their priorities presented with the Eco-cost/Value ratio. Vogtländer has a very strong opinion that monetary terms are the only way of communicating the value of a product to the consumers.

Using cost estimates as the only parameter makes it difficult to include all parameters relevant when evaluation building materials. Health aspects are completely left out of the Eco-cost/Value ratio. This means that the EVR system is not a sustainability evaluation, as it claims to be. For an expert user many of the cost estimating methods might also be questioned. Like for example the method used to price materials depletion. Here the cost of material depletion is set equal to market value of the raw material, if the material is not recycled.

4.2.3 Sustainability or target methods

Some methods use targets defined by environmental experts or politicians to find a weighting system for the different sustainability aspects. This includes the BUWAL Eco point method, the EcoIndicator'99 and the **E**nvironmental **T**heme (ET) method.

The **Ecopoint** method, also called the **Ecological scarcity (ECO**) method, is developed by **B**undesamt für **U**mwelt, **W**ald und **L**andschaft (BUWAL), the Swiss ministry of Environment). This system is based on political prioritisations, and the environmental effects are multiplied with a weighting factor seen in Equation 4-1 (Hanssen, 1994).

$$Ecofactor = \frac{1}{R_i} * \frac{E_i}{R_i} * C$$

Where

R_i = policy objective for environmental effect i

E_i = total current level of environmental effect i in a certain area.

C = dimensional number

Equation 4-1

Eco factors are available for emissions to air, emissions to water and consumption of energy, waste and metals. National environmental protection laws and regulations are used to set the target levels. By normalising it with the current level of a substance, the factor also includes the consideration of the distance to the target. The target levels can also be set from ecological critical loads, but few of these are available at the present. Baumann et al. (1992), have translated the Eco point system to Norwegian conditions. The system is also included in LCA programs like SimaPro (Pré Consultants, 1997).

Some criticisms have been raised regarding the methods that are based on political goals. This is mainly because political decisions are influenced by many factors other than environmental protection. In addition, many environmental problems are not on the political agenda. It is often a long way from a problem is recognised scientifically until it is placed on the political agenda. Finally, it is also difficult to relate these targets to "critical" or "sustainable" levels. This makes the results from an Eco point calculation difficult to communicate and interpret.

The **Environmental Theme (ET)** method is developed in cooperation between McKinsey & Company, Inc., The Centre of Environmental Science in Leiden (CML) and the Dutch National Institute of Health and Environment (RIVM). Originally, no specific set of weights was developed, but through a Swedish study, a set of weight was provided. The targets were set according to political targets in Sweden (Baumann et al. 1994).

The process of calculating impact in the ET method is in short:

1. Grouping of the environmental loads in selected environmental themes.
2. The sum of loads for an environmental effect is divided by the total load of the same effect within a geographical are relevant to the study.

3. The impact fraction are summarised to a total impact after multiplying with weight factors.

In the Swedish study, target loads were developed through linear interpolation of government environmental policies. If no policy targets existed, the target was set to keeping current level constant. For the weight set of 11 themes, four of them did not have any policy targets. The same remarks can be made about the Environmental Theme method as for the “Ecopoint” method from BUWAL on page 95.

The **EcoIndicator** methodology is developed by the PréConsultants in collaboration with RIVM (National Institute of Public Health) and LCA experts from different organisations in The Netherlands. The methodology evaluates three types of damages; this is human health, ecosystem quality and resources (Goedkoop et al., 2000). Damage models are developed to link the damage categories with the inventory result.

For graphical illustration, the EcoIndicator system is linked to the Mixing triangle developed by Hofstetter et al. (2000). The mixing triangle is known from chemistry, geology and metallurgy. Using such a presentation principle the results from all possible combinations of weights between the safeguard subjects can be illustrated, see Figure 4-13. The different damages are represented in the corners of the triangle, and the weighting between the respective categories is presented as percentages. The bright grey area is the weighting area for which Product 1 is best, and the darker area marks for which weighting Product 2 is best. The goal of using this type of presentation is to make the weighting more transparent than a single figure. To ease the interpretation, a “line of indifference” is included. The line of indifference marks where the products represent equal damage.

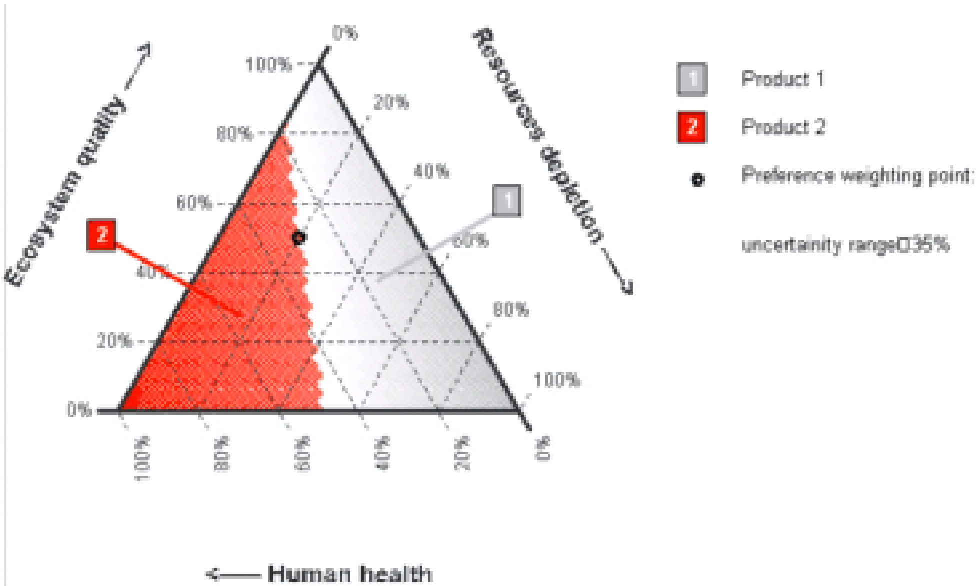


Figure 4-13: The mixing/weighting triangle. The Preference weighting point is placed where Human health weighs 30 per cent, Resource depletion weighs 20 per cent and Ecosystem quality weighs 50 per cent. The point is defined by following each side until the arrow aim towards the point inside the triangle (based on Hofstetter et al., 2000).

The EcoIndicator is the weighted sum of all the tree safeguard subjects (Hofstetter, et al. 2000).

A problem related to systems based on damage models is that only well known effects can be included, there are little room for the precautionary principle. All the fate models are based on data from the Netherlands. This means that the modelling for example of ecosystem quality is based on Dutch landscape and ecosystem types. For Norwegian conditions, the results might be totally different.

The principle of letting the "user" decide the relative importance between resource depletion, ecosystem quality ad human health is probably a good solution. Scientific methods are not available, and it is not likely that politicians will provide prioritisation on this level. In any case, there would be a subjective weighting, and that might as well be left to the decision maker.

The mixing triangle provides a good illustration on how the results may vary depending on how the different areas are valued. For example in Figure 4-13, product 1 is the best alternative if human health is highly valued, and product 2 is the best alternative if resource depletion is highly valued.

4.2.4 Social and expert methods

Experts and expert panels are used to develop weight sets in methods like the CML effect scores method. However, other groups of people can also be used with the same aim. From Chapter 4.1, it is seen that these types of methods is often used in Material evaluation systems.

The **CML effect scores method** is based on qualitative and quantitative multi criteria analyses, and use experts and expert panels for the scoring. In the qualitative analysis the different effect are weighted against each other by individual experts, or expert panels. In the quantitative method, the weighting involves applying a list of weighting factors. The normalised effect scores are multiplied with a weighting factor and aggregated into an environmental index (Hanssen et al., 1994).

There has been some discussion about the reproducibility of the CML method. The resulting scores are very dependent on the experts selected, their field of interest, subjective opinion and the material that is presented. Two expert panels will probably not reach the same conclusion unless they are "guided" very carefully.

4.2.5 Material evaluation methods and their presentation of final results

Large variations are seen in how the environmental information is presented in building material evaluation tools. The presentation of results spans from advanced classification methods to simple labelling systems. To get an idea of the various possibilities that can be used within the MaSe system, a brief summary is made. More information about the different systems is found in chapter 4.1. The goal is to see if there are solutions that have had any success, and that fulfils the requirements for the MaSe system.

Presentation of the results in classes is a common solution in environmental material and building evaluation. The number of classes in the systems studied varies from three to seven, and also the criteria and the descriptions varies widely. Often the classification systems have additional qualitative information, like the "Guide for material selection" from Sweden, “Hazardous building materials: A Guide to the selection of alternatives”, the “Environmental Resource Guide” from USA and “Environmental preference method” from the Netherlands. In the Norwegian system Ecoprofile, the results are presented in a profile with three classes (Pettersen, 2000).

Often there is a problem in the classification systems to express exactly how good a building or a building material is. It is therefore hard for the decision maker to see how much it is worth to invest in order to improve the design for example one class. On the positive side, a classification is easy to understand.

The EPM method from the Nederland does not include a graphical presentation, but a listing of the materials in their respective classes. The most serious objection against this method is that it is highly subjective, and has very low transparency. The system is presented as a book, and updating problems will arise. On the positive side the information in such a book is easily accessible. If accepting the classification procedure, the system could be a good support for decisions for example by architects. This was confirmed by the interviews of the architects described in Chapter 2. It does not affect much upon the working routines, it is very simple and straightforward to use. The same goes for the Swedish system, “Guide for material selection”, that is presented on CD-room and the Folksam guide.

A common way to present the results of various environmental assessment systems is the **presentation of the results relative to another material or building**. This type of presentation is used in methods for total evaluation of buildings, like EcoEffect (Glaumann, 1999), Equer (Peuportier et al., 1998) and EcoQuantum (IVAM, 2000), and in the earlier versions of BEES. Different methods are used to illustrate the results graphically, see figures in Chapter 4.1. Figure 4-14 shows how the results are presented in Equer. In Equer, the result from each area is presented in relation to a reference building. The “dotted” line shows the building in question. A small area means that the building represents a lower environmental load than the reference building. A large area indicates a higher ecological load.

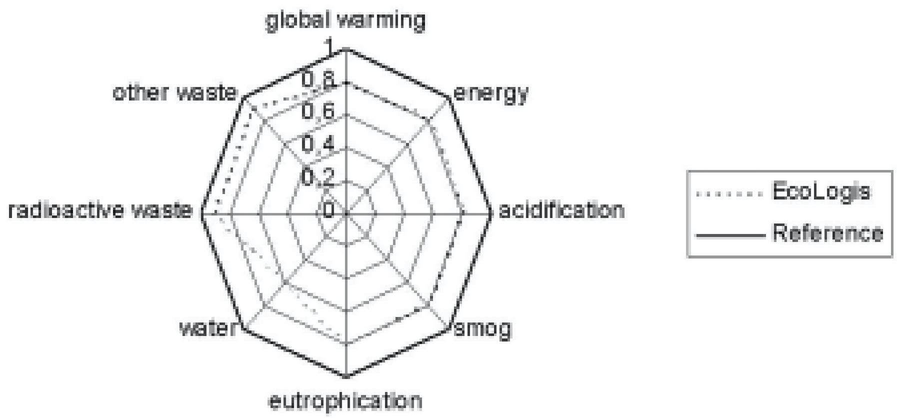


Figure 4-14: A comparative eco-profile between a solar versus a reference house in the EQUER system (Peuportier et al., 1998).

In all these systems, it is difficult for the designer to see if he/she is faced with a good or a bad material. It is stated that a material is for example 10 per cent better or worse than another material, but is not possible to say if any of the materials is a good material with respect to environmental qualities or that it is a sustainable material. Very much therefore depends on the definition of the reference building or reference material. If it is stated that the reference is for example the best available alternative, the comparison makes more sense. The evaluation then becomes some kind of benchmarking. A second reference could also be put into the system for a building it could be a "minimum" building for example built after today's building code. The reference could also be for example the most common material used for that specific purpose or the average of a defined material group.

The BEES 3.0 covers 200 materials, version 1.0 only covered 25. This means that the tool has been in limited use until now. Lipiatt (2000) does not know of any building project that has made use of the tool, except that in 2001, it will be used on a building on the campus of the University of Michigan. As described in Chapter 4.1.1, only 3 of the 550 users reported that they had used the tool for a specific decision.

Many people have downloaded the program from the Internet, the main reason for this is most likely that it is free, and the number can therefore not be used as an indicator for success. The main reasons mentioned for the tool being so popular, are that it is free, easy to obtain and easy to use (Lipiatt, 2000). It is also important that a Federal Governmental laboratory is the responsible developer. This means that an unbiased organisation take the lead in a very controversial area. It seems like the users like the presentation of results, and the possibility to see the detail of the evaluation. However, the combination of environmental and economic properties in the results does not seem to be accepted to the same degree.

According to Peuportier, the Equer system has been used in 4 building projects, for example the headquarters of the French agency for environment and energy management (ADEME) (Peuportier, 2000). The use of the tool is limited because the LCA methodology requires a list of data from the building and real estate industry about the impacts related to the fabrication of building products. In Equer they where forced to use a Swiss database (Oekoinvntare) to supply the data. Use of these data also introduces additional uncertainties, and according to Peuportier, the uncertainties related to the data makes it difficult to justify the choice of a building material based on LCA.

Damage potentials as for example GWP represent the highest level of aggregation that there is some scientific agreement upon within the LCA area. Several LCA studies therefore stop at this level, avoiding the disputed weighting methods. ATHENA^{TM} is an assessments system for buildings developed at the Sustainable Materials Institute in Canada, which presents the results as damage potentials.

The advantage of presenting the results as damage potentials is the scientific agreement. The final evaluation is however left to the user of the tool. Seeing the results, it is not in all cases clear which design is the best. To decide this must include an evaluation of what is worst: waste or global warming?

According to Trusty, ATHENA is used to assist clients with building assessment and design (Trusty, 2000). The tool has been used in two public projects; the Federal Department of Public Works and the Department of Defence. There is no information on how this worked in practice. ATHENA is also available on the Internet as freeware.

This has led to many people downloading the software, but there is no systematised knowledge about how the tool is being used.

GreenCalc is an example of a system that uses **monetary terms** in the handling of environmental problems. The GreenCalc is based on the TWIN model, which is a system developed through a PhD-study by Michiel Haas (1997). The GreenCalc currently consists of four modules, including materials, energy, water and commuter traffic. The environmental costs are calculated for the materials using the TWIN model.

GreenCalc have been used in many projects, mainly governmental buildings (Abrahams, 2000). Abrahams describes the GreenCalc as a success because the model provides understandable results. However, he also states that there have been some comments because some qualitative aspects are included in the model.

The **presentation of results in person equivalents** is one step further than the damage potential calculation. Expressing the results in person equivalents, means relating the results from LCA to the sum of emission from a population in a limited geographical area like a country or region. The Danish BEAT2001 database system is a system that uses this type of presentation.

ENVEST, developed at BRE in England, is described in Chapter 4.1.7. Eco point is used to communicate the environmental properties of an alternative in ENVEST. A score of 100 Eco points is equal to the environmental load from one UK citizen. All the materials included in the system is therefore evaluated and presented with one index. With ENVEST, it is possible to find which building element that represents the dominating part of the load.

ENVEST is a quite new tool, launched in May 2000. The tool is based on data from about 200 buildings, and a number of building materials, but at this point of time, there is no practical experience with the tool. Some critics have been raised because it presents the environmental load only as one index. There are also limited possibilities for searching into the reasons for one building being worse than another building.

The BEAT database is considered very expert oriented. According to Petersen (2000), there has been a substantial interest in the tool. The tool has been bought by a number of different users, but only about 10 consulting architects and engineers have the tool. They have little knowledge about the actual use of the tool, but it seems like it is used less in practice than they hade hoped.

Presentation of results as inventory data requires expert knowledge for interpretation. Building material declaration systems are examples of such systems. In addition, the Danish Handbook of environmental design ("Håndbog i miljørigitg projektering") presents the building materials only with data on emissions and resources use etc.

In a practical situation it is difficult to use inventory data directly, some kind of judgement is needed, and this should be based on a defined system rather than more or less coincidental judgements from non-specialists. This has also been the reaction to the Danish handbook; there is too little guidance for the user towards concrete action. However, the declaration system forms a good basis for further evaluation of the building materials.

Not many building products have been subjected to **labelling** yet. In Norway there is only one system used for labelling building products, and this is “Svanen” (the Swan). To obtain the label a product must meet a set of requirements stated in a criteria document. Up until now, there are such documents only for flooring and wallboards, paint and varnish, tapestry, furniture and windows.

In total, there are 14 building products available in Norway with “Svane” labelling (Miljømerking, 2000). The foundation responsible for the labelling has been active since 1989, so in ten years there have been very little activity in labelling building products. The most common criticism against “the Swan” labelling has been the costs and the doubt that the products that are labelled really are better than other products.

Other labelling systems relevant to building products are: “Der Blaue Engel”, “EU flower” and the Forest Stewardship. “Der Blaue Engel” is a German system active since 1986. The criteria for Der Blaue Engel seems like the least comprehensive set of criteria of the four systems studied. However, the “Blaue Engel” has had most success with respect to the number of products that has received the label. In January 2000, about four thousand products had received the label.

The “EU flower” has been active since 1993, and about 250 products have received the label. Indoor paint and varnishes are the only building products labelled up until now, and 22 producers have received the label. There is ongoing work for hard floor covering like ceramic tiles.

The Forest Stewardship Council is an international body certifying forest owners and managers for environmentally responsible, socially beneficial and economically viable management of forests. In Norway, there has been little interest among forest owners and managers in these certifications. VERITAS is a certification unit, but FSC has in many cases proven to fail as a system (Rainforest Foundation Norway, 2002).

The other relevant labelling organisations have also showed little activity on labelling building products. The focus has mostly been on consumer goods. The main problem with labelling is that it does not tell whether a product is better than another products, it only states that it satisfy certain set of criteria, none of them saying that this is a sustainable material or an eco-effective material.

4.3 Discussion and summary of findings

No tool is found that satisfy the identified needs for result presentation in a material selection system. By studying existing methods, however important information is gathered for possible solutions that could partly be used in a new tool. To study the existing tools has also been an important learning process valuable for the work with the MaSe system.

The first question to ask is why none of the methods studied are employed in the building process on a more regular basis. There are probably various reasons for this, but one aspect might be that the systems are very detached from the building process and its participant’s needs in many cases. There are little information on how the system is to be used, and little guidance for the different decision makers and how they may proceed when selecting more environmentally friendly building materials.

The first indicator of the insufficiency of the existing systems is found when comparing the summary of the different environmental considerations that should be included in the MaSe system (defined in Chapter 5), and the parameters for the different systems listed in Table 6-1. None of the systems completely cover the necessary aspects. Economy is only covered to any extent in one system, but experience with BEES suggests that this must be treated somewhat differently.

There are methods for aggregating quantitative environmental data into potentials. In addition, methods for including qualitative information must be found. In the aggregation of data, weighting is also necessary. It is concluded that more than one set of weights is needed, and possible solutions are equal weighting, user defined weights and expert panel weights. There are no expert derived weights for Norwegian conditions today. However, it is not considered as a task within the work in this thesis to develop a set of expert weights.

The aggregation procedure facilitates the comparison of building elements, materials and products. The inventory data are aggregated into damage potentials where possible. However, qualitative information needs to be included. This combination makes a new evaluation procedure necessary. How this is done is described in detail in Chapter 5.

The result from the MaSe system should be presented on several levels of information aggregation:

1. Index.
2. Results for the different main areas.
3. Results on the parameter level for the different lifecycle phases.
4. Material data, for example Ecodec.

Reviewing existing methods no results presentation is found to be completely satisfying. Studying the material evaluation methods first, large variation is found as to how they present the results. It is clear that to facilitate the listed aggregation possibilities a qualitative description is not useful, neither is labelling. Inventory data will serve as the input information in the MaSe system. The expression of the results in person equivalents is applicable if there are only quantitative parameters with relevant normalisation data. This is not possible for the time being for all the parameters in the MaSe system. Monetary methods might communicate the result well, but not if doubts is expressed about the way the cost estimates is performed.

Presentation of results relative to another material is a possible solution for the quantitative parameters. This reference material must then be selected with care. The presentation of results in damage potentials is applicable on level three above. These potentials can then be normalised using a reference material.

The data then needs further aggregation to level two and one. A scientific method would be preferable, but Hanssen recommends that as long as there is no generally available SANEL (Scientifically defined no effect levels)-values, weighting should be a reflection of political policies, and not from the basis for long-term policy measures (Hanssen et al. 1994). He also recommends that before one system is agreed upon internationally, several weighting systems should be applied in parallel to arrive at the best possible answer. Wanting to involve all relevant parameters however, political methods are not preferable as it excludes many of the effects. The conclusion is that a new method must be developed to make the MaSe system operable. It is important that this new method communicate the results to the user. Possible weighting methods are:

- Equal weights.
- Self defined weights.
- Expert weights.

The mixing triangle can be used as a good way of illustrating the dependency of the results of the applied weighting.

5 Evaluation procedures for building materials in the MaSe system

In Chapter 4, focus was set on how the environmental properties of a building material may be presented using existing material evaluation tools and/or other environmental evaluation methods. No satisfactory solution was found, and it was concluded that an improved method was needed. Valuable insight is however, provided through existing methods, and some aspects should be further developed. These are described in Chapter 4.1.9.

In order to develop a suited methodology for the evaluation and presentation of environmental qualities of building materials and products, **M**ultiple **C**riteria **D**ecision **M**aking (MCDM) techniques were found very useful. The reason for this is that the approach in environmental evaluation is very similar to multiple criteria decision problems.

The evaluation procedure in the MaSe system is discussed under the following headlines: Resources, Ecology, Human health and Economy. However, first a discussion of possible structure and main results of the MaSe system is included.

A copy of the MaSe system spreadsheet is included in Appendix A. While studying the different sub chapters, it might be useful to confer with the respective work sheets, to better understand the procedures.

5.1 Selection of structure for the MaSe system

A large number of MCDM methods are found in the literature, but in this work, no attempt is made to review all of them. Studies by Chen (et. al., 1992) and Hwang (et al., 1981) both include evaluations and systematisation of the MCDM methods. The work in this thesis is based mostly on the MCDM theory presented in these studies, but other sources of information are sought when necessary. The goal is to find a suitable basis for the MaSe system.

A methodology suited for the MaSe system must be simple and transparent, handle different types of criteria that may be in conflict, make tradeoffs possible, and handle both qualitative and quantitative information. To keep it as simple as possible, it is also an advantage if the method requires a minimum of calculations. The results should provide the decision maker with more than one single number.

MCDM methods handle decision problems with multiple criteria, and can be expressed in a matrix format as shown in Equation 5-1. This is coherent with what is seen in environmental assessment, where several alternatives with large set of attributes are included.

$$D = \begin{matrix} & X_1 & X_2 & .. & X_n \\ A_1 & x_{11} & x_{12} & .. & x_{1n} \\ A_2 & x_{21} & x_{22} & .. & x_{2n} \\ .. & .. & .. & .. & .. \\ A_m & x_{m2} & x_{m2} & .. & x_{mn} \end{matrix}$$

Equation 5-1

Where

A_{1-m} = alternatives

X_{1-n} = attributes

MCDM methods consist mainly of two phases (Hwang et al., 1981):

1. Final rating: Aggregation of the performance scores with respect to all the attributes for each alternative.
2. Rating order: Rank ordering of the alternatives according to the aggregated scores.

The classic MCDM methods are classified as shown in Figure 5-1.

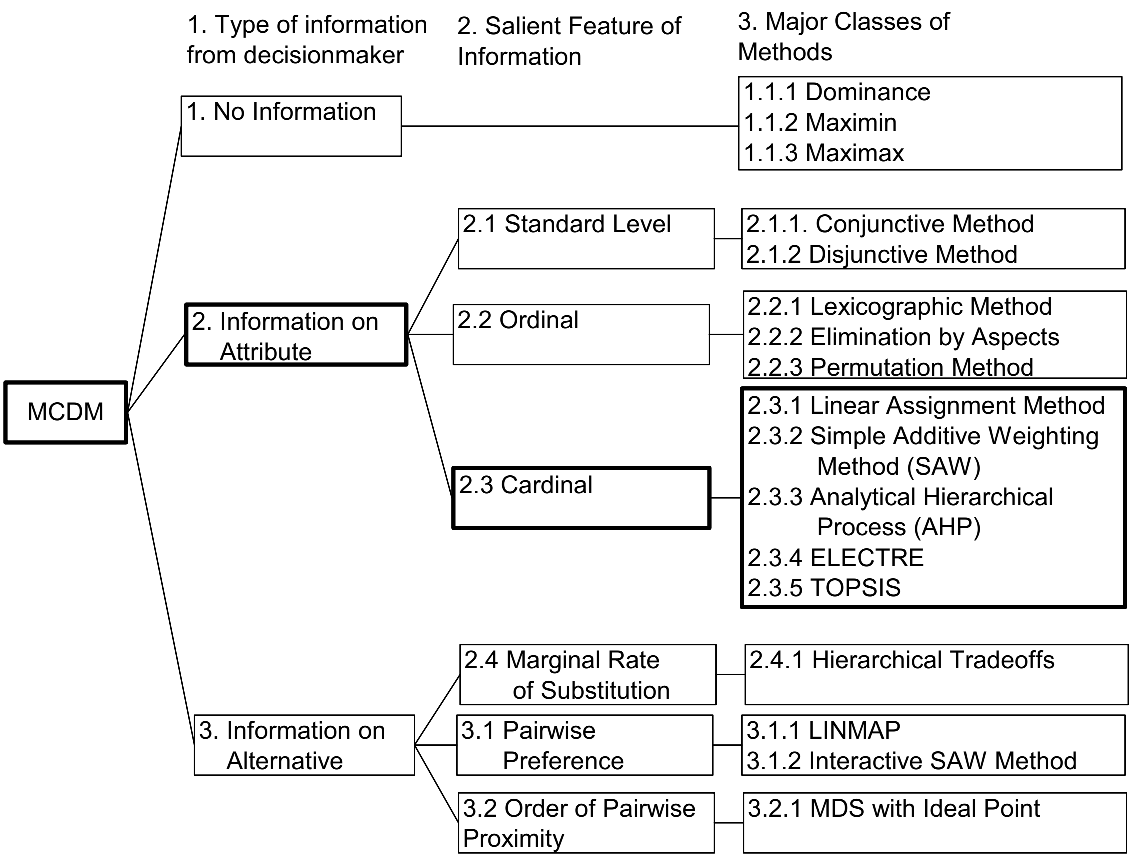


Figure 5-1: Classification of multiple criteria decision-making methods (after Hwang et al., 1981).

In a typical decision situation for building materials, there is available information on the attributes. These are the data found in the data input table shown in Chapter 7. Ordinal methods only consider rank order, and then convert the ranking into normalised weights. The ordinal cardinal methods also consider the magnitude of the difference. The methods 2.3 in Figure 5-1 are therefore the methods considered for the MaSe system.

Linear Assignment Method (LAM) is not considered a good alternative because it does not include the actual distance between the ranked alternatives. The method only generates a preference ranking which best satisfy a defined concordance measure. ELECTRE (**El**imination **E**t **C**hoix en **T**raduisant la **RÉ**alite) uses the concept of outranking relationship. This means that a decision maker accepts, with a certain risk, that one solution is better than another even if they do not mathematically dominate each other. This method gets increasingly complicated as the number of alternatives increases, and requires an extensive calculation procedure. Altogether, this indicates that the method is not suitable for the MaSe system. The following MCDM methods were found interesting with respect to the requirements for the MaSe system:

- SAW (**S**imple **A**dditive **W**eighting).
- AHP (**A**nalytical **H**ierarchy **P**rocedure).
- TOPSIS (**T**echnique of **O**rder **P**reference by **S**imilarity to **I**deal **S**olution).
- Distance from target.

Distance from target is not shown in Figure 5-1, but fits well in category 2.3.

5.1.1 Presentation of four MCDM methods relevant to the MaSe system

In **SAW**, the score of an alternative is computed as the weighted sum of the attribute values. According to Yoon (et al. 1995), this method is the best known and most widely used MCDM method. The method is simple and easy to understand, and enables trade-off between attributes. The SAW method is based on the assumption that the attributes are independent. This is not 100 per cent true for all attributes in this study. For example, high demand for energy is likely to lead to increased emissions of CO_2. However, studies also show that the SAW method yields very close approximations even when independence among attributes is not exactly true (Yoon et al., 1995; Andresen, 2000).

The SAW evaluation is made in two simple steps:

1. A score is calculated by multiplying the scale rating of each attribute with the importance weight of that attribute, and summing these products for all attributes for each alternative, see Equation 5-2.
2. The alternative with the highest score is selected.

$$A^* = \left[A_i \,\middle|\, \max_i \sum_{j=1}^{n} w_j x_{ij} \middle/ \sum_{j=1}^{n} w_j \right]$$

Equation 5-2

Where

x_{ij} = the outcome of the i'th alternative about the j'th attribute with a numerically comparable scale

w_j = the importance weight if the j'th attribute

The assumption that the weights are proportional with a unit change in each attribute's value function is the basis of the SAW methodology. Setting a value function, V, with two attributes, v_1 and v_2; $V= w_1*v_1 + w_2*v_2$, constant derives the relationship: w_1/w_2 = -æv_2/æv_1. This means that if w_1 = 0.33 and w_2 = 0.66, the decision maker is indifferent to the trade off between two units of v_1 and one unit of v_2 (Yoon et al., 1995).

AHP is also a well known and very simple MCDM method. The basis for AHP is the formation of a hierarchical structure, an attribute hierarchy, as illustrated in Figure 5-2. The focus on the first level is on a defined goal, the alternatives are defined by the attributes on the second level, and the competing alternatives at the bottom (Yoon et al. 1995).

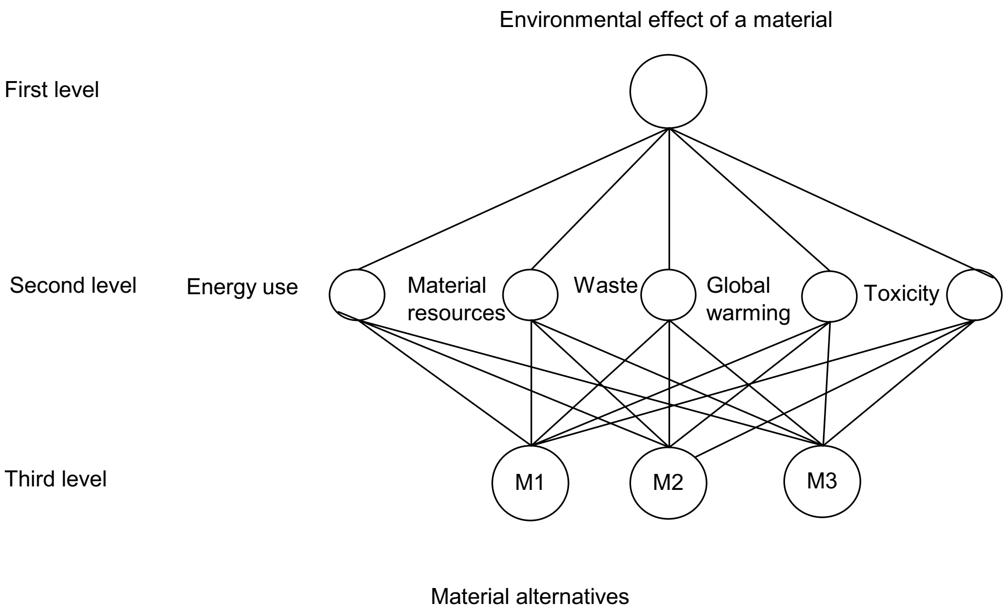


Figure 5-2: Example of hierarchical structure for a simplified evaluation of the environmental properties of a building material.

The relative importance between the attributes may be determined by different weighting techniques, as for example pair wise comparisons described in Chapter 5.1.4. The overall contribution of each material to the overall goal is calculated by aggregating the weights vertically. The overall priority is obtained by adding the product of the criteria weights and the contribution of the alternative, with respect to that criterion.

TOPSIS, is based on the principle that the chosen alternative should have the shortest distance from a defined ideal solution (A* in Figure 5-3), and the longest distance from a negative ideal solution (A^- in Figure 5-3) (Yoon et al., 1995). The ideal solution is where all parameters retain the best score possible, and the negative ideal solution is where all parameters receive the worst score possible. The principle is illustrated in Figure 5-3. Studying the two alternatives A_1 and A_2 in the figure, A_1 is closest to A^*, but A_2 is furthest from A^-.

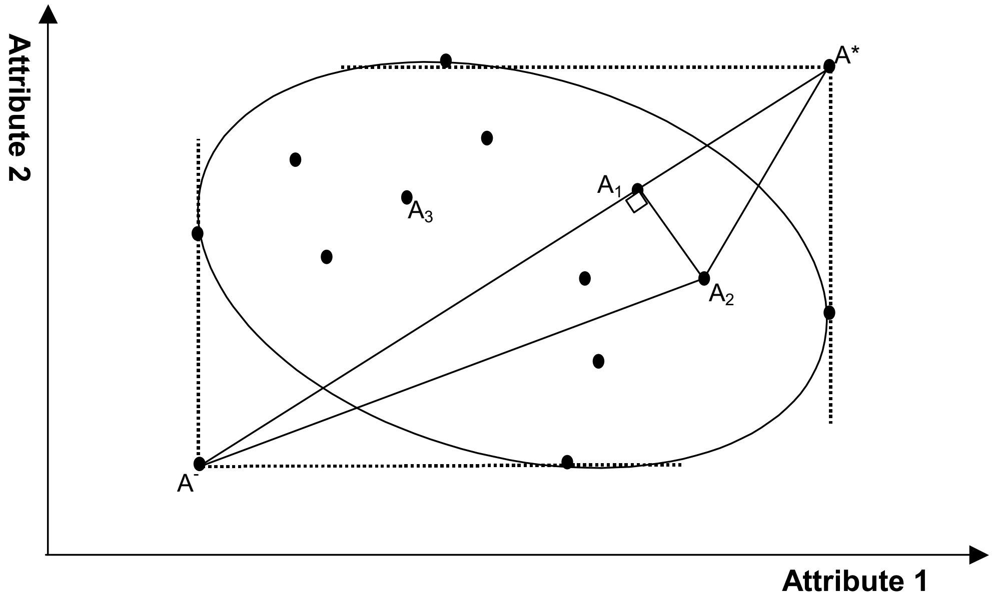


Figure 5-3: Distances to positive-ideal and negative-ideal solutions in two-dimensional space (after Yoon et al., 1995). A* is the attributes of the positive ideal solution and A^- is the negative ideal solution.

The calculation procedure is as follows:

1. The normalised decision matrix is calculated using Equation 5-3.

$$r_{ji} = \frac{x_{ji}}{\sqrt{\sum_{i=1}^{m} x_{ji}^2}}, i = 1,2...m; j = 1,2...n$$

Equation 5-3

Where

x_{ji} = the outcome of the i'th alternative about the j'th attribute with a numerically comparable scale

2. The weighted normalised decision matrix is calculated using Equation 5-4.

$$v_{ij} = w_j \times r_{ij}, i = 1,2...m; j = 1,2....n$$

Equation 5-4

Where

v_{ij} = the weighted normalised value
w_j = the importance weight if the j'th attribute

3. The ideal and negative-ideal solutions are defined as shown in Equation 5-5.

$$A^* = \left[(\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} \middle| j \in J') \middle| = 1,2...,m \right] = \{v_1^*, v_2^*, ..., v_j^*, ..., v_n^*\}$$

$$A^- = \left[(\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} \middle| j \in J') \middle| = 1,2...,m \right] = \{v_1^-, v_2^-, ..., v_j^-, ..., v_n^-\}$$

Equation 5-5

Where

J = {j= 1,2,…,nb j associated with benefit criteria}

J' = {j= 1,2,…,nb j associated with cost criteria}

4. The separation measures are calculated using Equation 5-6.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, i = 1,2,...m.$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, i = 1,2,...m$$

Equation 5-6

Where

S_i^* = separation from the ideal solution for the i'th alternative

S_i^- = separation from the negative ideal solution for the i'th alternative

5. The relative closeness to the ideal solution is calculated using Equation 5-7.

$$C_i^* = S_i^- / (S_i^* + S_i^-), 0 < C_i^* < 1, i = 1,2,...,m.$$

Equation 5-7

6. Rank preference order

In **Distance from target**, the best value for some attributes may be located in the middle of the attribute range. The method enables the selection of the alternative with the shortest "distance" from a defined target alternative. This requires that the decision maker has a set of defined targets for each attribute. The calculation procedure is as follows:

1. The deviation from the target is calculated for each alternative using Equation 5-8.

$$d_i = \sqrt{\sum_{j=1}^{n} w_j^2 (x_{ij} - t_j)}, i = 1,2,...,m.$$

Equation 5-8

Where

d_i = distance from target for i'th alternative

x_{ij} = the outcome of the i'th alternative about the j'th attribute with a numerically comparable scale

t_j = the target level for the j'th attribute

w_j = the importance weight if the j'th attribute

2. The alternative with the shortest distance is selected.

5.1.2 Discussion of the selected MCDM methods

In order to determine which method that best fulfils the identified needs for the MaSe system, the results of the different evaluation procedures are studied in detail. The factors studied are: the ability to handle both qualitative and quantitative criteria, the information value of final result, the simplicity in use, the degree of manipulation of data, the transparency, the trade-off possibilities and the ability to distinguish between the evaluated materials or products.

All methods require a common numerical scaling system that makes the different attributes comparable. The attributes are the data found in for example material declaration systems, such as kg CO_2/FU, kg renewable resources/FU or kg H_2SO_4/FU. These attributes must be normalized to a common scale for comparison. Traditional normalization methods are:

- The attributes of the worst material in a group.
- The average value for the attribute.
- The measure of the attribute for a defined geographical region.
- The measure of the attribute for a defined geographical region per person in that region (person equivalents).

A common problem with several methods is the required knowledge level of the user. Both TOPSIS and the Distance to target method require that the decision maker defines the targets, the ideal solution and the negative ideal solution for all parameters. In the MaSe system, it is not possible to require such insight for example from a client. He/she will probably not know for example which level of CO_2 that is acceptable for a given building material. In the MaSe system, the decision maker's preferences should be restricted to the determination of the weights.

SAW and AHP present the result as a weighted sum of the attributes, similar to many evaluation methods developed in LCA methodology. TOPSIS measures the closeness to an ideal solution. C* equal to 1, means that the solution is an ideal solution, while C* closer to zero, indicates a negative ideal solution. The Distance to target method measures the distance from a defined target, determined by targets for each attribute.

The results of both TOPSIS and Distance to target method therefore depend on the definition of the target level. The target levels for the Distance to target method could be set to zero, but then the method would be very similar to the SAW method. The target level could also be equal to the best value for each attribute. Alternatively, a sustainable material could be defined as the target measure, also representing the ideal solution in TOPSIS. However, TOPSIS also requires the definition of the negative ideal solution. A simple answer to this problem would be to let the worst measurement for each attribute define the negative ideal solution. However, such a definition could in some cases become very biased. If the measurements for an attribute were very close for a group of materials, it would be incorrect to define a negative ideal solution.

A simple study is performed in order to test the different methods discussed above. Three alternatives for upper floor constructions are studied, and the environmental data are shown in Table 5-1. For simplicity, only a few environmental criteria are included.

Table 5-1: Environmental data for three upper floor constructions. Functional unit is cradle to grave, 60-year life, 1m^2 for all elements.

Attribute	Element 1: Pre-Cast Concrete (PCC) slab, screed coat	Element 2: Timber joists, t&g floorboards	Element 3: In situ 255 mm concrete flat through, waffle slab
kg CO_2 eq.	85	36	30
kg SO_2 eq.	0.51	0.082	0.9
kg tox. air	0.8	0.095	1.4
kg ethane eq.	0.0068	0.022	0.013
kg PO_4 eq.	0.039	0.0092	0.067

Data source: BRE environmental database. Note: some of the data have been manipulated to better illustrate the example.

The results of the calculations are shown in Figure 5-4, Figure 5-5 and Figure 5-6. The details of the calculations are included in Appendix D. Note that for this example, the result will be identical applying AHP and SAW, and that all methods yield the same rank. The calculations show that the defined targets have a major influence on the results for both TOPSIS and Distance to target. For the Distance to target method, two strategies are tested. In the first calculation, illustrated as shown in Figure 5-5, the best value for each attribute is set as the target value. Alternatively, the target value could be set to zero, because the ultimate goal is to use materials with no emissions. The results using zero emissions as a target is shown in Figure 5-7. In this case the results differ less than in the previous calculation.

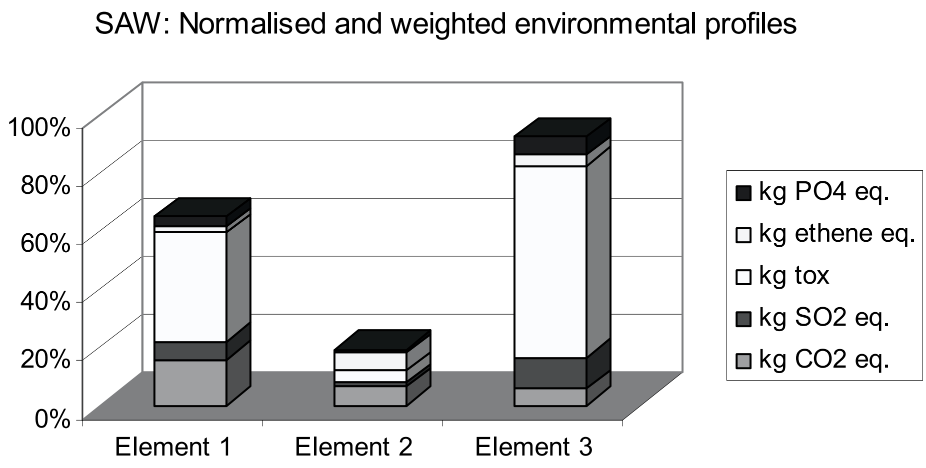


Figure 5-4: Results of calculation using the SAW or AHP methodology.

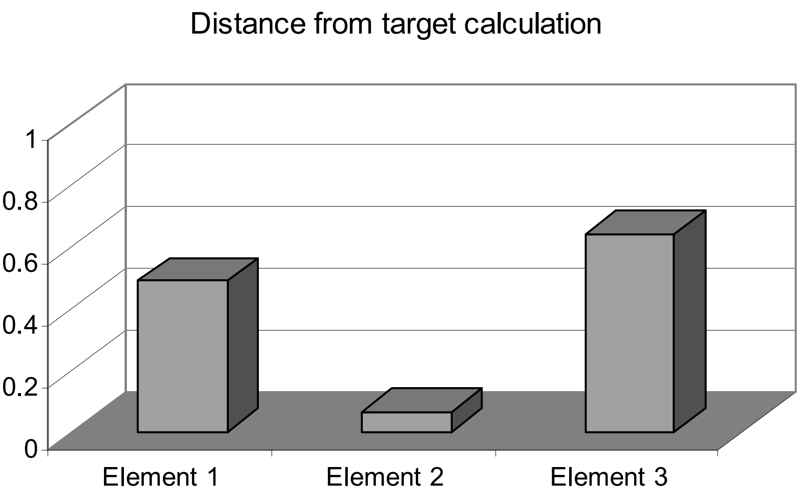


Figure 5-5: Results from calculation using the Distance to target calculation. The best value for each attribute is set as target value.

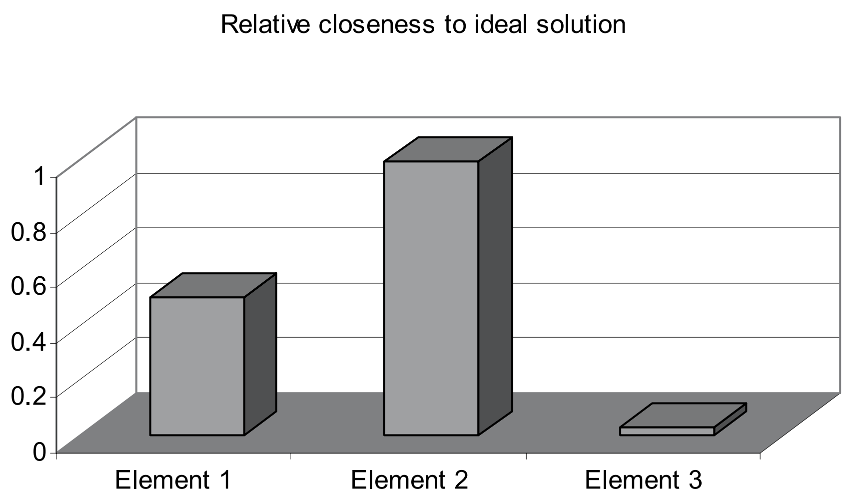


Figure 5-6: Results from calculation using the TOPSIS methodology.

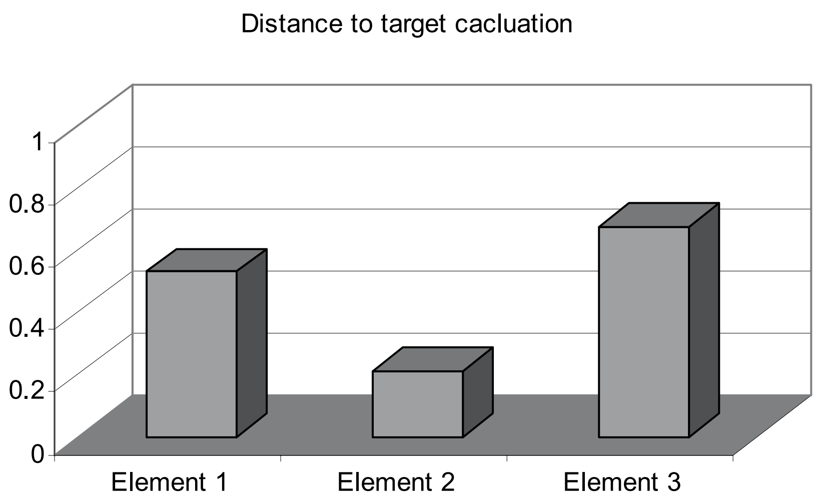


Figure 5-7: Result from Distance to target calculation, using zero emissions as target.

The same could be done in TOPSIS, but this would require an alternative definition of the negative ideal solution. Choosing the worst attribute values as the negative ideal solution, new results can be calculated. This, however, only leads to the results not coming as close to the ideal solution as the previous calculation. All the methods seem to be able to identify significant differences between the materials in the example.

Another aspect is the information on the y-axis. It is important that the assignment of a "number" to a material gives some sort of meaning for the user. In SAW and AHP, the meaning of the calculated value depends on the normalization procedure. In this example, the denomination is person equivalents (per cent of the load from one person in a geographical region in one year).

In the distance from target methodology, a low value indicates that the alternative is close to the target alternative. Some confusion may arise as to what distance represents any harm. In the TOPSIS methodology, the scale gives more meaning. The result is always presented as a number between zero and one. A value close to one, means that the solution is close to the ideal solution, and a value close to zero means that the alternative is close to the negative ideal solution.

The transparency of a method is the degree to which the user can see the reason for the results of the calculation. This factor is also linked to the information value aspect of an index. Using SAW or AHP, the explanation of the result is included in the illustration. It is seen that in the case illustrated in Figure 5-4, the air toxicity for humans causes Element 3 to be ranked as the worst alternative. This is also the case for the other techniques, but this is not seen directly from the results. It is seen that of the methods studied only SAW offers some degree of transparency. This is also the case for AHP, but this depends on the aggregation procedure.

An evaluation table is used in order to help determine the MCDM method that best meets the needs in the MaSe system, see Table 5-2. The criteria listed in the table are used to evaluate the methods. The criteria are weighted equally, thereby ranking the SAW and AHP methods as the best suited methods for the purpose of the MaSe system.

Table 5-2: The methods classified according to a set of requirements. 1 = Good, 2 = Medium, 3 = Not satisfactory.

Criteria	**SAW and AHP**	**TOPSIS**	**DFT**
Handling of both qualitative and quantitative criteria	3	3	3
Information value of final result	1	2	3
Simplicity in use and degree of manipulation of data	1	2	2
Transparency	1	3	3
Trade-off possibilities	1	1	1
Separation of result	2	2	2
Sum	*9*	*13*	*14*
Rank	*No. 1*	*No. 2*	*No. 3*

According to Table 5-2, SAW and AHP are the methodologies best suited for the MaSe system, and these two methods are closely related. The main difference is the construction of the hierarchy in AHP. This hierarchical structure should also be used in the MaSe system, where the nature of the criteria involves aggregation through several levels.

5.1.3 The MaSe system hierarchy

An illustration of the MaSe decision hierarchy is shown in Figure 5-8. It is seen that five levels are needed to aggregate the necessary information. Level one is the decision objective. Level two represents the main areas in the evaluation, level three is the effect categories, level 4 is the criteria, and finally the products evaluated represents a fifth level.

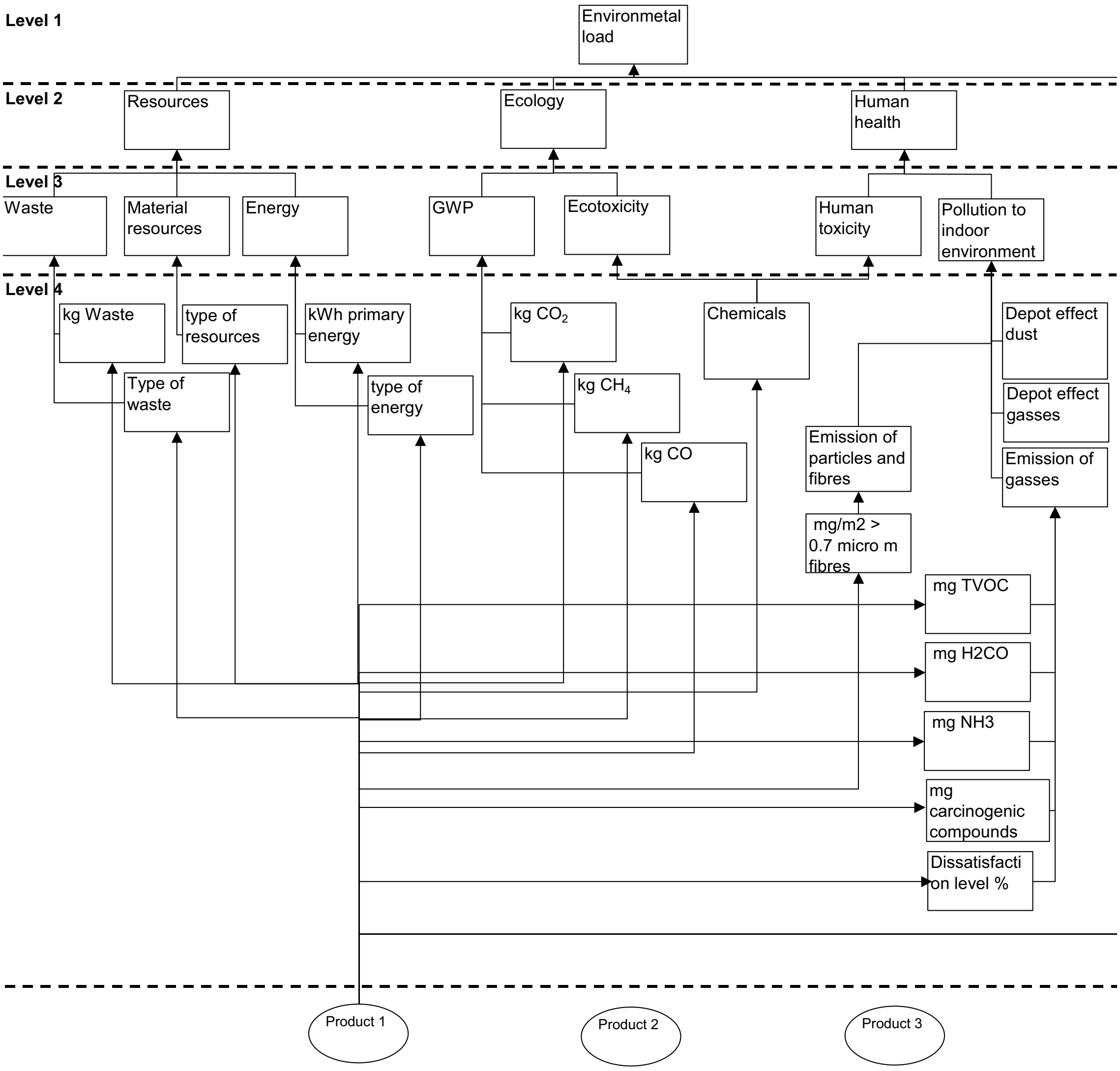


Figure 5-8: Illustration of the decision hierarchy in the MaSe system. Note that Economy and the links between product 2 and 3 and the criteria are excluded to simplify the illustration.

One of the major difficulties in this type of assessment is to include both qualitative and quantitative information of different types. The scaling table developed in the MCDM-23 project is considered as a good solution to this problem (Balcomb et al., 2000).

In MCDM-23 (a computer-program tool that can aid in organizing the information for the MADM method), a scale table is developed for the normalization of the different attributes (Balcomb et al., 2000). Table 5-3 shows how annual energy use in a building is scored using this scale table. This methodology can be used to include both qualitative and quantitative attributes in an evaluation system.

Table 5-3: The scale table used in MCDM-23 (Balcomb et al., 2000).

SCORE	Judgement	Annual energy use, kWh/m^2
10	excellent, best attainable	80
9	good to excellent	100
8	good	120
7	fair to good	140
6	fair	160
5	borderline fair	190
4	marginally acceptable	250

Starting with the scaling table defined by Balcomb et al. (2000), some changes are needed. First, the scale range is inverted. Since the MaSe system is an environmental evaluation system, it is logic to let a low value indicate low environmental load and a high value indicate high environmental load. This is also in accordance with other evaluation systems, like the Norwegian Eco-profile system (Pettersen, 1999) and the Swedish Eco-effect system (Glaumann, 1999).

Second, the number of classes in MCDM-23 is seven. This is based on theories of behavioural science, which argues that the mind cannot handle more information than a seven-point scale. Still one additional class is included in the MaSe system. This is to avoid the middle class, which often is a pitfall. Extending the number of classes to eight classes might involve some problems, but considerable work is laid down in defining the criteria in the MaSe system. It is therefore assumed that eight classes is a manageable number. A reduction to six classes is not considered a satisfactory solution, as this might reduce the systems ability to distinguish between the products.

As mentioned, the scale is inverted in relation to the MCDM-23 scale. The bottom of the scale is the “unacceptable” performance, assigned with a score 8, “Unacceptable” is not used in the MCDM-23, but in the MaSe system, this class must be included to be able to distinguish products that might be precisely that. The top of the scale is the “excellent” performance valued with the score 1. The scale used in the MaSe system is shown in Table 5-4. The column “Criteria” in the table is used to include both qualitative and quantitative information. This represents the normalisation step in the environmental assessment procedures, studied in Chapter 4. The work of defining the attributes, the scaling tables etc. is described in detail in Chapters 5.3, 5.4, 5.5 and 5.6.

Table 5-4: The score chart used in the MaSe system.

Score	Judgement	Criteria: ……
1	Excellent	…
2	Good	…
3	Fair to good	…
4	Fair	…
5	Borderline fair	…
6	Marginally acceptable	…
7	Poor	…
8	Unacceptable	…

5.1.4 Weighting methods

Having found the main structure of the system, weighting methods to aggregate the information is the next step. The weighting of attributes expresses the importance of each attribute relative to other attributes. The different methods for constructing weights are systematised in Table 5-5. As a main rule, the methods listed in Table 5-5 get increasingly complex moving from the methods in square 1 to the methods listed in square IV.

Table 5-5: Weighting techniques for constructing attribute weights (after von Winterfeldt et al., 1996).

	Stimuli used	
	Risk averse outcomes	Gambles
Numerical estimation	Ranking Direct rating Ration estimation Swing weights I	Not applicable II
Indifference	III Cross attribute indifference Cross attribute strength of preference	IV Variable probability method Variable certainty equivalent method

Numerical estimation involves assigning quantified weights to represent attribute importance for the overall determination of value (von Winterfeldt et al., 1996). The indifference methods are criticised for requiring complicated measurements and deduction techniques. For example, they involve the generation of equations that can be solved for the attribute weights. The procedures in square I are assumed easier to understand and to accept by a potential user of the MaSe system than the methods in squares III and IV.

Ranking involves listing of the most important attribute first, the least important attribute last, and the other attributes arranged from high to low between these extremes.

To derive weights from ranks is regarded as one of the simplest ways of assessing weights to different attributes (Edwards, 1982).

Edwards (1982) describes *rank sum weighting* in multi attribute evaluation. This method involves assigning the highest rank number to the most important attribute, the next highest number to the second most important attribute, until the least important attribute receives the rank 1. The rank sum weights are calculated using Equation 5-9. This results in what is called *inverse ranks*. The inverse ranks are then added, and each divided by the sum. This assures that the normalised numbers add up to 1. An example of rank sum weighting is shown in Table 5-6.

$$w_j = \frac{(n - r_j + 1)}{\sum_{k=1}^{n}(n - r_k + 1)}$$

Equation 5-9

Where

w_j = weight of attribute j

j = attribute j

n = number of attributes

r_j = rank of the j'th attribute

r_k = rank of the k'th attribute

Rank reciprocal weighting is also described in Edwards (1982). This method involves assigning the value 1 to the most important attribute, 2 to the next most important attribute etc. (normal rank). The least important attribute is given the rank n, where n is the number of attributes. Then the reciprocal value of each attribute is normalised (reciprocal of normal rank). This then assumes that the most important attribute receives the highest number, and the least important attribute the lowest value. The rank reciprocal weights are then calculated using Equation 5-10. An example of normal rank, reciprocal normal rank and rank reciprocal weighting is shown in Table 5-6.

$$w_j = \frac{\frac{1}{r_j}}{\sum_{k=1}^{n}\frac{1}{r_k}}$$

Equation 5-10

Where

w_j = weight of attribute j

r_j = rank of the j'th attribute

r_k = rank of the k'th attribute

Table 5-6: Example of application of rank weighting methods.

Attribute	Inverse rank	Rank sum weight	Normal rank	Reciprocal of normal rank	Rank reciprocal weight
Global warming	4	0.29	2	0.5	0.21
Eutrophication	1.5	0.11	3.5	0.29	0.12
Acidification	1	0.07	5	0.2	0.08
Ozone depletion	5	0.36	1	1	0.42
Photochemical ozone creation	2.5	0.18	2.5	0.4	0.17
Sums	14	1.0		2.39	1.0

Ranking is a demanding process for the decision maker. A system of paired judgements is developed to obtain such judgements. Paired comparison was developed by Dean and Nishry (1965), and then included in the AHP by Saaty (1994). The basis of the paired comparison method is to perform pair wise ranking of all attributes (or alternatives). In a system of n attributes a total of n(n-1)/2 judgements must be made (Yoon et al., 1995). The attribute with the highest × C, see Table 5-7, is ranked first and the attribute with the lowest × C last.

Table 5-7: Example of prioritisation matrix using the paired comparisons technique for ranked weighting.

Effect	Human toxicity	Ecotoxicity	Ozone depletion	Global warming	Acidification	Photochemical ozone creation	Eutrophication	× C
Human toxicity	1	1	3	7	9	9	9	39
Eco toxicity	1	1	3	7	9	9	9	39
Ozone depletion	1/3	1/3	1	7	7	1	1	17.7
Global warming	1/7	1/7	1/7	1	3	1	1	6.4
Acidification	1/9	1/9	1/7	1/3	1	1	1	3.7
Photochemical ozone creation	1/9	1/9	1/1	1/1	1/1	1	1	5.2
Eutrophication	1/9	1/9	1/1	1/1	1/1	1/1	1	5.2

To assist in the judgement of relative importance Saaty developed a fundamental scale, as shown in Table 5-8. Saaty here uses a scale from 1 to 9 instead of 0 to 1. The fundamental scale is a scale of absolute numbers used to assign numerical values to the judgements made between to attributes (or alternatives). The use of the scale is shown in Table 5-7.

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Table 5-8: The fundamental scales of the pair wise comparisons (Saaty, 1994).

Intensity of importance	**Definition**	**Explanation**
1.0	Equal importance.	Two activities contribute equally to the objective.
3.0	Moderate importance.	Experience and judgements slightly favour one activity over another.
5.0	Strong importance.	Experience and judgement strongly favour one activity over another.
7.0	Very strong demonstrated importance.	An activity is favoured very strongly over another. Its dominance is demonstrated in practice.
9.0	Extreme importance.	The evidence favouring one activity over another of the highest order of affirmation.
2.0, 4.0, 6.0, 8.0	For compromise between the above values.	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to describe it.
Reciprocal of above	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal valued when compared to i.	A comparison mandated by choosing the smaller elements as the unit to estimate the larger one as a multiple of that unit.
Rationales	Ratios arising from the scale.	If consistency were to be forced by obtaining n numerical values to span the matrix.
1.1-1.9	For tied activities.	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9.

Direct rating involves the distribution of 100 points over the criteria. The number of points for each criterion then represents their relative importance.

Ratio estimation, described by Edwards (1982), also starts with ranking the attributes in order of importance. The least important attribute is assigned a value of 10. The decision maker then estimates the relative importance between the attributes by assigning a numerical value to the next attribute on the list. This value is set according to how much more important he/she thinks that this attribute is, relative to the least important attribute. If two attributes are regarded as equal, they receive equal values.

Paired comparisons are used to derive weights as shown in Table 5-9. Here the simplified eigenvector method is used to derive the prioritisation (Yoon et al., 1995):

Step 1: Input coding

> The upper or the lower corner of a decision matrix is filled with judgements, and the rest of the matrix is calculated by employing the reciprocal property of the matrix.

Step 2: Computing

> The geometric means are calculated for each attribute. The geometric means are then normalised to reach a priority rating.

Table 5-9: Example of prioritisation matrix using the paired comparisons technique for ratio weighting.

Effect	**Human toxicity**	**Ecotoxicity**	**Ozone depletion**	**Geometric mean**	**Priority**
Human toxicity	1	1	3	1.44	0.43
Eco toxicity	1	1	3	1.44	0.43
Ozone depletion	1/3	1/3	1	0.48	0.14
			Sum	3.37	1.00

It is clear that such prioritisation can lead to inconsistency if the decision maker is in some doubt of his/her prioritisation. A matrix is only consistent if λ_{max} = n. In addition, we will always have $\lambda_{max} \geq$ n. The deviation of λ_{max} from n is a deviation from consistency, and can be represented by Equation 5-11.

$$C.I. = \frac{\lambda_{\max} - n}{n-1}$$

Equation 5-11

Where

C.I. = Consistency Index

λ_{max} = the largest eigenvalue of the matrix A'

n = order of matrix

When C.I. is calculated, it can be compared to the same index for a randomly generated reciprocal matrix from the scale 1 to 9, with forced reciprocals. The index of the random matrix is called the random consistency index; R.I. Different R.I.s are presented in Table 5-10.

Table 5-10: The order of the matrix and the average Random Consistency Index (R.I.) (after Saaty, 1994).

n	1	2	3	4	5	6	7	8	9	10
(R.I.)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The ratio of C.I. to the average R.I. for the same order matrix gives the consistency ratio; C.R, see Equation 5-12. The consistency ratio should, according to Saaty (1994) be of 0.1 or less to be a positive evidence of informed judgement.

$$C.R. = \frac{C.I.}{R.I.}$$

Equation 5-12

Following the example shown in Table 5-7, the consistency ratio is 0 ($\lambda_{max} = 3$). This confirms that the matrix is consistent. This consistency check may also be used for the ranking method presented in the previous section.

Swing weighting involves defining how much one attribute contributes to the overall value of the alternative, relative to other attributes. The name of the method refers to the situation that the alternatives compared "swing" between the worst and the best levels for each attribute. It is estimated which of the swings that contributes more in overall value, then it is assessed to which extent the values of the "swings" differ. This way the weights are determined by matching the strength of preference in one attribute to the strength of preference in another.

Trade off exercises might be used to verify the relative degree of importance of the attributes. For example, it may be decided that one attribute is more important than the others, and a trade off diagram is constructed to compare this attribute to the other attributes. It is considered how much of the attribute value that can be sacrificed in order to improve the value of a less important one.

5.1.5 Weighting procedure to be used in the MaSe system

Weights developed using rank weighting are at the best approximations. The rank weighting methods have been criticised because they assume that the decision maker is able to adjust the importance judgements in relation to the scales. This will also be the case for paired comparison, but some of the problems are solved using the fundamental scales developed by Saaty (1994), and the described consistency check. Direct rating is very simple, but gives less precise answers than all the other methods. It is also a rarely used method. Finally, swing weighting is a more demanding procedure, but will probably produce more precise results that the other three methods.

Evaluating the pros and cons of the different methods, using pair wise comparisons and consistency checks, SAW and AHP are the best alternatives. They are more precise than the direct rating, and not as demanding as the swing weighting process. It is also assumed that the potential user of the MaSe system easier accepts this process. AHP is preferred because of the hierarchical structure.

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A weighting procedure is a learning process. Important aspects for a weighting procedure are that it is easy to understand and use for non-experts. In addition, the information supplied to the decision maker, and the knowledge he/she has about the different aspects, is important for the result of the weighting procedure. Information on environmental effects can be presented for example as abatement cost, costs related to the caused effects or level of damage expressed as number of species affected. However, the cost information related to the different environmental effects is very limited. In addition, the level of damage caused by emissions is disputed. The information about the level of damage that can be related to different effects is often inadequate, inconsistent, or it does not exist.

It is important that the amount and level of information are the same for the different effects. Excessive information about some effects can lead the decision maker to the conclusion that this effect is more important than others with less information. All effects should therefore be presented with a qualitative description including the consequences that can be seen in Norway and on a global scale. If data on the extent of the effect exists, this should be presented, but one should be careful with cost estimates. First these estimates are highly unreliable. Second, such information by many decision makers may be found to be weightier than other types of less quantified information. See Appendix A for illustration of the weighting procedure.

For the user of the MaSe system to develop his/her own weight set, he/she is guided through the procedure of ranking using paired comparisons. The paired comparison is at two levels: between the main areas “Resources”, “Human health“, and “Ecological effects”, and between the parameters under the different main areas. The main area weighting-matrix is shown in Equation 5-13. The weighting matrix for the resource parameters energy, raw materials and waste is illustrated in Equation 5-14. The ecology parameters are presented in Equation 5-15, while the human health parameters are compared in Equation 5-16.

$$\begin{pmatrix} 1 & w_{HH}/w_{EE} & w_{HH}/w_{R} \\ w_{EE}/w_{HH} & 1 & w_{EE}/w_{R} \\ w_{R}/w_{HH} & w_{R}/w_{EE} & 1 \end{pmatrix}$$

Equation 5-13

Where

w_{HH}= Importance of Human health area

w_R = Importance of the Recourse area

W_E = Importance of the Ecology area

$$\begin{pmatrix} 1 & w_{E}/w_{Rm} & w_{E}/w_{W} \\ w_{Em}/w_{E} & 1 & w_{Rm}/w_{W} \\ w_{W}/w_{E} & w_{W}/w_{Rm} & 1 \end{pmatrix}$$

Equation 5-14

Where

w_E = Importance of Energy resources

w_w = Importance of Waste

w_{Rm} = Importance of Raw material resources .

$$\begin{pmatrix} 1 & w_{E-tox} / W_{GWP} \\ w_{GWP} / w_{E-tox} & 1 \end{pmatrix}$$

Equation 5-15

Where

w_{E_tox} = Importance Ecological toxicity.

w_{GWP} = Importance of Global warming (GWP).

$$\begin{pmatrix} 1 & w_{H-tox} / W_P \\ w_P / w_{H-tox} & 1 \end{pmatrix}$$

Equation 5-16

Where

w_P= Importance of Pollution to indoor environment.

w_{H-tox} = Importance of Human toxicity

The user should be able to choose between the following sets of weights:

- Expert panel derived weights.
- Equal weighting.
- User defined weights.

The expert panel weights should be derived through a careful process involving representatives from different areas. The process of obtaining these weights is not included in this study. For information on methodology, it is referred to Hwang et al. (1987) and Brunner (1998).

5.2 Main results of the MaSe system

The results from each sub area are weighted into one index, referred to as the environmental index; this is the main result from the evaluation. Each material is then characterised with a score and a judgement defined in Table 5-4, as seen in Figure 5-9. Equal weighting between the main areas is the default in the system, but the user might change these weights according to the needs in each building project. In future, an expert panel weight set should be included.

In Figure 5-9, plaster board is evaluated to an index of 4.6, which results in the judgement Borderline fair. The scoring refers to the left y-axis, and the y-axis to the right represents the NPV expressed in NOK per FU.

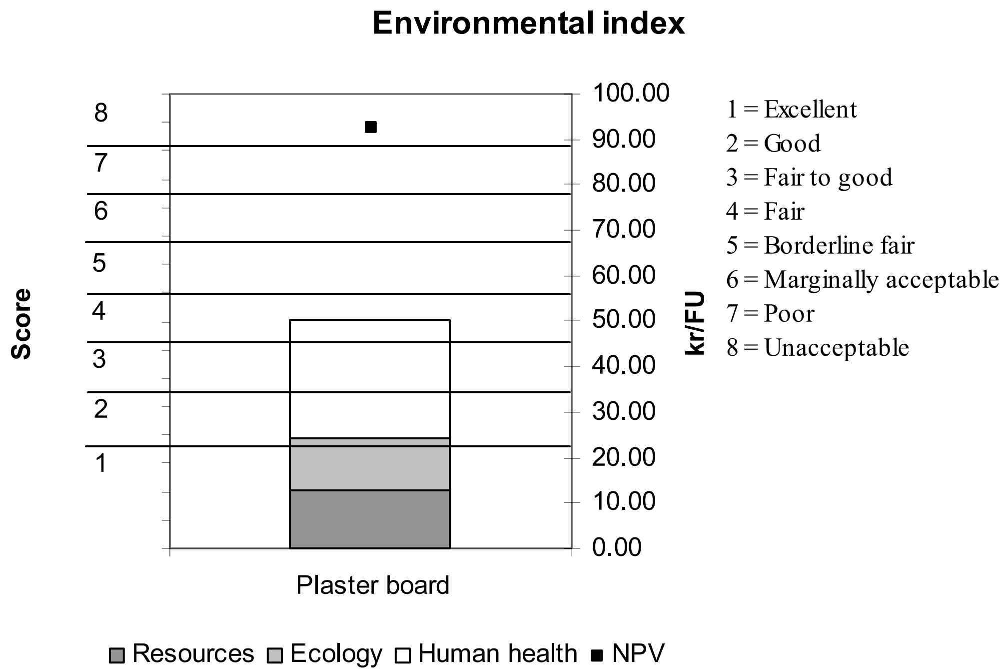

Figure 5-9: The MaSe Environmental index for an example material.

Table 5-11 illustrates the evaluation procedure for the main areas, sub areas and parameters in the MaSe system. The information is aggregated from the left to the right in the table. The different aggregation steps are described in the following chapters.

Table 5-11: Summary table of parameters and evaluation steps in the MaSe system.

Parameter	Combined scoring	Classification of main areas	Total classification
Raw materials type	"Raw material"	"Resources"	"Environmental index"
Energy type	"Energy"		
Energy amount			
Waste handling	"Waste"		
Waste amount			
Global warming	"Ecology"		
Eco-toxicology			
Human toxicity	"Human toxicity"	"Human health"	
Depot effect dust	"Pollution"		
Depot effect gases			
Emission of gases			
Emission of particles and fibres			
Purchase	("Economy")		Net Present Value (NPV)
Transport to building site			
Construction			
Maintenance and Management			
Demolition			
Waste treatment			
Residual value			
Transport to waste handling site			

5.3 Evaluation of resources

The evaluation of the resource use related to a material or a product includes aspects like raw material use, recycling, energy use, materials for maintenance, durability, re-use etc. A list of parameters to be evaluated has been made, based on literature studies, existing evaluation systems and requirements from the industry and the government. A set of score charts with belonging criteria, as illustrated in Table 5-4, needs to be identified for the different parameters. Sources of information are other material

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evaluation methods and LCA methods. The following parameters should be evaluated for all lifecycle phases:

– Use of raw material resources.
– Use of energy resources.
– Production f waste.

5.3.1 Material evaluation methods and their evaluation of resource use

Different material evaluation systems and other sources of information are studied to find a suitable method to define the criteria in the score charts for the parameters.

BEES, presented in Chapter 4, uses a scarcity evaluation based on the US Department of the Interior, Bureau of Mines (Lipiatt, 1998). These estimates of availability are hampered with many factors of uncertainty, and it is decided not to include such detailed assessment of scarcity in the MaSe system.

In the “Guide for material selection”, another approach is selected to evaluate the resource use. The system is very simple, and based on a set of qualitative criteria that classifies the materials in four classes, described in **Table 4-2**. The materials are subjectively evaluated after these criteria.

The “Environmental Resource Guide” (ERG), also includes resource depletion, but only as virgin resource depletion. The impact assessment in ERG does not include a quantitative characterisation process that associates a specific level of impact with a given parameter in the material life cycle. Both quantitative and qualitative information is used to identify and classify the different impacts. Resource depletion, process energy, transport energy, effects on operational energy, durability, reusability and recycleability are impact categories included in the evaluation. Experts perform the evaluation, and determine the relative performance of a material by classifying the impact categories from “good” to “poor”. No information is given on how these experts perform this evaluation. The “Handbook of sustainable building”, also uses a subjective evaluation by experts to classify the materials. Shortage of raw materials, energy, water and waste are the resource relevant parameters included in this system.

5.3.2 LCA weighting methods and their valuation of resources

LCA related methods that evaluate resource use are the EPS system, Eco-scarcity, Eco-cost/Value ratio, UMIP (**U**dvikling af **M**iljøvennlige **I**ndustri**P**rodukter/development of environmental friendly industrial products) and EcoIndicaor’99. In Chapter 3, it was concluded that a detailed evaluation of the scarcity of the different recourses are uncalled for. As LCA is a quantified method, these methods are based upon some type quantified scarcity evaluation. The methods will not be described in detail, but it is interesting to see the basic principle used in the different methods, a simple listing of the methods is therefore provided:

ь The EPS system (Steen, 1995), (described in Chapter 4.2.2) is based on known resources that can be utilised with today’s technology. These are valued according to the Willingness To Pay (WTP) to restore it to a “Reference state”. Most likely the WTP today is nil, but this value may increase as the metal concentration in the ores decreases. For the loss of natural resources, actual commodity prices are used.

- The EcoScarcity method calculates the Ecofactor related to the use of resources based on the extent of natural resources that can be extracted as an input to the civilisation system (Nordic Council of Ministers, 1995).
- The UMIP method used in BEAT2001 is based on an evaluation of the depletion horizon with today's consumption (Wenzel et al., 1996).
- The EcoIndicator'99 (Goedkoop et al., 2000a), values the marginal effects of today's extraction of resources. The primary assumption behind this method is that if the resource quality is reduced, the effort needed to extract the remaining resources increases. Depletion of resources is specified as MJ surplus energy. The surplus energy is the difference between the energy needed to extract a resource now and at some point in the future.

5.3.3 Evaluation of Resources in the MaSe system

As seen in sub-chapters 5.3.1 and 5.3.2, there are many alternatives for evaluating the resource use related to a product. The underlying theory of the methods varies. The following solutions are used in the existing methods:

1. Scarcity evaluation based on estimated reserves (UMIP, BEES).
2. Scarcity evaluation based on economic aspects like the willingness to pay based on commodity prices (EPS).
3. Scarcity evaluation based on marginal effects like surplus energy (EcoIndicator'99).
4. A set of qualitative and/or qualitative criteria as basis for classification (ERG and Handbook of sustainable building).

In light of the conclusion on the scarcity discussion in Chapter 3.2, the fourth method is relevant for the MaSe system.

In Chapter 3, it was also found that the Norwegian authorities have expressed wishes to increase the re-use and the recycling to reduce the load on the world's resources. Products made from renewable resources, products that facilitate re-use or recycling, products made from recycled materials, biological diversity and energy use in materials, are identified areas of importance to the authorities. Internationally, the focus is set on biological diversity. The degree of scarcity of the different materials used is not in particular focus. This last aspect, together with the previously mentioned drawbacks linked to the scarcity evaluation methods, leads to the conclusion that a set of qualitative and quantitative criteria is considered to be the best solution.

SCORE CHARTS

The score chart described in Chapter 5.1.2 enables the inclusion of different types of evaluation criteria, both qualitative and quantitative. The criteria used in the MaSe system, are based on the previous chapters, describing needs for changes in the building and real estate industry and existing methods. Scoring is performed for the following parameters in production, use and disposal:

- Raw material types.
- Energy type.
- Amount of energy used.
- Handling of waste.
- Amount of waste produced.
- How the waste is disposed of.

The score chart in Table 5-12 shows a scoring method for qualitative criteria, where the different resource types are given scores from 1 to 8. To be classified as “Excellent”, the material must be reused. Further, recycled materials are judged as “Good”, down cycled materials as “Fair to good”, sustainable renewable materials as “Fair”, non-renewable virgin materials as “Borderline fair” and unsustainable renewable raw materials are considered to be “Unacceptable”.

Table 5-12: Example of score chart for parameter “raw material type”, Score_{RmT}.

Score_{RmT}	Judgement	Criterion: Raw material type
1	Excellent	Reuse
2	Good	Recycled
3	Fair to good	Down cycled
4	Fair	Sustainable renewable
5	Borderline fair	Non-renewable
6	Marginally acceptable	-
7	Poor	-
8	Unacceptable	Unsustainable renewable

In Table 5-13 the amount of energy used, is scored relative to a reference product. This reference could be either a selected product in each building project, a product that is the common for a specific purpose, the worst-case product or an average value. An average value for each attribute based on the materials registered in the database is considered as the best solution in the MaSe system. If the reference were set to be the average value for each attribute, the best attainable score would be zero per cent of this value. The criterion for being assigned the lowest score is that the attribute performance is 190-200 per cent higher than the average value. The classification between these two extremes has two aims, to separate the different materials into different classes and especially to differentiate between the best and the worst materials. See Figure 5-10 for illustration of the size of the intervals.

The parameter “energy amount” in the production phase includes all energy input in all processes involved until the product is at the “gate”, hence “cradle to gate” data. This amount is then divided by the durability of the function to be fulfilled. Scoring of the energy amount is also performed for the user phase, for the demolition/rehabilitation of the building and for the whole lifecycle.

Table 5-13: Example of score chart of the parameter "energy amount", $Score_{EA}$.

$Score_{EA}$	Judgement	Criterion: Use of energy (kWh/FU)
1	Excellent	Ò10% of reference value
2	Good	10 %< AND Ò40% of reference value
3	Fair to good	40 %< AND Ò70% of reference value
4	Fair	70 %< AND Ò100% of reference value
5	Borderline fair	100 %< AND Ò130% of reference value
6	Marginally acceptable	130 %< AND Ò160% of reference value
7	Poor	160 %< AND < 190% of reference value
8	Unacceptable	Ó190 % of reference value

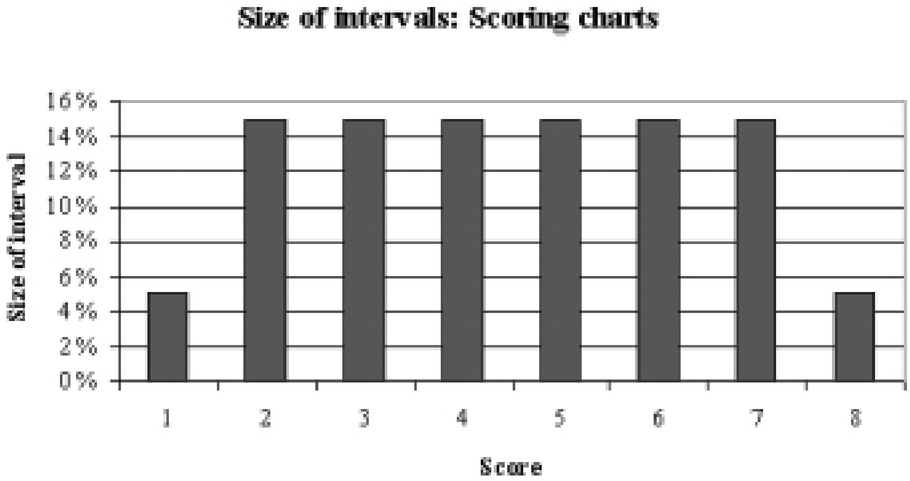


Figure 5-10: The scoring intervals, used in the score chart.

The energy sources are scored relative to each other based on availability, as seen in Table 5-14. Renewable sources include energy from the sun, wind, wave and tidal currents, geothermal and ambient heat. These energy sources can be exploited with today's technology. In the US, geothermal energy is theoretically available in quantities that are thousands of times higher than the energy contained in domestic coal reserves (Sagoff, 2000). In addition, for the exploitation of solar power, Brown (1991), states that "*technologies are ready to begin building a world energy system largely powered by solar resources*".

Hydropower is also defined as a renewable energy source, but considered less available than other sources, because the exploitation potential is limited. The next step is bio fuels, which include chips, wood and waste. These are also renewable energy sources, but less available than the two foregoing groups. Finally, coal is considered slightly better than oil and natural gas, because the supply horizon is longer, 224 years, compared to 42 years for oil and 62 years for gas, with today's identified reserves and consumption (Norwegian Public Reports, 1998).

Nuclear energy is also an available energy source. Known uranium sources represent over 70 years of current consumption (Nuclear Energy Agency, 2000). Uranium is abundant in the earth crust, and conventional resources are estimated to represent some 250 years of current consumption. If unconventional resources are included, as marine phosphates and seawater, this number increases by two orders of magnitude. Uranium access is good and the resources are distributed all over the world.

Globally, the nuclear energy share of energy consumption is about 7 per cent, and this share is assumed to fall to 5 per cent within 2030 (International Energy Agency, 2002). In OECD countries, 15 per cent of the energy demand is covered by electricity produced from nuclear power plants. In the last years, the trend in North America and Europe is that nuclear power plants are closed down because of the risk they impose. Important key words are radioactive waste, transport of radioactive substances, production of radioactive material that might be used in nuclear weapons, and the risk of serious accidents like Windscale, Three Mile Island and Tsjernobyl. However, there are exceptions, Finland has recently decided to build a new nuclear power plant, and the nuclear power industry in Japan, South Korea and China is growing.

Objectively seen nuclear power may be a good alternative for replacing fossil energy in western countries where the necessary security measures are taken seriously. In Norway, it is stated by the government that nuclear power is not an acceptable energy source, and no nuclear power plants are to be built in Norway (Ministry of Petroleum and Energy, 1998). In the MaSe system, nuclear energy is therefore placed in the category “unacceptable”, together with fossil energy.

Because a product often is produced using different sources of energy, the score must be calculated according to the energy mix. For the plaster board example, this product uses 12 per cent hydropower, 18 per cent energy from waste combustion and 70 per cent oil in the production process. The calculation is shown in Table 5-14 is as follows: 0.12*3 + 0.18*4 + 0.70*8 = 6.7 (“Poor”).

Table 5-14: Scoring according to energy sources used in production, use and disposal.

$Score_{ET}$	**Judgement**	**Criteria**	**%**
1	Excellent	Renewable energy	
2	Good	-	
3	Fair to good	Hydropower	12 %
4	Fair	Biofuels	18 %
5	Borderline fair	-	
6	Marginally acceptable	-	
7	Poor	Coal	
8	Unacceptable	Oil, natural gas, nuclear energy	80 %
		Average score	6.7

Waste is also an important aspect of resource use. Waste is covered using two parameters, waste type and waste amount. These parameters are scored using the score charts illustrated in Table 5-15 and Table 5-16. In Table 5-15 the different types of waste are scored according to the form of treatment. Reuse is the best way to exploit the waste produced. Recycling is the second best alternative. Down cycling, is where the materials are recycled to a simpler form of use. Examples are concrete crushed and used for filling ditches, newspapers turned into toilet paper, and crushed asphalt used in road base. The characteristic factor in down cycling, as opposed to recycling, is that the material properties requirements are lower in a product resulting from down cycling than in the original product. The economic value of the material is in all cases reduced. Recycling requires that the material properties be maintained in the new product, together with the economic value.

Energy recovery is from a resource perspective a poorer solution compared to recycling and down cycling. The materials contribute with a certain amount of energy, but then they are lost. Deposition is placed in the category "poor" and special waste handling is placed in the least wanted category, "unacceptable".

The following types of special waste may be found in buildings: tar and tar-products, insulation materials containing asbestos, all materials that contain over 0.005 per cent PCB, un-tempered paint and fluorescent tubes that contain mercury (Ministry of Environment, 1994). A new "List of Wastes" is now on hearing, based on the new European classification of waste, and EU's new "List of Waste". The building and real estate industry will be affected by the new regulations with 15 new entries on the list. Appendix F gives the different categories of special waste according to the EU "List of Waste". This new list includes the term "dangerous substances". This term is defined in the regulations for classification and labelling of dangerous chemicals (State Pollution Agency, 2002b).

Table 5-15: Scoring according to waste type in production, use and disposal.

Score$_{WT}$	**Judgement**	**Criteria**	**%**
1	Excellent	Reuse	
2	Good	Recycling	
3	Fair to good	Down cycling	
4	Fair	Energy recovery	
5	Borderline fair	-	
6	Marginally acceptable	-	
7	Poor	Deposit	100 %
8	Unacceptable	Hazardous waste treatment	
		Score	7

As for energy, the amount of waste produced is also included in the evaluation. This is done the same way as for energy. In the production of plaster board waste is used in 100 per cent is deposited, resulting in the score “Poor”.

Table 5-16: Scoring according to waste amount in production, use and disposal.

Score$_{WA}$	Judgement	Criterion: Amount of waste (kg/FU)
1	Excellent	Ò10% of reference value
2	Good	10 %< AND Ò40% of reference value
3	Fair to good	40 %< AND Ò70% of reference value
4	Fair	70 %< AND Ò100% of reference value
5	Borderline fair	100 %< AND Ò130% of reference value
6	Marginally acceptable	130 %< AND Ò160% of reference value
7	Poor	160 %< AND < 190% of reference value
8	Unacceptable	Ó190 % of reference value

The durability of a product is included in the Functional Unit, but not as a separate attribute (see Chapter 6). The function the different materials is the basis for the evaluation in the MaSe system. If the durability of the product is equal to or longer than the service life of the building, then no replacements are needed, and the product is assumed reused, recycled or deposited after use. If the durability of a product is shorter than the service life of the building, it must be replaced. And the load from the replacement is added in the user phase.

All the scored parameters in the resource area are summarised in one table, as shown in Table 5-17.

Table 5-17: The nomenclature of the scored parameters in the area “Resources”.

Phase Parameter	Production	Use	Disposal	Total
Raw material type	Score $_{\text{RmT-Production}}$	Score $_{\text{RmT-Use}}$	Score $_{\text{RmT-Disposal}}$	Score $_{\text{RmT-Total}}$
Energy type	Score $_{\text{ET-Production}}$	Score $_{\text{ET-Use}}$	Score $_{\text{ET-Disposal}}$	Score $_{\text{ET- Total}}$
Energy amount	Score $_{\text{EA-Production}}$	Score $_{\text{EA-Use}}$	Score $_{\text{EA-Disposal}}$	Score $_{\text{EA- Total}}$
Waste handling	Score $_{\text{WT-Production}}$	Score $_{\text{WT-Use}}$	Score $_{\text{WT-Disposal}}$	Score $_{\text{WT- Total}}$
Waste amount	Score $_{\text{WA-Production}}$	Score $_{\text{WA-Use}}$	Score $_{\text{WA-Disposal}}$	Score $_{\text{WA- Total}}$

COMBINED SCORING

To find the total score for the parameter “Energy use”, Score$_{E}$, the two scores for “Energy type”, Score$_{ET}$, and “Energy amount”, Score$_{EA}$, are multiplied and classified according to a set of classification criteria showed in Table 5-19. The same is done for waste, illustrated in Table 5-20. The classification criteria in Table 5-19 and Table 5-20 are set according to the following objectives:

ь To separate the best and worst material.

ь To distribute the rest among the 6 other groups.

Table 5-18: Classification criteria to reach a combined score for the use of energy.

Score	Judgement	Interval: $Score_{EA}$*$Score_{ET}$
1	Excellent	1ÒScore < 3.2
2	Good	3.20ÒScore < 12.8
3	Fair to good	12.80 ÒScore < 22.4
4	Fair	22.40 ÒScore < 32
5	Borderline fair	32.00 ÒScore < 41.6
6	Marginally acceptable	41.60 ÒScore < 51.2
7	Poor	51.20 ÒScore < 60.8
8	Unacceptable	60.80 ÒScore

Table 5-19: Combined scoring and classification criteria for use of energy.

Use of energy; $Score_E$	Amount of energy used, $Score_{EA}$	Ò10% of reference value	10 < AND Ò40% of reference value	40 < AND Ò70% of reference value	70 < AND Ò100% of reference value	100 < AND Ò130% of reference value	130 < AND Ò160% of reference value	160 < AND < 190% of reference value	Ó190 % of reference value				
Energy type, $Score_{ET}$	**Score**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Judgement**	**Score**	**From**	**To**
Renewable energy	**1**	1	2	3	4	5	6	7	8	*Excellent*	**1**	1	1.9
-	**2**	2	4	6	8	10	12	14	16	*Good*	**2**	1.95	8.9
Hydropower	**3**	3	6	9	12	15	18	21	24	*Fair to good*	**3**	8.95	19.2
Biofuels	**4**	4	8	12	16	20	24	28	32	*Fair*	**4**	19.25	32.0
-	**5**	5	10	15	20	25	30	35	40	*Borderline fair*	**5**	32.05	44.8
-	**6**	6	12	18	24	30	36	42	48	*Marginally acceptable*	**6**	44.85	55.0
Coal	**7**	7	**(14)**	21	28	35	42	49	56	*Poor*	**7**	55.05	62.1
Oil, gas, nucl. energy	**8**	8	16	24	32	40	48	56	64	*Unacceptable*	**8**	62.15	64

Table 5-20: Combined scoring and classification criteria for the production and handling of waste.

Production of waste; $Score_W$	Amount of waste; $Score_{WA}$	Ò10% of reference value	10 < AND Ò40% of reference value	40 < AND Ò70% of reference value	70 < AND Ò100% of reference value	100 < AND Ò130% of reference value	130 < AND Ò160% of reference value	160 < AND < 190% of reference value	Ó190 % of reference value				
Waste handling; $Score_{WH}$	**Score**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Judgement**	**Score**	**From**	**To**
Reuse	**1**	1	2	3	4	5	6	7	8	*Excellent*	**1**	1	1.9
Recycling	**2**	2	4	6	8	10	12	14	16	*Good*	**2**	1.95	8.9
Down cycling	**3**	3	6	9	12	15	18	21	24	*Fair to good*	**3**	8.95	19.2
-	**4**	4	8	12	16	20	24	28	32	*Fair*	**4**	19.25	32.0
Energy recovery -	**5**	5	10	15	20	25	30	35	40	*Borderline fair*	**5**	32.05	44.8
-	**6**	6	12	18	24	30	36	42	48	*Marginally acceptable*	**6**	44.85	55.0
Deposit	**7**	7	14	21	28	35	42	49	56	*Poor*	**7**	55.05	62.1
Hazardous waste treatment	**8**	8	16	24	32	40	48	56	64	*Unacceptable*	**8**	62.15	64

After the combined scoring, the result is presented as seen in Table 5-21. The next step, Classification, will develop more details about the materials, and form the basis for comparison. The score for the total lifecycle is calculated the same way as for the different lifecycle phases.

Table 5-21: Un-weighted results from the combined scoring of the different attributes of the plaster board example.

Results combined scoring: Sub area:	Production	Use	Disposal	Total lifecycle
Raw materials	4	-	-	4
Energy	3	4	4	3
Waste	3	1	5	5

CLASSIFICATION

The results from the combined scoring are summarised into one class for resource use. The same is done for the total lifecycle.

Some users might wish to include weighting between the sub-areas Raw materials, Energy, and Waste. As concluded in Chapter 5.3.3, the user must set individual priorities. By default, the sub-areas are weighted equally, as seen in Table 5-22.

Table 5-22: Sub-area default weights in the MaSe system.

Parameters	**Production**	**Use (incl. transport and construction)**	**Disposal**	**Total**
Raw material resources	0.33	0.33	0.33	0.33
Energy resources	0.33	0.33	0.33	0.33
Waste production and handling	0.33	0.33	0.33	0.33

The score for Resources for the total lifecycle of the material or product is calculated using **Equation 5-17**.

$$Class_{Resources} = \sum_i Score_i * Weight_i =$$
$$Score_{RmT} * 0.33 + Score_{Energy} * 0.33 + Score_{Waste} * 0.33$$

Equation 5-17

Where

$Class_{Resources}$ = Class for Recourses

i = sub area

$Score_{Rm-T}$ = Score for Raw material type, Table 5-12

$Score_{Energy}$ = Score for Energy resources, Table 5-19

$Score_{Waste}$ = Score for Waste, Table 5-20.

The evaluation result of the resource related aspects for plaster board is illustrated in Figure 5-11. The result might also be displayed per lifecycle phase, but this is not included in the system at this stage. The total lifecycle score for Recourses in the example is 0.33*4 + 0.33*3 + 0.33*5 = 4, which equals the judgement “Fair”.

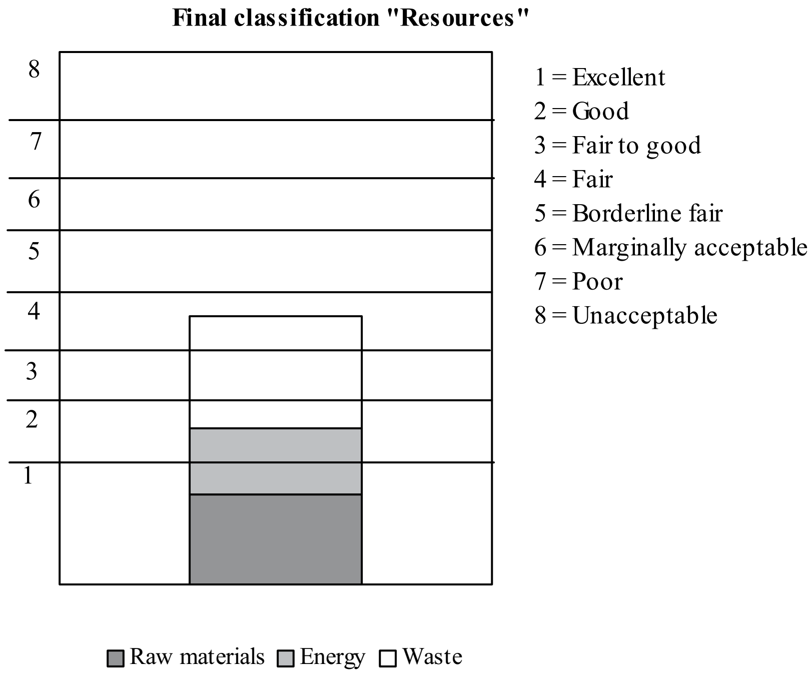


Figure 5-11: Illustration of the results after the weighting of the sub-area scores and the final classification of the main-area Resources, $Class_{Resources}$, for the plaster board example. This is the result for the total lifecycle of plaster board.

Other available information includes information about resource use per lifecycle phase, energy use per lifecycle phase and waste production and handling per lifecycle phase, as illustrated in Figure 5-12. The results are here presented per FU and lifecycle phase, compared to a reference value represented by the average of the total lifecycle for all the functionally equivalent materials in the MaSe system.

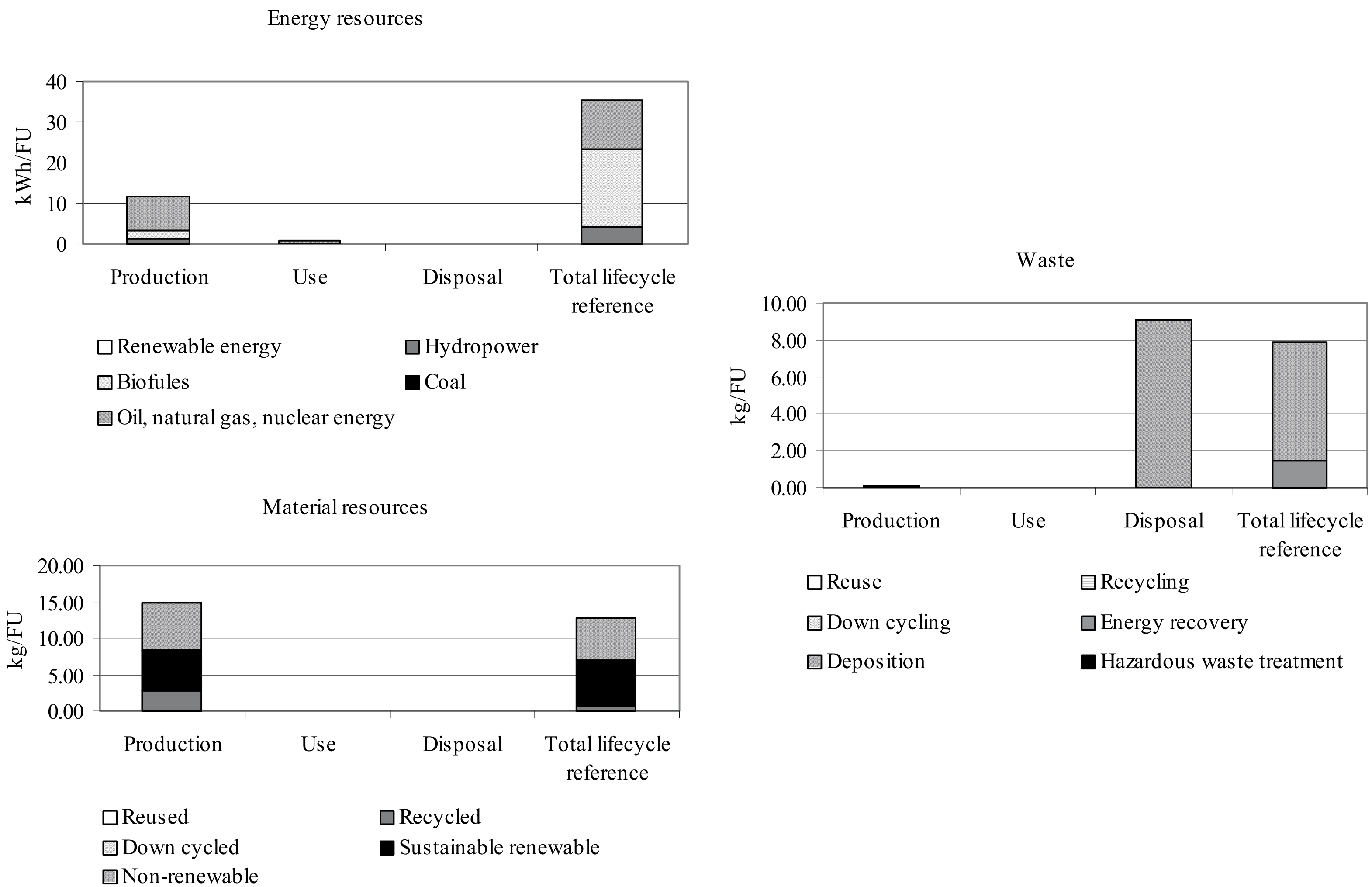


Figure 5-12: Available “in-depth” information about the resource related properties of a material in the MaSe system.

To summarise, the classification of resource use consists of three main steps, as illustrated in Figure 5-13:

1. Scoring of the parameters according to the score charts.
2. Combined scoring.
3. Weighting and classification to reach one single class for resources; $Class_{Resources}$.

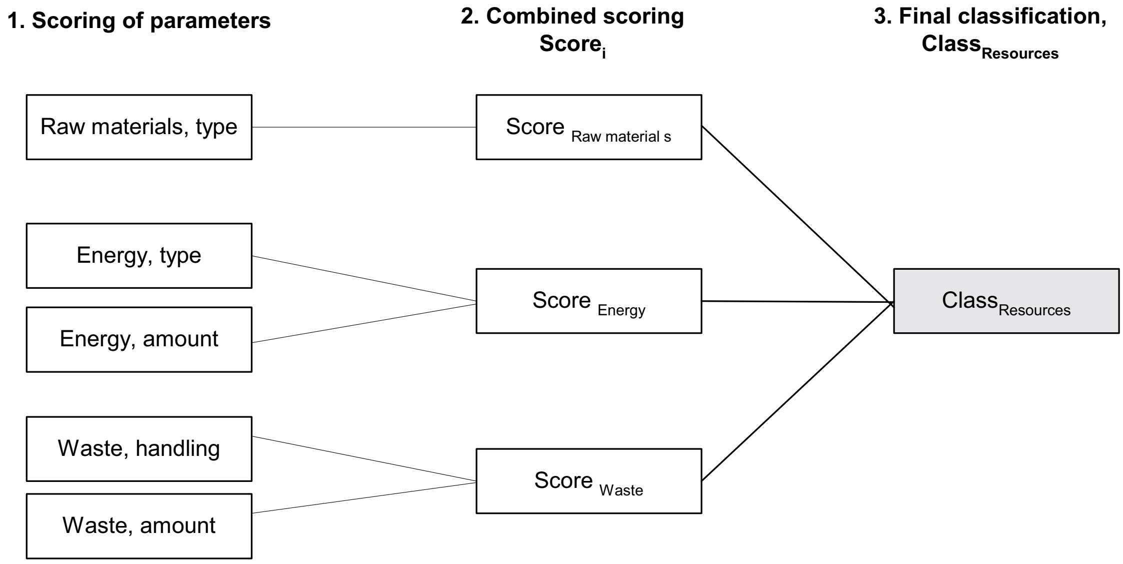


Figure 5-13: Illustration of the classification of resource use.

5.4 Evaluation of ecological effects

It is demonstrated in Chapter 3 that the production and use of building materials lead to ecological effects that must be accounted for. It is for example estimated that the production of building materials in Europe is responsible for 8-12 per cent of the total CO_2 emissions. In addition, there are emissions related to the transport, construction, use and waste handling of these materials. Studying existing material assessments and LCA methods, most of them also include several ecological parameters.

In Norway, it is political agreement upon promoting use of materials that cause less environmental impacts. Climate effects have received much attention in agreements and protocols. Eco-toxicity is receiving increased attention through new regulations, including the Substitution obligation.

Based on previous chapters, it is found that the following parameters need to be evaluated for all lifecycle phases, in order to assess the ecological consequences related to the use of a material or product:

- Climatic change.
- Acidification.

- Photochemical ozone creation potential.
- Eco toxicity.

The different areas are discussed separately. First, a study is performed to see if the GWP may be suited as an index for ecological load.

5.4.1 Global warming as an indicator for evaluating the materials

Global warming is the single most important environmental concern internationally today. For building materials, these gases also represent the largest proportion of the national emissions. For other effects, the proportion related to the production, use and transport of building material is smaller.

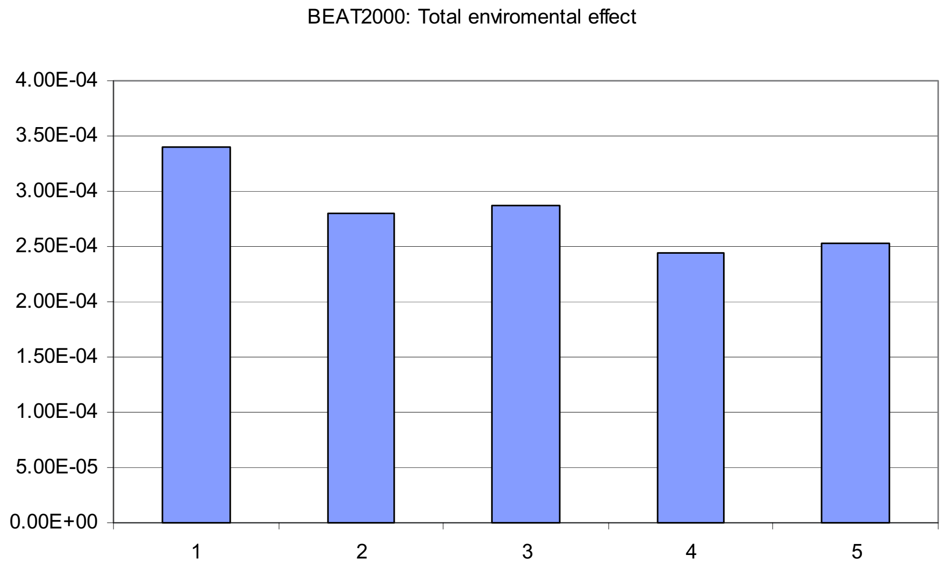
An interesting question whether the building materials with substantial global warming potential also cause large emissions of other substances. Forty-nine material evaluations are carried out using different evaluation systems (all explained in Chapter 4), and 13 comparisons of exchangeable materials were made. Some of the calculations are presented here. It was concluded that there where little correlation between CO_2 emissions and other emissions. However, since gasses with a GWP potential seem to dominate the total emission picture, could it be that GWP can represent the total load from the products?

Studying the overall results, the ranking of the materials was the same in eight of thirteen cases, using CO_2 and the total results as the ranking parameter respectively. In some cases, the results from the evaluations were very close, with only small difference in emissions. With such small differences, a change in the ranking order is likely to occur (three cases), one example is illustrated in Figure 5-14.

In Figure 5-14, different wall construction alternatives have been assessed using the BEAT2001 system from Denmark. The alternatives are:

1. Yellow massive bricks/glass wool/red massive bricks/plaster (108/125/168/10).
2. Plaster/porous concrete/rock wool/porous concrete/plaster (10/100/125/10).
3. Yellow massive bricks/glass wool/porous concrete (108/125/100).
4. Yellow massive brick, wood frame & glass wool/plaster board (108/200 & 200/26).
5. Red massive bricks/rock wool/red massive bricks/plaster (108/125/168/10).

There are very small differences between most of the alternatives and alternative 3 and 4 change places going from “GWP ranking” to “total result” ranking. These two alternatives have insignificant differences in both GWP and the total results.



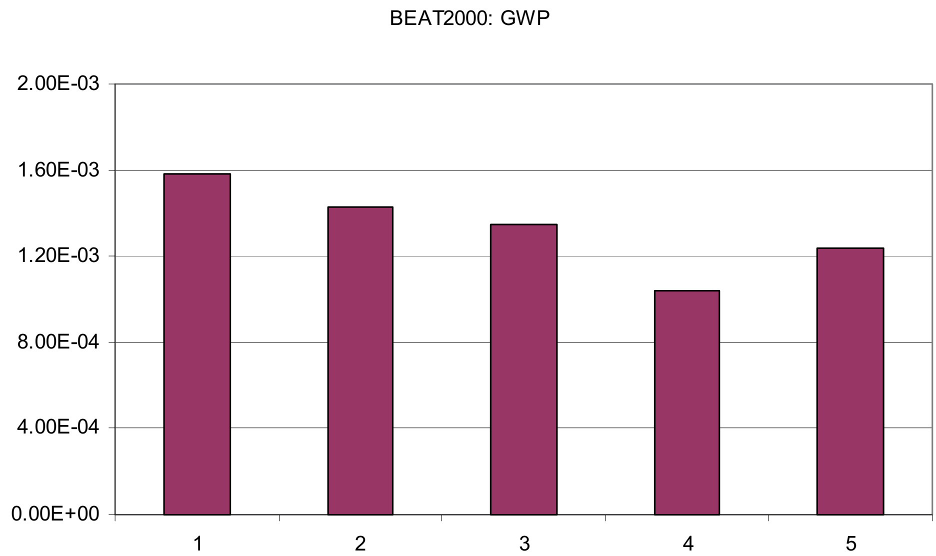
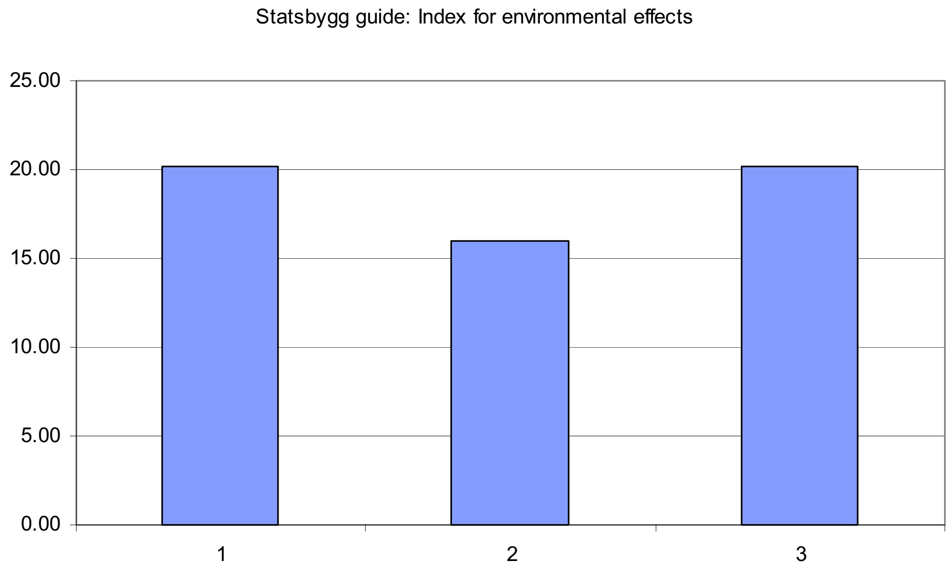


Figure 5-14: The results from the evaluation of different exterior wall alternatives compared to result using only GWP. The calculations are performed using the BEAT2001. Note that the walls have different U-values, so they are not entirely functionally equivalent.

The second evaluation is made using the Statsbygg guide for different roof constructions; the result is presented in Figure 5-15:

1. Pitched, rock wool, edpm (ethylene propylene diene monomer) felt, battens and clay tiles.
2. Pitched, glass wool, felt battens and clay tiles.
3. Pitched, rock wool, edpm felt, battens and concrete tiles.



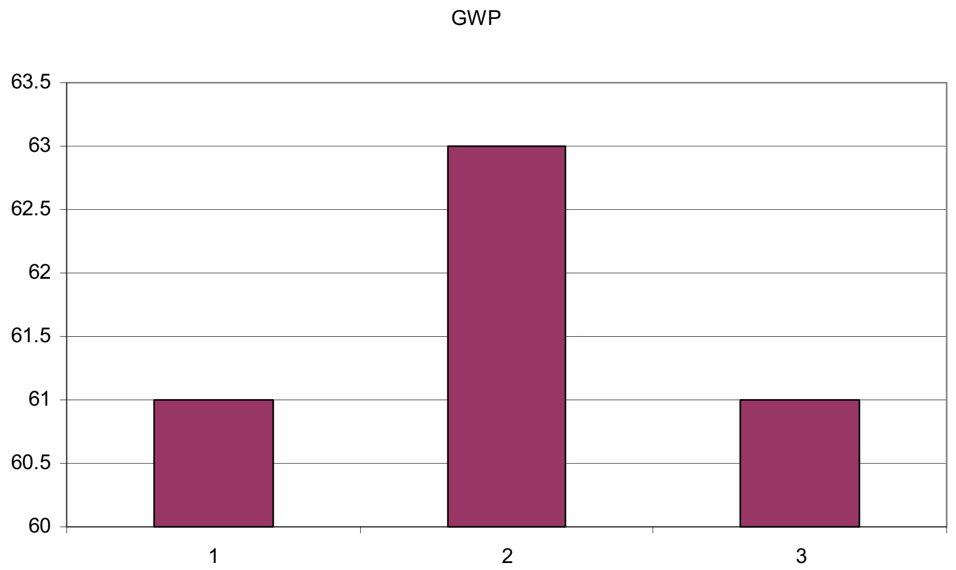


Figure 5-15: The total results from the evaluation of different roof construction alternatives and the results using only GWP. The calculations are made using the Statsbygg guide.

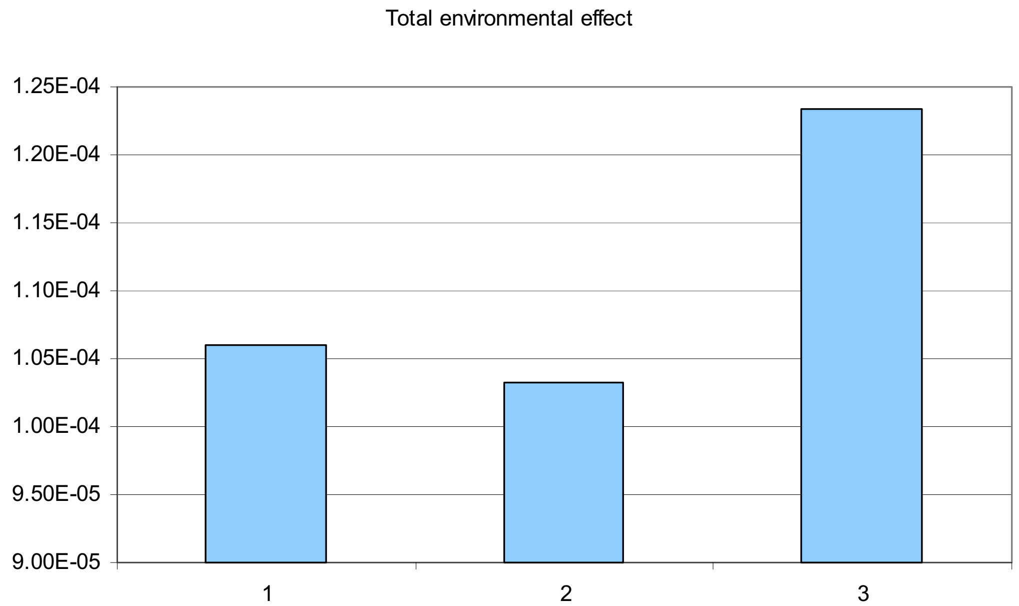
The ranking of the material changed dramatically in two cases shifting from total ranking to GWP ranking, as seen in Figure 5-15. It must be noted that the environmental data used in the Statsbygg evaluation system is data from BRE. Using the BRE Ecopoint calculation method, CO_2 is found to be a satisfactory indicator for the environmental load caused by emissions.

The last study of the possibility of using GWP as an indicator for emission of gasses is made using BEAT2001 to evaluate different slab-on-grade alternatives:

1. Prefabricated, reinforced/glass wool/shingle (100/125/150).
2. Alternative 2: Prefabricated, reinforced/polystyrene/shingle (100/125/150).

3. Alternative 3: Prefabricated, reinforced/rock wool/shingle (100/125/150).

It is seen from the figure that ranks number one and two change places, switching from total environmental effects and GWP ranking.



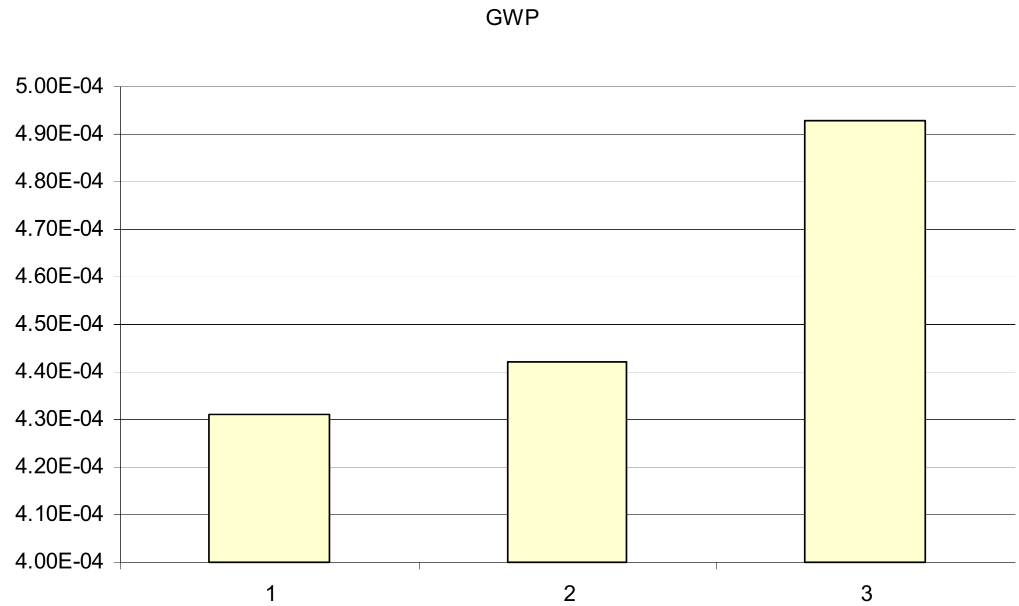


Figure 5-16: The total results from the evaluation of different slab-on-ground alternatives compared to the result using only GWP. The calculations are made using the BEAT2001 system.

The degree of success in using GWP as an indicator depends on the normalisation and weighting factors used in the different systems. The comparison of different roof constructions is illustrated in Figure 5-15, while slab-on-grade alternatives are studied in Figure 5-16. In both cases, rank one and two change places when going from total result ranking to GWP ranking.

It is seen that in the cases where the ranking changes, there are only small differences between the products initially. In the case illustrated in Figure 5-16, 1.2 g CO_2 equivalents per FU represent the difference.

Based on the studied building materials and components, the simplification of replacing the calculations of airborne emissions with only the global warming potential is not 100 per cent correct. However, two important remarks must be made. First of all it is seen that the ranking of the materials is changed not only switching between GWP and total ranking, but also depending on which evaluation method that is used. It is seen that for some systems it could be an acceptable simplification. Second, it is seen from Chapter 3, that for other emissions than CO_2, building materials represent a smaller part of the total emissions. As a first step, GWP is therefore used as an indicator for emissions, except from the emissions with eco toxicological effects. If this is shown to result in misjudgements, the MaSe system is flexible enough to include the other emission factors at a later stage.

5.4.2 Material evaluation methods and their assessment of ecological effects

In order to find an evaluation procedure to be used in the MaSe system, existing methods have been studied. The focus is set on how to express damage to the environment from eco-toxins, as there is more consensus on the Global warming potential as a parameter.

In "Guide for material selection" from Sweden, emissions are evaluated qualitatively with respect to known health risks, and chemicals are evaluated according to the National Chemicals Inspectorates list and the Obs list. This system is the least comprehensive system studied, but the link to the Obs list is interesting.

In ENVEST, eco-toxicity is expressed as m^3 polluted water (m^3 tox). This assessment is based on maximum tolerable concentrations (MTCs) (Heijungs, 1992). Aquatic ecotoxicity is the amount of water necessary to dilute the emission in question into a tolerable concentration. The calculated effect category is normalised to the load from one UK citizen in one year. The normalised effects are then weighted with expert panel derived weights.

5.4.3 LCA and the evaluation of ecological effects

LCA methods are often included in material evaluation, and the different methods are described in Chapter 4. The **E**co-cost/**V**alue **r**atio (EVR) seems like a promising system, but it is not completed to the extent that it can be implemented in the MaSe system. Prevention costs lack for most effects, and there is very little agreement on how to define the sustainable level.

The Ecopoint method from BUWAL uses policy objectives to evaluate the environmental effects. This means that the method limits the evaluation to the issues implemented on the political agenda. Looking at the situation in Norway, there are no defined and clear political targets for effects like eco-toxicity, except from the A- and B list. In strict terms, this means that most effects will be regarded as having little importance in a political weighting method. Both Environmental Theme and the UMIP methodology are related to the Ecopoint method.

In the EcoIndicator'99 method, the eco-toxicological effects are evaluated using a damage function approach. The damage to ecosystem quality is given as the percentage of species that have disappeared in a certain area due to the environmental load. For eco-toxicity, the load is expressed as per cent of all species present in the environment living under toxic stress (PAF). The diversity of these species is used as an indicator of the ecosystem quality. The ecosystem damage is then expressed as the number of species threatened, or that have disappeared from a defined area in a given time period. The eco-toxic damage is modelled with EUSES (the **E**uropean **U**niform **S**ystem for the **E**valuation of **S**ubstance), a multi media environment fate model (air, water, sediment, soil). To be able to use the results from EUSES in LCA the model had to be modified in order to reach a closed space simulation. This involves setting the wind speed and run off transfer as close to zero as possible. The simulation is performed on a regional scale, using Europe as the area of simulation. Another problem is that EUSES is developed for organic substances. To be able to evaluate heavy metals the model is combined with other sources of information. The list of eco-toxic substances evaluated in EUSES includes 43 substances. About 15 of these substances are found on the Obs list from the Norwegian government.

At the University of Leiden, they have developed a similar multi-media fate exposure model called the USES-LCA. This model is designed especially for use in the priority assessment step of LCA (Huijbregts, 2000). This method was launched as a new and better damage model as the method treats inter media transport more realistically and comprehensively. The model includes human toxicity, aquatic toxicity, sediment and terrestrial eco-toxicity after emission to fresh water, air, seawater or agricultural areas. Western Europe is used as the computation area. All risk characterisation factors are normalised to 1-4 **dic**hloro**b**enzene (1-4 DCB). The toxicity effect is expressed as toxicity potentials, 1-4 DCB equivalents. For the time being, there are 181 available toxicity potentials in the USES-LCA. Of these substances, 11 are found on the Norwegian Obs list.

5.4.4 Evaluation of ecological effects in the MaSe system

No method has been found among the studied material evaluation methods or LCA methods that can be implemented directly into the MaSe system. The implementation of a scientific evaluation method seems unattainable at present. The existing economic methods are also disputed and, according to some experts, hampered with inaccuracies. USES-LCA seems to be the existing method that looks as the most promising, with respect to scientific requirements.

Selecting the suitable methodology for the evaluation of toxicological effects is a good example of the conflict between the desire to be scientifically correct and the goal to include as much as possible in the evaluation. Neither USES-LCA nor EUSES include many of the substances on the Obs list. In the context of building materials, it is considered more important to include as many substances as possible rather than giving a scientifically correct evaluation of only a few substances. The solution used in the Swedish guide for material selection (see Chapter 4) is therefore used as a model also in the MaSe system. The Swedish guide supplies a set of qualitative requirements for chemical compounds in a product.

SCORE CHARTS

In order to have a uniform evaluation method, the score charts used for the Resource evaluation, are used also for the scoring of the Ecological effects. For Global Warming the basic principle is similar as for resources; comparing the studied material with a reference, defined as the average value for the functionally equivalent materials or products registered in the database.

Table 5-23: Score chart for Emission of greenhouse gasses in production, use, disposal and the total lifecycle, $Score_{GWP}$.

$Score_{GWP}$	Judgement	Criteria: Emission of greenhouse gasses, GWP (kg/FU)
1	Excellent	Ò10% of reference value
2	Good	10 % < AND Ò40% of reference value
3	Fair to good	40 %< AND Ò70% of reference value
4	Fair	70 %< AND Ò100% of reference value
5	Borderline fair	100 %< AND Ò130% of reference value
6	Marginally acceptable	130 %< AND Ò160% of reference value
7	Poor	160 %< AND < 190% of reference value
8	Unacceptable	Ó190 % of reference value

For eco-toxicological effects, regulations, **H**ealth **E**nvironment and **S**afety (HES) data sheets, the substance list and the priority list are used as aids to set the evaluation criteria.

Substances subjected to regulation should be included in the category “Unacceptable”. It is assumed that the national regulations include all EU regulations and directives. The MaSe system therefore includes only a list of substances listed in national regulations. Note that this part of the MaSe system only covers the substances listed because of their ecological damage.

The State Pollution Agency has developed the Obs list. The list includes substances that represent problems on a national level, and that should be avoided if they impose a risk for the health and/or the environment in use, production, storage or waste handling. This list is not complete, but the Substitution obligation is in force, and the user must decide if the alternative includes the same or worse effects than the original substance. As an aid to do this, the authorities have developed a set of criteria for environmental damage, as seen Appendix E.

Included in the Obs list are the A- and B lists. The A list constitutes substances of which emissions are to be reduced substantially within 2000, and stopped within 2005. The B list includes substances that are to be reduced substantially no later than in 2010. These two groups should therefore receive more focus than the other substances on the Obs list.

The substance list is a list of substances as a part of the regulation on classification and labelling of dangerous substances, and contains about 3000 chemicals. Harmful substances must be labelled according to the substance list. This substance list, or the HES-data sheets, may also be used as aids in evaluating the eco-toxicological properties of the substances used in the production, use or disposal of a material.

In addition, the Product register is a source of information about a substance and its potential for environmental damage. The Product register is the government's central register of substances and chemical products (chemicals). The Register keeps information on chemical products that are on the market in Norway, and carry warning labels because they contain dangerous chemicals. Here the N-classification and the R classification R50 to 53 are used to describe the effect on the environment. N means that the chemical is harmful to the environment. The symbol "N" and the appropriate risk phrase is assigned for a substance classified as dangerous to the environment based on R50, R50/53, R51/53, R54, R55, R56, R57, R58, R59, R52, R52/53 or R53. R50 is used for chemicals that are very toxic for water living organisms, R51 is used for chemicals toxic for water living organisms, R52 is used if the chemical is harmful to water living organisms, and R53 is used for chemicals that can cause unwanted effects in water environments. The rest of the classification is included in Appendix G.

In addition, the partition coefficient K_{ow} or P_{ow} (n-octanol/water) or the bio concentration factor is presented. Information about environmental risks related to a special component in the product like EC_{50} [5], LD_{50} [6], LC_{50} [7], together with the biological degradability are also presented.

Based on the substance list, Obs list, A list and B list, a set of criteria is developed to score the eco-toxicity in production, use and disposal. The score chart in Table 5-24 is used for both the production phase and the user phase. The different lists are included in the MaSe system spreadsheet.

[5] The concentration that will cause a toxic effect in 50% of the subjects.

[6] The dose that will kill approximately 50% of the subjects.

[7] The concentration in air, water, or food that will kill approximately 50% of the subjects.

Table 5-24: Score chart for Eco-toxicity in production and use of a product. Note that only the eco toxicological effects are evaluated, human toxicological effects are included in the sub section human health.

Score $Score_{E\text{-}Tox}$	Judgement	Criteria: Eco toxicity
1	Sustainable	No substances on the Obs, A or B list, or with similar or worse characteristics.
2	Good	Trace amounts of substances on the Obs list, or with similar, or worse characteristics, may be present.
3	Fair to good	Trace amounts of substances on the A- or B list, or with similar or worse characteristics, may be present.
4	Fair	Substances on the Substance list, or with similar or worse effects may be present, but in very small amounts.
5	Borderline fair	Substances on the Obs list may be present, but in very small amounts.
6	Marginally acceptable	Substances on the Substance list may be present.
7	Poor	Substances on the A, B or the Obs list or with similar, or worse, may be present.
8	Unacceptable	Substances that are forbidden by law may be present.

The score chart for the disposal phase, seen in Table 5-25, is based on the suggested revision of the regulations for dangerous waste (Ministry of Environment, 2002a). Dangerous waste is here defined as waste that cannot, in a suitable way, be treated together with consumption waste because this might involve serious pollution or hazards for humans or animals. Threshold values for when waste is regarded as dangerous are included in the regulations.

Table 5-25: Score chart for Eco-toxicity in the disposal phase. Note that only the ecological risk is assessed.

$Score_{E\text{-}Tox}$	Judgement	Criteria: Ecotoxicity
1	Excellent	Contains no substances that can constitute future damage to the environment.
2	Good	
3	Fair to good	
4	Fair	
5	Borderline fair	Contains only trace amounts of substances that can constitute future damage on the environment, but within the limits defined in the regulations.
6	Marginally acceptable	
7	Poor	
8	Unacceptable	The material is defined as dangerous waste, because of possible ecological damage, according to the regulations.

When the different parameters are scored, the preliminary results can be presented as a summary table, as seen in Table 5-26. It must be noted that the score for Eco-toxicity in the total lifecycle is, as a main rule, set to the average of the scores in the different lifecycle phases. However, if the score for the user phase or disposal phase is higher than this average score, the score for the total lifecycle is set equal to the highest score of these two phases. The main reason for this is the duration of user phases, and the potential duration of the disposal phase, compared to the production phase. If the material is designated for reuse or recycling, it should be considered not include the disposal phase in this "highest score" consideration.

Table 5-26: Results from the scoring of the different parameters.

Effect	Production	Use	Disposal	Total life cycle
Global warming	5	7	5	5
Eco-toxicity	6	1	5	5

To get an overview of the scored parameters, Table 5-27 gives a summary of the nomenclature of the parameters in the Ecology assessment in the MaSe system.

Table 5-27: The nomenclature of the scored parameters in the area Ecology.

Phase Parameter	Production	Use	Disposal	Total lifecycle
Global warming	$Score_{GWP\text{-}Production}$	$Score_{GWP\text{-}Use}$	$Score_{GWP\text{-}Disposal}$	$Score_{GWP\text{-}Total}$
Eco-toxicological effects	$Score_{E\text{-}Tox\text{-}Production}$	$Score_{E\text{-}Tox\text{-}Use}$	$Score_{E\text{-}Tox\text{-}Disposal}$	$Score_{E\text{-}Tox\text{-}Total}$

CLASSIFICATION

The results from the score charts are weighted together and classified into one total score. By default, the parameters are weighted equally, and the scores are multiplied with these weights in order to reach a score for the total lifecycle. The user may also set individual weights. The classification may also be done for each lifecycle phase, but this is not included in the current system.

The score for Ecology in each lifecycle phase is calculated the same way as for Resources, using Equation 5-18.

$$Class_{Ecology} = \sum_i Score_i * w_i = Score_{Score_{GWP}} * w_{GWP} + Score_{ETox} * w_{ETox}$$

Equation 5-18

Where

$Class_{Ecology}$ = Score for ecological load

i = parameter

$Score_{GWP}$ = Score for emission of gasses with global warming potential, from Table 5-23.

$Score_{E\text{-}tox}$ = Score for emission of substances with potential eco-toxicological effects, from table Table 5-24.

w_i = Corresponding parameter weights

The resulting classification of Ecological effects is illustrated in Figure 5-17.

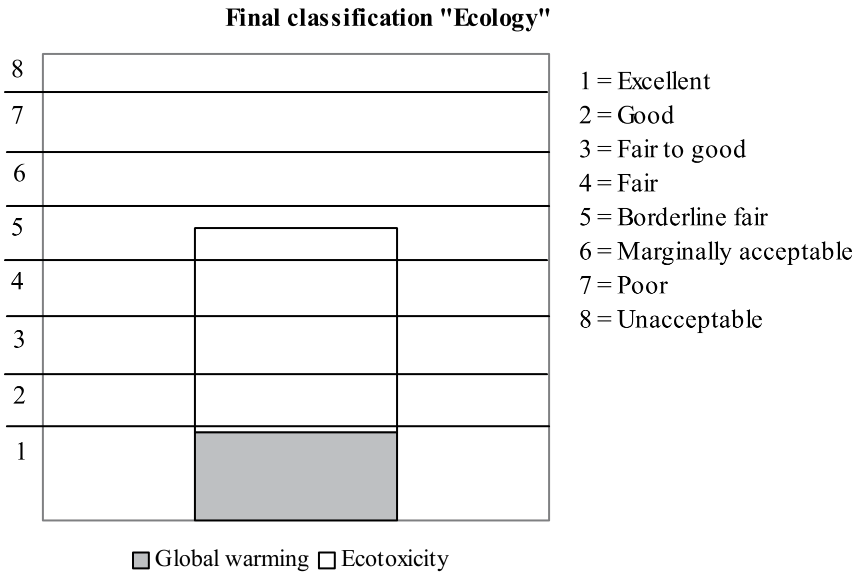


Figure 5-17: Presentation of classification results for the main area Ecology.

Further, “in depth” information about the distribution of the environmental load in the different lifecycle phases may also be presented. The GWP for the different lifecycle phases, compared to the reference, is illustrated in Figure 5-18. The scoring for the eco-toxicological effects is also included in the illustration. In the case of plaster board the emission of gasses with a global warming potential is about 66 per cent of average for the production phase, 43 per cent of average for the user phase and 10 per cent of average for the disposal phase. For the total lifecycle, plywood causes 60 per cent of the GWP of the average wallboard material.

No information about chemicals is provided on the plywood environmental declaration. However, plywood is normally produced using a glue of formaldehyde and urea. Formaldehyde is classified as harmful to the environment, N, so the product involves a risk in the production phase. A Danish dataset lists emission of lead, cadmium, mercury, all and the B list, but in very small amounts. In total however this indicates that the product might involve ecological risk in the production phase, and as no information is provided from the producer, the product is given a score 6, “Marginally acceptable”, for eco-toxicology in production.

It is not likely that there are any chemicals involved in the user phase of the product directly, surface treatments might involve chemical risk in the user phase but this is not included in the example. In the disposal of the product, it is again uncertainty involved, but it is assumed relatively safe. Trace amounts can however, not be excluded based on information about the product, the score for the disposal phase is therefore set to 5, “Borderline fair”. The total score is then (6+1+5)/3 = 4, “Fair”.

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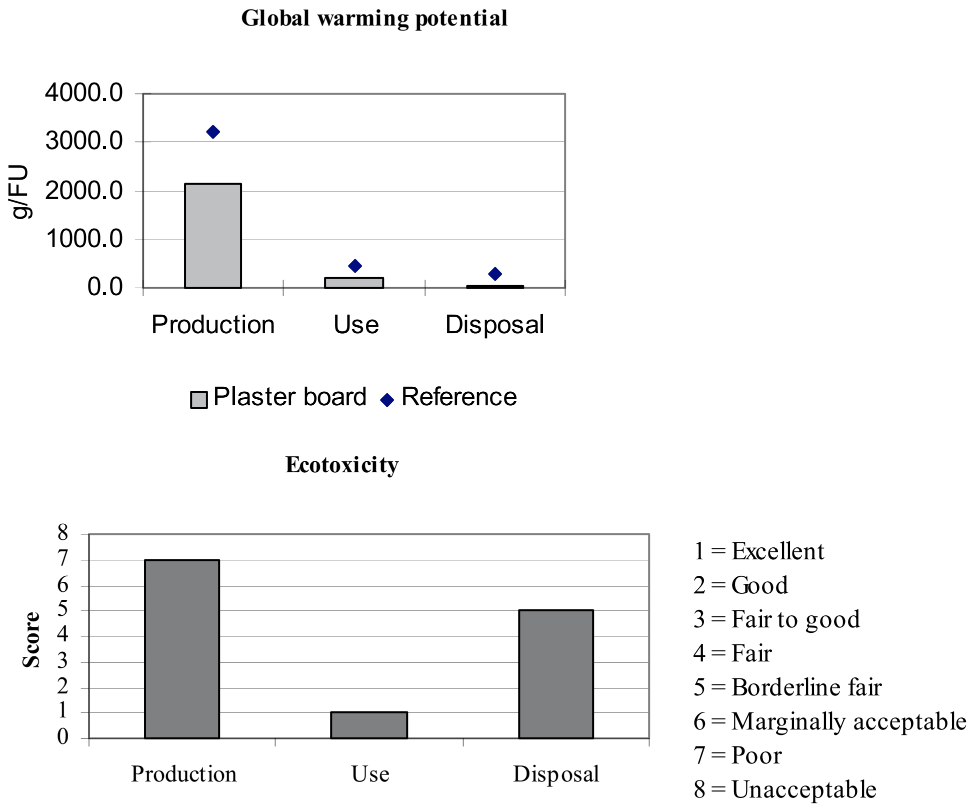

Figure 5-18: Available "in-depth" information about the ecological parameter properties of a material in the MaSe system.

Figure 5-19 illustrates the calculation procedure for the ecological load. The evaluation of the ecological properties of a material is performed in two steps:

1. Scoring of the parameters according to the score charts
2. Weighting of the scored attributes and classification of the different effects into one single class for ecological effects, $Class_{Ecology}$.

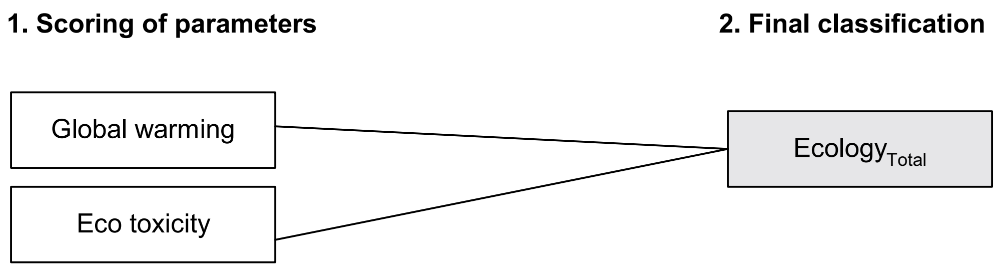

Figure 5-19: Illustration of the classification of ecological load.

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5.5 Evaluation of human health effects

The "Human health" area includes potential effects on humans during production, use and disposal of the building materials. The nature of the parameters is quite different from those included in both the "Ecology" and "Resource" areas. The evaluation procedure will therefore vary slightly from these areas, especially for the combined scoring.

Based on the literature studied, existing evaluation systems and requirements from the industry and the government, the following areas are found relevant with respect to human health and building materials:

- Emissions from the material to the indoor environment.
- Cleaning properties.
- Emissions from cleaning agents.
- Emissions from maintenance materials.
- Use of chemicals that may cause health problems.
- Sound insulating abilities.

As explained in Chapter 8.3, cleaning is included in the FU, and sound insulation is included in the technical specifications of the material. This leaves the four emission parameters and toxic chemicals to be assessed in the MaSe system.

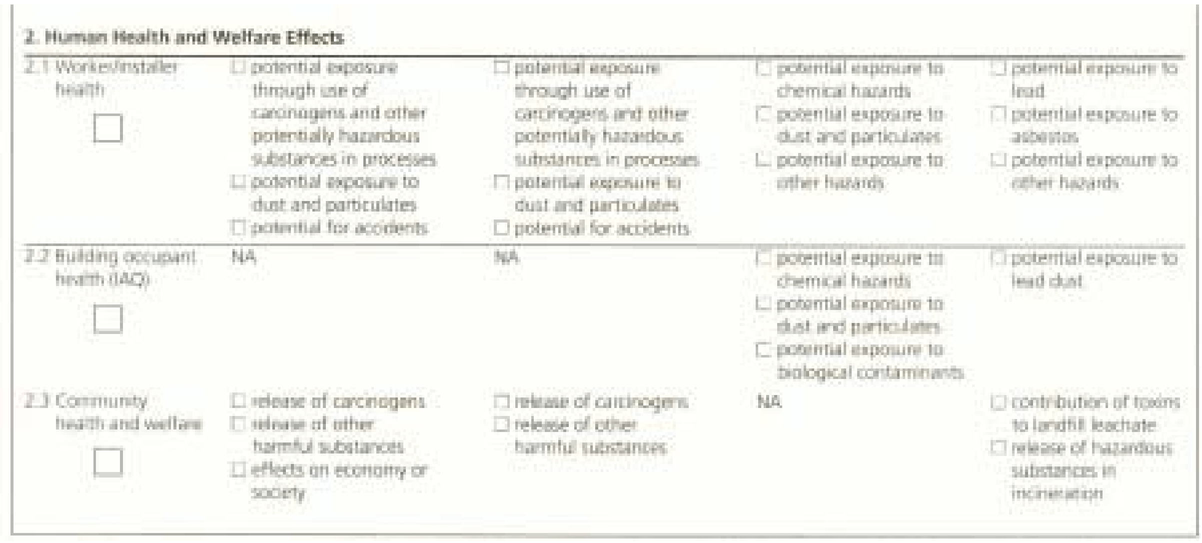
5.5.1 Material evaluation methods and their assessment of indoor environment

Existing material evaluation systems are studied to find the correct parameters, and how they should be treated in the scorecards described in Chapter 5.3.3. BEES evaluates only the TVOC as a proxy for indoor air quality. This includes emissions from the product installed, the installation adhesives and associated maintenance products. Studying the database and the manual it was found that for most products this evaluation is omitted. The only material that is evaluated with respect to indoor environment is floor covering.

The total VOC emissions over an initial number of hours is multiplied by the number of times over the 50 year calculation period those "initial hours" will occur. This s is then used as an estimate of total VOC emissions per functional unit of a product. The result is entered into the life cycle inventory for the product, and used directly to assess the indoor air quality impact. The TVOC is normalized to 30 per cent of the US TVOC emissions per year and capita.

The Swedish "Guide for material selection" is, as mentioned earlier, based on a set of mainly qualitative criteria. The indoor environment criteria are presented in **Table 4-2**.

Another system based on qualitative criteria is the ERG. In this system, the category "human health" includes workers/installers health, community health and welfare together with building occupant health. The materials are evaluated by experts, rating the parameters shown in Figure 5-20 using in the categories "good to excellent performance", "intermediate performance", poor performance" or "performance varies within a given range depending on factors specified in notes". One problem with the ERG is that there is little explanation about how the experts perform this evaluation.



2. Human Health and Welfare Effects

2.1 Worker/installer health ☐	☐ potential exposure through use of carcinogens and other potentially hazardous substances in processes ☐ potential exposure to dust and particulates ☐ potential for accidents	☐ potential exposure through use of carcinogens and other potentially hazardous substances in processes ☐ potential exposure to dust and particulates ☐ potential for accidents	☐ potential exposure to chemical hazards ☐ potential exposure to dust and particulates ☐ potential exposure to other hazards	☐ potential exposure to lead ☐ potential exposure to asbestos ☐ potential exposure to other hazards
2.2 Building occupant health (IAQ) ☐	NA	NA	☐ potential exposure to chemical hazards ☐ potential exposure to dust and particulates ☐ potential exposure to biological contaminants	☐ potential exposure to lead dust
2.3 Community health and welfare ☐	☐ release of carcinogens ☐ release of other harmful substances ☐ effects on economy or society	☐ release of carcinogens ☐ release of other harmful substances	NA	☐ contribution of toxins to landfill leachate ☐ release of hazardous substances in incineration

Figure 5-20: Impact assessment categorization and rating worksheet, Human Health and Welfare Effect (AIA, 1996).

Other material selection systems described in Chapter 4, as for example ATHENA, Handbook of sustainable building, BEAT2001 and ENVEST, does not include evaluations of human health aspects.

5.5.2 LCA weighting methods and their evaluation of Indoor environment

In LCA, there are several problems involved in finding an impact assessment method for Human health aspects. LCA is a quantitative calculation procedure, where the parameters are first quantified and then an evaluation procedure determines the seriousness of the effect. Many of the parameters in the human health area are not quantifiable, and for those who are, there are difficulties in how they should be evaluated. First, it is difficult to say if a person really is exposed to a substance, second it is difficult to say if the total exposure level is exceeded for an observable effect. The evaluation must be based on assumptions, as it is often little knowledge about the respective in-use situations.

Studying existing LCA weighting methods, the EPS system is one of the few systems that include "Human health" aspects. In this system, human health is evaluated based on WTP for preserving lives. However, this system is earlier considered unsuitable for the MaSe system.

EcoIndictor'99 also includes human health as one of the categories. However this is damage to human health caused by climatic change, ozone layer depletion etc. It has no relevance to the problems that is to be included in the MaSe system. Other well-known LCA methods as BUWAL, EcoPoint and the Effect category method do not include evaluation of human health. The Danish UMIP methodology includes human health exposure, but only as effects in the working environment in the production of the materials.

An attempt is made in the Netherlands (Meijer et al. 2002) to develop a method to include health effects associated with indoor air pollution in the LCA of a dwelling. This method is based on the "**D**isability **A**djusted **L**ost **Y**ears" (Daly) concept developed by Goedkoop et al. (2000a and b), included in the EcoIndicator'99 system, described in Chapter 4. A problem, also identified by the authors of the method, is that it is dependant on a relative detailed model of the in-use situation, including time spend on each floor of the building, number of persons living there and the volume of each room. Before the dwelling is build, this will be a serious obstacle in the practical application of the model.

5.5.3 Evaluation of Human health in the MaSe system

Neither material evaluation methods nor LCA methods fulfil the needs for evaluating a material with respect to potential effects on human health. A fully quantified solution is considered impossible, and the evaluation is therefore based on the same principles as the Swedish "Guide for material selection" and the ERG.

One of the main problems with evaluation of human health effects of building materials is that the emissions data presented often are incomplete, incomparable or contradictory. If emission tests are performed, some relevant gases might be excluded from the measurements, making the results for the material incomplete. If the measurements for two materials are performed with different techniques, or under different conditions, the results will not be comparable. This last step might also cause the results for the same material, using different test methods, being contra dictionary. Data to be used in material comparisons is therefore scarce.

In addition, data will differ between different producers of the same material. This means that data, for example emissions from linoleum flooring from one producer cannot be used as an average for emissions from linoleum in general. Emissions also change over time, and the decay rates for emission are different for various products and under different conditions. This means that if emissions are to be compared, they need to be measured at the same time, and under the same conditions using the same techniques.

Many sources for information have been searched in order to find the background of this qualitative evaluation procedure in the MaSe system. A system worth mentioning is the ISS cleaning and indoor environmental guide (ISS Indeklima service, 1997). This guide is interesting, as it includes a quite comprehensive set of different criteria. The basis for the system is a set of evaluation-schemes, as illustrated in Figure 5-21. The materials are evaluated as being good, medium or poor for the different criteria.

Different material groups are evaluated in the ISS system, but indoor wall surfaces, flooring and ceilings are the most relevant groups. The evaluation criteria covers Indoor environment (depot effect dust, emissions of gasses and particles together with sound absorbing ability), Material properties (acid and alkali, resistance against mechanical wear and tear, cleaning friendliness, maintenance need and durability) together with cleaning methods and economy (construction, use and maintenance). A problem also with the ISS system is that there is no information on how the evaluation is made.

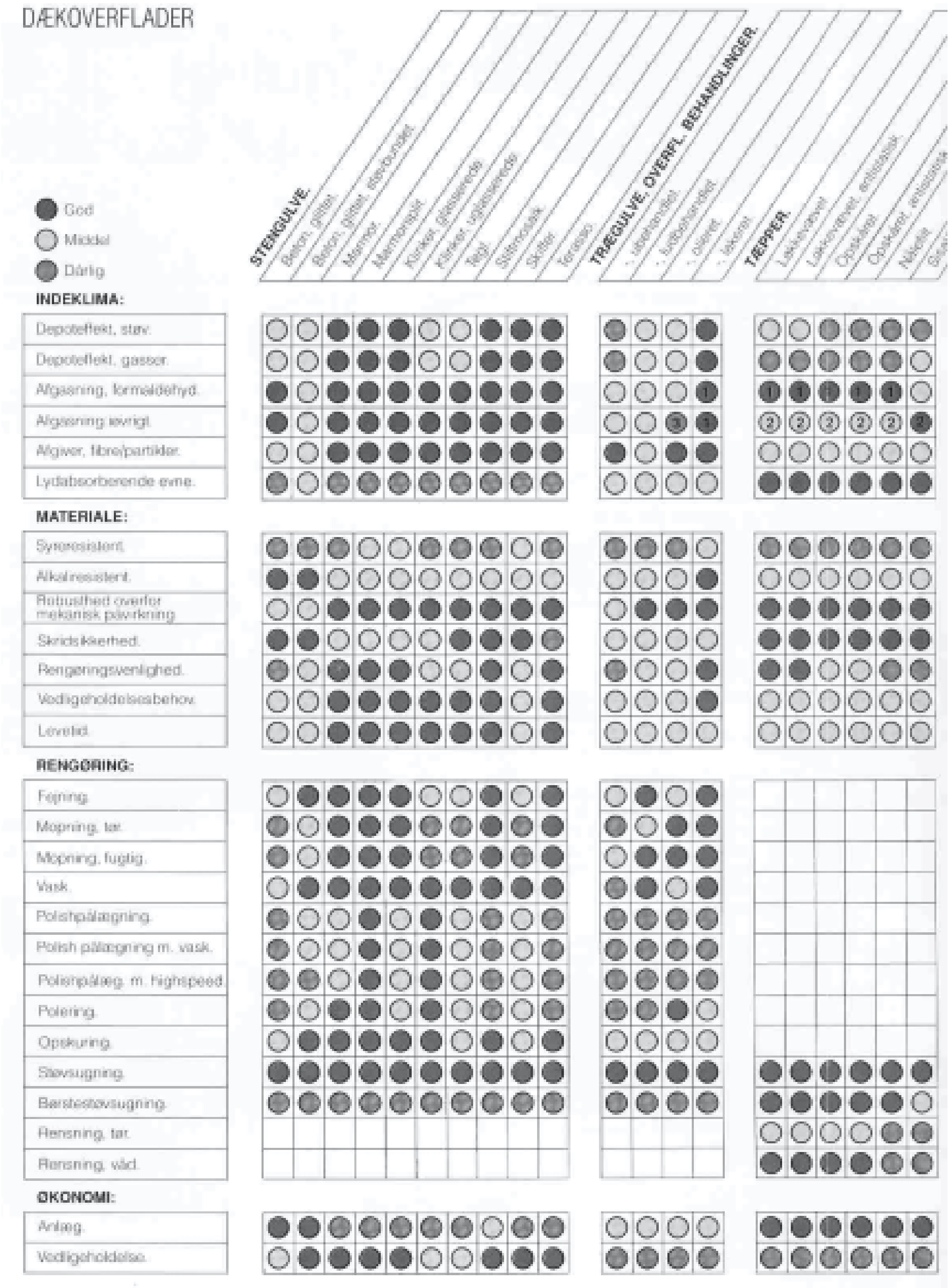


Figure 5-21: Example of evaluation-scheme in the ISS system (Section of evaluation scheme for flooring materials) (ISS Indeklima service, 1997).

One of the most interesting methods for evaluation of indoor environmental properties of a material is the classification method developed by the Finnish Society of Indoor Air Quality and Climate in 1995 (Neuvonen, 2000). The goal of this classification system is to increase the development and use of low emitting materials so that material emissions do not contribute to increased ventilation needs. The criteria of the classification system are presented in Table 5-28.

Table 5-28: Criteria used in the Finish classification system (after CEN CR 1752, 1998).

Substance	M1 criteria	M2 criteria	M3 criteria
Total Volatile Organic Compounds, TVOC	< 0.2 mg/m^{2}h	< 0.4 mg/m^{2}h	> 0.4 mg/m^{2}h, or no emission data
Formaldehyde, H_2CO	< 0.05 mg/m^{2}h	< 0.125 mg/m^{2}h	> 0.125 mg/m^{2}h, or no emission data
Ammonia, NH_3	< 0.03 mg/m^{2}h	< 0.06 mg/m^{2}h	> 0.06 mg/m^{2}h, or no emission data
Carcinogenic compounds according to category 1 of IARC classification	< 0.0005 mg/m^{2}h	< 0.0005 mg/m^{2}h	> 0.0005 mg/m^{2}h, or no emission data
Odour	Dissatisfaction level < 15%	Dissatisfaction level < 30%	Dissatisfaction level > 30%

The system is referred in CEN report CR 1752 "Ventilation of buildings - Design Criteria for the Indoor Environment" (CEN CR 1752, 1998). It is also included in a simplified product evaluation system developed at the Norwegian Building Research Institute for Statsbygg (Strand et al., 2000a). Apart from the chemical testing, the system also includes a complementary test using sensory panels.

This Finnish system is gaining increasing recognition, and over 500 materials have received the M1 classification (Kukkonen et al., 2002). Säteri (2002) concluded that almost all major building materials in Finland would meet the M2 criteria. The fact that the systemic is valid for all types of building material makes M1 difficult to achieve for some materials and easy for other. Compared to the control system from the flooring materials trade organization, M1 is a relatively easy measure to achieve. This organisation set the TVOC limit at 0.15 mg/m^{2}h, after 4 weeks.

The Danish Association of Indoor Climate Labelling is also a well recognised system for indoor environmental assessment of materials. This system includes the evaluation of emissions and particles, and guides of indoor climate relevance. The following criteria include particles and fibres with diameter > 0.7 µm (Danish Association of Indoor Climate, 2000):

Low: Ò0.75 mg/m^2

Medium: > 0.75 mg/m^2

High: > 2 mg/m^2

The Danish system also uses the indoor relevant time value to evaluate the materials. The indoor relevant time value is based on the time it takes for the slowest emitting single substance, with the lowest odour- or irritation threshold, to reach half of this value in a simulated standard room. The criteria for being awarded with the label vary with the material in question. For wall systems, semi hard flooring materials, laminates and wooden flooring, textile floor coverings, windows and outer doors the value must not exceed 30 days, for inner door the limit is 80 days, for mobile walls 160 days, for wall systems and interior painting 100 days and for wood oil 120 days.

SCORE CHARTS

In the MaSe- system principles have been drawn from the "Guide for material selection", the Danish association of Indoor climate, the classification system from the Finnish Society if Indoor Air Quality and the ISS-system, to develop the criteria in the score charts.

Emission of gasses from materials is an important aspect and can be separated in three types (NBI, 1993):

1. Emissions of free pollutants.
2. Substances bound in the material are emitted after deterioration because of aging, humidity etc.
3. Emissions from materials that have absorbed the pollutant from other sources and then desorb them.

The material is evaluated regarding emissions of free unbound pollutants as shown in Table 5-29. The scoring criteria are based on the Finnish classification system presented in Table 5-28. In the score chart for emission of gasses, the class M1 in the Finnish system is judged as "fair", M3 is labelled "unacceptable", and M2 is placed in the middle of M1 and M3.

It is the impression from the number of material that have passed the M1, the statement from Säteri (2002) that most building materials in Finland will reach M1 and the fact that the industry's own requirements to flooring materials is stricter, that forms the basis for M1 not being placed at the top level of the scale. In addition, a Finnish study of **i**ndoor **a**ir **q**uality (IAQ) and material emissions in new buildings, it was concluded that when using only tested low emitting materials, the IAQ did not reach the best classification in any of the 7 buildings studied before occupancy (Järnstöm et al. 2002).

It is important that relevant cleaning and maintenance methods are included when the material is tested. If a material with no emissions has to be treated with a cleaning agent that involves emissions, this must be included in the assessment of the material. Emissions from cleaning agents, as for example silicone or tensides can also, even in very low concentrations, lead to problems like eye- and mucous membrane irritation for those disposed for such reactions (ISS Indeklima service, 1997). Emissions from cleaning agents and surface treatments (e.g. polish) may in time prove to have larger influence on the indoor air quality than the initial material emissions.

Table 5-29: Score chart for emission of gases from a material including cleaning and maintenance activities and agents, $Score_G$.

$Score_G$	Judgement	Criteria: Emissions of gases
1	Excellent	Stone, glass, steel and other metals, brick, concrete and ceramic tiles.
2	Good	
3	Fair to good	
4	Fair	M1 classification
5	Borderline fair	
6	Marginally acceptable	M2 classification
7	Poor	
8	Unacceptable	M3 classification

Other problems involve differences in how people react to the exposure of a certain substance. There is increasing awareness of people being hypersensitive. The question is whether this should be included in a system like the MaSe system or not. An architect using the system may be presented with the requirement to design a building for people with this type of problems. This is considered to be a situation so special, that it will need more attention than what is provided in a general material assessment tool like the MaSe system.

Indoor relevant time constant is also a description of the emission properties of a material. This constant can be described as an extension of the TVOC requirement in the Finnish classification system. No criteria exist in order to make a classification of indoor relevant time constant. Whether a material is acceptable with respect to VOC emissions or not, will vary from building project to building project. The important aspect is if the emissions are below acceptable level when the building is put into use. If the indoor relevant time constant is shorter than the period after installation and before the building is put into use, then the constant has no significance. In the MaSe system it is assumed that the Finnish classification system is a satisfying system for the evaluation of gaseous emissions from a material. The same conclusion was drawn in the development of a material selection tool for Statsbygg (Strand et al., 2000a).

Emission of particles is also an important criterion of evaluation, included for example in the Danish indoor labelling system. In the MaSe system the Danish indoor labelling system is adapted to the score chart, see Table 5-30. In order to reach the top score it is necessary to document no emissions, but materials like glass, marble and steel do not need any documentation to reach the top score. As for the gases emissions classification, “Low” in the Danish system is set equal to “Fair” in the MaSe system. High is placed at the bottom and medium equals “marginally acceptable”.

Table 5-30: Score chart emission of particles and fibres from a material including cleaning and maintenance, $Score_{PF}$.

$Score_{PF}$	Judgement	Criteria: Emissions of particles and fibres
1	Excellent	Stone, marble, glass, steel etc. (0 mg/m^2)
2	Good	
3	Fair to good	
4	Fair	Ò0.75 mg/m^2
5	Borderline fair	
6	Marginally acceptable	> 0.75 mg/m^2
7	Poor	
8	Unacceptable	> 2 mg/m^2

Pollutants emitted during the aging process of the material are seldom studied in laboratory tests. Some of the serious problems with emissions can, however, be this type of pollution (NBI, 1993). A requirement of accelerated aging followed by emission testing could be a solution for the future. This factor will not be included in the MaSe system at this stage, but future advances in testing can be included when time comes.

The third type of emission, gasses that are adsorbed and the desorbed from the material, can be just as important as the direct emissions from a material. It is even reported that emission rates for wall covering material in laboratory tests was lower than measured in house (Funaki et al. 2002). The sink effect was one of the explanations behind this result. This type of emissions is in very little degree tested in laboratories (NBI, 1993). But as suggested by Funaki et al. (2002), the sink effect may be measured using a small **Ad**vanced **P**ollution and **A**ir quality **C**hamber (ADPAC).

The depot effect says something about the material's ability to absorb pollutants from other sources, and release them to the indoor environment at a later stage. The depot effect of the different materials is also included in the MaSe system. It is no classification criteria for the depot effect as it is for direct emissions. The classification is therefore based on the ISS system, which also includes a depot effect evaluation of dust. The classification based on depot effect for dust is shown in Table 5-31 and the depot effect for gasses in Table 5-32. Materials not found in the ISS system must be evaluated using the existing evaluations as guidelines. The scoring table of depot effect for dust is shown in Table 5-33, and for gases in Table 5-34.

Table 5-31: Classification of depot effect for dust in the ISS system.

Material type	High	Medium	Low
Inner wall surfaces	Untreated masonry with withdrawn joints, untreated masonry of hollow brick, wallpaper and acryl paint, un-planed boards without paint.	Untreated masonry, with smooth joints, silicate paint, structured fibreglass wall covering and acryl paint, wallpaper, unglazed tiles.	Masonry with fine plaster, acryl or alkyd paint, vinyl wallpaper, glazed tiles, marble tiles, acryl paint, coarse plaster and acryl paint, planed boards with paint, wood panel.
Doors			Ply wood, painted or laminated.
Architrave, casings and skirting	.		Oil based paint, water based paint, laminated.
Window inside casing			Oil based paint, water based paint, laminated aluminium.
Jointfillers	Polysulphated	Polyurethane	Acryl based, silicone.
Flooring	Untreated wood, cut carpet, felt, coco or sisal carpet.	Hardened and dust bounded concrete, unglazed ceramic tiles, brick, lye treated wood, oiled wood, wowed carpet, rubber.	Marble glazed, glazed ceramic tiles, mosaic, slate, terrazzo, wood with varnish, vinyl/PVC (joint free), cork vinyl (joint free), cork with varnish (joint free), linoleum.
Ceiling	Mineral wool, untreated, sound attenuators, suspended ceiling of lamellas, grates etc., suspended “isles” with open sides.	Plaster with painted acoustic board, surface treated mineral wool, suspended ceiling, plaster with painted acoustic board, suspended ceiling, painted acoustic metal, suspended ceiling.	Concrete with acryl paint, steel plates, painted wood, painted plaster, plaster with fibreglass covering and paint, painted plaster boards, suspended ceiling, painted metal, suspended ceiling.

Table 5-32: Classification of depot effect for gases in the ISS system.

Material type	**High**	**Medium**	**Low**
Inner wall surfaces		Alkyd paint, wall paper, structured fibreglass wall covering and alkyd paint, boards with alkyd based paint	Untreated masonry, with withdrawn joints, untreated masonry of hollow bricks, untreated masonry, with smooth joints, acryl paint, silicate paint, structured fibreglass wall covering with acryl paint, vinyl wallpaper, glazed or unglazed tiles, marble tiles, structured plaster and acryl paint.
Doors		Ply wood, laminated.	Painted.
Architrave, casings and skirting	.		Oil based paint, water based paint, laminated.
Window inside casing		Laminated.	Oil based paint, water based paint, aluminium.
Joint-fillers			
Flooring	Untreated wood, wowed carpet, cut carpet, felt carpet.	Hardened concrete, hardened and dust bounded concrete, unglazed ceramic tiles, unglazed, brick, lye treated wood, oiled wood, coco or sisal carpet, vinyl/PVC, rubber.	Marble, glazed, ceramic tiles, glazed, mosaic, slate, terrazzo, wood with varnish, cork vinyl (joint free), cork with varnish (joint free), linoleum.
Ceiling		Painted wood, plaster with acryl paint, plaster with painted acoustic board, mineral wool, untreated sound attenuators, surface treated mineral wool, suspended ceiling, plaster with painted acoustic board, suspended ceiling,	Concrete w. acryl paint, steel plates, plaster with alkyd paint, plaster with fibreglass covering and paint, painted plaster board, suspended ceiling, painted metal, suspended ceiling, suspended ceiling of lamellas, grates etc. suspended “isles” with open sides.

Table 5-33: Score chart for depot effect dust during use of the material, $Score_{DED}$.

$Score_{DED}$	Judgement	Criteria: Depot effect dust
1	Excellent	High
2	Good	
3	Fair to good	
4	Fair	Medium
5	Borderline fair	
6	Marginally acceptable	
7	Poor	
8	Unacceptable	Low

Table 5-34: Score chart for depot effect gases during use of the material, $Score_{DEG}$.

$Score_{DEG}$	Judgement	Criteria: Depot effect gases
1	Excellent	High
2	Good	
3	Fair to good	
4	Fair	Medium
5	Borderline fair	
6	Marginally acceptable	
7	Poor	
8	Unacceptable	Low

Another effect that might cause problems when dealing with different kinds of products at the same time is the synergistic effect. Synergic effects are combinations that create unfortunate effects. For example, if a detergent is applied on a surface that it is not adapted to. These effects are difficult to include in a system like the MaSe system, as it requires knowledge also of other materials present in the building. This requires the development of a specific simulation method, in order to predict possible effects. It is not considered relevant to include this in the MaSe system for the time being.

The only parameter included for all lifecycle phases is Human toxicity. The evaluation of this parameter is strongly linked to the Eco-toxicity evaluation under the "Ecology" area. Under "Ecology", it is the ecological environmental damage caused by the chemical that is evaluated, but the chemicals often have consequences for human health directly. The same sources of information are used for the evaluation of the health effects as for the ecological effects. Some substances may get a poor score under both areas and this may seem like "double counting", but it is the potential that is evaluated, and it is not known which effect that actually will occur. 2-metoxypropanol (used in paint and varnish) can cause foetus damage and propiconazol (used in wood stain) is toxic for water living organisms. These chemicals will only be subjected to evaluation in one of the areas. Phthalates, on the other hand, which is both toxic to water living organisms and suspected to reduce reproduction, is included in both sub-areas.

The score chart for human health effects of chemical substances is shown in Table 5-35. Materials with no substances on the Substance list, Obs list, A or B list or with similar, or worse, human toxicological effects are judged as "Excellent". If there are trace amounts of substances on the Obs list, A list or B list (or with similar or worse characteristics) the product is judged as "Fair to good". If very small amounts of substances on the Substance list occur, the product is judged as "Fair". The judgments gradually get poorer as small amounts of substances on the Obs list, A list or B list is discovered. Moreover, the worst category is reserved the cases where forbidden substances are discovered. The criteria for selection of substances on the Obs list because of their damage to human health are different from the environmental hazard test criteria; all criteria are presented in the Appendix.

This last criterion may seem unnecessary, but it is seen every now and again that a material in fact does contain such substances. In the work at the Norwegian Building Research Institute, a producer performing environmental declarations discovered that a substance used in the production of the product was in fact illegal. Therefore, it seems necessary to include this last class.

Table 5-35: Score chart for the evaluation of Human toxicity production, use or disposal.

Score	Judgement	Criteria; Human toxicity
1	Excellent	No substances on the Obs, A or B list, or with similar or worse characteristics.
2	Good	Trace amounts of substances on the Obs list, or with similar, or worse characteristics, may be present.
3	Fair to good	Trace amounts of substances on the A- or B list, or with similar or worse characteristics, may be present.
4	Fair	Substances on the Substance list, or with similar or worse effects may be present, but in very small amounts.
5	Borderline fair	Substances on the Obs list may be present, but in very small amounts.
6	Marginally acceptable	Substances on the Substance list may be present.
7	Poor	Substances on the A, B or the Obs list or with similar, or worse, may be present.
8	Unacceptable	Substances that are forbidden by law may be present.

Table 5-36: Score chart for Human toxicity in the disposal phase.

Score $Score_{H\text{-}Tox}$	Judgement	Criteria: Human toxicity
1	Excellent	Contains no substances that can constitute future damage to human health.
2	Good	
3	Fair to good	
4	Fair	
5	Borderline fair	Contains only trace amounts of substances that can constitute future damage to human health, but within the limits defined in the regulations.
6	Marginally acceptable	
7	Poor	
8	Unacceptable	The material is defined as dangerous waste, because of possible damage to human health, according to the regulations.

COMBINED SCORING

Combined scoring is performed to combine the parameters into a score for the different properties. For Indoor environment, the parameters are combined into one score for indoor air pollution and one for human toxicity. The ability the material has to pollute the indoor environment is determined by several parameters, including direct emission of gases and particles, depot effect gases and depot effect dust.

For the classification of the indoor air pollution properties, the parameters are judged following a set of logic rules. If the material is proven to have high emissions of either gases or particles, the judgment should be poor regardless of the other parameters. This is to avoid a product with high gaseous emissions and no fibre emission to be classified as for example "fair" with respect to the indoor environment. The same applies if the material has a high potential for accumulating other pollutants and emitting them to the environment later. The score for the three parameters is first summarised, the judgment of the material is then performed after the criteria presented in Table 5-37.

This means that in order to reach the top score, the material is allowed one 4, "Fair" score, and the rest must be 1, "Excellent". To reach the judgment 4, "Fair", a material is allowed one 6 score, and the rest must then be 4 or better. If the material has received the score 8 for one of the parameters the combined score is automatically set to 8, "Unacceptable".

Table 5-37: Combined scoring of the Human health parameters.

Parameter	Score
Emission of gasses, $Score_G$	3
Emission of particles or fibres, $Score_{EF}$	3
Depot effect dust, $Score_{DED}$	4
Depot effect gasses, $Score_{DEG}$	4
Ɇ	14

→

Score	Judgment	Criteria
1	Excellent	Ɇ Ò 4
3	Fair to good	4 < Ɇ Ò8
4	Fair	8 < Ɇ Ò14
5	Borderline fair	14 < Ɇ Ò18
8	Unacceptable	Ɇ > 18

The results of the scoring for plaster board are presented in a simple table, as illustrated in Table 5-38.

Table 5-38: Results from the scoring of the different sub-areas.

Results combined scoring	Production	Use	Disposal	Lifecycle as a whole
Human toxicity	7	1	5	5
Pollution to indoor environment		4		4

The example plaster board qualify the M1 requirements. Emission of particles and fibres are low, the depot effect for dust and gasses is set to medium. The score for pollution to indoor environmental in the user phase then ends up on 4, “Fair”.

For Human toxicity, the basis for the scoring is the same as for eco-toxicity. An additional incentive for letting the user phase dominate is that the user of the building must be in focus. If a material receives good scores in production disposal, but a high score in use or disposal, the total result cannot be better than the result for the user or disposal phase. This is secured in the calculation procedure using a set of logical rules.

CLASSIFICATION

In the classification step, the results from the score charts and the combined scoring are weighted together into one score for each lifecycle phase and one score for the lifecycle as a whole. This can be done for all phases, but this is not included in the current version of the MaSe system. The user, depending on the use of the material, decides the weights. Equal weights are the default in the system. The score for indoor environment is calculated as presented in Equation 5-19.

$$Class_{HumanHealth} = \sum_i Score_i * w_i = Score_{ScoreH-tox} * w_{H-tox} + Score_P * w_P$$

Equation 5-19

Where

$Class_{Human\ health}$ = Score for Human health

$Score_{H\text{-}toxj}$ = Score for Human toxicity, from table Table 5-35

$Score_P$= Score for Pollution to the indoor environment.

w_i = weight for parameter i

The result is illustrated graphically in Figure 5-22. The user may also for this area find “in depth” information behind the classification. This is illustrated in Figure 5-23. Here the human toxicity scores for each lifecycle phase are illustrated, together with the scoring for indoor air pollution in the user phase.

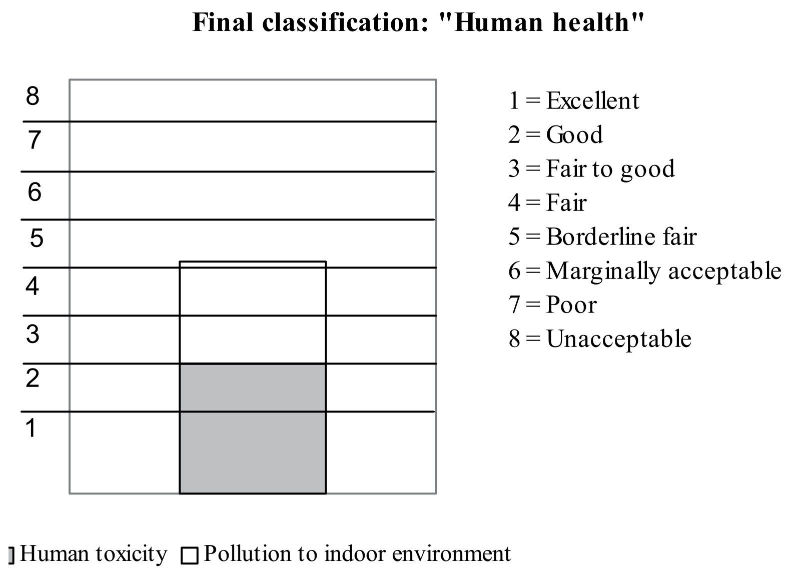
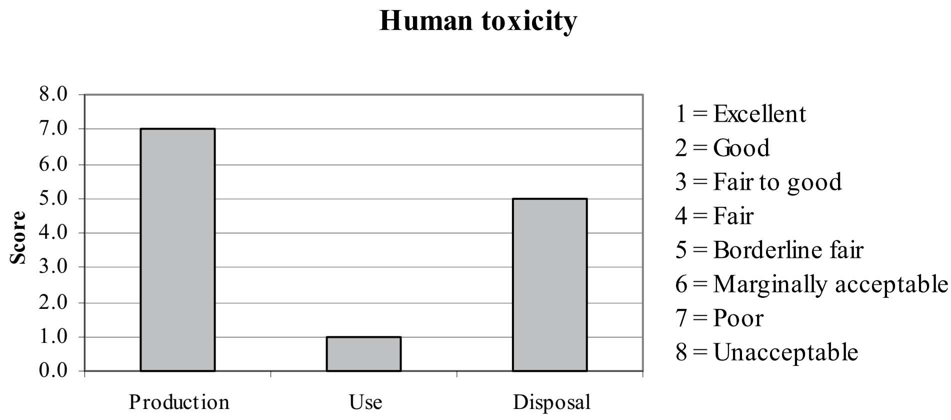


Figure 5-22: Graphical illustration of the results for human health.



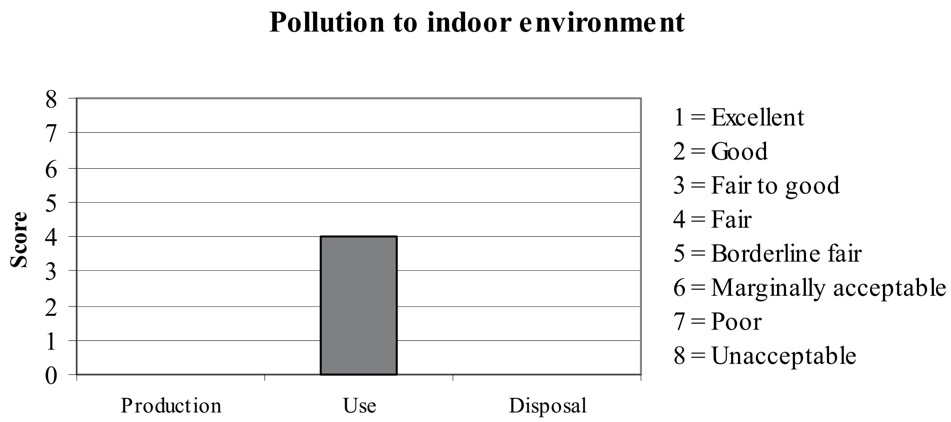


Figure 5-23: The "in depth" information behind the results for human health.

To summarise, the classification is carried out mainly the same way as for Resources:

1. Scoring of the parameters according to the score charts
2. Combined scoring
3. Weighting and classification, $Class_{Human\ health}$.

Figure 5-24 illustrates how the different parameters are aggregated into a classification for human health.

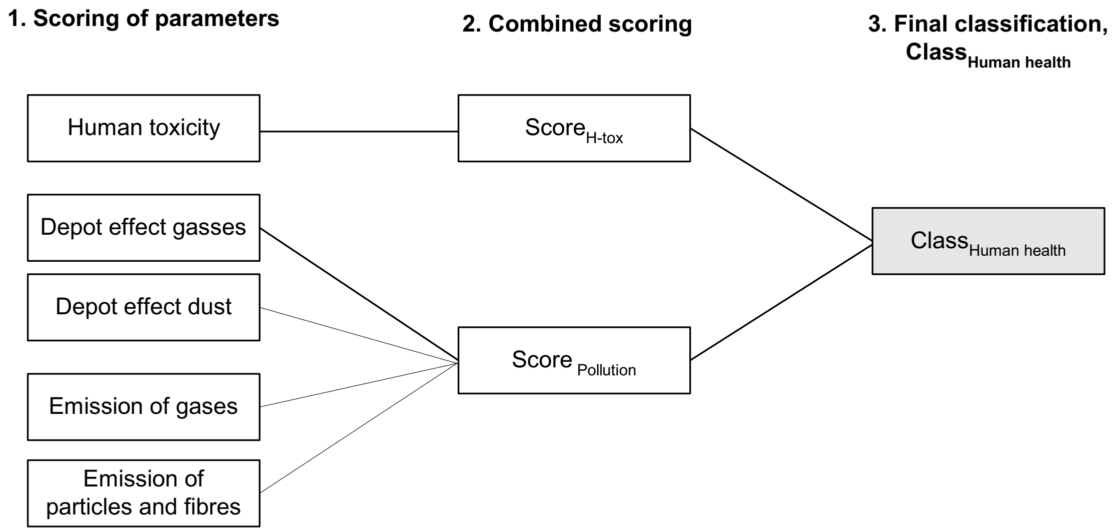


Figure 5-24: Main structure of the classification procedure of the area "Human health" in the MaSe system.

5.6 Evaluation of economic properties

All costs related to the production, use and disposal of a material is included in the MaSe system evaluation. The material costs include the parameters listed in Table 5-39. Material acquisition is the cost from the builders' merchant, transport excluded. Transport in the second column is transport from the builders' merchant to the construction site, and transport in the last column is transport from the building site to the waste treatment site. The nature of the economic parameters has lead to economy being evaluated different from the parameters in the other main areas. This is further explained in Chapter 5.6.3.

Table 5-39: The cost elements included in the different lifecycle phases.

Raw materials, production	Transport, construction and use	Disposal
Material acquisition	Transport	Dismantling
	Construction	
	Cleaning	Transport
	Maintenance and repair	Waste treatment
	Replacements	Residual value

5.6.1 Material evaluation methods and their evaluation of economical consequences

Not many material evaluation methods include economic considerations. BEES is the only one found to include this to some extent. This method includes a calculation of costs based on the ASTM standard method for conducting economic performance evaluations (ASTM, 1994). LCA methods is not relevant in this context, instead a simple study of methods for evaluation of economic performance is included.

5.6.2 Method for economic performance evaluation in the MaSe system

Several methods are used to calculate the costs related to a construction project. As it is important to include costs over a long period covering the lifecycle of a material, methods for calculating lifecycle costs are central.

The annual cost method is used in construction projects to calculate the total cost for a building over a period in order to get a better picture of the profitability of a construction project. There is a Norwegian standard for the calculation of annual costs, NS 3454 (1999) “Annual costs for buildings”. According to NS 3454, annual costs include capital costs, administration costs, management costs and maintenance costs.

Not all items included in a total annual cost analysis are relevant when studying building materials. Capital costs are the costs related to the investment of capital in a project. This, for a building material, includes the cost of the material acquisition, the transport and the construction costs. A discounted remaining value should also be included in the capital costs. For a material, the remaining value for the client is probably nil. However, if the material is reusable it should have a value compared to a non-reusable material. The problem is predicting this reuse-value. If a material needs to be deposited or treated in some way at the end of its service life, a negative rest value is relevant.

Administration costs include taxes, water and sewage charges, sanitation fees, insurances etc. All these factors would be the same regardless of which material that is selected in a building project, and need not be included in a comparative cost calculation for a material.

Management costs include cost for the daily use of the building. Cleaning is directly related to the material surfaces in the building. The frequency and wages for the cleaning staff are factors that affect this parameter. Energy is also an important factor for the management costs. However, as explained in Chapter 6, only functionally equivalent materials are compared, and this means the energy is excluded from the comparison.

The maintenance costs are relevant when comparing building materials. The maintenance intervals are dependent on the required service life (esthetical, functional etc.). The necessary maintenance intervals should be given by the material producer together with the expected technical service life, see Chapter 6.6. Using material declarations as a source of information, the maintenance intervals are stated in the top of the declaration. If the material needs to be exchanged during the building service life, these costs must also be included.

The lifetime costs according to NS 3454 are calculated as shown in Equation 5-20.

$$C = C_0 + \sum_{t=1}^{T} \left[(1+r)^{-t} \times AOM_t \right] - R_t (1+r)^{-T}$$

Equation 5-20

Where

C = Lifetime costs or NPV

C_0 = Project costs

AOM = Administration, Operation and Management costs

R = Remaining value

r = interest rate

t = moment in time where cost accrue

T = Calculation period

Multiplying the lifetime cost with the annuity factor gives the annual costs, as shown in Equation 5-21.

$$AC = b \times C$$

Equation 5-21

Where

AC = Annual Cost

b = annuity factor, given in Equation 5-22.

C = Lifetime cost

$$b = \frac{r}{1-(1+r)^{-T}}$$

Equation 5-22

Where

b= annuity factor

r = rate of interest

T = Calculation period

The annual cost method is the LCC calculated per year. In standard LCC calculation methods as described in for example the ASTM standard (ASTM, 1994), the results are presented as net present value, as calculated in Equation 5-20.

5.6.3 Discussion and description of evaluation system for economic properties

In the calculation of the cost of a building material, the principles in NS 3454 will be followed, but the results will be presented only as NPV/FU in Equation 5-21. A set of assumptions must be made in order to perform this calculation:

– Calculation period: 60 years

– Inflation: 2.5 per cent (based on information from Statistics Norway).

– Discount rate: The nominal discount rate, including inflation, is a reflection of the investor's time value of money. The client in each case should therefore set the discount rate. A default nominal discount rate is set to 10 per cent.

  The nominal discount rate, i and its corresponding real discount rate, r, are related as shown in Equation 5-23.

$$r = \frac{1+i}{1+I} - 1$$

Equation 5-23

Where

r = real discount rate

i = nominal discount rate

I = the rate of price inflation

– Cost data: The costs in the database may be based on cost-databases as for example Holteprosjekt (HolteProsjekt Innovation, 2002). The different users may also use their own cost data.
– The residual value of a material is linked to the selected disposal method. For a material that needs to be deposited, this will include demolition costs, transport costs and deposition costs. For a material that is recycled, the deposition costs will be replaced with expected income from the sale of the material. Today's prices must be the basis for estimating this value.

It is decided that the LCC, expressed as NPV/FU, is the best way to present the economic properties of a material. But, how should these parameters be evaluated and presented in the MaSe system? The evaluation of the economic parameters is quite different from the other parameters seen in the MaSe system, and economy is also included in most decisions made in a building project. Initially, the thought was to include economy using the same methodology as for the other main areas, making Economy the fourth main area. During this process, it was recognised that integrating economy completely in the environmental evaluation procedure "blurred" the result. Economy is a parameter decision makers are used to handle, and they are probably also used to handle this information, together with other types of information, as for example sound absorption, heat loss, aesthetics etc. These properties are common material properties, but they are not combined with economy into a new value that the decision makers is expected to use as their basis for decision. Similarly, should environmental parameters not be combined with economic data. The selection of a product must be based on economic, technological and environmental considerations.

The economic properties of a material are included in the final presentation of the evaluation result in the MaSe system as the NPV/FU. Figure 5-25 shows the evaluation of plaster board shown together with other evaluated products. Such an evaluation forms the basis for the first comparison of alternative building products or solutions. In this case, product 2 proves to be the best alternative both with respect to Economy and Environment.

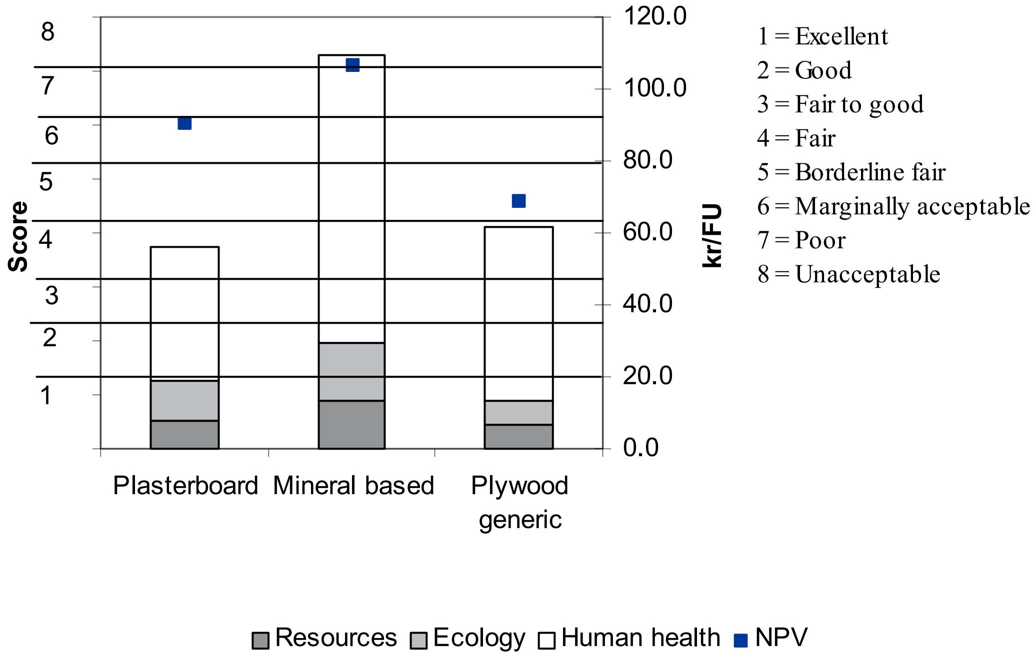


Figure 5-25: Presentation of the resulting evaluation of three materials. The squares illustrate the NPV, and refer to the right y-axis, the stables are the score in the MaSe system, and refer to the y-axis to the left.

"In depth" information is available as illustrated in Figure 5-26. This is the NPV of the product in the different lifecycle phases compared to a reference product. As for the other main areas, the reference is the average of the functionally equivalent material included in the system.

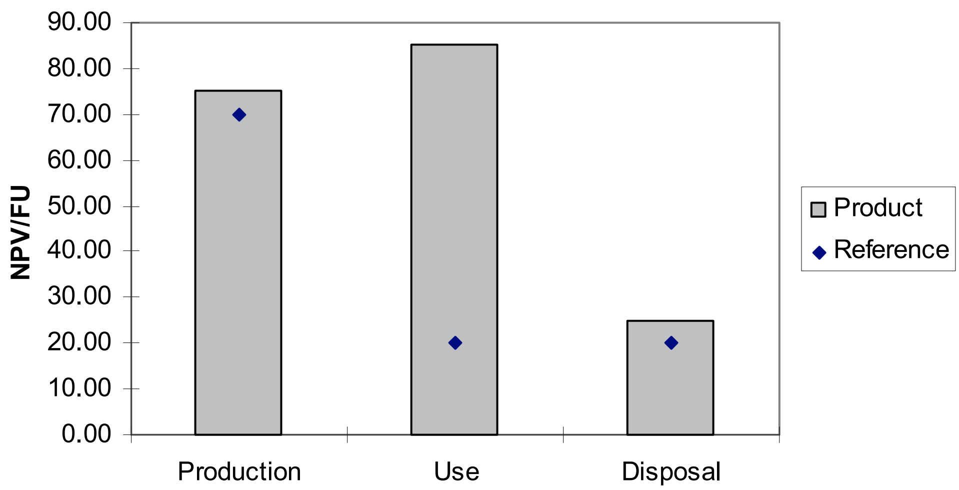


Figure 5-26: Presentation of the economic properties of a material in relation to the average values.

5.7 Summary of the MaSe methodology

The total procedure is illustrated in Figure 5-27.

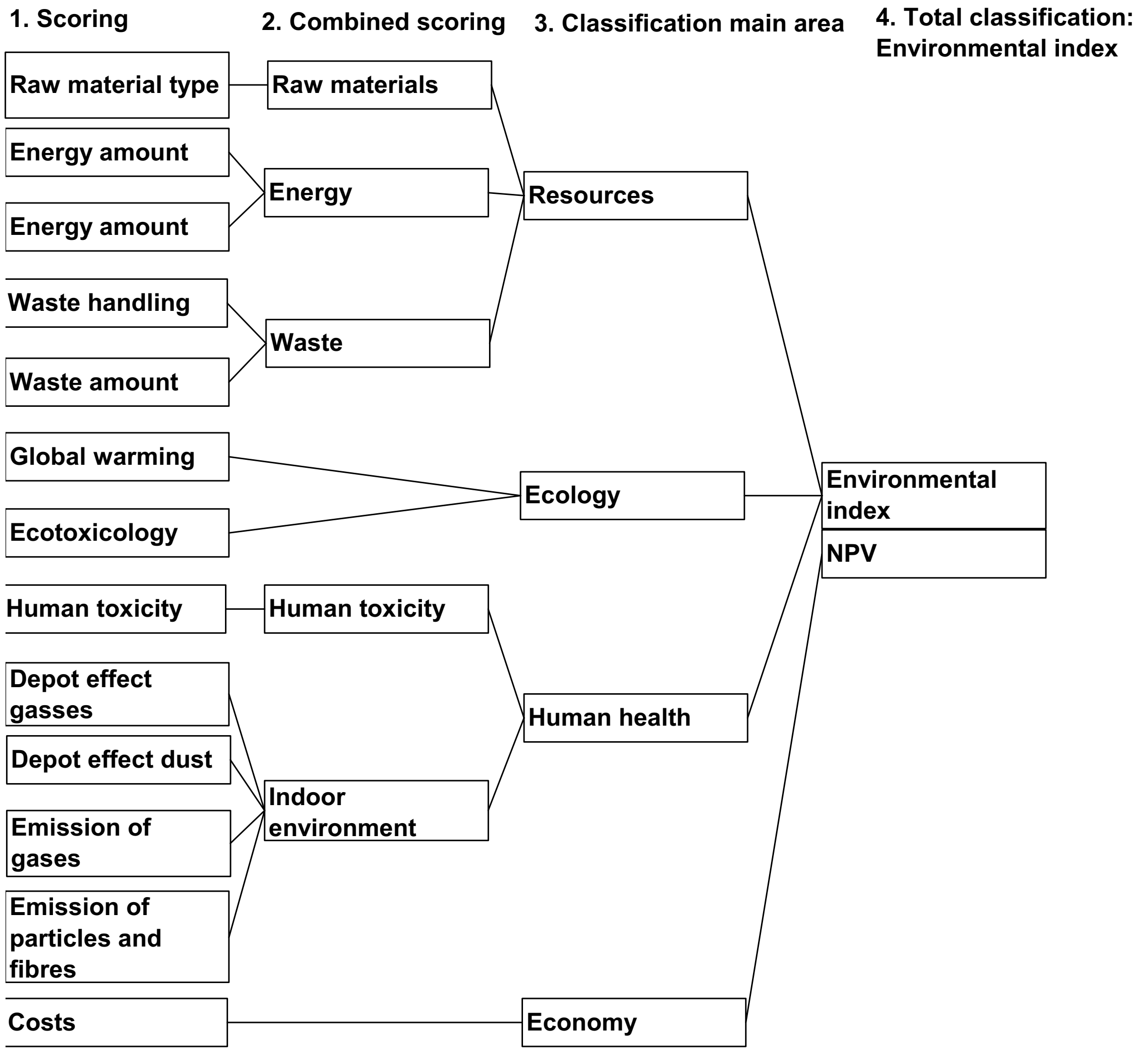


Figure 5-27: Illustration of the evaluation procedure in the MaSe system towards the Environmental index.

6 Input data for the decision support system

The quality of the input data, and knowledge about this quality, are important aspects when considering the results of any environmental material evaluation system. Low or insufficient quality of the input reduces the value of the result. This makes the aspects included in this chapter very important, including discussions regarding the functional unit, durability, allocation, system borders, data availability and validity, together with details about the input data in the MaSe system. Existing environmental evaluation and declaration systems and relevant standards are important sources of information in this context.

6.1 Lessons learned from material evaluation systems

Table 6-1 illustrates that the material evaluation and selection systems presented in Chapter 4, do not encompass entirely the same parameters. In addition, the way the parameters are utilized varies. This means that atmospheric emissions can be included qualitatively as global warming or as CO_2 equivalents. This is the reason that the number of parameters stated in the second row, in some cases, is not in coherence with the number of x'es and q's in the table. One parameters defined in the table might in one system consist of two sub parameters, or one parameter in a system may incorporate two of the parameters defined in the table.

The input data in the different systems has been difficult to assess. Only a small amount of information is available for the users, and personal contact with the developers is therefore necessary. This complicates the comparison of the evaluation results of the different systems.

For a new material evaluation and selection system such as the MaSe system, the input data must be clearly defined, and the experienced user must be provided with the possibility to inspect the main input data of a product. Also details on how the data are collected, allocation rules and system limits must be easily available.

Table 6-1: Parameters included in the different systems and in LCA. q=qualitative, x=quantitative. Several x's or q's means more than one parameter is used to describe the effect.

Method:	**BEES**	**ENV-EST**	**FOLK-SAM**	**ATHE-NA**	**ERG**	**EPM**	**BEAT 2001**	**LCA**	**GMS**
Parameters	7	13	7	6	14	12	11	12	6
Atmospheric emissions					q	q			
Global warming	x	x		x			x	x	
Acidification	x	x					x	x	
Ozone depletion		x						x	
Eutrop-hication	x	x					x	x	
Photochem. oxidants		x					x	x	
Chemicals			q						q
Human tox.		xx		x		q	x	x	q
Persistent tox.							x		
Eco tox. water		x		x				x	
Eco tox. terrestrial								x	
Waste	x	x	q			q	x		
Hazardous waste							x		q
Slag and ash							x		
Reuse-/recycling					q	q			q
Water		x			q	q			
Biodiversity					q	q			
Resources	x	x	q	x	q	q	x	xx	q
Energy		x		x		q	x		
Transport					q	q			
Production energy					q	q			q
Operational energy					q	q			
Primary energy						q			

Cont. Table 6-1.

Method:	BEES	ENV-EST	FOLK-SAM	ATHE-NA	ERG	EPM	BEAT 2001	LCA	GMS
Maintenance					q	q			
Longevity/durability					q				
Costs	x								
Malodorous air						q		x	
Noise						q			
Healthy building issues	x		q		q				
Community health					q				
Workers environment			q		q				
Land and soil quality					q				

6.2 Building material declarations

The interest for environmental declarations of building materials has increased the last few years. Parallel projects have been carried out in several countries like Sweden, Norway and UK. The data sheets are included in Appendix G, but the different systems will not be discussed in detail. Because of the increasing number of declaration, assessment and indicator systems, a need was identified to coordinate these different declaration systems, and a standardisation work has been initiated, the ISO TC 59/SC17.

6.2.1 The different types of environmental declarations

There are three main types of environmental declarations and labels:

Type I: Environmental labelling based on ISO 14024, "Environmental labels and declarations - Type 1 environmental labelling".

Type II: Self – declared declarations based on ISO 14021, "Environmental labels and declarations – Self declared environmental claims (Type II environmental labelling)".

Type III: Declaration controlled by independent third party, based on ISO TG 14025 – "Environmental labels and declarations - Type III declarations".

The differences and similarities of the different types are illustrated in Table 6-2. Note that the main difference between Type II and Type III is the certification procedure and the LCA connection. This is supposed to make data from type II declarations comparable, but this is not always the case.

Table 6-2: Comparison of the different types of environmental declaration (Svenska Miljöstyringsrådet, 2000).

	Type I	Type II	Type III
Basis for calculation	Lifecycle perspective	Lifecycle perspective	Life cycle analysis (ISO 14040-43)
Information	Qualitative/aggregated	Qualitative/Quantitative	Quantitative
Scope	Certain products and services	All products and services	All products and services
Comparability	None	Limited	Good
External quality control	Verification of the labelling organization	None	Certification of an accredited and independent third party.

Within the standardisation on sustainable construction, a branch-oriented approach of material declaration is developed, ISO TC 59/SC3 N468 (2002) "Building construction - Sustainable building - Environmental declaration of building products". It is not finally decided if this is going to satisfy Type III declaration requirements. It is based on the LCA standards, but the parties have not yet agreed upon the external quality control. According to Fossdal (2002), the result will probably be that the standard aims at Type III declarations, but that the quality control will be voluntarily.

6.2.2 Material declaration in Norway

Two of the material declaration systems described in Chapter 6.2.1, are available in Norway:

- Type I labelling: The Nordic Swan Label (Stiftelsen miljømekring, 2000).
- Type III environmental declarations: the NIMBUS-model, developed at Østfold Research Foundation (STØ), and the Ecodec declaration system for building materials developed at the Norwegian Building Research Institute.

The only system aimed specifically at building materials is the Ecodec system developed at the Norwegian Building Research Institute. This Norwegian declaration system is not producer specific as a rule, but based upon a mixture of generic and specific data. The types of data are stated on the front page of the declarations.

The NIMBUS model is a set of guidelines for Environmental product declarations, and how they should be performed. Different LCA tools are used to gather and systematise information in the declarations in the NIMBUS project. In principle, Ecodec may also be used to fill in the data needed in the NIMBUS-model. Today two different LCA tools are used to fill in the data, and different allocation rules and limits make comparison of products problematic. The practical use of the NIMBUS model for comparison of products is therefore questioned. A coordination of the Ecodec and the NIMBUS-model is carried out at the present, and the result of this project will probably lead to improvements for both methods.

The Ecodec is based on ISO standards for environmental declarations (ISO 14020, 14021, 14024 and 14025) as well as the ISO standards for LCA (ISO 14040, 14041, 14042, 14043). This makes the Ecodec closer to type III declarations, but the certification aspect is missing. Table 6-3 illustrates what is included in the declaration system. The figure also illustrates which parameters that are included in both the Swedish and the UK systems. The NIMBUS-model is left out, as this is not a methodology, but a set of guidelines.

Table 6-3: Lifecycle phases and environmental loads included in the Norwegian (N) English (UK) and Swedish (S) material declarations. The black fields indicate that the environmental effects are not regarded as relevant in the lifecycle phase in discussion, and the grey fields that the parameter is included in all three systems.

Life-cycle phases / Environmental loads	Raw matr.	Trans-port	Product-ion	Trans-port	Building site	Use	Demoli-shing	Trans-port	Deposit
Energy	N, UK, S	N, UK, S	N, UK, S	N, UK, S	N, UK	N, UK, S	N, UK	N, UK, M	
Resources	N, UK, S	N, UK, S	N, UK, S	N, UK, S	N	N, UK, S	N, UK	N, UK, M	N, UK
Re-use/re-cycling	N, S		S, N	N; S	N		S		
Emissions to air	N, UK, S	N, UK, S	N, UK, S	N, UK	N, S	N, UK, S	N, UK	N, UK, M	N, UK, S
Emissions to water	N, UK, S	N	N, UK, S	N	N, S	N, UK, S	N, UK	N	N, UK, S
Effect on soil	S		S		S	S			S
Solid waste	N, UK		N, UK, S		N	N, UK	N, UK, S		N, UK, S
Hazardous waste	S, N		S, N		S, N	N			S, N
Indoor environment						N, S, UK			

6.3 Goal and scope

The goal of a study involves the definition of why a study is performed and for whom. The scope involves the definition of what is included and what is impossible or not desirable to include.

6.3.1 Goal

The goal of the inventory is to collect input data to be used in the MaSe system for evaluation and comparison of building products for a defined application. First of all the data are aimed at the operator of the MaSe system. The best way of running a system like the MaSe system is to establish an organisation responsible for the operation of the database and the system.

6.3.2 Scope of the study

The scope of the study according to LCA includes the definition of system boundaries and the functional unit (FU). The **system boundaries** determine what is included in a dataset or not. This depends on several factors, but the intended application of the dataset is the most important factor. For the MaSe system, it is clear the total lifecycle of the product in question must be included. Not all parameters in traditional LCA and environmental declarations need to be included in the inventory for the MaSe system, as seen in the input data table in Appendix A. Figure 6-1 illustrates the system boundaries for the MaSe system. Waste and emission define the output, while materials and energy define the input.

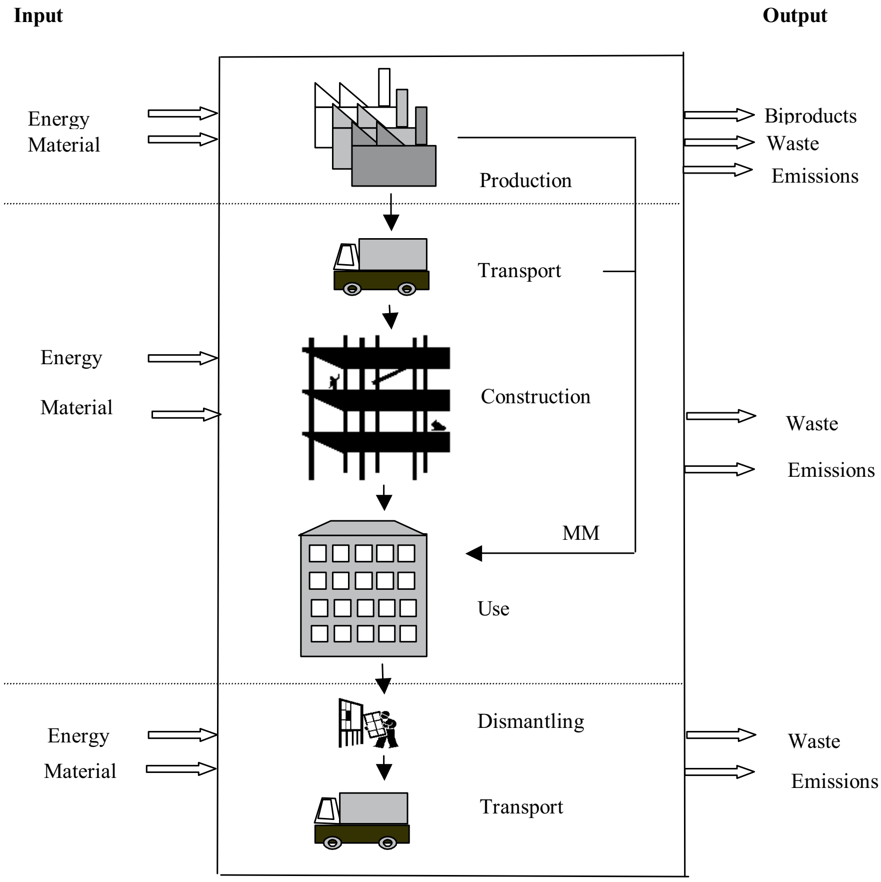


Figure 6-1: System boundary in the MaSe system.

When including the total lifecycle of a building product the long timescale makes it necessary to make some assumptions about the user phase and the disposal. According to some studies, the cleaning and maintenance potentially represent a large part of the environmental load from a product (Paulsen, 2001, Salmelin et al., 2002, Strand et al., 1999 and Hendriks et al., 1999).

Paulsen found that in some cases the environmental load of the user phase of flooring materials exceeds the load from production because of the cleaning procedures. In a study of service life data in LCA of building materials, it was found that the environmental load is closely related to the painting interval (Strand et al., 1999). Using the SimaPro LCA tool, the result demonstrated that longer painting intervals with a resulting shorter service life resulted in a lower environmental load than shorter intervals with a longer service life. This underlines the importance of including user phase data of a product.

The cases presented by Salmelin (2002) and Hendriks et al., (1999) illustrate that for some products and installations the environmental load depends on the energy use in the operation of the building. The dominance of the user phase depends, among other things, on the electricity mix used. For wall insulation, increasing the insulation thickness increases the environmental load in the production and disposal phase, but reduces the load in the user phase. However, it is recognised that this has an optimum, and exceeding this optimum increased insulation thickness cannot be justified through reducing the environmental load in the user phase.

The **Functional Unit (FU)** is primarily known from the LCA theory, and describes a product system and its primary functions. This is the basis for alternative products being declared as functionally equivalent, and therefore the basis for the selection of products using environmental evaluation systems. In the ISO system FU is defined as (ISO, 1998):

> *"...quantified performance of a product system for use as a reference unit in a lifecycle assessment study. This reference is necessary to ensure comparability of LCA results*".

In LCAs and other assessment methods, it is important for the results of the study, that the FU is carefully selected. Studies show that the result may change depending on the FU used.

All mass and energy flows in the system analysed in an LCA is normalized to the FU. Important elements to ensure comparability are that the application is well defined, that the user efficiency is the same (e.g. covering properties), that the lifespan, maintenance intervals and standards for application (given guarantee standards) are stated (Hanssen, 1997/98). Examples of functional units for different systems are:

- Light fitting system: 25 m^2 room sufficiently lit for 20 years.
- Paint: 1 m^2 indoor painted surface maintained for 25 years.
- 1 kg concrete
- Building: 1 m^2 floor area, maintained at a satisfactory level for 100 years.

To ensure the comparability of the products in the MaSe system, the functional unit must be well defined. First, the time span over which the products are compared must be defined. It is not possible to make precise estimates for the service life of a building, but over the years, it has been commonly agreed to use an assessment period of 60 years (Fossdal, 2002). A reason for that is that 60 is an easy number to use in calculations; compared to 50, 75 and 100, 60 is divisible with 2, 3, 4, 5 and 6. However there are also cases where periods of 50, 75 or 100 years have been used. In the MaSe system, the producer states the technological service life of the product under different conditions, but the comparison period of the products is 60 years.

For the different building products, the service life will vary. How this is handled in the MaSe system is described in Chapter 6.6. The products are not always expected to last 60 years, but the service they supply is. If the service life of a material is shorter than 60 years, replacements are necessary. This extra environmental load is then included in the user phase of the building. This will be calculated automatically in the MaSe system.

Technical requirements are included in the functional unit and include strength, sound insulation value, fire resistance, heat transfer, maintenance level and cleaning level. It may seem unusual to include the cleaning level, but this is done the same way as for the maintenance level. It is relevant only for interior materials, and their data sets must include necessary cleaning to a satisfactory level. The cleaning intervals vary from case to case, but again the data must be valid for normal use. The same conditions must be used for all the materials being compared. Cleaning agents, and energy used in the cleaning procedures, must be included in the input data. Environmental effects related to these operations will then be input to the relevant sub areas in the MaSe system.

It is the responsibility of the user of the system, to select and compare materials with the same FU. The materials must be listed, including their FU, for example as the following:

- Flooring material: 1m^2, cleaned and maintained to an acceptable level exposed to normal loads for 60 years.
- Exterior wall covering: 1m^2, maintained to an acceptable level exposed to normal loads for 60 years.
- Paint on interior wall: 1m^2 painted surface, cleaned and maintained to an acceptable level exposed to normal loads for 60 years.
- Wall insulation: 1m^2, U = 0.2, 60 years.

These functional units must be carefully selected in a prospective computer version of the MaSe system. The BEAT2001 system from Denmark and the BEES from USA, are important information and inspiration sources. In these systems, the user first selects the building elements or material types to study. A list of available flooring materials then "pops up" and the user selects the materials or product alternatives acceptable for a particular situation. These materials are then undertaken the evaluation.

The documentation of the environmental loads related to the construction phase is poor. In the material declaration systems studied, very few of the systems supply data from the construction phase. Relevant parameters are waste, energy used (as a rule of thumb 10 per cent of the embodied energy is used in the erection of the building (Howard et al., 1999)) and auxiliary materials. In addition, the use of chemicals at the site must be registered. Construction impacts should be included in the underlying data of an assessment. If not, this must be made clear to the recipient of the information from the system.

Also all maintenance is included, involving the materials and the energy used. Emission to the indoor environment is also relevant. Cleaning should be included, but this type of data are not available in the current declarations. The findings by Paulsen, (2001) suggest that effort should be put into collecting data for relevant cleaning products.

In addition, some building materials contribute to a building achieving the U-value requirements in the regulations. When products or elements are selected for comparison, this means that their U-values should be within a comparable range. A calculation of e.g. the transmission loss in the user phase is therefore not included, as it will be about the same for the products compared.

6.3.3 Data sources

One of the largest obstacles in bringing a system like the MaSe system into use will without doubt be the availability of satisfactory data. Sources of data include (after Wenzel et al., 1996):

- Material declaration systems.
- Databases like:
  - ~ SimaPro: Pre Consultants, The Netherlands (www.pre.nl)
  - ~ IVAM LCA data, the IVAM Environmental research LCA database, the Netherlands (www.ivambv.uva.nl) or
  - ~ BYogBYG database, Danish Building Research Institute, Denmark (www.BYogBYG.dk).
  - ~ Boustead Model, Boustead Consultants, UK (http://www.boustead-consulting.co.uk/)
- Individual LCA studies.
- Literature.
- Un-reported LCA data.
- Measurements or calculations.

Producers who do not want to "reveal" environmental data about their products are seen as a problem. The reason for the secrecy may be that they are protective, not wanting to reveal any business secrets. However, studying the main results from the declarations it is hard to see what secrets could reveal presenting only the aggregated data. The reason might be that the declarations involve a new arena for competition.

Another problem that could explain why the producers hold back information is the uncertainty about how the data will be used. The producers see that the data may be used as a basis for comparison and decision on which products to buy, but not how this will favour them. Using a system like the MaSe system does mean that the materials and products are compared, but by knowing the system and its parameters, the producers have something concrete to relate to. This brings focus on another problem: if the data are to be used as a basis for selection, they should be properly controlled. Earlier practise in Ecodec was minimal control of the data; one producer could use data from another producer, as long as he/she stated that these data were not producer specific. This should be avoided by requiring a third-party control, and/or producer specific data. Today the Ecodec declaration data are subjected to a more detailed control.

The last objection from the producers about providing data is the lack of demand. The reality for today's contractor is that some clients set requirements, for example about emissions to the indoor environment or toxicity. The problem is that there is no consistency in these requirements. This is probably because clients do not know what data that are available, or what to ask for.

Finally, architects, project managers and others claim that there is no use setting requirements because there are few products with declarations. The situation is then that the different professions argue about who is to blame, but no obvious solution is found. One solution might be trough the regulations. In the technical framework for the Planning and Building Act in Norway, it is stated that the building materials with the lowest lifecycle environmental load should be selected (§8-23). The problem is that there is no follow up on this point, generally or in the form of specific methods. A closer focus on this aspect would increase both the supply and demand of data.

6.4 Inventory data collection

The MaSe system may include data from many sources, and as mentioned the data must be carefully assessed before they are entered into the system. The input data for the MaSe system is included in Appendix A. Important aspects are the Functional Unit, allocation rules, specific or generic data, validity of the data, and system limits.

The parameters included are described under the headlines representing the main areas in the MaSe system. In addition, general information about a product is included under the headline "Main product".

6.4.1 Cut-off

Cut-off allows the inventory to be simplified. According to the relevant ISO standards and the different declaration systems, cut off is based on mass, energy or environmental relevance. A common cut-off rule that is used in the UK material declaration system is: "*Data should be included on all materials with a mass greater that 2 per cent of the output from the process. Information should also be provided for materials which contributes to less that 2 per cent of the mass, but possibly have significant effects in their extraction, their use or disposal, or are highly toxic, or classed as hazardous waste*" (Howard et al., 1999). This method is also adopted in the Norwegian and Swedish declaration systems.

In the UK system, a material must be included if it possibly (Howard et al., 1999):

- Have significant effects in extraction, use or disposal.
- Are highly toxic.
- Are classified as hazardous waste.

These rules are also included in the Ecodec system. In the Swedish system, it is stated that the limit is 0.2 per cent if the substance is on the National Chemical Inspectorate Observation list, Restricted Substances list or other lists. In Norway, the Substance list of hazardous chemicals may be used, classified according to regulation of criteria for classification of hazardous chemicals.

A problem with using lists to define what is to be included as input, is that not all hazardous materials found in products are listed. This is further explained in the BY og BYG report, regarding problematic substance in building products (Krogh, 1998). At this stage, no other solution is found than to base the system on a list, like the Substance list of hazardous chemicals. The rules described in this lists are therefore chosen for the MaSe system.

6.4.2 Main product

Information under the first headline of the input data sheet includes general information about the product in question and the data quality. The different points are relatively self-explaining, but some remarks must be made.

It is important that the producers can document the input data and the statements included in the input. This especially involves the statement about the technical service life of the product. If certain factors cause the Service Life (SL) to be reduced, these factors should be listed, including an indication of the magnitude of their influence.

The maintenance is subdivided in frequent, periodic and upgrading. Frequent maintenance is repeated one ore more times per week, periodic maintenance is repeated some number of times per year, while upgrading happens 0-2 times during the service life of the product. The frequencies must be related to a resulting service life.

Dismantling includes information on how the product should be removed after the end of its SL.

Input data for the MaSe-system

Product:	Plaster board
Date:	27.11.02
Producer:	
Data quality	
Data source(s):	Ecodec
Generic data:	%
Specific data:	99 %
Coverage:	94 % of the materials is included
Lifecycle coverage:	Cradle to gate
1. Main product	
Use:	Inner wall plate
Additional materials:	Steel fasteners, 15
Functional unit (FU):	1 m^2 wall
Thickness (mm):	13 Weight (kg/m^2): 9.05
Place of production:	Oslo, Norway
Technical service life:	60

Conditions for the material fulfilling its function throughout its technical service life (maintenance and treatments etc., including intervals):
That it is not exposed to rough mechanic strain
Factors known to reduce the service life of the product:

Maintenance	Type	Frequency		Included in the data (yes/no)
Frequent			per year	
Periodic	Painting	5-10	years interval	NO
Upgrading			years interval	

Dismantling:

Figure 6-2: Input data sheet for general information about the product.

6.4.3 Economy

The costs are calculated using the **N**et **P**resent **V**alue (NPV). This is included in the system, but the producer must enter the costs for a normal user situation. Alternatively, the MaSe system could be directly linked to the cost-database of the firm, or to systems such as HolteProject.

2. Economy		
Purchase price:	______________	NOK/FU
Transport:	______________	NOK/FU
Installing:	______________	NOK/FU
Cleaning:	______________	NOK/FU
Maintenance:	______________	NOK/FU
Repair:	______________	NOK/FU
Replacement:	______________	NOK/FU
Demolition:	______________	NOK/FU
Transport of waste:	______________	NOK/FU
Waste handling	______________	NOK/FU

Figure 6-3: Input data sheet for the Economy area.

6.4.4 Resources

The parameters under the main area Resources are thoroughly described in Chapter 5.3. The input parameters are shown in Figure 6-4. The data are presented in the different sub areas, and the information is split on the different lifecycle phases, presented per FU.

3. Resources

Raw material type	Production (kg/FU)	Transport, construction and use (kg/FU)	Transport and disposal (kg/FU)	Total (kg/FU)
Reused	0.00			0.00
Recycled	2.80			2.80
Down cycled	0.00			0.00
Sustainable renewable	5.60			5.60
Non-renewable	6.60			6.60
Unsustainable renewable	0.00			0.00
SUM	15.00	0.00	0.00	15.00

Energy type	Production (kWh/FU)	Transport, construction and use (kWh/FU)	Transport and disposal (kWh/FU)	Total (kWh/FU)
Renewable energy	0.00	0	0	0.00
Hydropower	1.40	0.01	0.01	1.42
Biofules	2.10			2.10
Coal	0.00			0.00
Oil, natural gas, nuclear energy	8.20	0.8	0.1	9.10
SUM	11.70	0.81	0.11	12.62

Waste handling	Production (kg/FU)	Transport, construction and use (kg/FU)	Transport and disposal (kg/FU)	Total (kg/FU)
Reuse	0.00	0.036		0.04
Recycling	0.00	0		0.00
Down cycling	0.00			0.00
Energy recovery	0.00			0.00
Deposition	0.10		9.05	9.15
Hazardous waste treatment	0.00			0.00
SUM	0.10	0.036	9.05	9.19
Conditions for the stated waste handling scenario to be possible:				

Figure 6-4: Input data sheet for the Resource area.

Some remarks are needed regarding the energy and the waste parameters. The total amount of energy used in order to produce the raw materials; the product and the by-products must be stated. This number should preferably include the energy loss in the production of energy from the primary source, and the loss in the transfer of the energy to the location it is used; this is then the primary energy. In practice, however, this transmission loss is difficult to calculate.

The demolition of the building and the following waste treatment is seldom in focus in the design phase of a building. But the possibilities for the product to be recycled must be included in the MaSe system, together with recommendations for how it must be installed to facilitate reuse or recycling. It is no way of knowing if this will happen, because this depends on many factors like innovations in recycling techniques and changes in market values for different scrap materials and wastes. The scenarios for recycling are therefore very uncertain. In the MaSe system, this information will be based on current knowledge, and what is the common solution today.

Design for reuse is an issue of interest shared also by architects. For dwellings, there have been some projects like for example the **A**ssembly – for – **DISA**ssembly (ADISA) project. ADISA consist of three main concepts (Nordic Council of Ministers, 1999):

- Separate layers: Interior, space plan, structures, skins (cladding) and site should be technically separated.
- Possibilities for disassembly within each layer.
- Use of standardised mono-material components.

These principles do not fit in a declaration system, whereas in a design system they are very relevant. If reuse is stated as the waste treatment scenario on the declarations when the materials' service lives end, any special efforts needed to facilitate reuse must be stated. Erection based upon principles like ADISA, is one example on how the materials can be considered having a reuse potential.

6.4.5 Ecology

Ecological effects include emission of gasses with a GWP and emissions of toxic substances to soil, water or air. All the materials used in the production, construction and use of a product must be assigned with their relevant emissions. Figure 6-5 illustrates the input data on the Ecology sub-area in the MaSe system.

URN:NBN:no-6424

4. Ecology

Emission of gasses that contribute to global warming	Production (kg/FU)	Transport, construction and use (kg/FU)	Transport and disposal (kg/FU)	Total (kg/FU)
GWP	2133.8	193.9	27.8	2355.6

Chemicals:

Substances with ecotoxicological effects	Production (mg/FU)	Transport, construction and use (mg/FU)	Transport and disposal (mg/FU)	Total (mg/FU)
Chemicals on the OBS list:				
Arsenic (As)	0.047			0.047
Cadmium sulphate (10124364)	9000			9000
A-list				
B-list				
Pb	0.068			0.068
Cd	0.006			0.006
Hg	0.009			0.009
Zn	0.003			0.003
Substance list:				
Ni	0.0026			0.003
Forbidden substances				

Figure 6-5: Input data sheet for the main area Ecology.

The GWP is the parameter that probably has the best data availability. It is important to remember that the assumptions behind the data collection will affect the result. When using data from different sources to compare two products, it is important to investigate these assumptions, and how they may influence the result. Assumptions are normally made regarding the energy source, for example if it is 100 per cent hydropower, a European energy mix or Norwegian energy mix? This factor may have a major effect on the result. In addition, the transport means and distances might be important. Finally, it is sometime assumed that most of the GWP arises from electricity use and transport, and not from the production process itself. This might be true, but not to the extent that it is a rule.

For ecotoxic substances, lack of data is common. Not many of the about 70 declarations in the Ecodec system include substances with ecotoxic effects. This seems strange, as it is known that the building and real estate industry is responsible for using huge amounts of these chemicals. For example, the declaration of glass wool does not contain any information about borax, but this is common as an additive in the production of insulation. Perhaps it was omitted from the declaration because the declaration is limited to substances on the Obs list. However, the Obs list is constantly changing, and in the last revision, borax was included based on the possible effects on reproduction and foetuses. This makes also another important point, the listing of chemicals should not be linked to any sort of black list, but include all substances in the labelling regulations. In the current situation, much is up to the quality control of the data entered into the system database also when it comes to the evaluation of ecotoxic substances. The most important reason for excluding ecotoxicity is, however, that no common assessment method is identified; the effect is therefore generally excluded in most declaration methods (Sverre Fossdal, 2002).

6.4.6 Human health

The input data table for the human health aspects is shown in Figure 6-6. Human health includes a limited evaluation of the working environment in the production of the different products, the construction, the maintenance and the demolition. As seen in the previous chapter it has proven difficult to find proper methods to visualise these effects. The evaluation of the production, construction and disposal is therefore limited to substances with human toxicological effect. The same problems are related to this aspect, as for the evaluation of ecotoxicity discussed in Chapter 6.4.5.

The user phase of the building receives special attention because of the length of this period. Absorption and desorption of gasses are evaluated, together with measurements of TVOC, formaldehyde, ammonia, carcinogenic compounds, emission of particles and fibres, and the per cent dissatisfied level. This is also a typical area of data deficiency. In the new ISO standard for building material declaration the area is included, but will probably be regarded as voluntarily. In the MaSe system it is possible to leave out some areas of the evaluation, to get started is spite of data scarcity. However, effort should be put into gathering data on this important area.

5. Human health

Chemicals:

Substances with humantoxicological effects	**Production (mg/FU)**	**Transport, construction and use (mg/FU)**	**Transport and disposal (mg/FU)**	**Total (mg/FU)**
Chemicals on the OBS list:				
Arsenic (As)				
Cadmium sulphate (10124364)	9000			9000
A-list				
B-list				
Pb	0.068			0.068
Cd	0.006			0.006
Hg	0.009			0.009
Substance list:				
Ammonia (NH3)				
Formaldehyde				
Nickel (Ni)	0.003			0.003
Phenol				
Forbidden substances				

	Good/Medium/ Poor
Characterisation of the products depot effect for gasses:	Medium
Characterisation of the products depot effect for dust and particles:	Medium

Total Volatile Organic Compounds, TVOC (mg/m^{2}h):	0.01
Formaldehyde, H_2CO (mg/m^{2}h):	-
Ammonia, NH_3 (mg/m^{2}h):	-
Carcinogenic compounds according to category 1 of IARC classification	-
Emissions of particles and fibres (mg/m^2):	-
Dissatisfaction level (%)	-

Figure 6-6: Input data sheet for the human health area

6.5 Inventory data handling

The discussion of allocation in data inventory is very complicated. Trinius (1999) wrote an entire PhD work on the subject of allocation in LCA. In this work, it was shown that different allocation rules give different results in a LCA. In the present work, this discussion will not be followed in detail, but it is pointed out that there has to be uniform rules also for allocation in order to produce data that facilitate comparison of building products. This makes it necessary to include a brief discussion on system borders and allocation for the MaSe system.

6.5.1 Allocation

Allocation is in ISO 14 040 defined as "Partitioning the input or output flows of a unit process to the product system under focus" (ISO, 1997). Allocation concerns processes with more than one function, meaning for example where several products come out of one process. In the case of recycling and reuse allocation rules are also needed. There are mainly three allocation principles:

- By system expansion to avoid allocation.
- By physical property (e.g. mass or calorific value).
- By other relationships as for example product value.

In the ISO draft for the Environmental declaration of building materials, it is referred to ISO 14 041 regarding allocation procedures (ISO TC59/SC3, 2002). In the ISO 14 041 standard, it is stated that the selection of the allocation procedure depends on the scope of the study, but it is important that the procedure is documented and that it is fair. The ISO standard is criticised for not considering the problem that different allocation rules might result in different results, and that the selected allocation rules must be related to the goal of the study (Ekvall, 2000).

Allocation by expanding system limits is not applicable for environmental declaration of products. It seems like allocation by mass is a common solution. This is acceptable, but some will consider economic allocation as more correct. This principle is seen as fair because the product with the highest economic value is likely to control the process, this process should therefore be assigned with most of the environmental load. In the coordination of NIMBUS and Ecodec the following allocation rules have been chosen (Vold et al., 2003):

- If it is possible, allocation between systems should be avoided.
- When allocation between products from a multi-output process, it is recommended to use economic allocation between products as the general principle.
- Allocation of loads from waste handling systems should be based on the physical dependency between the materials.
- In open loop recycling no allocation is used.
- Expansion of system limits as an alternative to allocation is not allowed in this type of studies.

6.5.2 Allocation and recycling

It is important to define a set of allocation rules in recycling to avoid under or over counting. For hazardous waste or waste that is deposited, it is natural to burden the product in question with the waste treatment. If the product is used for energy recovery, this energy must be subtracted from the result to avoid double counting in the future. The environmental load related to the incineration must be assigned to the product using this energy. For recycling and reuse, it is a bit more complicated.

The allocation in the case of recycling is solved differently in various declaration systems. In the ISO draft standard for environmental declaration of building products it is referred to ISO 14041. This means that the allocation rules must be defined for each product declarations system. For the Norwegian system, all the environmental burdens are assigned the original product. In the English system they try to allocate a part of the environmental load to the future recycled product based on economic value. This is also proposed in a study by Borg et al. (2001).

Figure 6-7 illustrates the English declaration system where "old" scrap is leaving the system and assigned an environmental load depending on its value, future recycling is therefore a way of reducing a system's environmental load.

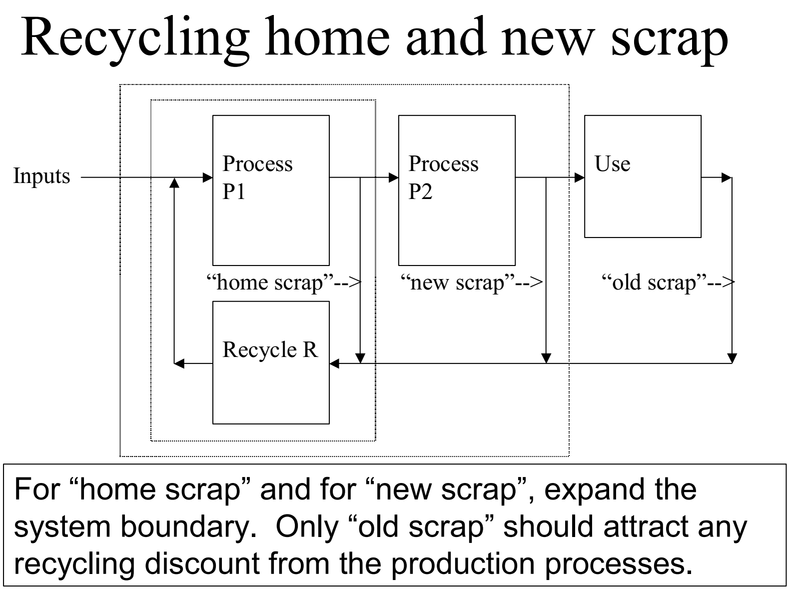


Figure 6-7: Illustration on the allocation of environmental load in recycling in the English declaration system (Howard et al. 1999).

For materials with long service life, it seems difficult to assign a part of the environmental load to a future product if it is recycled. In some cases, it might be assumed that scrap is recycled into the same product, or product type, but in many case it is not even that simple. Using economic allocation, the future value needs to be discounted to net present value, in order to be assigned an environmental load today. With a 7 per cent rate of interest, 1000 NOK in 60 years is worth 17.25 NOK today. Accepting that the future value must be discounted, it is only possible to forward very small amounts of the environmental load related to future recycling.

The alternative is open loop recycling, were no allocation is made for material subjected to recycling. If a recycled material is included, they have no assigned environmental burdens because of their "earlier" life, only from possible upgrading procedures or transport of the product. The most important arguments for this solution are that this is about actions that might happen in about 30-60 years, depending on the service life of the product. It is not guaranteed that it will happen at all. A premium should be offered for facilitating reuse and recycling in the future. This is also done in the MaSe system, but only under the "Waste" sub area. On the other hand, the producer will be rewarded for using recycled material in the production, because this reduces the environmental loads under both the ecology area and the "Raw material" sub area.

In the MaSe system, there is little or no influence on the allocation principles applied for the collection of the data, as different systems might be used for data input, like Ecodec and NIMBUS. Nevertheless, for the products to be comparable, the same allocation principles should be followed, and this must be controlled when adding data into the MaSe system.

6.6 Service life of building materials

The definition of the FU is closely related to the predicted or forecasted service life of a building material. Service life is defined in 15686-1 as the period after installation during which a building or its parts meets or exceeds the performance requirements (ISO, 2000). Service life planning is a systematic way of defining the predicted service life of components and a project, the maintenance needs and the replacements needs. These are also central elements in the FU discussion.

6.6.1 Service life estimation and prediction

The service life of a building and its components has different definitions (NBI, 1991):

- Aesthetic service life: Depending on fashions for example colours and design. Can be seen as one of the factors determining functional service life.
- Economic service life: The time interval when the difference between the present value of the expected economic profit and the original investment cost is positive.
- Functional service life: The time where the product satisfies certain functional requirements, also depending on changing requirements and new products that better fulfil the requirements.
- Technical service life: The time that a material, component or a building can last technically. It is the manufacturer and the constructor/designer who decide the technical service life, or the planned service life.

For a material selection system, it is the functional service life that counts. At least this is true for interior materials like for instance inner walls. For other materials like exterior wall covering, it might be the technical service life that is important. In order to decide the technical service life, service life prediction methods are required.

Service Life Prediction is based on recorded performance over time as found in service life models, or testing. Three groups of methods for service life prediction are listed as the current alternatives (Moser et al. 2002):

- Scientific methods (probability, stochastic) methods.
- **E**ngineering **D**esign **M**ethods (EDM).
- Factorial method.

The probabilistic methods are used on large infrastructure projects, to develop tailor made solutions. The factorial method is described in this chapter. The EDM method is something in-between the other two methods. Here density functions are applied instead of using single numbered factors. This is also described later in this Chapter. The method is described in detail in an article from Moser (et al. 2002).

It is not straightforward which method to use for a material selection system. In Ecodec, they have solved the problem letting the producers state the replacement interval of the products, without requirements for how this should be done. The durability of the product it stated together with a description of required maintenance, this indicates that it is the technical service life.

Part 1 of ISO/CD 15686 describes the general principles of service life planning, and Part 2 describes the methods of service life prediction of materials, components and assemblies in specific conditions. In the ISO Standard, service life forecasting, service life prediction based on test data, and the factorial method for estimating service life, are presented as three methods to predict service life of a material. The factorial method is based on a defined **r**eference **s**ervice **l**ife of the **c**omponent (RSLC), which is the documented period in years that the component or assemenbly can be expected to last in a reference case, under certain well-defined conditions. The **e**stimated **s**ervice **l**ife of the **c**omponent (ESLC) is calculated using a set of modifying factors as shown in Equation 6-1.

$$ESLC = RSLC*A*B*C*D1*D2*E*F$$

Equation 6-1

Where

ESLC = Estimated service life of the component
RSLC = Reference service life of the component
Modifying factors:
A: Performance of materials
B: Design level
C: Work execution level
D1: Indoor environment
D2: Outdoor environment
E: In use conditions
F: Maintenance

An aspect that has received attention the last years is that these modifying factors are not represented as single figures, but as density distributions. The estimated service life will consequently also be a distribution. Moser illustrates this in an example using facade windows (et al., 2002). The result using Monte Carlo simulation is presented in Figure 6-8. It was found that for the purpose of investment planning, the 16 per cent fraction seemed to be a good indication of the point in time for replacement.

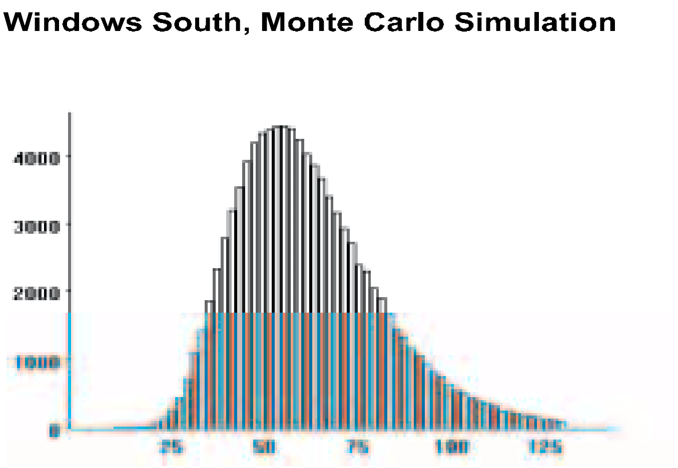


Figure 6-8: The Predicted Service Lives Distribution of the Components, PSLDC, of the south façade windows. Densities are the result of 10^5 runs of Monte Carlo Simulation (after Moser et al., 2002).

The factorial method is promoted through the ISO standards 15 681 – 1, but documentation is scarce on the use of the method. Neither the usefulness nor the reliability of the method is known (Sjöström et al., 2002). Ongoing work within the CIB W80/RILEM-175, on Prediction of service life of building materials and components, involves:

- Determining the level of detail required to develop the factors.
- Studying limitation of the use of this method for estimating service life of material and components, and instances in which it can be successfully applied.
- Development of factors and their reliability.

In the future work of **Pe**rformance **B**ased **B**uilding (PeBBu) Thematic network, Domain 1, Construction materials and components, the focus is set on (Sjöström et al., 2002):

- Further development of the Factorial Approach:
  - ~ theoretical engineering approaches,
  - ~ the basic knowledge base of different factors,
  - ~ the development of pedagogic application examples and
  - ~ training of practitioners.

– Exploring and description of the conditions and prerequisites for reference life (performance) data for classes of building materials and components.

6.6.2 Service life in the MaSe system

All together, the equation and the modifying factors in the factorial approach give a picture of how complicated the estimation of the service life of a material or a component can be. However, this is completely irrelevant if the aesthetic service life determines the service life. For example if a building is be rented out to different tenants successively, the interior is likely to change in periods of maybe two to ten years, extensive testing then has little value.

The predicted service life and the identified maintenance and replacements needs are important for the result of an environmental assessment. A separate study was carried out to determine the importance of service life data to the results of an LCA of the different alternatives for exterior wall coverings (Strand et al., 1999). Wooden cladding and brick veneer with different mainenance scenarios was included in a LCA study. The result showed large variations of environmental load, calculated using LCA, for the different user conditions. This showed that it is important to assess the surroundings in which the materials are used and the maintenance of the materials during use.

Also in the MaSe system the predicted service life and the maintenance are important for the result. As for the environmental declaration systems, there are no specific requirements for how accurate the estimates must bee, or which metod to be used to predict the service life. It is, however, important that this information is presented on the data-input scheme, and made avalable to the user in the material selection scenarios.

The producers generally have quite detailed knowledge of the performance characteristic of their own products (ISO 15 686, 2000). The industry must supply a normal service life scenario and the assumptions behind this scenario. The normal service life is preferably equal to the reference service life described in ISO 15868-1. They must also inform the user of specific user scenarios or agents that may affect this estimated service life of the product. The factorial approach described in ISO 15686-2, might then be used to predict the resulting service life. A better basis is provided through EDM. As illustrated in Table 6-4 the factors are listed in connection with the relevant conditions, and the PSLDC may be calculated on this basis. In this case Moser does the calculation using VaP 1.6, and the result was:

– East: Mean value: 72.6 Std. dev.: 11.5 16% damaged: 61
– North: Mean value: 69.0 Std. dev.: 11.2 16% damaged: 58
– West: Mean value: 61.7 Std. dev.: 10.5 16% damaged: 51
– South: Mean value: 65.3 Std. dev.: 10.9 16% damaged: 541

Table 6-4: Fraction values for factors (after Moser et al., 2002). The factors for the 5%, 50% and 95% are defined according to the Delphi method (an exercise in group communication among a panel of geographically dispersed experts).

Factor	face	relevant conditions	Factors for the fraction 5%/50%/95%
f_A Quality of Component	all	general variation of components	1.2/1.5/1.8
f_B Design level	all	good, identical value	1.2
f_C Work execution level	all	general variation but insufficiently quality repaired	1.0/1.2/1.5
f_D Indoor environment	S W N E	occasional risk of condensation medium risk for condensation high risk of condensation medium risk of condensation	0.9/1.0/1.2 0.8/0.9/1.1 0.7/0.8/0.95 0.8/0.9/1.1
f_E Outdoor environment	S W N E	occasional cycling dry/damp regular cycling dry/damp sheltered from rain occasional cycling dry/damp	0.8/1.0/1.3 0.6/0.8/1.0 1.0/1.2/1.5 0.8/1.0/1.3
f_F In use conditions	S W N E	occasional access by children regular access by children occ./reg. access by children occasional access by children	0.8/1.0/1.2 0.6/0.8/1.0 0.7/0.9/1.1 0.8/1.0/1.2
f_G Maintenance level	all	painted on judgement from caretaker	0.9/1.0/1.1

6.7 Data quality

Data quality involves many aspects, including data representativity, uncertainties and validity. Data quality can be made explicit including the variability in the declarations as suggested in ISO TC 59/SC17. Here an expression is suggested that indicates the quality of the data, for example:

- 42.5 [41.4-43.8] kg M indicates that this data are based on a measurement, and the data are expressed as a range.
- 42.5 +/- 2 kg S indicates that the data are a result of a scenario based on assumptions, and the variability is expressed as absolute uncertainty.

In the future work of SLP, the variability is, as seen in Chapter 6.6, included as one of the main tasks. The variability of the durability data will also cause variability in the environmental load from a material or a product. For example a shorter service life, normally leads to a higher environmental load per FU, and high maintenance needs will normally lead to a higher environmental load, but not necessarily when calculated per FU. The definition of the factors in Table 6-4 is important to cover these aspects, and forms a good basis for calculating the environmental load in different user conditions.

The validity period of a data set is the period where the data are regarded to be a correct picture of the situation. This aspect is in the ISO standard for building material declaration included in what is called data representativity, which is related to time, geography and technology. In the Ecodec system in Norway, the year the data are collected is included, but no requirements are set as to when the declaration must be renewed. The same principle is used in the BRE Environmental Profiles system and the Swedish environmental declaration system (Howard, 1999, Swedish Building Centre, 1999). It is the producer's responsibility to see that the declaration is updated with regard to possible process or property changes. According to Fossdal (2002), three to four years would be correct. In the NIMBUS, Type III environmental declarations, some declarations include a defined period of validity, while others do not. At the Norwegian Building Research Institute, a project started in January 2003, where one of the tasks is to study the validity of the data. The conclusion from this study must then be implemented in the MaSe system.

Including the variability, the result might then be presented as illustrated in Figure 6-9. In the system as it is today, Product 1 and 2 will be presented as having Environmental index 3 and 4 respectively. From the illustration of the distribution of the load, it is seen that in some cases Product 2 will be a better choice than Product 1. It is important to reveal this, and inform the user in what user circumstances this will be a reality.

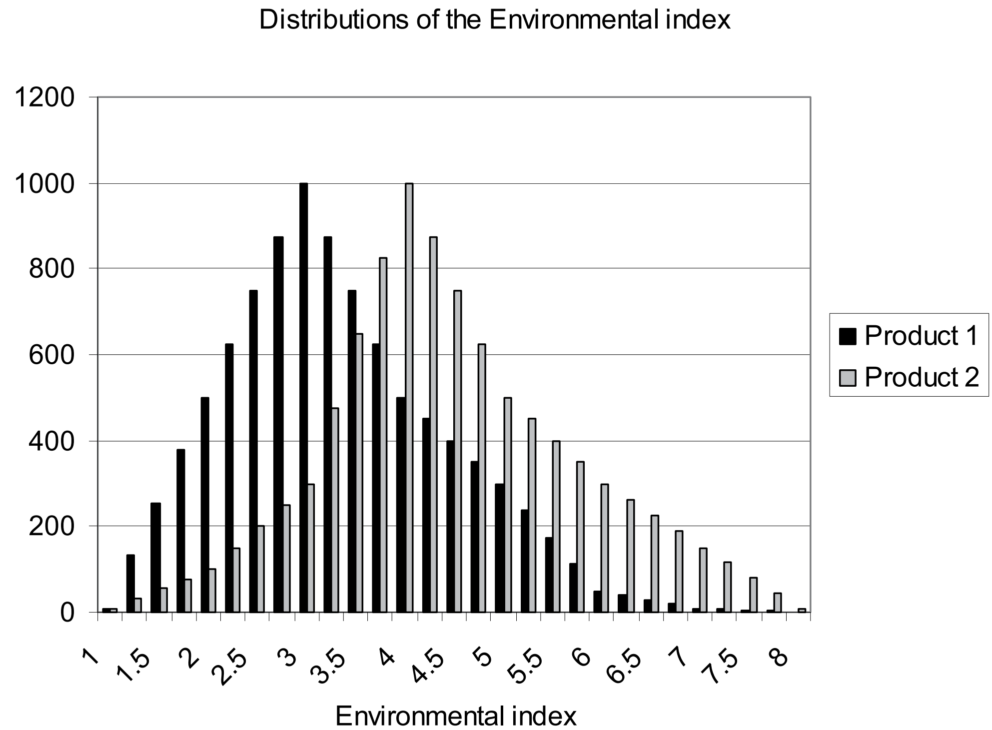


Figure 6-9: Presentation on how the distribution of the environmental load distribution for two products might be illustrated.

In the MaSe system, as it is now, the basic rule, is to use the mean value, unless weighty arguments can be presented for doing otherwise.

In all the studied material declaration systems, the manufacturer decides how complete the building material declarations should be. Incomplete information gives an inaccurate basis for evaluation and selection of materials and products. This may in turn increase the risk of a product not being considered for possible purchase, or on the opposite found to be an excellent choice, superior in environmental qualities related to other competing products. This problem must be handled when entering the data into the MaSe system. Preferably this is done by an expert, who can reveal these flaws, and for example disqualify these materials.

Representativity is also related to the requirement of producer specific data. Type II declarations include no requirement to use producer specific data. In Type III declarations, this is a requirement because these declarations are meant to form a basis for comparison. In the NIMBUS declarations in Norway, minimum 80 per cent of the data must be producer specific (Hanssen et al., 2000). This is also preferred in the MaSe system, unless it can be documented that using other data are likely to cause minimum deviation.

6.8 Discussion and summary of findings

The detailed input data in the MaSe system will not be public. It is however preferable that the data are presented as total results, representing the total lifecycle of the product, similar to the main results from a material declaration, and per lifecycle phase. The final solution depends on the cooperation with the producers in a possible realisation of the MaSe system. In any case, in a realisation of the system, the different participants in the industry must agree upon a way of establishing an organisation responsible for the operation of the system, the management of the data would then be one of the aspects to be discussed.

In order to use data to compare building products, the data should be producer specific, unless it can be proven that using generic data only leads to insignificant changes of the result compared to using producer specific data. However, for indoor environmental data, the tests must be producer specific. The MaSe system handles both generic and specific data, but at different stages in the selection procedures of building materials, as described in Chapter 7.

The input data to the MaSe system must cover the whole lifecycle of the product in question. From existing data sets, it is obvious that the user phase must be brought into focus. Data gaps are a problem for indoor environment, cleaning and maintenance. Many of these factors are related to service life prediction. Little data are available also on the Service Life of a product. The key for providing these data are the producer, and the goal is to move towards the EDM method, but for now this is rather unattainable as a general solution. The producer should, however, be able to provide data of the type illustrated in Table 6-4, allowing the factorial method to be used for providing a single figure service life.

Another aspect is that the MaSe system has no current way of including deviations, but this should be implemented in a future computerised system. If no data exists at that point in time either, the possibility to enter data should be kept open.

The FUs ensure that the products compared can in fact replace each other. The user of the decision system is responsible for defining the acceptable quality range. Therefore, even if the FU is not 100 per cent identical, the user might decide that the products satisfy the function needed in a specific project.

All products are compared over a period of 60 years. The number of replacements depends on the durability of the product. When a product is replaced, it is important that auxiliary materials and implications for other products are included. More effort needs to be put into collecting the SL and other user phase data in existing material declarations.

As for other areas, the MaSe system has little influence on the allocation procedure followed. What should be controlled is that the allocation procedure reflects reality the best possible way, and that it seems reasonable. For future recycling of a product it seems reasonable that the original product is responsible for the environmental load. This means, that if someone in future should reuse or recycle the product, it has no initial environmental load. This must also be seen as an inducement for increased reuse and recycling. If on the other hand, it is about recycling or reuse internally in a production facility or on the constructions site, the products normally have an economic value, and economic allocation may be used.

The MaSe system is compatible with both third party declaration systems and Type II declarations. In some cases additional information needs to be collected, for example an additional check should be run for chemicals. Indoor environmental data are also a common field of underreporting. The MaSe system has the advantage that it is possible to exclude some of the main areas from the evaluation.

For the time being, only the Ecodec system offers any amount of data for building materials in Norway. The problem is that these data are not publicly available and not 100 per cent satisfying when it comes to some data quality aspects. Effort must be put into completing the datasets, making sure that the FU and the allocation procedures are coherent before entering the data. If the products compared have data from different sources, this must be made clear in the result of the assessment, and it must be documented that the products are comparable.

Regarding the producers attitude, this will probably change a soon as they realise they must supply the information in order to be included in the competition at all. It is seen that larger companies like Statsbygg, Veidekke and NCC have formulated requirements on environmental product information. This pressure will hopefully increase and result in better access to environmental information (Ministry of Environment, 2002a). Some help may come through a new act about the right to have access to environmental information. The purpose of this law is to *"secure access to environmental information with respect to oneself, the environment and the possibility to participate in public decision processes*" (translated from Norwegian by the author). The law also includes products, but its relation to other laws like the law of product control is not completely clarified. No discussion on the different aspects of the law is included here. However, it may offer a new opportunity to demand environmental information about building products.

The validity of the declaration is normally 2-3 years. However, if significant changes are made these must be reported. In the English system, the producers are responsible for the supply of data if significant changes are introduced, but only random checks are made. Assuming a substantial amount of products in the database, the revision of the data will take a lot of time. It might be worthwhile considering the combination if the two systems. Expanding the validity period to for example 5 years, and make the producers responsible to report significant changes.

The variability of the SLP and its influence on the MaSe system is not studied. In today's version of MaSe, it is not possible to include a detailed evaluation of this aspect, unless repeated evaluations using different scenarios are made, but in a computerised version of the system the result of the assessment may be given as a distribution.

URN:NBN:no-6424

7 Practical use of the MaSe system

The focus in this chapter is to show how the MaSe system may function in the building process, and the different ways of exploiting the information available within the system. Examples are included to illustrate how the MaSe system may support environmentally conscious material selection. Some details of these examples are presented, but not all the calculations. First, to better see the totality of the process, a general description of the different steps in the working procedure is preseneted.

7.1 Main stages in the practical application of the MaSe system

The main steps in the use of the decision support system are:

Step 1: Preferences:
The client systematically generates weights for the main areas. The ranking serves as a guidance for the selection of the materials and products in the following steps.

Step 2: Material and product specification:
The user of the MaSe system includes the weights from step 1, and ranks the materials with respect to environmental considerations. The output of this step is a specification of the materials or product groups to be used in the building. The properties of the selected material or product form the basis for the next step.

Step 3: Producer selection:
The contractor is responsible for selecting the best possible producer in compliance with the specification from the previous steps.

Step 4: Final result and calculation of result for the building in total:
After the building is completed, a material profile may be calculated, forming an illustration of the environmental quality of the materials in the building in total. It is important that all main areas and parameters are included, and that standard weighting is applied if the result is to be compared with other buildings. This is not included in the present version of the system).

Figure 7-1 illustrates the application of the MaSe system.

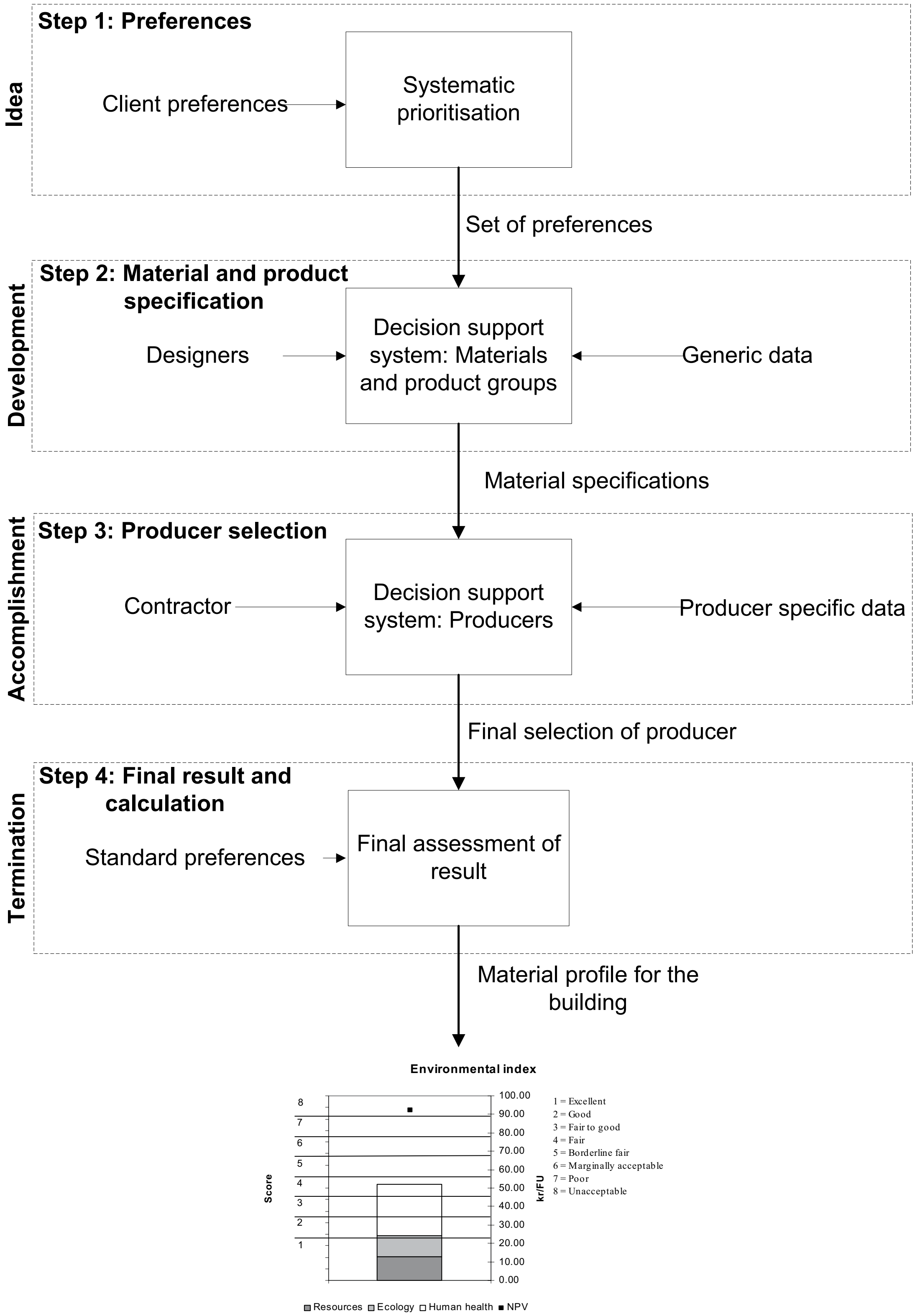


Figure 7-1: Main steps in the application of the MaSe system, including an example of a total material profile for the total building.

The principal idea is that the information flow shall be integrated in the work that is done in the building process today. The process may therefore vary according to type of contract and structure in each project, but it is possible to adjust the MaSe system so that it satisfies these different conditions. More details about the different steps and different examples are presented in the following sections.

7.2 Example 1: Insulation for exterior wall

In this first example, the objective is to find the best exterior wall insulation alternative. Environmental data are extracted from BEAT2001 (BYogBYG, 2001). This database contains information about different insulation alternatives, but the selection is limited to those that may be regarded as functionally equivalent. The following materials and products are included in the study:

- Rock wool, 30 kg/m^3, U = 0.2 W/m^2K, cradle to gate.
- Ecofibre, 31 kg/m^3, U = 0.2 W/m^2K, cradle to gate.
- Environmental insulation paper 32 kg/m^3, U = 0.2 W/m^2K, cradle to gate.
- Generic cellulose, 31.5 kg/m^2, U=0.2 W/m^2K, cradle to gate (data represents an average of Ecofibre and Environmental insulation paper).

Note that the data in this example only covers cradle to gate data. The economic data are based on own estimates, and information from Statsbygg. The materials have about the same U-value and the same service life, so an evaluation based on cradle to gate information most likely provides a good indicator for comparison.

7.2.1 Step 1: Preferences

In this first step of the MaSe system, the goal is to clarify the decision maker's preferences with regard to the main areas in the MaSe system. This defines the design criteria, which is the baseline that a given design is to be compared with.

The client is guided through a prioritisation procedure, using pair wise comparisons to systematise the process. The prioritisation table is illustrated in Table 7-1, and Saaty's (1994) fundamental scale, described in Chapter 5, is used to guide the decision on the relative importance of the areas.

Table 7-1: Weighting table for the main areas in the MaSe system.

Main area	Resources	Ecology	Human health	Geometric mean	Weight
Resources	1	1	1/2	1	25%
Ecology	1	1	1/2	1	25%
Human health	2	2	1	2	50%

In this step, environmental quality standards that the complete building must satisfy may also be defined. For example:

– No material with an Environmental index above 6, is to be used in the building
– 80 per cent of the materials should have an Environmental index of 4 or better.

In addition, it would be useful with a statement to which degree an increase in costs is accepted, if this will improve the design with respect to environmental criteria. This statement can for example be expressed as an acceptable per cent increase, and/or a definition of how much better a more expensive product must be with regard to environmental performance.

7.2.2 Step 2: Material specification

The architect receives the environmental prioritisations from the client together with the rest of the requirements for the building. The situation is that the architect faces requirements to select more environmentally preferable materials in a specific building. It may be found that it is possible to make some changes in the selection of insulation materials. After reviewing the technical requirements, it is decided that both rock wool and generic cellulose are acceptable with respect to technical requirements.

If the client's prioritisation is entered into the MaSe system, it is possible to compare the environmental qualities of the two materials. But first, a more detailed weighing is needed for the following parameters:

– Main area Ecology: Global warming vs. Ecotoxicity.
– Main area Human health: Indoor air pollution vs. Human toxicity.
– Main area Resources: Waste vs. Energy vs. Raw materials.

Available weight sets in the MaSe system are at present:

– Equal weighting
– User defined, following the same guidelines as in step 1.

Equal weighting is used in this example, and the results are then presented as shown in Figure 7-2. These weights might also be provided by the client or developed in cooperation with the client.

It is seen that generic cellulose is evaluated as better with respect to both total environmental qualities, and for the NPV. For this project, cellulose insulation is the best choice. The architects then specifies that cellulose insulation is to be used, but that the MaSe system must also applied for quality control of the producer selected. The producer must be equal to or better than the generic material upon which the decision is based. This task will be passed on to the third step, the product selection step.

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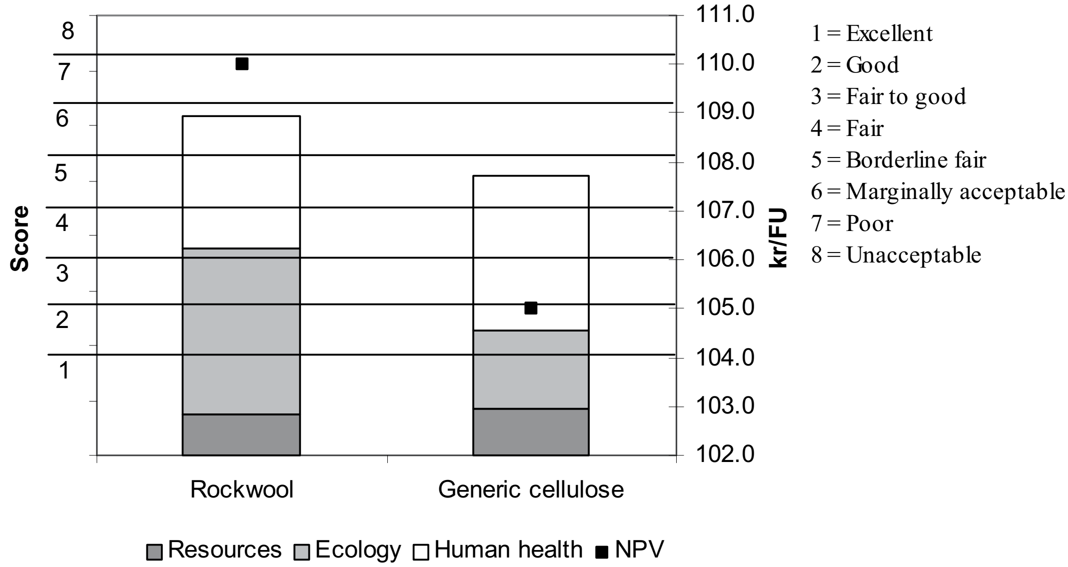

Figure 7-2: Evaluation results in the MaSe system. Cellulose insulation and Rock wool, with data collected from BEES2001, only cradle to gate average data.

7.2.3 Step 3: Producer selection

The specific producer selected determines the final environmental load. Figure 7-3 presents the evaluation result of two types of cellulose insulation, together with the results from the generic cellulose material (in this case the average of the two products). This is to ensure that the producer selected is not worse than the generic material. If so, the user must go back and check if the products within the other material groups might give better results.

In this case, there are only small differences between the two products. Environmental insulation paper is slightly better that Ecofibre, but Ecofibre has a lower NPV. The producer selected depends on the environmental preferences of the client. In any case, the underlying reason for the index might be investigated.

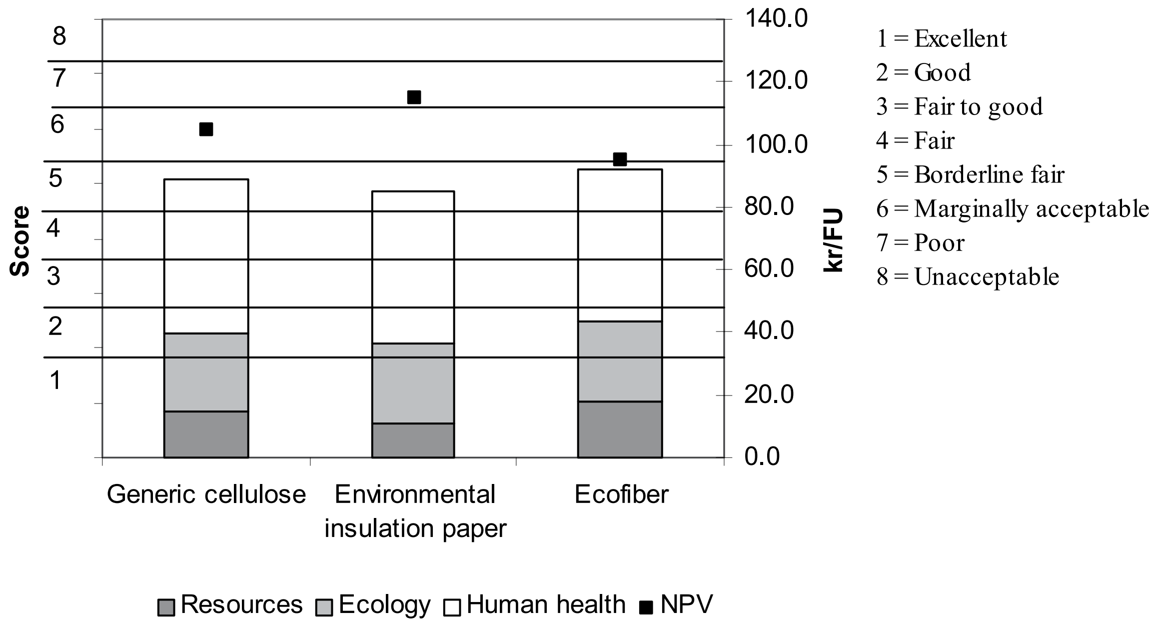

Figure 7-3: Producer specific evaluation in the MaSe system. Two types of cellulose insulation are included and compared with the evaluation result of a generic cellulose insulation material (calculated as the average of the two specific materials).

From Figure 7-3, is seen that the score on the Resource area constitutes the difference between the two products. The indices for this main area, presented in Figure 7-4 and Figure 7-5, may then be studied The figures confirm what is seen in the main results, that Environmental insulation paper has better properties than Ecofibre when it comes to the resource parameters. It is seen that the energy use causes this difference. It is also seen that the differences in the Resource area are quite substantial; "Fair to good", compared to "Borderline fair". This does not appear as clearly studying only the total results, because the Resources area in this case is weighted low compared to the Human health area.

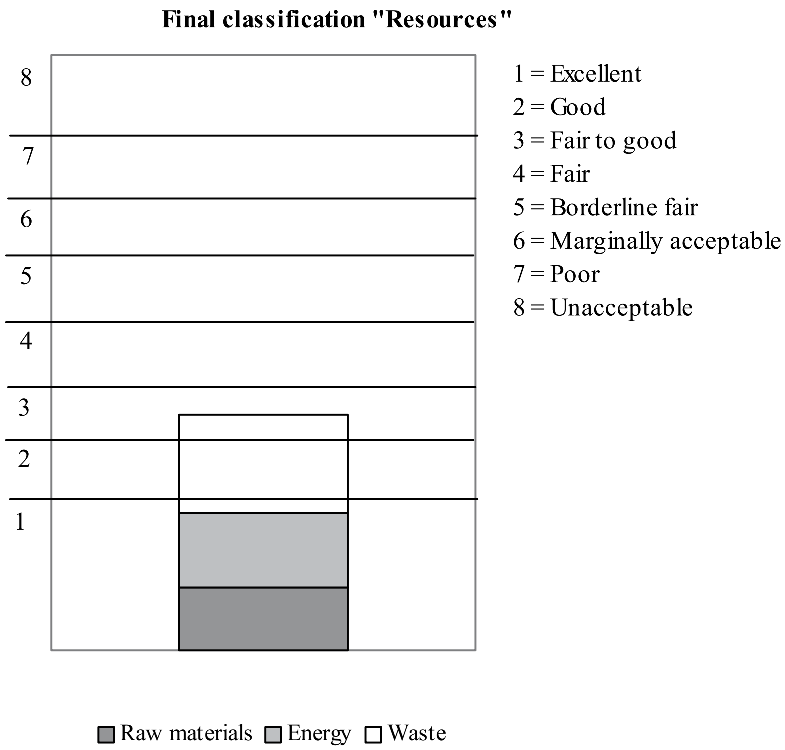

Figure 7-4: Results for the main area "Resources", for Environmental insulation paper.

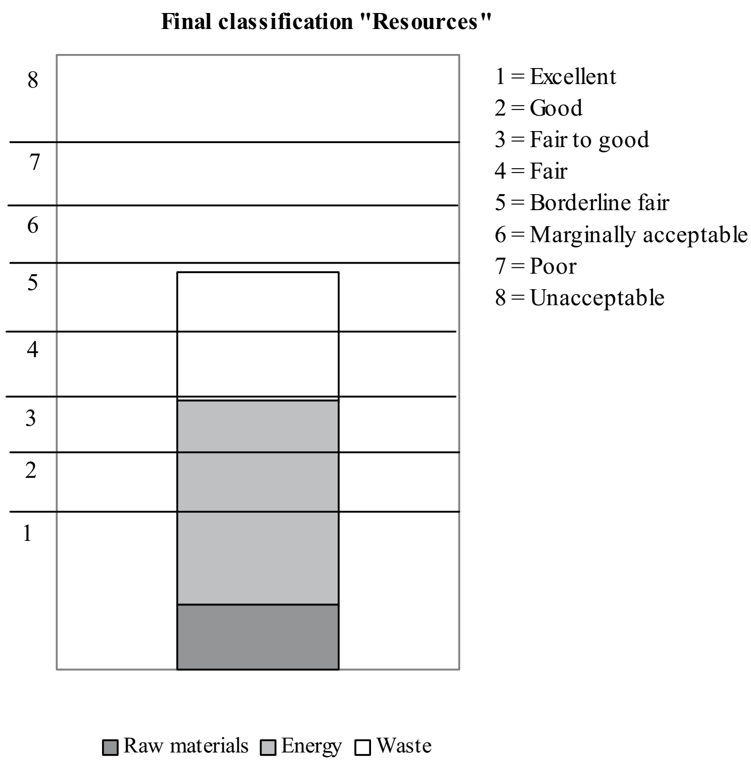

Figure 7-5: Results for the main area "Resources", for Ecofibre insulation.

A further investigation reveals that the energy use in the production of Ecofibre is about three times higher than for Environmental insulation paper, see Figure 7-6 and Figure 7-7.

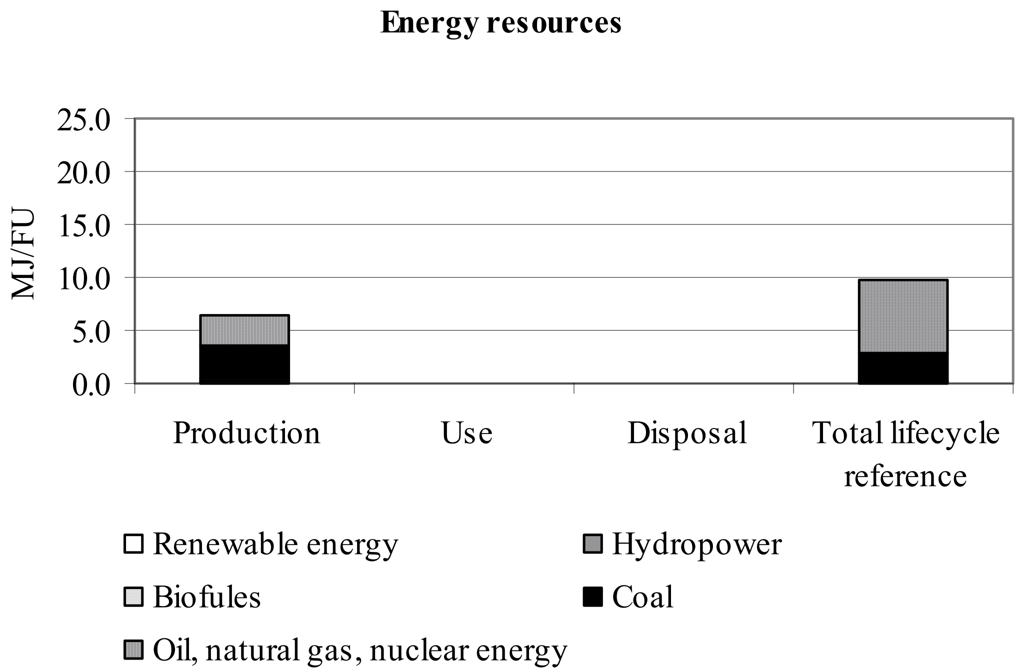

Figure 7-6: Energy use in the production of Environmental insulation paper.

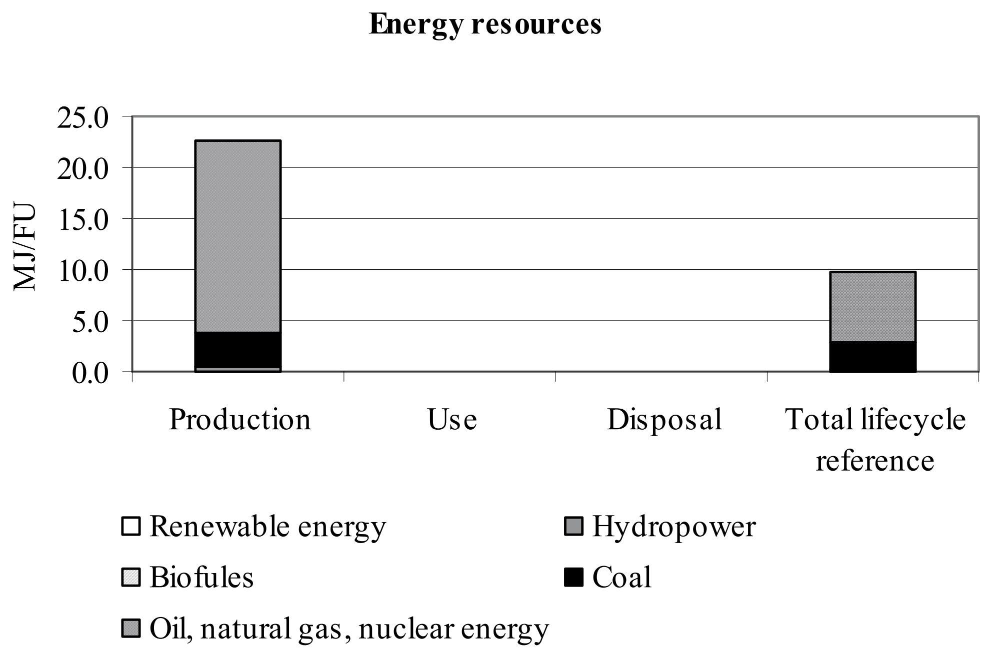

Figure 7-7: Energy use in the production of Ecofibre insulation.

In a "close race" like this, it is difficult to defend the selection of the Environmental paper alternative, as both alternatives end up in the same index area. If the Environmental paper product does not have other advantages than lower energy use in the production phase, the next best alternative probably will be selected because of the lower NPV.

The results may also be used to set requirements for the insulation product to be used in the building, especially for public actors:

- The insulation material must be made of recycled cellulose.

And perhaps also:

- The use of energy in production of the wall insulation product should not exceed 10 kWh/m^2, U = 0.2 W/m^{2}K. In addition, the energy source should be renewable.

7.2.4 Step 4: Final results and calculation

After having done the calculations and recorded the selection of products, an environmental index for the whole building may be calculated. The index may be calculated using the cost of the building as a distribution key. A project from Statsbygg is used as an example of how the building related costs could be distributed. Table 7-2 presents the costs of the building divided in main cost bearing elements, and further specified down to insulation, wind barrier etc.

Table 7-2: Example distribution of building related costs.

POST	NOK/net area	%
Foundations	1 826	20.0 %
Load bearing structure	160	1.8 %
Exterior walls	2 800	30.7 %
Primary construction	1 826	26 %
Frame	500	27 %
Insulation	105	6 %
Wind barrier		
Moisture barrier		
Exterior cladding and surface		
Windows and doors		
Interior cladding and surfaces		
Interior walls	1 467	16.1 %
Floors	982	10.8 %
Exterior roof	1 430	15.7 %
Permanent interiors	388	4.3 %
Stairs and balconies etc.	55	0.6 %
SUM	9 111	

Of the building related costs, exterior walls represent 30.7 per cent, of the exterior wall the primary construction represent 26 per cent, and of the primary construction again, insulation represents 6 per cent of the costs. Of the total building related costs the insulation of exterior walls in this case represents about 1 per cent. It must be noted that this is only valid for this example, for other projects, the distribution of costs may be entirely different. This proportion of the overall environmental load makes it less probable that resources will be used for such a marginal enhancement of the environmental profile of the building that the insulation material selection in this case represents. This confirms the sense in the economic prioritisation leading to the selection of the Ecofibre insulation in step 3.

Alternatively, the conclusion might be that since insulation material resents such a small proportion of the total costs, a slight increase of the product costs is acceptable to improve the environmental profile.

The total index might also be calculated using mass or volume of the building materials as the distribution key.

7.3 Example 2: Selection of exterior wall framing

In the second example, the objective is to find the best wall framing material. In this case, the environmental data are also collected from the Danish BEAT2001 database, but assumptions about transport, construction and demolition are made in order to estimate the environment loads for the total lifecycle.

In the following sections, the main steps in the material selection procedure are presented, as it was done for the wall insulation example. However, step 1, Initial ranking is the same as described in Chapter 7.2.1, so this is not included.

7.3.1 Step 2: Material specification

As for Example one, the prioritisation from the client is presented together with a weighting of the sub areas. The acceptable materials are defined, and in this case, it is wood and steel framing.

As shown in Figure 7-8, one class separates the alternatives. The wood frame is just at the upper limit of Class 2, “Good”, while the steel frame alternative is at the upper limit of Class 3, “Fair to good”. The best alternative with respect to environmental considerations is also the alternative with the lowest NPV. Reuse is not considered, including this aspect would improve the respective indices, but not to any extent that will affect the ranking of the materials.

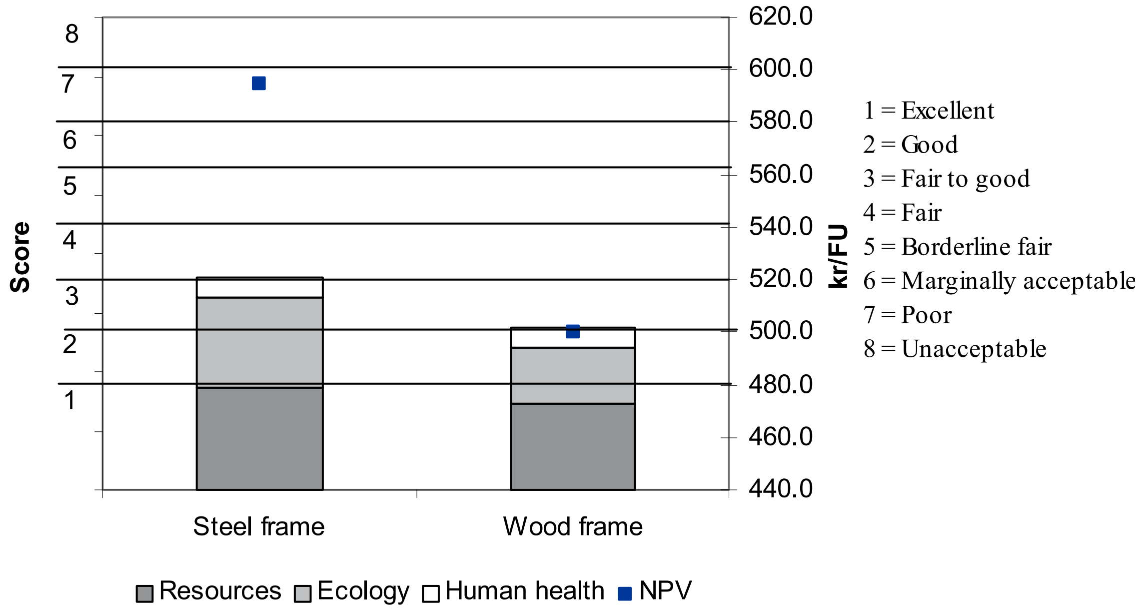

Figure 7-8: Result of the evaluation of two framing alternatives in the MaSe system.

The material specification is in this case is to recommend the use of wood in the exterior wall frame. The selection of the best product is made in the next step of the selection process. The MaSe system must then be used as a quality insurance, to make sure that the selected product is not inferior to the generic material.

7.3.2 Step 3: Producer selection

It has in this case not been possible to find data for different producers. An alternative procedure is therefore selected. The wall frame product selected must not score higher than index 2.7 (the index for wood frame). Studying the input data for the generic wood frame it is found that the product must:

- Have a total emission of gasses with a CO_2 potential below a maximum of about 2 kg for the total lifecycle of the product.
- Be produced of sustainable raw materials.
- Keep the amount of waste below a maximum of about 8 kg for the total lifecycle of the product. For example demonstrating increased probability of future reuse will reduce this fraction substantially.

These are the relevant criteria to be forwarded to the producers in question.

7.3.3 Step 4: Final results and calculation

As seen in Table 7-2, exterior wall framing represents 27 per cent of the costs for the exterior wall, and 5 per cent of the total building related costs in the example. If the requirement for the building as a total is to use a minimum of 80 per cent materials equal to or better than the index four, "Fair", selecting wood framing gives some margins for the other products, as trade offs are possible. If the insulation material in example one is selected this trade off is needed because all the insulation materials are placed in class five or worse.

7.4 Example 3: Selection of interior wall boards

In this third example, the objective is to identify the best interior wall board. Data are collected from the Norwegian declaration system, Ecodec. The alternatives for interior wall boards in the evaluation are:

- Plaster board, 13 mm, 9.05 kg, cradle to grave
- Mineral based wall board, 9 mm, 14.7 kg, cradle to grave
- 2 Plywood, 12 mm, 6 kg, cradle to grave

Paint and other surface treatments are not included in the evaluation.

Step one, Preferences, is as described in Chapter7.2.1.

7.4.1 Step 2: Material and product specification

The result of the evaluation of the three different wallboards is illustrated in Figure 7-9. It is seen that mineral based wall board receives the judgement "Unacceptable", and a relatively high NPV. Generic plywood and plaster board are both within the "Fair" category, but plaster board has the best environmental properties, and generic plywood has the lowest NPV. It must be noted that the economic data are not real data, but based on estimates, which again are based on price information in HolteProsjekt (HolteProsjekt innovation, 2002), and from different distributors. The mineral based alternative is in this case evaluated as "Unacceptable".

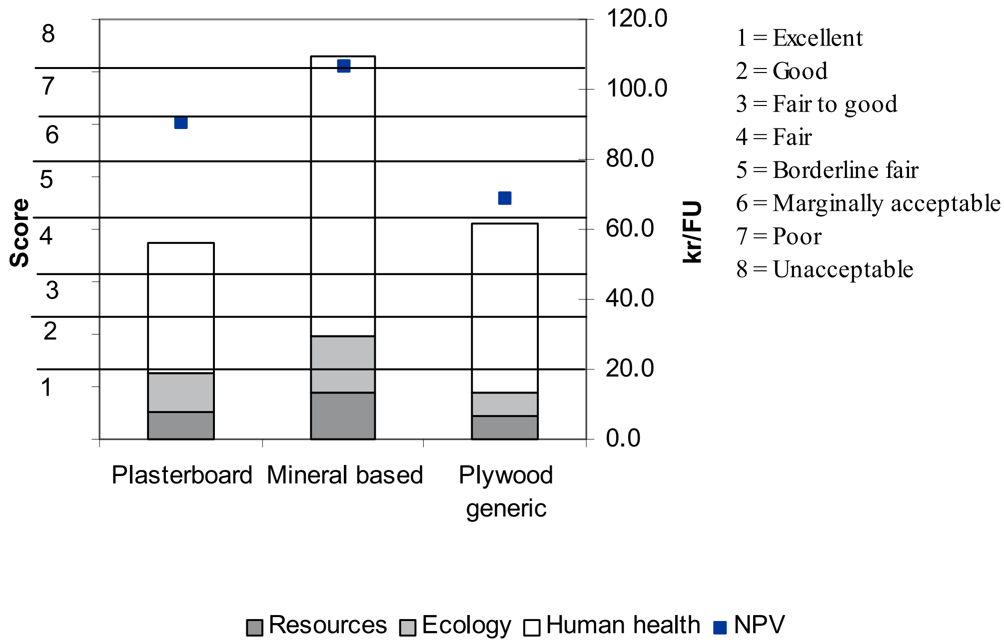

Figure 7-9: Result of the MaSe system evaluation of three interior wallboard alternatives in the MaSe system.

It might seem strange that plaster and plywood ends up in the same index area. The reasons for this are mainly the following:

– Ecology: The different materials do not show large differences in GWP. Plaster has a human toxicity potential because substances on the B list are used in the production.
– Resources: Plywood uses only renewable materials and plaster involves also non-renewables. However, the difference is mostly related to the fact that plaster produces more waste than plywood. The waste in the plaster production goes to deposit, while the waste in plywood production goes to incineration. Plaster is deposited after use, while plywood could be reused or used in energy recovery.

There are some differences also on the Human health area. Plywood is poorly documented while plaster board passes the M1 requirements for indoor environmental classification. If the plywood data were supplied with information on the indoor pollution, and passes M1, the score would be 3.4, "Fair to good".

The recommendations from step one should be to use plywood, but including requirements to make sure that the final product is not worse than the generic material. In addition it must be required that the product of interest must document its Human health properties.

7.4.2 Step 3: Producer selection

When the specific producer is selected, a comparison is made between two available plywood products. The main result of the evaluation of these products is illustrated in Figure 7-10. Here it is seen that the best alternative from an environmental perspective is not the most economic alternative. Plywood 1 is just within the "Fair to good" category while Plywood 2 falls within the "Borderline fair" category.

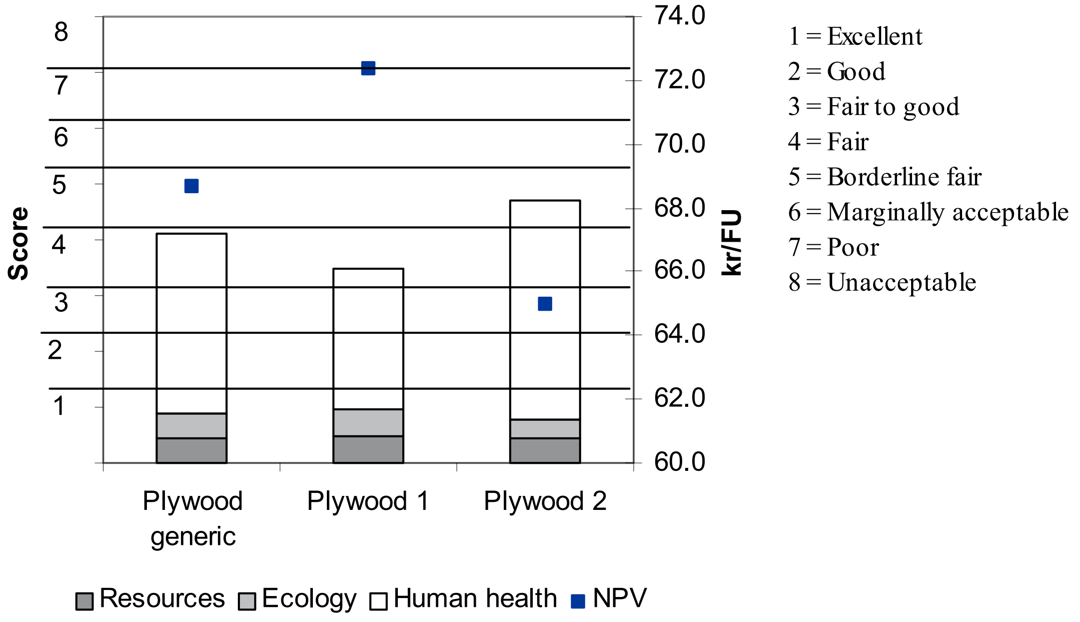

Figure 7-10: Result of the evaluation of two plywood products in the MaSe system.

Plywood 2 has a higher load in the Human health area than Plywood 1. Plywood 1 again represents larger loads in the Recourses and Ecology areas, than Plywood 2. Because Plywood 2 also has the lowest NPV, the reason for the score on the indoor environment is studied in detail.

Final classification: "Human health"

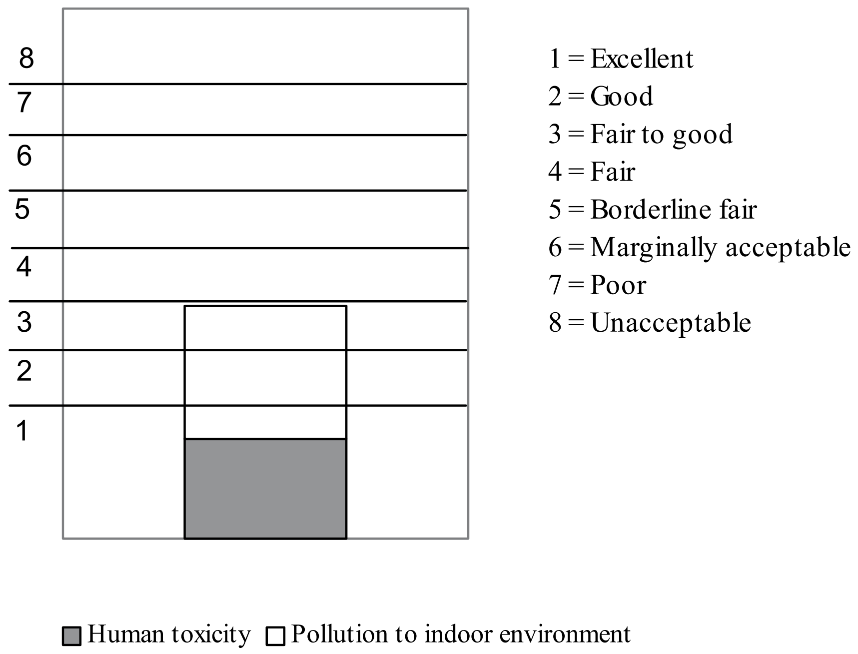

Figure 7-11 and Figure 7-12 illustrates the results for the main area Human health for the two products. It is seen that the user phase represents the difference between the products. Studying the scoring and the underlying data, it is clear that no data are available for the emission properties for Plywood 2. The product specification should then include the requirement that the producer must document that the product satisfy the M1 requirements in CEN CR 1752 (1998). This puts pressure on the Plywood 2 producer to provide information about the indoor environmental qualities of the product. Altering the Plywood 2 input data so that the products fulfils the M1 criteria places Plywood 2 in the “Fair to good” range with a better margin than both the Plywood 1 product and the Plaster board. The contractor should therefore select Plywood 2, provided that the indoor environmental properties of the product are documented. If it is shown that Plywood 2 does not fulfil the M1 requirements, Plywood 1 should be the product used in the building.

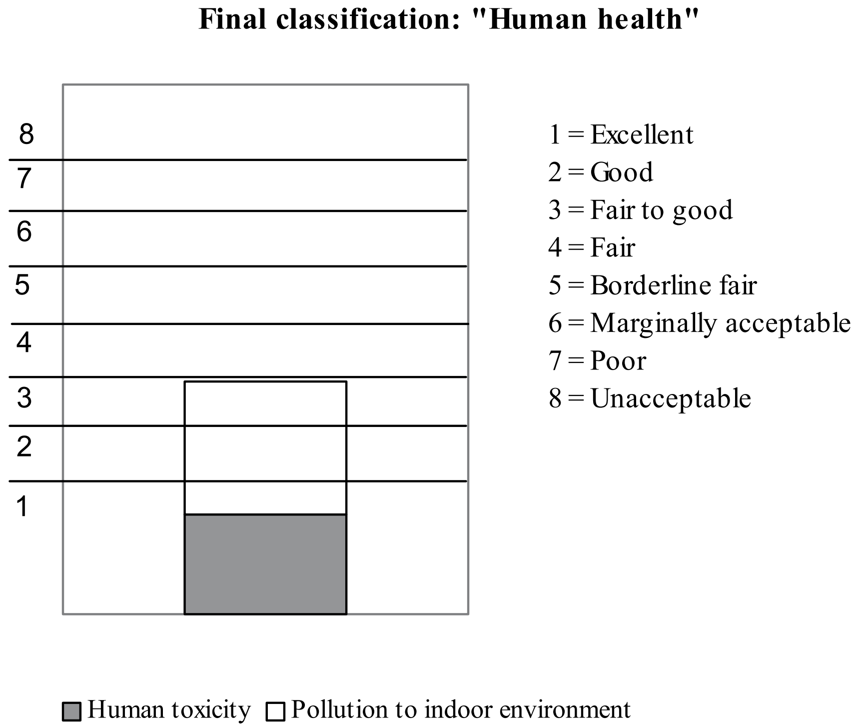

Figure 7-11: Result for Plywood 1 on the main area Human health.

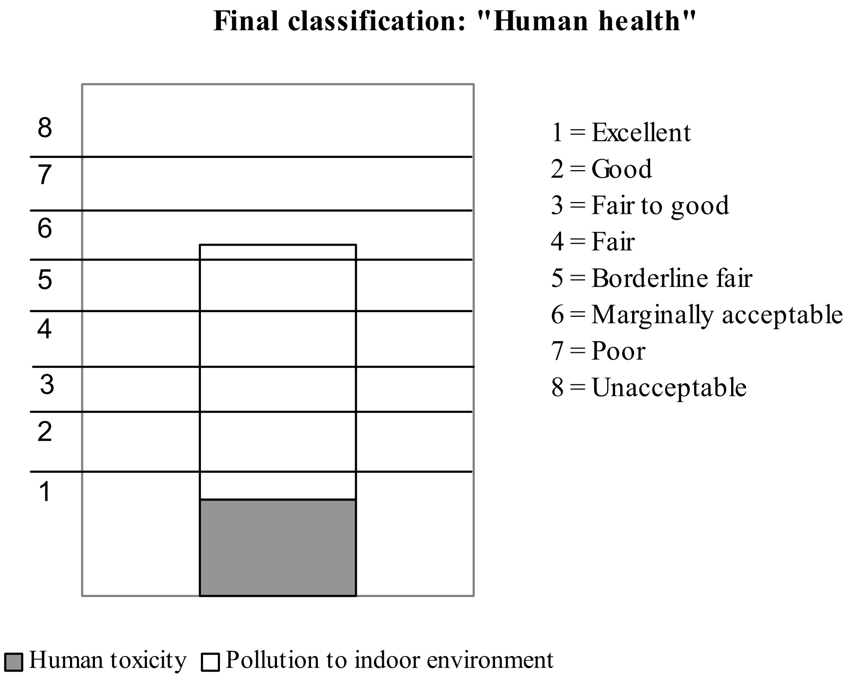

Figure 7-12: Result for Plywood 2 on the main area Human health.

7.4.3 Step 4: Final results and calculation

The evaluation of the building after construction will show how the solution really turned out. If the Plywood 2 product is selected, and the indoor environmental documentation is produced, this represents an index of three in the MaSe system. This lies within the defined limits from the client, described in Chapter 7.2.1, and will be positive contribution to the complete profile.

7.5 Discussion

The examples presented in this chapter are not sufficient to state that this system is perfect for the intended use. However, in the examples included, the MaSe system made it possible to define the environmentally and economically preferable material, product or producer.

Example one showed that on the producer level, the differences might be small, and that the economic aspect is likely to determine the alternative selected. It must also be noted that if the prioritisation of the main areas were different, the result of example one might be altered.

For example two, only generic data were studied, but is seems reasonable that wood is the best alternative. It is also an example of the system being used to set specific requirements for a product and its lifecycle, without access to producer specific data.

In example three, one alternative is clearly evaluated as poorer that the others. This example is also a good case to show how the user of the system should be familiar with the evaluation procedures in the MaSe system. This knowledge is used to obtain an even better index than available for the products in the MaSe system in the first place. In the real world, the different plaster products available should also have been studied in step 2, but this was not included in the MaSe system because there is no available data at present.

One additional aspect that is studied is the influence on the total results of example three by the main area weighting. MixTri 2.0 (Doka, 2000), was used to produce the mixing triangle illustrated in Figure 7-13. It is seen that for the weights defined in the example, plywood is the best alternative. However, if Human health is weighted higher than 50 per cent, plaster board is the best alternative. Plywood is, however, the best alternative for most weight combinations. See also the line of indifference in the figure. This indicates the weight combinations where the product ranks changes.

Finally, it must be noted that the user may not only focus on the index, but also use the system as a tool to reveal the differences between the products on a more detailed level. This knowledge could then be used to improve the material specifications, and set specific environmental criteria for the products.

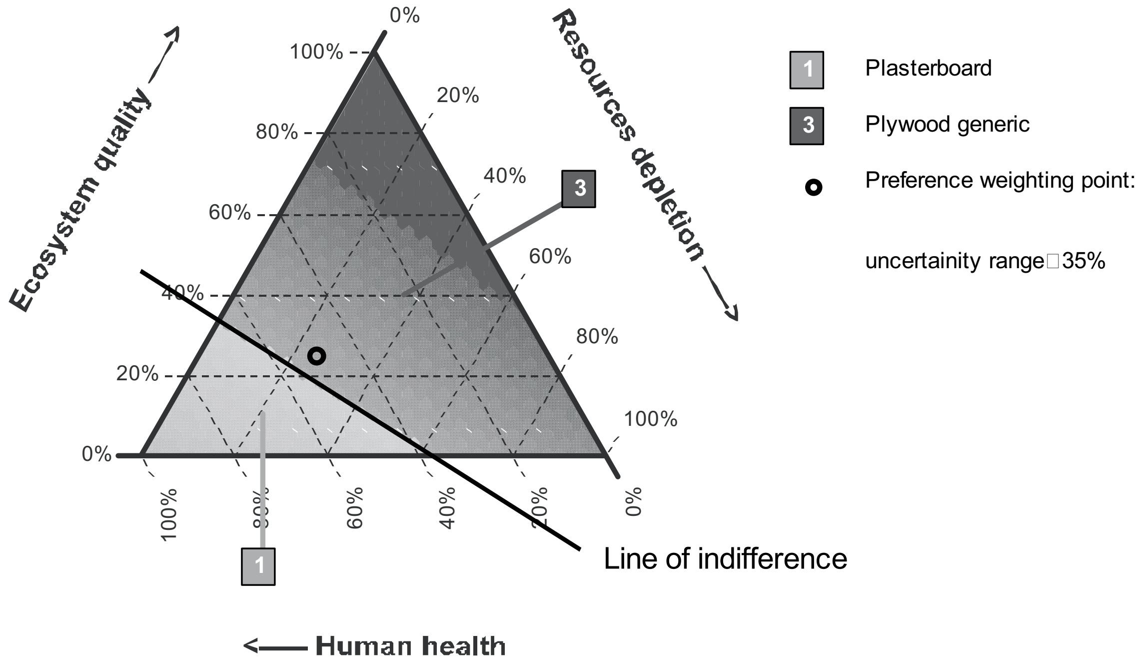

Figure 7-13: Example of result presentation using the Mixing triangle method, MixTri 2.0. The preference weighting point is where Human health weights 50 per cent, and Resources and Ecosystem quality 25 per cent respectively.

In the following section, the MaSe system will be commented using mainly the same points of evaluation as for the existing systems in Chapter 6:

– The MaSe system is suited for use in the relevant phases of the building process. It is possible to use the system on different levels and with different input, all from client priorities to details of the different products studied by the contractor.

– The user decides how deep he/she wants to go into details. Using only the total index in the MaSe system, it is very simple to use. Going into more detail requires more from the user, but this can produce better results. The user decides the weighting and which parameters to be included in the evaluation. However, using the index in for example marketing of a building, a defined weight set must be used, and a prospective client must be informed if any of the parameters or areas has been excluded from the evaluation.

– Economy is included in the system, and this separates the MaSe system from many of other existing systems.

– Many different products and materials can be handled by the system as long as the functional unit of the data is carefully defined. This FU is very important as it forms the basis for comparison.

– The structure of the scorecards and the aggregation of information into one index using AHP and pair wise comparison makes it possible to included new information as it becomes available.

As seen, especially in example three, the system might be demanding in producer selection step.

8 Conclusion

Studying the material selection procedure, important factors were found that have implications for a material and product selection system like the MaSe system. The trade term “building process” involves many activities and many different actors, from the client to the contractor and sub contractors. The producers and the distributors of materials and products are also implicated in the procedure of material and product selection. They supply much of the data entered into the system, and this is identified as one of the bottlenecks in putting a material selection system into use. Development in the areas of building material declarations, regulations, changes in public opinion and the development of a material selection system(s), are all factors that should encourage elimination of this bottleneck.

The parties involved in material and product selection have different perceptions of the building process, and so will the users of the MaSe system. For the system to be accepted and used, all participants are given a chance to see where they fit into the MaSe system, and understand the basis for it. Some main phases have been identified: Idea, Development, Accomplishment and Use. In general, it is assumed that the initial prioritisation is made in the idea phase, the material selection in the design phase and the product selection in the Accomplishment phase. In the user phase, it is important that the system is used to select the best possible material and products for maintenance and refurbishment, as this phase represents 30 per cent of the material consumption.

Through the interviews and the theoretical study of the building process, it was also confirmed that the potential users of the MaSe system have different needs, from a simple handbook to a database. It was concluded that a database system is a good way of providing information in various ways. A database may be used as it is, but it may also be used to systematically provide other types of information like for example a handbook.

Other important key discoveries related to the user requirements of the systems, included possible conflicts of interest. First it must be simple to use, second it should provide all necessary information to satisfy varying needs. The calculations in a tool must be visible for an interested user, but need not be visible for others. To satisfy all users needs involved careful development of the calculation procedures and result illustrations, both information overload and information shortage is negative. Another important aspect brought into focus was the user phase of the building, and the importance of this phase for the user of a material selection system. Economy and indoor environment are important areas identified in the interviews. In addition, it was emphasised by some potential users that they wanted the possibility to influence on the system, like for example weighting and the selection of parameters to be included in the evaluation.

After studying the needs in the building and real estate industry, it was natural to turn to the environmental reasons for such a system. Since the estimate from the World Watch Institute, the building and real estate industry has been known as the 40 per cent industry. For energy and material resources, this seems to be correct also for Norway. Renewables, reuse, recycling and dangerous substances are important focus areas for the authorities with respect to building materials. From the sustainability discussion, it

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is seen that climate change, degradation of renewable resources and accumulation of emissions and wastes are agreed aspects within the different concepts of sustainability.

Scarcity is not included as a parameter in the MaSe system, but some evaluation of the material input is needed. This is limited to the differentiation of the input in non-renewable, sustainable and unsustainable renewable recourses. From the study of the building materials and their environmental load in Chapter 3, it is concluded that relevant aspects in the evaluation of the environmental load from building materials involves:

- Energy.
- Recycling.
- Reuse.
- Sustainable use of material resources.
- Waste.
- Global warming.
- Acidification.
- Formation of photochemical oxidants.
- Toxicity.

Only the Global Warming Potential (GWP) represents global warming, acidification and photochemical oxidants.

The next step was to study the existing systems and tools, and this was an important learning process. First, it is noticed that little information is available on how to use the systems in a decision situation. Many systems are detached from the situation in which they are intended to be used and the industry that is the targeted users. This may be one of the reasons why none of the tools are used on a regular basis for the selection of building materials.

Second, none of the systems include all the parameters identified as important in Chapter 2 and 3. Even if a parameter is included; it was often found that it did not satisfy the needs of the MaSe system. When investigating the details of the different evaluation systems, it is also seen that both qualitative and quantitative parameters will be needed to evaluate all the identified parameters for the MaSe system.

Some of the existing systems provide important direct or indirect inputs to the MaSe system. The BEES solution on how to include cost is a good example. ATHENA presents a good example of structuring the building data. The Guide for Material Selection illustrates how qualitative criteria may be used in material evaluation. However, when studying the various methods for aggregating data and presentation of the results, it was found that the MaSe system needed a new method to aggregate the identified parameters. This is mainly to avoid important parameters to be excluded, and to facilitate a result presentation in line with the needs in the building process.

The MCDM methods, AHP and the MADM-23 project, form the general basis for the development of the MaSe system. Equal weighting, expert panel weighting and subjective weights are identified as solutions to the weighting problem. The main result from the MaSe system is presented as an environmental index and load distribution, together with the NPV. This represents the primary basis for the comparison of the different material and product alternatives.

The details of the evaluation procedure are discussed under the main areas: Resources, Ecology, Human health and Economy. The general procedure consists of the following steps:

1. Scoring of the parameters.
2. Combined scoring.
3. Weighting and classification of main areas.
4. Total weighting and classification.

It has been necessary to base the evaluations upon many different sources of information, and there are therefore some differences between the evaluation procedures under the respective main areas. Most importantly economy is very different from the others, and is not included as a part of the environmental index, but as the NPV.

Life cycle data are needed as input in the MaSe system, but to a more limited extent than for a complete LCA, because the number of parameters is reduced and simplified. A traditional LCA involves 12 quantified effect categories, limiting the comparison only to the areas covered by traditional LCA (excluding economy and indoor environment), the MaSe system uses only 6 categories in the assessment. However, the MaSe system also includes indoor environment and economy, in total 11 sub areas. The following sub areas are included in the MaSe evaluation:

- Raw materials.
- Energy.
- Waste.
- Global warming.
- Ecotoxicity.
- Human toxicity.
- Depot effect gasses.
- Depot effect dust.
- Emission of gasses to the indoor environment.
- Emission of particles and fibres to the indoor environment.
- Costs.

One of the major obstacles identified for the MaSe system to be used is the input data. There are mainly two problems related to this aspect: availability and comparability. Considerable amounts of data are available through Ecodec, NIMBUS, various LCA studies and LCA tools like SimaPro, BEES and BEAT2001. The problem is that these data are not comparable, because the inventory assumptions vary. The MaSe system depends upon data preferably from building material declarations, with comparable data. Other datasets might also be used, but quality control routines must be included when entering the data into the MaSe system, ensuring comparability.

The testing of the system using insulation, framing and wallboards, showed that the MaSe system might be used in different ways depending on the case in question. The differences between the materials and products were demonstrated. The system is also suited as an aid in product and material specification. To illustrate how the system might work within the framework of the building process, the use is described in 3 steps: User preferences, Material specification and Product specification. The fourth step, the evaluation of the total results when the building is erected, may be included in the computerised version.

In the current version, the reference in the score charts the average is set to the predefined mateirls. In the step where products from different producers are compared, using these specific materials average as the reference would increase the difference of the respective Environmental Index. However, this change of reference complicates the evaluation procedure, and makes it difficult to perform evalautiosn in loops, meaning checking the results of the producer evaluations with the genric evaluations performed in the previos step.

It is concluded that the MaSe system fits well in the building process as it is identified in this work. The user may select the sub areas included in the evaluation and prioritisation in the system. The results can also be presented at different levels of detail, from the environmental index to for example kg GWP/FU. The evaluation procedure is kept as simple as possible, and the flexibility of the system makes it easy to implement new knowledge. The result presented as an index is easy to understand, and the graphics provides the decision maker with further information. In total, the requirements for the system identified in Chapter 2, 3 and 4 seem to be satisfied. However, environmental evaluation is not an exact science, the MaSe system does not claim to be either, but the evaluation results in the examples seem reasonable.

As the MaSe system is still only a framework, only manageable by an expert, it is not possible to draw a firm conclusion about the user functionality. However, the result so far provides a good basis for a user-friendly tool.

8.1 Further work

The MaSe system should be developed into a computerised tool, preferably a database allowing distribution of data and the results through the Internet.

The user interface of the framework may be different for the different user modules. For the client, the use will be quite simple, but in the design phase, it is bound to be a bit more complicated. For a tool to be operable in the process of designing and constructing buildings, there are several important aspects to include when developing a "decision-desktop", these aspects include:

- Different users should have different user interfaces.
- It should always be possible to track the reason for the evaluation result of a material or a product.

At the start of this project it was a goal that the decision support system should be closely related to the computer tools that are used in the process, there are however two aspects of this goal:

- by a close integration with a tool used for example by the designers it is a risk that this will limit the freedom and creativity of the design phase,

but also that:

- by a close integration, the designer is reminded to actually use the system because the barriers may be reduced.

Most former attempts to include environmental considerations in material selection have ended with systems very detached from the decision process in the different phases of the building process. The development of a computerised version must be made in close co-operation with the industry and the potential users. Several factors are important for the system to become a success:

- A satisfactory amount of data on materials and products must be available.
- The practical use of the system must appeal to the user.
- The user must have faith in the tool, in the scientific basis and that it provides reasonable results.
- The user of the tool should preferably go through a simple training course, simply to enhance the user value of the tool.

There are some bottlenecks to overcome beyond the system itself, before a tool like the MaSe system can become a success. These are mainly the data availability and the actors in the building and real estate industry and their willingness to spend time and money, in order to improve their respective environmental profiles.

To ability to present the results aggregated to the total building level, is seen as an important issue for the building owner and for the further development of the system. The ability to exchange information between organisations or companies is also an important aspect to make the tool operable.

The last few years in a standardised way of exchanging computer files with drawings, product data and other types of information has been developed through AIA (International Alliance for Interoperability) (AIA Forum Norway, 2003). A digital building model is developed controlling this type of information, the Industrial Foundation Classes (IFC). This model is a natural basis also for the implementation of environmental data for the different products. When the structure and the relationships between the building elements are established, and the environmental information is available for all elements, the total material environmental index may be calculated. The model may be used for exchanging information between different decision makers in the building process. The development of the MaSe system into an operable tool could be related to the IFC model.

9 Definitions and abbreviations

Material:	The substance or substances of which a thing is made or composed of.
Product:	A thing produced by labour.
Generic:	Applicable to, or referring to all the members of a group or a kind.
Parameter:	In this work it is used about a measure of a property of a material or a product.
Index:	A number expressing some property or something indicated.
LCA:	Life Cycle Assessment
LCC:	Life Cycle Cost
Evaluate:	To determine or set the value or amount of something.
FU:	Functional Unit
GWP:	Global Warming Potential
NPV:	Net Present Value
Eco-efficiency:	The efficiency with which ecological resources are used to provide a service. It can be considered as a ratio of an output divided by an input. The "output" is the value of products and services produced by a firm, a sector, or the economy as a whole, and the "input" is the sum of environmental pressures generated by the firm, sector or economy.
Assess:	To estimate or judge the value of something.
IAQ:	Indoor Air Quality
VOC:	Volatile Organic Compounds
TVOC:	Total Volatile Organic Compounds
MCDM:	Multi Criteria Decision methodology
Decision maker:	A general term used in this work about an individual, an organisation or any other decision-making entity.
AHP:	Analytical Hierarchy Process

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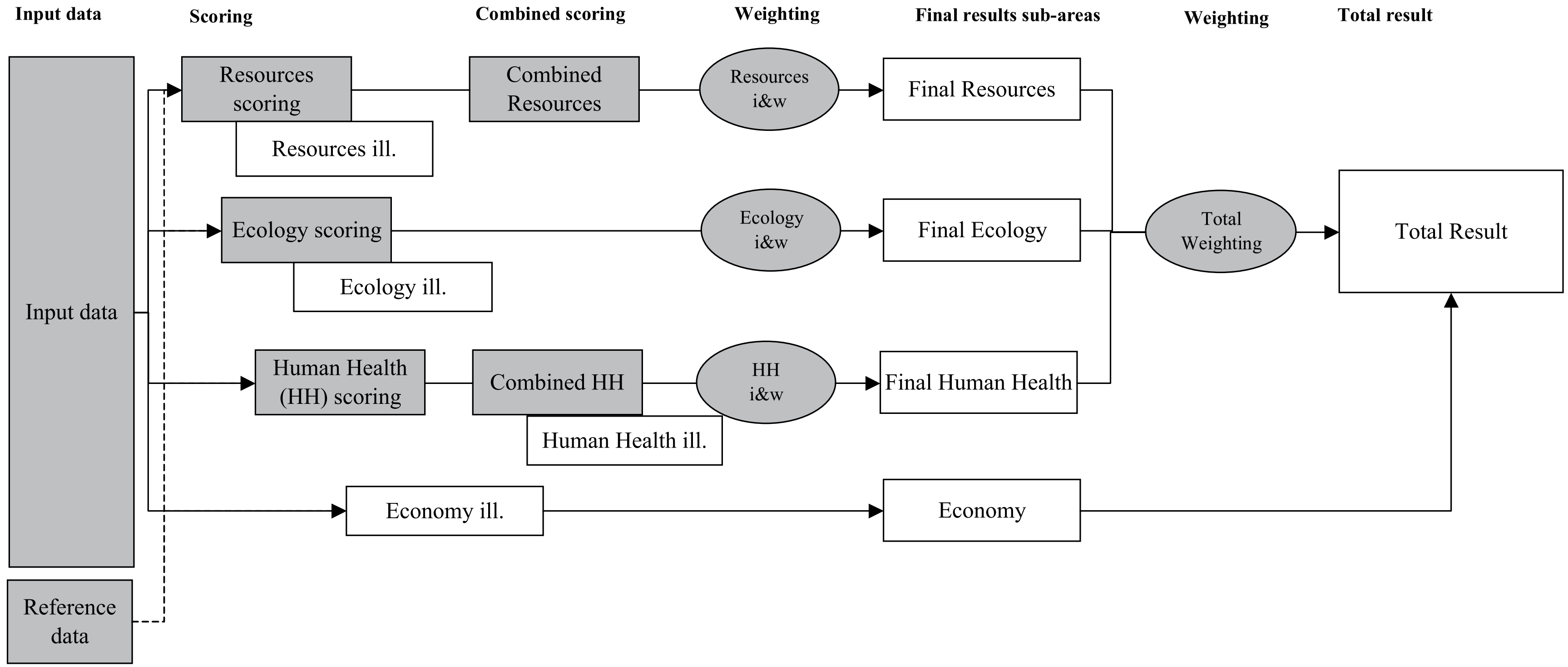
11 Appendix

Appendix A: The MaSe system

STRUCTURE OF THIS SPREADSHEET



Grey boxes: Require manual operations
White boxes: Illustrations and results

Input data for the MaSe-system

Product: Plaster board
Date: 27.11.02
Producer:

Data quality
Data source(s): Ecodec
Generic data: %
Specific data: 99 %
Coverage: 94 % of the materials is included
Lifecycle coverage: Cradle to gate

1. Main product
Use: Inner wall plate
Additional materials: Steel fasteners, 15
Functional unit (FU): 1 m^2 wall
Thickness (mm): 13 Weight (kg/m^2): 9.05
Place of production: Oslo, Norway
Technical service life: 60

Conditions for the material fulfilling its function throughout its technical service life (maintenance and treatments etc., including intervals):
That it is not exposed to rough mechanic strain
Factors known to reduce the service life of the product:

Maintenance	Type	Frequency		Included in the data (yes/no)
Frequent			per year	
Periodic	Painting	5-10	years interval	NO
Upgrading			years interval	

Dismantling:

2. Economy
Purchase price: 58.33 NOK/FU
Transport: 2.92 NOK/FU
Installing: 29.17 NOK/FU
Cleaning: 0.00 NOK/FU
Maintenance: 0.00 NOK/FU
Repair: 0.00 NOK/FU
Replacement: 0.00 NOK/FU
Demolition: 0.00 NOK/FU
Transport of waste: 0.00 NOK/FU
Waste treatment: 0.00 NOK/FU
Residual value: 2 NOK/FU

3. Resources

Raw material type	**Production (kg/FU)**	**Transport, construction and use (kg/FU)**	**Transport and disposal (kg/FU)**	**Total (kg/FU)**
Reused	0.00			0.00
Recycled	2.80			2.80
Down cycled	0.00			0.00
Sustainable renewable	5.60			5.60
Non-renewable	6.60			6.60
Unsustainable renewable	0.00			0.00
SUM	15.00	0.00	0.00	15.00

Energy type	**Production (kWh/FU)**	**Transport, construction and use (kWh/FU)**	**Transport and disposal (kWh/FU)**	**Total (kg/FU)**
Renewable energy	0.00	0	0	0.00
Hydropower	1.40	0.01	0.01	1.42
Biofules	2.10			2.10
Coal	0.00			0.00
Oil, natural gas, nuclear energy	8.20	0.8	0.1	9.10
SUM	11.70	0.81	0.11	12.62

Waste handling	**Production (kg/FU)**	**Transport, construction and use (kg/FU)**	**Transport and disposal (kg/FU)**	**Total (kg/FU)**
Reuse	0.00	0.036		0.04
Recycling	0.00	0		0.00
Down cycling	0.00			0.00
Energy recovery	0.00			0.00
Deposition	0.10		9.05	9.15
Hazardous waste treatment	0.00			0.00
SUM	0.10	0.036	9.05	9.19

Conditions for the stated waste handling scenario to be possible:

4. Ecology

Emission of gasses that contribute to global warming	**Production (kg/FU)**	**Transport, construction and use (kg/FU)**	**Transport and disposal (kg/FU)**	**Total (kg/FU)**
GWP	2133.8	193.9	27.8	2355.6

Chemicals:

Substances with eco toxicological effects	**Production (mg/FU)**	**Transport, construction and use (mg/FU)**	**Transport and disposal (mg/FU)**	**Total (mg/FU)**
Chemicals on the OBS list:				
Arsenic (As)	0.047			0.047
Cadmium sulphate (10124364)	9000			9000
A-list				
B-list				
Pb	0.068			0.068
Cd	0.006			0.006
Hg	0.009			0.009
Zn	0.003			0.003
Substance list:				
Ni	0.0026			0.003
Forbidden substances				

5. Human health

Chemicals:

Substances with human toxicological effects	**Production (mg/FU)**	**Transport, construction and use (mg/FU)**	**Transport and disposal (mg/FU)**	**Total (mg/FU)**
Chemicals on the OBS list:				
Arsenic (As)				
Cadmium sulphate (10124364)	9000			9000
A-list				
B-list				
Pb	0.068			0.068
Cd	0.006			0.006
Hg	0.009			0.009
Substance list:				
Ammonia (NH3)				
Formaldehyde				
Nickel (Ni)	0.003			0.003
Phenol				
Forbidden substances				

	Good/Medium/ Poor
Characterisation of the products depot effect for gasses:	Medium
Characterisation of the products depot effect for dust and particles:	Medium

Total Volatile Organic Compounds, TVOC (mg/m^2h):	0.01
Formaldehyde, H_2CO (mg/m^2h):	-
Ammonia, NH_3 (mg/m^2h):	-
Carcinogenic compounds according to category 1 of IARC classification	-
Emissions of particles and fibres (mg/m^2):	-
Dissatisfaction level (%)	-

REFERENCE MATERIAL(S)

2. Economy

Purchase price:	52	NOK/FU
Transport:	2.6	NOK/FU
Installing:	26.2	NOK/FU
Cleaning:	0	NOK/FU
Maintenance:	0	NOK/FU
Repair:	0	NOK/FU
Replacement:	0	NOK/FU
Demolition:	0.09	NOK/FU
Transport of waste:	0.01	NOK/FU
Waste treatment	0.01	NOK/FU
Residual value:	2	NOK/FU

3. Resources

Raw material type	**Production (kg/FU)**	**Transport, construction and use (kg/FU)**	**Transport and disposal (kg/FU)**	**Total (kg/FU)**
Reused				0.00
Recycled				0.7
Down cycled				0.00
Sustainable renewable				6.2
Non-renewable				5.9
Unsustainable renewable				0.00
SUM	12.8			12.78

Energy type	**Production (kWh/FU)**	**Transport, construction and use (kWh/FU)**	**Transport and disposal (kWh/FU)**	**Total (kg/FU)**
Renewable energy				0.00
Hydropower				4.2
Biofules				19.3
Coal				0.00
Oil, natural gas, nuclear energy				11.9
SUM	33.5	1.7	0.2	35.37

Waste handling	**Production (kg/FU)**	**Transport, construction and use (kg/FU)**	**Transport and disposal (kg/FU)**	**Total (kg/FU)**
Reuse				0.01
Recycling				0.0
Down cycling				0.00
Energy recovery				1.40
Deposition				6.4
Hazardous waste treatment				0.0
SUM	0.3	0.1	7.5	7.85

4. Ecology

Emission of gasses that contribute to global warming	**Production (kg/FU)**	**Transport, construction and use (kg/FU)**	**Transport and disposal (kg/FU)**	**Total (kg/FU)**
GWP	3228.5	449.7	273.2	3951.4

Scorecards used for production, use, disposal and total:

Raw materials type; $Score_{RmT}$						
Score	**Judgement**	**Criteria**	**Production**	**Use**	**Disposal**	**Total**
1	Excellent	Reuse	0%	#DIV/0!	#DIV/0!	0%
2	Good	Recycled	19%	#DIV/0!	#DIV/0!	19%
3	Fair to good	Down cycled	0%	#DIV/0!	#DIV/0!	0%
4	Fair	Sustainable renewable	37%	#DIV/0!	#DIV/0!	37%
5	Borderline fair	Non-renewable	44%	#DIV/0!	#DIV/0!	44%
6	Marginally acceptable	-	-	-	-	-
7	Poor	-	-	-	-	-
8	Unacceptable	Unsustainable renewable	0%	#DIV/0!	#DIV/0!	0%
		Score	**4.1**	**#DIV/0!**	**#DIV/0!**	**4.1**

Energy type; $Score_{ET}$						
Score	**Judgement**	**Criteria**	**Production**	**Use**	**Disposal**	**Total**
1	Excellent	Renewable energy	0%	0%	0%	0%
2	Good	-				
3	Fair to good	Hydropower	12%	1%	9%	11%
4	Fair	Biofuels	18%	0%	0%	17%
5	Borderline fair	-	-	-	-	-
6	Marginally acceptable	-	-	-	-	-
7	Poor	Coal	0%	0%	0%	0%
8	Unacceptable	Oil, natural gas, nuclear energy	70%	99%	91%	72%
		Score	**6.7**	**7.9**	**7.5**	**6.8**

Amount of energy used; $Score_{EA}$		
Score	**Judgement**	**Criteria**
1	Excellent	Ò10% of reference value
2	Good	Ò10% of reference value
3	Fair to good	10 %< AND Ò40% of reference value
4	Fair	40 %< AND Ò70% of reference value
5	Borderline fair	70 %< AND Ò100% of reference value
6	Marginally acceptable	100 %< AND Ò130% of reference value
7	Poor	130 %< AND Ò160% of reference value
8	Unacceptable	160 %< AND < 190% of reference value

Phase	%	$Score_{EA}$
Production	34.9 %	2
Use	48.6 %	3
Disposal	55.0 %	3
Total	35.7 %	2

Waste handling; $Score_{WT}$						
Score	**Judgement**	**Criteria**	**Production**	**Use**	**Disposal**	**Total**
1	Excellent	Reuse	0.0%	100.0%	0.0%	0.4%
2	Good	Recycling	0.0%	0.0%	0.0%	0.0%
3	Fair to good	Down cycling	0.0%	0.0%	0.0%	0.0%
4	Fair	Energy recovery	0.0%	0.0%	0.0%	0.0%
5	Borderline fair	-	-	-	-	-
6	Marginally acceptable	-	-	-	-	-
7	Poor	Deposit	100.0%	0.0%	100.0%	99.6%
8	Unacceptable	Hazardous or dangerous waste treatm	0.0%	0.0%	0.0%	0.0%
		Score	**7.0**	**1.0**	**7.0**	**7.0**

Amount of waste;Score$_{WA}$		
Score	**Judgement**	**Criteria**
1	Excellent	Ò10% of reference value
2	Good	10 %< AND Ò40% of reference value
3	Fair to good	40 %< AND Ò70% of reference value
4	Fair	70 %< AND Ò100% of reference value
5	Borderline fair	100 %< AND Ò130% of reference value
6	Marginally acceptable	130 %< AND Ò160% of reference value
7	Poor	160 %< AND < 190% of reference value
8	Unacceptable	Ó190 % of reference value

Phase	%	Score$_{WA}$
Production	37.0 %	**2**
Use	37.9 %	**2**
Disposal	121.2 %	**5**
Total	117.0 %	**5**

Scorecards used for production, use, disposal and total:

Global warming potential; $Score_{GWP}$		
Score	**Judgement**	**Criteria**
1	Excellent	0-10%
2	Good	10.5-40%
3	Fair to good	40.5-70 %
4	Fair	70.5-100%
5	Borderline fair	100.5-130%
6	Marginally acceptable	130.5-160%
7	Poor	160.5-190%
8	Unacceptable	190.5-200+%

Ecotoxisity; $Score_{ETox\text{-}Production\ and\ Use}$		
Score	**Judgement**	**Criteria**
1	Excellent	No substances on the OBS, A or B list or with similar, or worse, characteristics.
2	Good	Trace amounts of substances on the OBS list, or with similar, or worse, may be present.
3	Fair to good	similar, or worse, characteristics may be present.
4	Fair	Substances on the Substance list, or with similar, or worse effects, may be present, but in very small amounts.
5	Borderline fair	Substances on the OBS list may be present, but in very small amounts.
6	Marginally acceptable	Substances on the Substance list may be present.
7	Poor	Substances on the A, B or the OBS list or with similar, or worse, may be present.
8	Unacceptable	Substances that are forbidden by law may be present.

Lifecycle phase	$Score_{GW}$	$Score_{E\text{-}tox}$	Comment
Production	3	7	
Use	3	1	FDV not inlcuded
Disposal	1	5	Not known
Lifecycle	3	4.3	

Lifecycle phase	Plaster board	Reference	% of average
Production	2133.8	3228.5	66%
Use	193.9	449.7	43%
Disposal	27.8	273.2	10%
Lifecycle	2355.6	3951.4	60%

Ecotoxisity; $Score_{ETox\text{-}Disposal}$		
Score	**Judgement**	**Criteria**
1	Excellent	Contains no substances that can constitute future damage to the environment.
2	Good	
3	Fair to good	
4	Fair	
5	Borderline fair	Contains only trace amounts of substances that can constitute future damage on the environment, but within the limits defined in the regulations.
6	Marginally acceptable	
7	Poor	
8	Unacceptable	The material is defined as dangerous waste, because of possible ecological damage, according to the regulations.

Human toxicity; ScoreHTox-production, Use, Total

Score	Judgement	Criteria
1	Excellent	No substances on the OBS, A or B list or with similar, or worse, characteristics with respect to eco-toxicological effects.
2	Good	
3	Fair to good	Trace amounts of substances on the OBS list, A- or B-list (or with similar, or worse, eco-toxicological effects) may occur.
4	Fair	Substances on the substance list (or with similar, or worse, eco-toxicological effects) may occur, but in very small amounts.
5	Borderline fair	Substances on the OBS list (because of its eco-toxicological effects), but in very small amounts.
6	Marginally acceptabl	Substances on the Substance list (because of the eco-toxicological effects).
7	Poor	Substances on the A, B or the OBS list or with similar, or worse, eco-toxicological effects.
8	Unacceptable	Substances that are forbidden by law.

Human toxicity; Score$_{HTox-Disposal}$

Score	**Judgement**	**Criteria**
1	Excellent	Contains no substances that can constitute future damage to human health.
2	Good	
3	Fair to good	
4	Fair	
5	Borderline fair	Contains only trace amounts of substances that can constitute future damage to human health, but within the limits defined in the regulations.
6	Marginally acceptable	
7	Poor	
8	Unacceptable	The material is defined as dangerous waste, because of possible damage to human health, according to the regulations.

Depot effect dust; $Score_{DED}$

Score	Judgement	Criteria
Score	Judgement	Low
1	Excellent	
2	Good	
3	Fair to good	
4	Fair	Medium
5	Borderline fair	
6	Marginally acceptable	
7	Poor	
8	Unacceptable	High
	Score	4

Emission of particles and fibres; $Score_{PF}$

Score	Judgement	Criteria
Score	Judgement	Stone, marble, glass, steel etc. (0 mg/m2)
1	Excellent	
2	Good	
3	Fair to good	Ò0.75 mg/m^2
4	Fair	
5	Borderline fair	> 0.75 mg/m^2
6	Marginally acceptable	
7	Poor	
8	Unacceptable	> 2 mg/m^3
	Score	3

Depot effect gasses; $Score_{DEG}$

Score	Judgement	Criteria
Score	Judgement	Low
1	Excellent	
2	Good	
3	Fair to good	
4	Fair	Medium
5	Borderline fair	
6	Marginally acceptable	
7	Poor	
8	Unacceptable	High
	Score	4

Emission of gasses; ScoreG

Score	Judgement	Criteria
Score	Judgement	Stone, marble, glass, steel etc.
1	Excellent	
2	Good	
3	Fair to good	M1 classification
4	Fair	
5	Borderline fair	M2 classification
6	Marginally acceptable	
7	Poor	
8	Unacceptable	M3 classification
	Score	3

Phase	$Score_{H-tox}$	Comments		
Production	7			
Use	1	Based on assumptions		
Disposal	5	Based on assumptions		
Total	4.3			
Phase	$Score_{DED}$	$Score_{EPF}$	$Score_{DEG}$	$Score_{EG}$
Production	IR	IR	IR	IR
Use	4	3	4	3
Disposal	IR	IR	IR	IR
Total	4	3	4	3

Substance	M1 criteria	M2 criteria	M3 criteria
Total Volatile Organic Compounds, TVOC	< 0.2 mg/m^2h	< 0.4 mg/m^2h	> 0.4 mg/m^2h, or no emission data
Formaldehyde, H_2CO	< 0.05 mg/m^2h	< 0.125 mg/m^2h	> 0.125 mg/m^2h, or no emission data
Ammonia, NH_3	< 0.03 mg/m^2h	< 0.06 mg/m^2h	> 0.06 mg/m^2h, or no emission data
Carcinogenic compounds according to category 1 of IARC classification	< 0.0005 mg/m^2h	< 0.0005 mg/m^2h	> 0.0005 mg/m^2h, or no emission data
Odor	Dissatisfaction level < 15%	Dissatisfaction level < 30%	Dissatisfaction level > 30%

Lifecycle phase	Product	$Score_E$
Production	13.37	3
Use	23.81	4
Disposal	22.64	4
Total	13.54	3

Use of energy; $Score_E$	Amount of energy used, $Score_{EA}$	Ò10% of reference value	Ò10% of reference value	10 %< AND Ò40% of reference val	40 %< AND Ò70% of reference val	70 %< AND Ò100% of reference va	100 %< AND Ò130% of reference v	130 %< AND Ò160% of reference v	160 %< AND < 190% of reference v
Energy type, $Score_{ET}$	**Score**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Renewable energy	**1**	1	2	3	4	5	6	7	8
-	**2**	2	4	6	8	10	12	14	16
Hydropower	**3**	3	6	9	12	15	18	21	24
Biofuels	**4**	4	8	12	16	20	24	28	32
-	**5**	5	10	15	20	25	30	35	40
-	**6**	6	12	18	24	30	36	42	48
Coal	**7**	7	14	21	28	35	42	49	56
Oil, natural gas, nuclear energy	**8**	8	16	24	32	40	48	56	64

Judgement	**Score**	**From**	**To**
Excellent	**1**	1	3.15
Good	**2**	3.2	12.75
Fair to good	**3**	12.8	22.35
Fair	**4**	22.4	31.95
Borderline fair	**5**	32	41.55
acceptable	**6**	41.6	51.15
Poor	**7**	51.2	60.75
Unacceptable	**8**	60.8	64

Lifecycle phase	Product	$Score_E$
Production	14.0	3
Use	2.0	1
Disposal	35.0	5
Total	34.9	5

Production of waste; $Score_W$	Amount of waste; $Score_{WA}$	Ò10% of reference value	10 %< AND Ò40% of reference value	40 %< AND Ò70% of reference value	70 %< AND Ò100% of reference value	100 %< AND Ò130% of reference valu	130 %< AND Ò160% of reference valu	160 %< AND < 190% of reference valu	Ò190 % of reference value
Waste handling; $Score_{WH}$	Score	1	3	4	5	6	7	8	10
Reuse	1	1	2	3	4	5	6	7	8
Recycling	2	2	4	6	8	10	12	14	16
Down cycling	3	3	6	9	12	15	18	21	24
-	4	4	8	12	16	20	24	28	32
-	5	5	10	15	20	25	30	35	40
-	6	6	12	18	24	30	36	42	48
Deposit	7	7	14	21	28	35	42	49	56
Hazardous or dangerous waste treatment	8	8	16	24	32	40	48	56	64

Judgement	Score	From	To
Excellent	1	1	3.15
Good	2	3.2	12.75
Fair to good	3	12.8	22.35
Fair	4	22.4	31.95
Borderline fair	5	32	41.55
Marginally acceptable	6	41.6	51.15
Poor	7	51.2	60.75
Unacceptable	8	60.8	64

Results combined scoring	Producti	Use	Disposal	Total
Raw materials	4.1	#DIV/0!	#DIV/0!	4.1
Energy	3.0	4.0	4.0	3.00
Waste	3.0	1.0	5.0	5.00

Score	Judgement
1	Excellent
2	Good
3	Fair to good
4	Fair
5	Borderline fair
6	Marginally acceptable
7	Poor
8	Unacceptable

Parameter	Score
Emission of gasses, ScoreG	3
Emission of particles or fibres, $Score_{EF}$	3
Depot effect gasses, $Score_{DEG}$	4
Ɇ	10

Score	Judgment	Criteria
1	*Excellent*	Ɇ Ò 6
4	*Fair*	6 < Ɇ Ò 12
8	*Unacceptable*	Ɇ > 12

Pollution to indoor environment; $Score_P$:	4

Results combined scoring	Production	Use	Disposal	Total
Sub-area	Score	Score	Score	Score
Human toxicity	7.0	1.0	5	5.0
Pollution to indoor environment	IR	4.0	IR	4

This is the first step in the evaluation of the "Resource" use for the material. The evaluation is divided in sub-areas: Material resources, Energy resources and Waste. Preferably all areas should be included in a evaluation, but this is up to the user of the system. To exclude one of the sub- areas, uncheck the cross in the respective box below.
After the selection of sub.-areas to include in the evaluation the importance between the areas must be decided. There are two alternatives:
- Pairwise comparison
- Predetermined weights.
Note that you can only use the sustainability index at the end if all sub-areas are included and the inherent weighing in the system is used. If you exclude some of the sub-areas or use your own weight the products can only reach the classification "excellent".

Selection of sub-areas to be included in the evaluation:

☑ Material resources

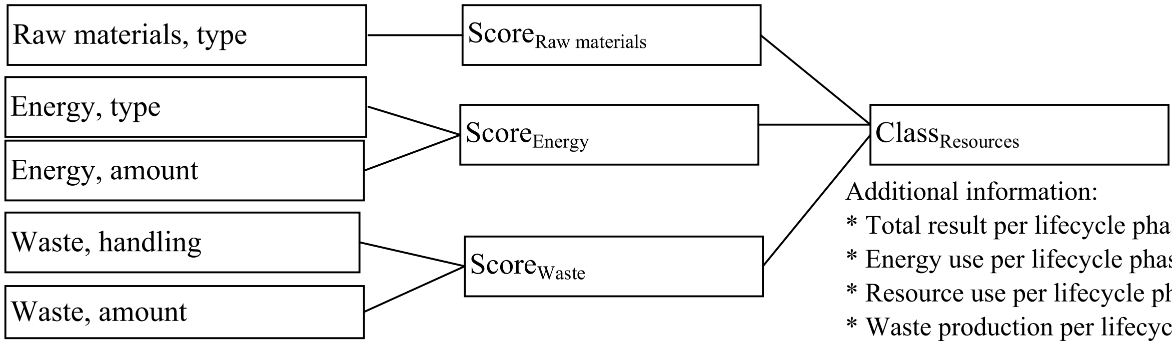
The building industry uses 40 to 60 % of the natural resources consumed in Norway annually. This amount leaves the industry with a special responsibility to reduce the load on our natural resources by selecting products produced from recycled materials or direct reuse.
Biological diversity is identified as one of he major environmental treats we are facing today. Renewable natural resources must therefore also be selected with care. Using products made from wood, the producer must make sure that is sustainable grown and harvested. It is recommended to look for FSC certified timber.

☑ Energy

Energy use in buildings represent about 40 % of the energy use in Norway. Energy use in the operational phase is the dominating factor, and the production and use of building materials is the second most important factor. It is agreed that clean renewable energy is scarce. It is seen as an important step towards a sustainable future to move away from fossil energy towards renewable energy recourses, and promote energy -efficient technologies (WWF, 2002). Both the amount of energy and the source of this energy is considered in the evaluation.

☑ Waste

Waste from the building industry represent about 40 % of the waste produced from our society. Regardless of the view taken in the sustainable development discussion (se chapter 5.1) The accumulation of waste has serious consequence as deposits it occupy large areas of land, emission of methane and other gasses and leaching of toxics into the ground. The treatment of waste by incineration in turn give birth to other environment problems. The amount of waste should be reduced, and the waste produced should be handled as a resource for further exploitation in new products.



Additional information:
* Total result per lifecycle phase
* Energy use per lifecycle phase
* Resource use per lifecycle phase
* Waste production per lifecycle phase

Pairwise comparisons:

Sub-area	**Raw materials**	**Energy**	**Waste**	**Geom. mean**	**Weight**
Raw materials	1	1	1	1.00	**33%**
Energy	1	1	1	1.00	**33%**
Waste	1	1	1	1.00	**33%**

The fundamental scales of the AHP (Staaty, 1998):

Intensity of	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgements slightly favour one activity over another.
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong demonstrated importance	An activity is favoured very strongly over another, its dominance is demonstrated in
9	Extreme importance	The evidence favouring one activity over another of the highest order of affirmation
2.0, 4.0, 6.0, 8.0	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is n o good word to describe it
Reciprocal of above	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal	A comparison mandated by choosing the smaller elements as the unite to estimate the larger one as a multiple of that unit
Rationales	Rations arising form the scale	If consistency were to be forced by obtaining n numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9

This is the first step in the evaluation of the "Ecology" properties for the material. The evaluation is divided in sub-areas: Global warming and ecotoxicity. Preferably both areas will be included in a evaluation, but this is up to the user of the system. To exclude one of the sub areas, remove the cross in the respective boxes below.
After the selection of sub-areas to include in the evaluation the importance between the areas must be decided. There are two alternatives:
- Pairwise comparison
- Predetermined weights.
Note that you can only use the sustainability index at the end if all sub-areas are included and the inherent weighing in the system is used. If you exclude some of the sub-areas or use your own weight the products can only reach the classification "excellent".

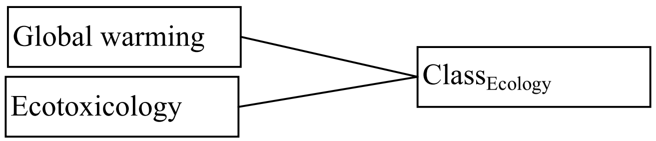
Sub-areas to be included in the evaluation:

☑ Global warming

About 10 % of the Norwegian emissions of CO_2 is related to the production and use of building materials. The importance of global warming leads to the conclusion that this aspect must be included in the ecological evaluation of a building material.

☑ Ecotoxicity

The us of toxic chemical is of concern for the user of a building and of the authorities. Thousands of chemicals is added in unknown number of products circulation in the European market. Several building materials contains substances that are under observation because if there effects.



Additional information:
* Results per lifecycle phase
* Global warming potential per lifecycle phase
* Eco toxicological score per phase

Weighting using pairwise comparison:

Sub-area	Global w.	Ecotoxicity	Weight
Global w.	1	1	**50%**
Ecotoxicity	1	1	**50%**

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgements slightly favour one activity over another.
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong demonstrated importance	An activity is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another of the highest order of affirmation
2.0, 4.0, 6.0, 8.0	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is n o good word to describe it
Reciprocal of above	If activity i has one of the above numbers assigned to it when compared to activity j,	A comparison mandated by choosing the smaller elements as the unite to estimate the larger one as a multiple of that unit
Rationales	Rations arising form the scale	If consistency were to be forced by obtaining n numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9

This is the first step in the evaluation of the "Human health" properties for the material. The evaluation is divided in sub-areas: Human toxicity, Robustness in use, cleaning friendliness and pollution . Preferably all areas should be included in a evaluation, but this is up to the user of the system. To exclude one of the sub- areas, uncheck the cross in the respective box below.
After the selection of sub-areas to include in the evaluation the importance between the areas must be decided. There are two alternatives:
- Pairwise comparison
- Predetermined weights.
Note that you can only use the sustainability index at the end if all sub-areas are included and the inherent weighing in the system is used. If you exclude some of the sub-areas or use your own weight the products can only reach the classification "excellent".

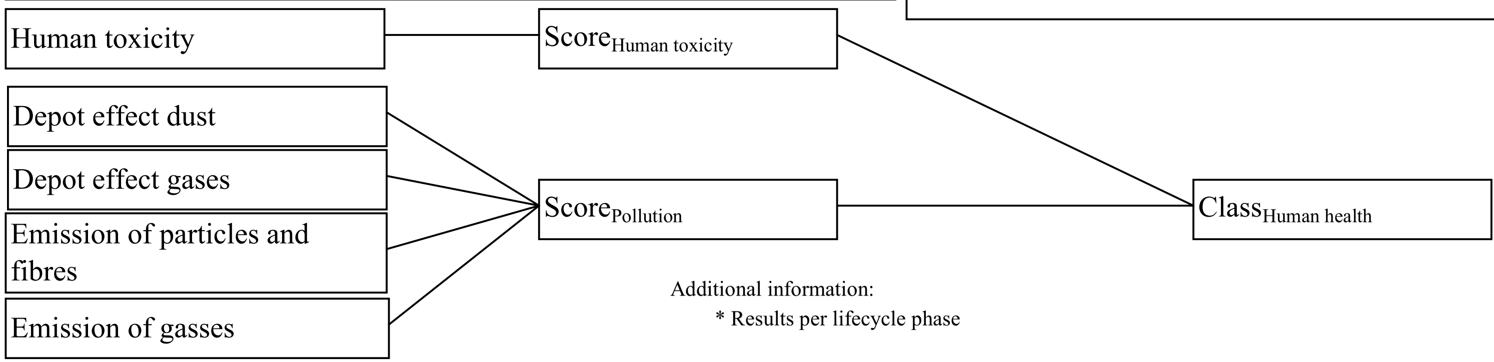
Selection of sub-areas to be included in the evaluation:

☑ Pollution to indoor environment

Pollution to the indoor environment includes particles, fibres and gasses directly or indirectly emitted from a product. Gasses emissions from building materials might cause health problems, smell and reduced comfort.
The direct emissions should b tested according to CEN standard CEN CR 1752. The emissions of particles and fibres should be tested according to the recommendations in the Danish association of indoor climate. The indirect emissions are evaluated after the ISS system who supply a qualitative evaluation of the depot effect for dust and gasses. Pollution to indoor air is only relevant ins the user phase of the building.

☑ Human toxicity

Human toxicity is relevant in all lifecycle phases of a building material. In the production phase it is the exposure of the workers in the manufacturing of the building materials that is evaluated. In the user phase it is the exposure of the occupant in the building. It is important that the cleaning and maintenance methods are included in the assessment. In the demolition phase it is the exposure of the workers in the deconstruction process that is evaluated or relevant consequences in waste treatment.
As for Eco toxicity the different substances must be checked with respect to the OBS-list (including the A- and B-list) and the substance list.

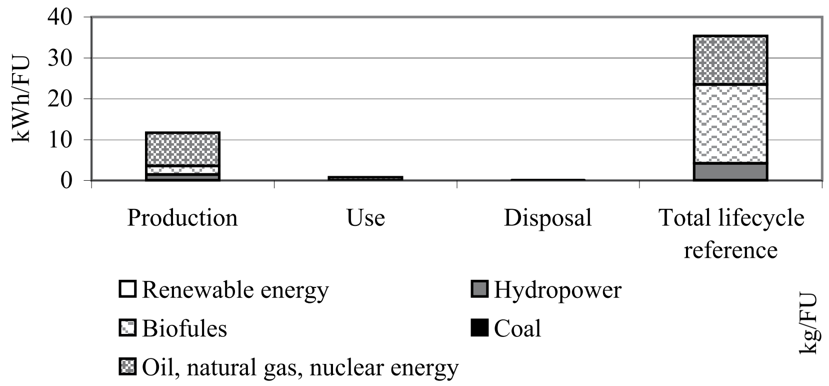


Additional information:
* Results per lifecycle phase

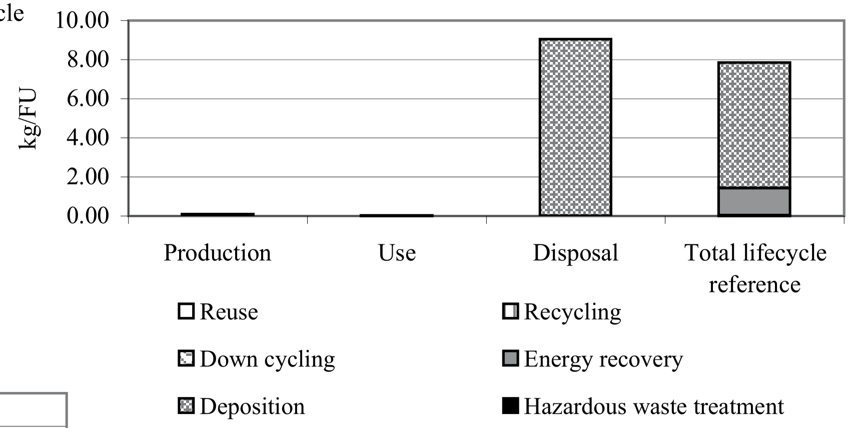
Sub-area	Human toxicity	Pollution to indoor environment	Weight
Human toxicity	1	1	**50%**
Pollution to indoor environment	1	1	**50%**

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgements slightly favour one activity over another.
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong demonstrated importance	An activity is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another of the highest order of affirmation
2.0, 4.0, 6.0, 8.0	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is n o good word to describe it
Reciprocal of above	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal valued when compared to i	A comparison mandated by choosing the smaller elements as the unite to estimate the larger one as a multiple of that unit
Rationales	Rations arising form the scale	If consistency were to be forced by obtaining n numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9

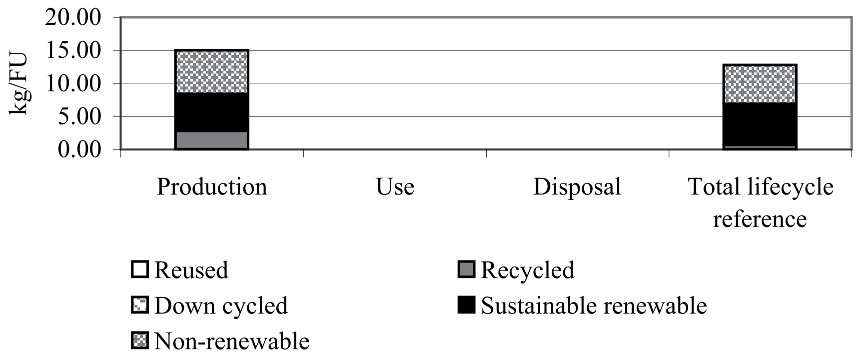
Energy resources



Waste

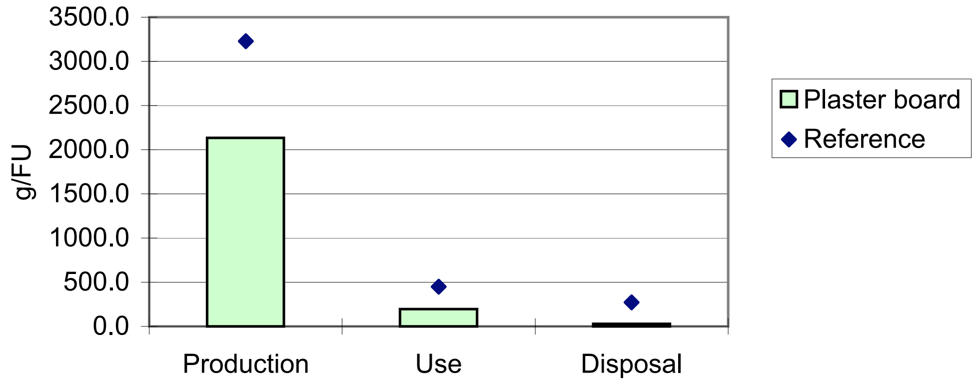


Material resources

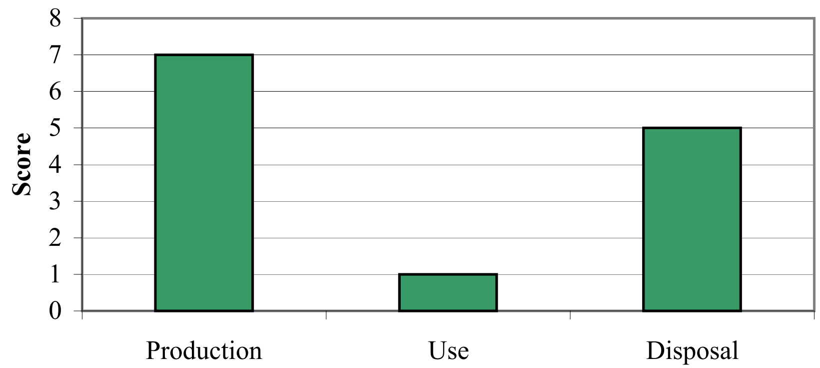


MaSe-system

Global warming

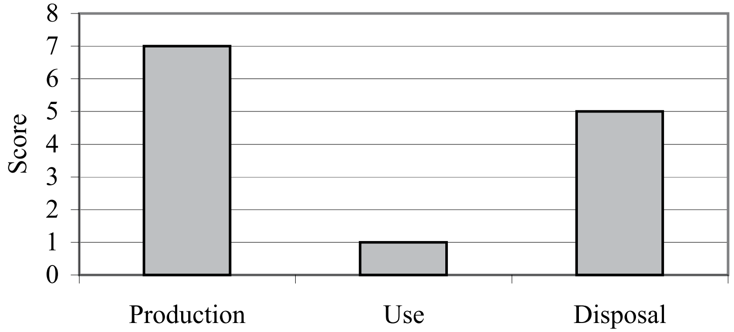


Ecological toxicity



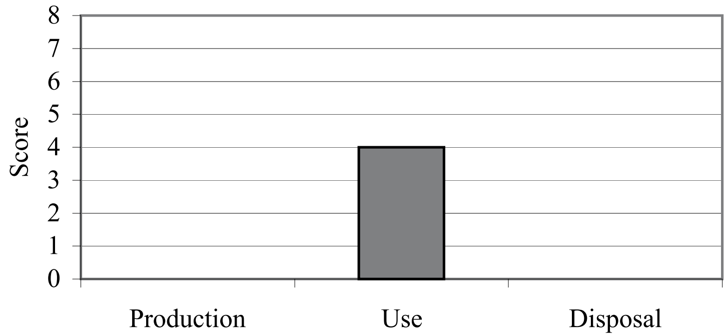
MaSe-system

Human toxicity



1 = Excellent
2 = Good
3 = Fair to good
4 = Fair
5 = Borderline fair
6 = Marginally acceptable
7 = Poor
8 = Unacceptable

Pollution to indoor environment



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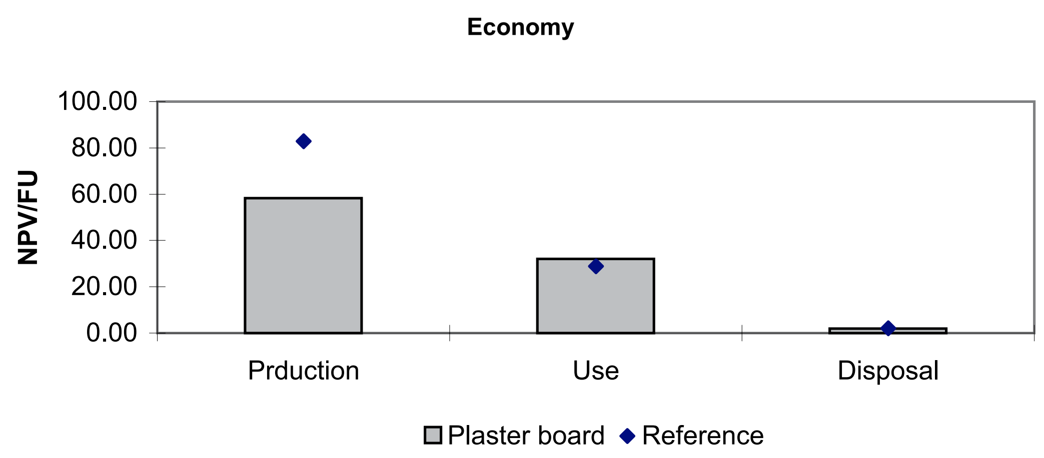
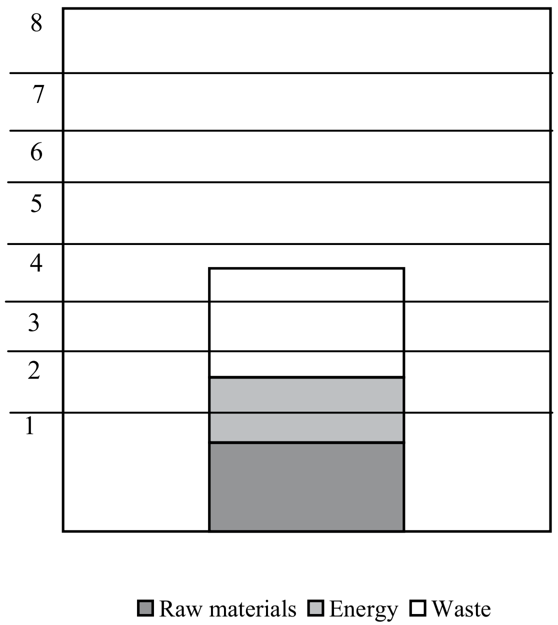
8 = Unacceptable

HH ill.


Economy
NPV/FU
100.00
80.00
60.00
40.00
20.00
0.00
Prduction
Use
Disposal
Plaster board
Reference

Sub area	Score	Max	Min	Parameter weight	*Weighted score*	Max	Min
Raw materials	4.07	8	1	33%	1.4	2.7	0.3
Energy	3.00	8	1	33%	1.0	2.7	0.3
Waste	5.00	8	1	33%	1.7	2.7	0.3
				Final classifiaction	4.0		

Final classification "Resources"

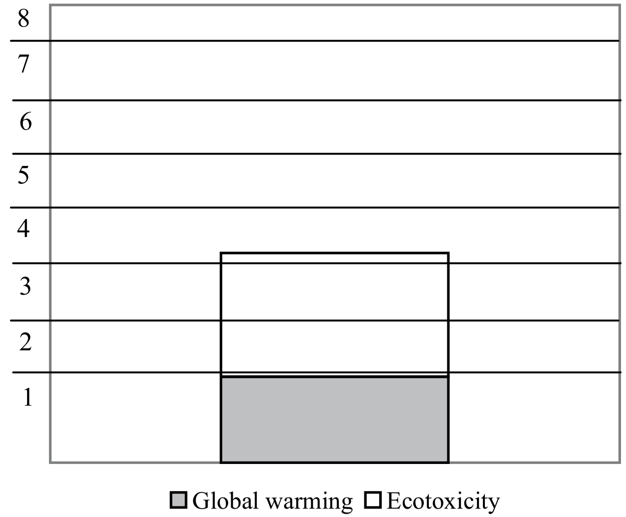


1 = Excellent
2 = Good
3 = Fair to good
4 = Fair
5 = Borderline fair
6 = Marginally acceptable
7 = Poor
8 = Unacceptable

Sub-areas excluded from the classification:

Effect	Score	Max	Min	Parameter weight	*Weighted score*	Max	Min
Global warming	3	8.00	1	50%	1.5	4.0	0.5
Ecotoxicity	4	8.00	1	50%	2.2	4.0	0.5
Final classification					3.7	8.0	1.0

Final classification "Ecology"

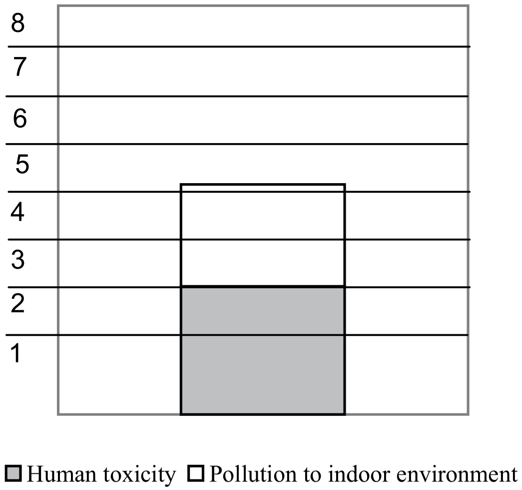


1 = Excellent
2 = Good
3 = Fair to good
4 = Fair
5 = Borderline fair
6 = Marginally acceptable
7 = Poor
8 = Unacceptable

Sub-areas excluded from the classification:

Obtained scoring	Unweighted score	*Max*	*Min*	Selected weight	Weighted scores	Max	Min
Human toxicity	*5*	*8.00*	*1.00*	50.0 %	2.5	**4.00**	**0.50**
Pollution to indoor environment	*4*	*8.00*	*1.00*	50.0 %	2.00	**4.00**	**0.50**
			Final classification		4.5	**8.00**	**1.00**

Final classification: "Human health"

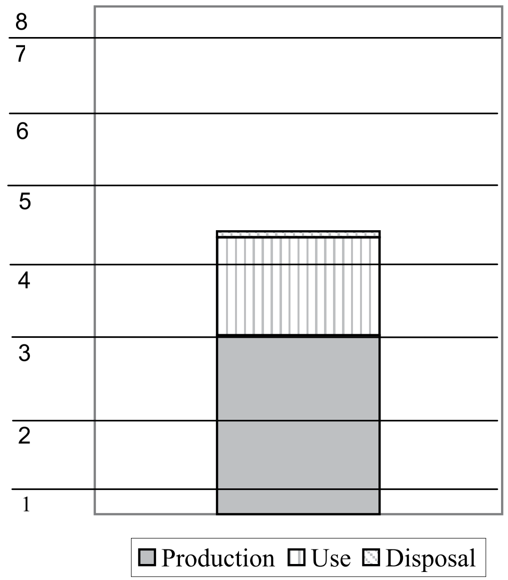


1 = Excellent
2 = Good
3 = Fair to good
4 = Fair
5 = Borderline fair
6 = Marginally acceptable
7 = Poor
8 = Unacceptable

Sub-areas excluded from the classification:

Cost elements	Product	Reference	% of reference
Total	92.42	82.91	111%
Production	58.33	52	112%
Purchase price ex. transport	58.33	52	112%
Use	32.08	28.8	111%
Transport	2.92	2.6	112%
Installing	29.17	26.2	111%
FDV	0.00	0	#DIV/0!
Disposal	2.00	2.11	95%
Demolition	0.00	0.09	0%
Waste treatment	0.00	0.01	0%
Residual value of materials	2.00	2	100%
Transport	0.00	0.01	0%

Final classification, "Economy"



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2 = Good
3 = Fair to good
4 = Fair
5 = Borderline fair
6 = Marginally acceptable
7 = Poor
8 = Unacceptable

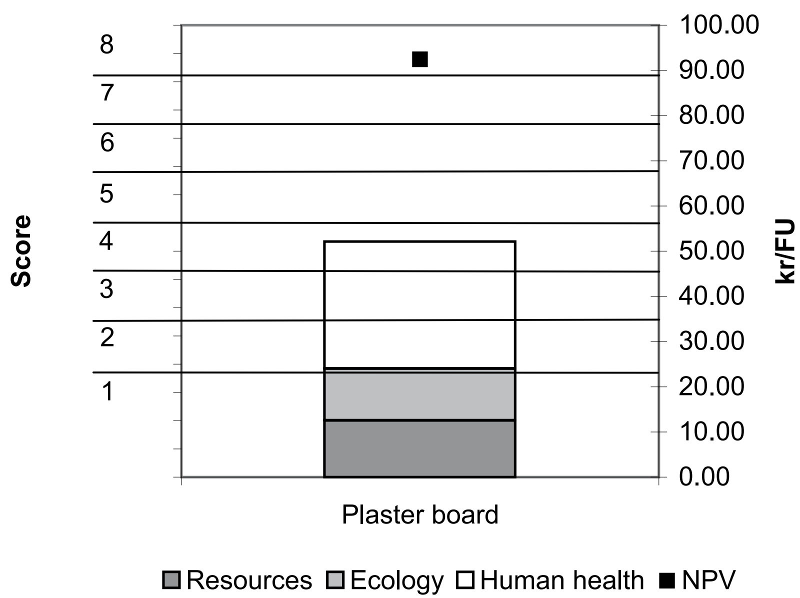
Pairwise comparions

Main area	Resources	Ecology	Human health	Weight
Resources	1	1	1/2	**25%**
Ecology	1	1	1/2	**25%**
Human health	2	2	1	**50%**

The fundamental scales of the AHP (Saaty, 1998):

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgements slightly favour one activity over another.
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong demonstrated importance	An activity is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another of the highest order of affirmation
2.0, 4.0, 6.0, 8.0	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is n o good word to describe it
Reciprocal of above	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal valued when compared to i	A comparison mandated by choosing the smaller elements as the unite to estimate the larger one as a multiple of that unit
Rationales	Rations arising form the scale	If consistency were to be forced by obtaining n numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9

Environmental index



1 = Excellent
2 = Good
3 = Fair to good
4 = Fair
5 = Borderline fair
6 = Marginally acceptable
7 = Poor
8 = Unacceptable

Results main areas

Product	Resources	Ecology	Human health	NPV	Average
Plaster board	4.0	3.7	4.5	92.42	4.1

Weighted results

Product	Resources	Ecology	Human health	NPV	Weighted index
Plaster board	1.0	0.9	2.3	92.42	4.2

Appendix B: The interviews

Note that the interviews are performed in person, and that the questions may be adapted to the different situations. The exact phrases in this document were only used as guidance. Illustrations were also used to explain the different questions or available alternatives, where this was necessary. The interviews took 1 – 2 hours.

This investigation is performed with two goals in mind. First, to increase the knowledge on how the final material and product selections are made in larger building projects. Where are the central decision makers on the different levels, and what is decisive for their choices? Second, the investigation will also contribute to reveal the decision makers consciousness around environmental considerations. Do they want to be able to make more environmentally preferable choices, and what do they need to be able to do this?

The questions

1.1 It is environmental remedial actions in buildings that interest me, and in special how this affects the material and product selections in new buildings (also in rehabilitation). A great deal has happened in this area in the last years, both when it comes to increased knowledge and to the general understanding of the environmental problems that we face. However, often it is seen that this increased knowledge is hard to make use of in the day-to-day practical live, maybe especially in the building and real estate industry. It would be interesting to hear how you will describe the development in your organisation when it comes to environment and building/construction the last 5 years? (The view on environmental considerations in general? Do you have a clear opinion on how your action affects the environment?)

1.2 Kan you say something about how you think the development will be for your organisation the next 5 years?

1.3 I am also very interested in how material selections take place in the process of constructing larger buildings. In what way/at which level is your organisation/field involved in the material selections?

1.4 What are the most important factors for a material, that determines if it is selected or not?

- Technical qualities
- Aesthetics
- Costs installed in the building
- Maintenance costs
- Maintenance qualities/durability
- Tradition
- Indoor environmental qualities
- Other environmental qualities

- ç Ohter: ___________________________

1.5 What do you think will control the material selections in the years to come? (5-10 years) Will this be different than the previous question; will other criteria become more important? – And why is this?

Answer in prioritised order:

- ç *Technical qualities*
- ç *Aesthetics*
- ç *Costs installed in the building*
- ç *Maintenance costs*
- ç *Maintenance qualities/durability*
- ç *Tradition*
- ç *Indoor environmental qualities*
- ç *Other environmental qualities*
- ç *Other:* ___________________________

Environmental considerations in material selection

1.6 With the profession you represent in mind; are environmental considerations something you recon to be important to consider when selecting between different materials?

1.6.1 In that case, which environmental considerations is it that should be considered?

1.7 Is it any will to accept increased investment costs related to documented environmentally friendly materials?

1.8 Ref. 2.2. If rice in costs is accepted, is it a documentation requirement (for a material being better with respect to environmental criteria)? How would you in that case prefer that this be done? (Is it enough that an conslutant says it is more environmentally friendly? Is it god enough if a recognised tool says the same?)

1.9 If yes on 1.6.1, how large can the increase in costs be for increased environmental efficiency in a building?

In %:___________

1.10 As we discussed earlier, it varies to which degree the increased knowledge on the environmental area is set out in practise. Many do say they use this knowledge, but so far, it has been easy to say so without being checked for the truth in these statements. “Environment” is also a term that is seen more often in marketing, without any documentation that it really is better than for example common practice. How would you describe your organisation and its competence on the environmental area?

Do you have knowledge about the area, and in that case do you use it?

1.11 Especially when it comes to material selection, I am interested in the knowledge level. Can you say something about this?

1.12 Do you have examples of projects where ”environment” has been a topic, and your organisation has been involved?

- Something on material selection?

1.13 What, in your opinion, has been the largest obstacle for more environmentally friendly choices so far?

1.14 How do you think these obstacles can be surpassed?

A system for selection of environmentally preferable materials

In this part it is assumed that a system exists that can aid in deciding on what is the best material alternative with respect to environmental considerations. The questions and answers will be an aid in getting an impression of what is expected of such a system, and what requirements the users will have.

1.15 What type of system do you think would fit best in your organisation?

Database, Web based, Handbook, Declarations?

1.16 What kind of information would you expect of such a system? (see examples!)

1.17 Is it important that a material selection system is transparent, in the respect that you can trace the reasons for each material evaluation.?

1.18 If yes on 3.3, what will you use this information for?

1.19 Do you think professionals in you organisation will prefer to affect the result of a system (through selection of parameters, weighting etc.)?

1.20 The basis for environmental materiel evaluation is typically CO_2 per m^2 material, kg NOx per m^2 material etc., this is a type of material declaration system. All these factors contribute to different effects like the greenhouse effects, disrupting the ozone layer, acid rain etc. For a tool to function, these effects must be weighted against each other. Now there are small possibilities for a scientifically correct weighting, a weighs-set is based on political prioritisations, economical considerations, subjective prioritisations and/or professional environmental evaluations.

- Do you mean that weights should be used at all?
- Is it important what type of weights that is used?

1.21 Finally, it is interesting to hear if you think that your organisation needs assistance in performing the right prioritisations when it comes to environmental considerations, especially regarding material selection?

1.22 Have you earlier considered the problems we have discussed now, and how they can be handled?

Appendix C: List of factors included in the BEES system

Flow (i) [g/m^2]	*Equivalence factors*
Global warming	Potential Equivalence factors, GWP_i (CO_2-equivalents)
Carbon dioxide	1
Methane	24.5
Nitrous oxide	320
Acidification	Potential Equivalence factors, AP_i (Hydrogen-equivalents)
Sulphur oxides	0.031
Nitrogen Oxides	0.022
Ammonia	0.059
Hydrogen fluorides	0.05
Hydrogen chloride	0.027
Eutrophication Potential	Potential Equivalence factors, NP_i (Phosphate-equivalents)
Phosphates	1
Nitrogen oxides	0.13
Ammonia	0.42
Nitrogenous matter	0.42
Nitrates	0.095
Phosphorus	3.06
Chemical Oxygen Demand	0.022
Natural resource depletion	Equivalence factor[1/kg yr]
Oil (in ground)	5.6E-17
Natural gas (in ground)	1.2E-16
Coal (in ground)	5.0E-16
Bauxite (Al2O3*2H2O, ore)	1.4E-16
Cadmium (Cd, ore)	2.1E-11
Copper (Cu, ore)	2.6E-14
Gold (Au, ore)	5.9E-10
Iron (Fe, ore)	4.3E-17
Lead (Pb, ore)	1.9E-13
Manganese (Mn, ore)	2.9E-16
Mercury (Hg, ore)	5.4E-11
Nickel (Ni, ore)	7.6E-14
Phosphate Rock (in ground)	1.2E-16

Potash (K2O, in ground)	9.1E-17
Silver (Ag, ore)	7.9E-11
Tin (Sn, ore)	1.8E-12
Uranium (U, ore)	1.8E-13
Zinc (Zn, ore)	6.5E-14
Indoor air quality	Measure [Mg/m^2/hr at 24 hours]
Total Volatile Organic Compounds (TVOC)	

Appendix D: Test calculations in Excel using different MCDM methods

SAW

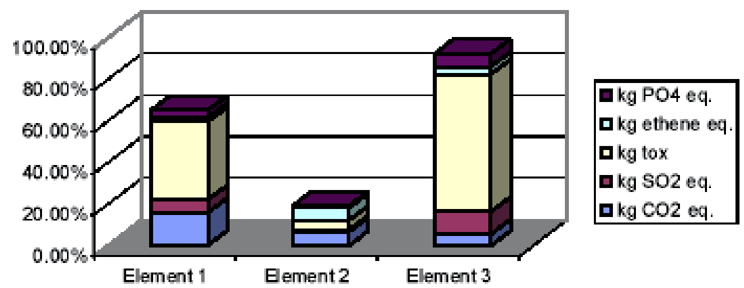
Inventory	Element 1	Element 2	Element 3	Average
kg CO2 eq.	85	36	30	50.333
kg SO2 eq.	0.51	0.082	0.9	0.497
kg tox	0.8	0.095	1.4	0.765
kg ethene eq.	0.0068	0.022	0.013	0.014
kg PO4 eq.	0.039	0.0092	0.067	0.038

Effect	Global warming	Acidification	Photochemical ozone creation	Eutropication	Human toxicity	Sum	Geometric mean	Priority
Global warming	1.00	3.00	3.00	3.00	0.14	10.1	1.31	0.16
Acidification	0.33	1.00	1.00	1.00	0.11	3.4	0.52	0.06
Photochemic	0.33	1.00	1.00	1.00	0.11	3.4	0.52	0.06
Eutropicatior	0.33	1.00	1.00	1.00	0.11	3.4	0.52	0.06
Human toxic	7.00	9.00	9.00	9.00	1.00	35.0	5.52	0.66
0.2						55.476		
							8.38	1

Normalised	Element 1	Element 2	Element 3	Weight	Normalisation data	Worst case
kg CO2 eq.	100.0 %	42.4 %	35.3 %	0.16	kg CO2 eq.	85
kg SO2 eq.	100.0 %	16.1 %	176.5 %	0.06	kg SO2 eq.	0.51
kg tox	57.1 %	6.8 %	100.0 %	0.66	kg tox	1.4
kg ethene eq.	30.9 %	100.0 %	59.1 %	0.06	kg ethene eq	0.022
kg PO4 eq.	58.2 %	13.7 %	100.0 %	0.06	kg PO4 eq.	0.067

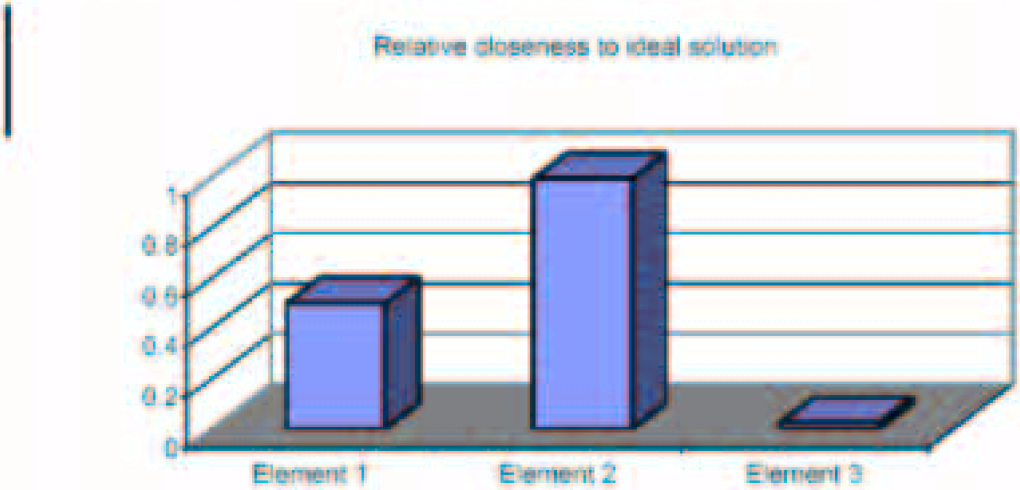
Normalised and weighted	Element 1	Element 2	Element 3
kg CO2 eq.	15.64%	6.62%	5.52%
kg SO2 eq.	6.17%	0.99%	10.90%
kg tox	37.62%	4.47%	65.84%
kg ethene eq.	1.91%	6.17%	3.65%
kg PO4 eq.	3.59%	0.85%	6.17%
	64.94%	19.11%	92.08%
Rank	2	1	3
Relationship	3.40	1.00	4.82

SAW: Normalised and weighted environmental profiles

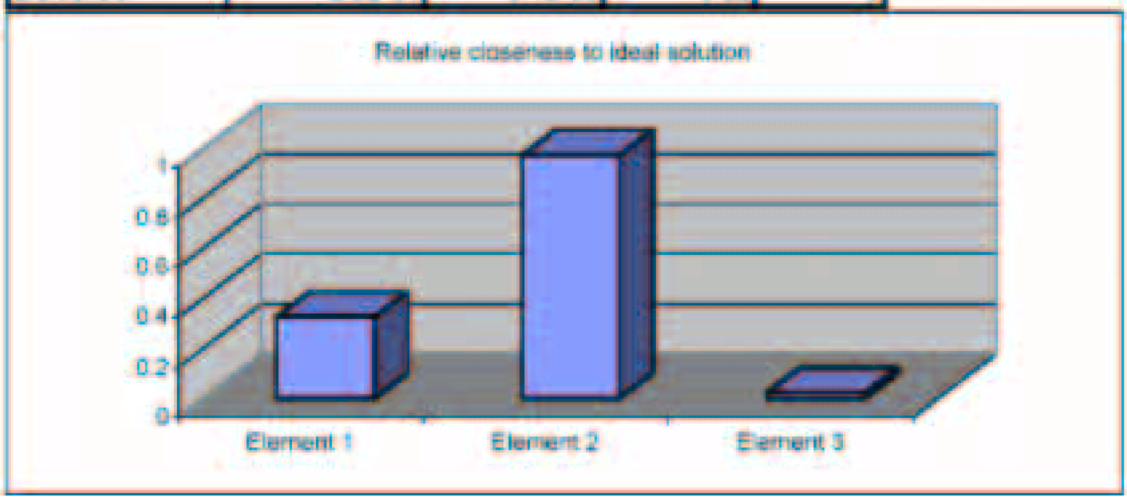


TOPSIS

Normalised and weighted	Element 1	Element 2	Element 3	Positive ideal	Negative ideal
kg CO2 eq	15.64%	6.62%	5.52%	5.52%	15.64%
kg SO2 eq	6.17%	0.99%	10.90%	0.99%	10.90%
kg tox	37.62%	4.47%	65.84%	4.47%	65.84%
kg ethene eq	1.91%	6.17%	3.65%	1.91%	3.65%
kg PO4 eq	3.59%	0.86%	6.17%	0.86%	6.17%
	S⁺	S-	C⁺	Rank	Realtionship
Element 1	6.2E-02	6.2E-02	0.50	2	0.50
Element 2	9.7E-04	2.0E-01	1.00	1	1.00
Element 3	1.9E-01	5.1E-03	0.03	3	0.03



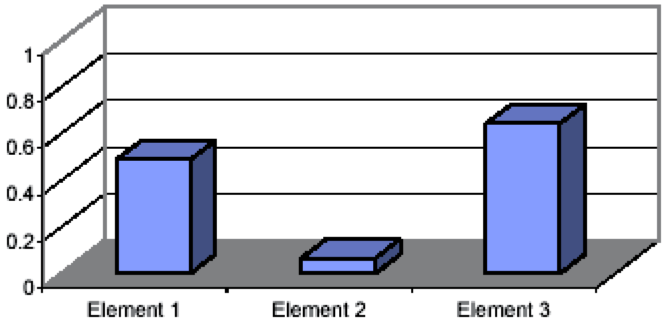
Normalised and weighted	Element 1	Element 2	Element 3	Positive ideal	Negative ideal
kg CO2 eq	15.64%	6.62%	5.52%	0.00%	15.64%
kg SO2 eq	6.17%	0.99%	10.90%	0.00%	10.90%
kg tox	37.62%	4.47%	65.84%	0.00%	65.84%
kg ethene eq	1.91%	6.17%	3.65%	0.00%	3.65%
kg PO4 eq	3.59%	0.86%	6.17%	0.00%	6.17%
	S⁺	S-	C⁺	Rank	
Element 1	8.6E-02	4.1E-02	0.33	2	
Element 2	5.2E-03	2.0E-01	0.97	1	
Element 3	2.3E-01	5.1E-03	0.02	3	



DFT

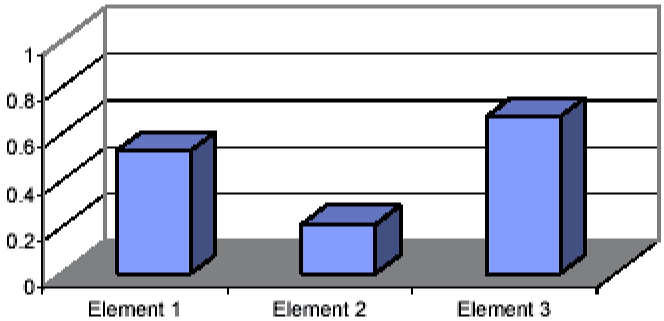
Normalise	Element 1	Element 2	Element 3	Weight	Target
kg CO2 eq	100.00%	42.35%	35.29%	0.156373	35.29%
kg SO2 eq	100.00%	16.08%	176.47%	0.06175	16.08%
kg tox	57.14%	6.79%	100.00%	0.658377	6.79%
kg ethene	30.91%	100.00%	59.09%	0.06175	30.91%
kg PO4 eq	58.21%	13.73%	100.00%	0.06175	13.73%
	d	rank			
Element 1	0.488872	2			
Element 2	0.066034	1			
Element 3	0.643837	3			

Distance from target calculation



Normalised	Element 1	Element 2	Element 3	Weight	Target
kg CO2 eq	100.00%	42.35%	35.29%	0.156373	0.00%
kg SO2 eq	100.00%	16.08%	176.47%	0.06175	0.00%
kg tox	57.14%	6.79%	100.00%	0.658377	0.00%
kg ethene	30.91%	100.00%	59.09%	0.06175	0.00%
kg PO4 eq	58.21%	13.73%	100.00%	0.06175	0.00%
0	d	rank	Realtion		
Element 1	0.528541	2	2.50		
Element 2	0.21147	1	1.00		
Element 3	0.674452	3	3.19		

Distance from target cacluation



Appendix E: The Obs list criteria

Criteria for the selection of substances on the Obs list because of environmental hazard (State Pollution Agency, 2000).

Criteria number	Properties	Requirements
1a	High bioaccumulation potential, combined with low degradation.	Bio concentration factor, BCF>1000 or log Kow[1)]>4. Low degradation in degradation test* (R35)
1b	High potential for bioaccumulation, combined with very high acute toxicity.	Bio concentration factor BCF>1000 or log Kow>4. EC50[2)] in short term test Ò1mg/l for water organisms (R50/53)
1c	Low degradation combined with very high acute toxicity	Low degradation in degradation test* EC50 in short-term test (R35) Ò 1mg/l for water organisms (R50/53)
2	Very high acute toxicity for water living organisms.	EC50 in short term test Ò0.1mg/l for water living organisms (R50)
3a	High potential for bioaccumulation combined with very high chronic toxicity.	Bio concentration factor, BCF > 1000 or log Kow>4. NOEC[3)] in long term test Ò 0.01mg/l for water living organisms
3b	Low degradation combined with very high chronic toxicity for water living organisms.	Low degradation in degradation test. NOEC in long-term test Ò 0.01mg/l for water living organisms.
4	Very high chronic toxicity.	NOEC in long term test Ò0.001mg/l
5	Depletion of the ozone layer.	Ozone depletion potential, ODP > 0 on the UNEP list or substances classified as ozone degrading (R59)

[1)] logKow = Octanol-Water partition coefficient
[2)] EC50 = Effective Concentration 50, medium lethal dose
[3)] NOEC = No Observed Effect Concentration

URN:NBN:no-6424

Criteria for the selection of substances on the Obs list because of their potential damage to human health (State Pollution Agency, 2000).

Criteria number	Properties	Requirements
6	Acute toxicity	Substances with very high acute toxicity (R25, 27, 28) [1)] LD_{50} oral, rat: Ò25 mg/kg [2)] LD_{50} dermal, rat or rabbit: Ò50 mg/kg LC_{50} inhalation, rat: Ò0.5 mg/l/4 hours (gasses, damps) [3)] LC_{50} inhalation, rat: Ò 0.25 mg/l/4 hours (aerosols, particles) Substances that with high probability can give (irreversible) damages after one single exposure. (All substances fulfil criteria for R39[1)])
7	Allergenic properties	High potent allergenic substances with specific concentration limits (R42, 43) [1)]
8	Chronic toxicity	All substances that fulfil the criteria for R48[1)]
9	Fertility damage/damages during nursing period	All substances that fulfil the criteria for R 60, 61, 62, 63 and 64[1)]
10	Mutagenic	All substances that fulfil the criteria for R46 and R40[1)] (mut 3[4)]).
11	Carcinogenic	High potent and medium potent carcinogenic (with reservation that the Norwegian potent grading system is maintained) (R45, 49[1)])
12	Interception criteria of health and environment	Substances that do not fulfils today criteria, but is suspected to have other serious properties, as for example hormone imitators or immunotoxic properties, gasses wit global warming potential, substances that form dangerous degradation products, soil pollution problems.

1) Refers to the Regulations on classification of dangerous chemicals (Ministry of Environment, 2002b)

2) LD_{50} = the amount of a material, given all at once, which causes the death of 50% of a group of test animals

3) LC_{50} = concentration of the chemical in air that causes the death of 50% of a group of test animals in a given time.

4) mut 3 = Mutagenic category 3: Substances that give reason to concern because of possible mutagenic effects on humans.

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Appendix F: The new categories of special waste

Table 11-1: The EU list of hazardous waste categories (European Commission, 2000).

Category nr.	Waste category
17	**Construction and demolition wastes (including excavated soil from contaminated sites)**
17 01	**concrete, bricks, tiles and ceramics**
17 01 06	mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing dangerous substances
17 02	**wood, glass and plastics**
17 02 04	glass, plastic and wood containing or contaminated with dangerous substances
17 03	**bituminous mixtures, coal tar and tarred products**
17 03 01	bituminous mixtures containing coal tar
17 03 03	coal tar and tarred products
17 04	**metals**
17 04 09	metal waste contaminated with dangerous substances
17 04 10	cables containing oil, coal tar and other dangerous substances
17 05	**soil (including excavated soil from contaminated sites), stones and dredging spoil**
17 05 03	soil and stoned containing dangerous substances
17 05 05	dredging spoil containing dangerous substances
17 05 07	track ballast containing dangerous substances
17 06	**insulation material and asbestos-containing construction materials**
17 06 01	insulation materials containing asbestos
17 06 03	other insulation materials consisting of or containing dangerous substances
17 08	**plaster-based construction material**
17 08 01	plaster-based construction materials contaminated with dangerous substances
17 09	**other construction and demolition waste**
17 09 01	construction and demolition waste containing mercury
17 09 02	construction and demolition waste containing PCB (for example PCB-containing sealants, PCB-containing resin-based floorings, PCB-containing sealed glazing units, PCB-containing capacitors)
17 09 03	other construction and demolition wastes including mixed wastes) containing dangerous substances.

Appendix G: Risk sentences

Table 11-2: Summary of risk sentences used in classification of chemicals.

CLASSIFICATION OF SUBSTANCES AND SUBSTANCE MIXTURES
Part A: Classification is substances and substance mixtures fir fire-, explosion risk and oxidising properties
R1 Explosive in dry condition
R2 Explosion risk by shock, friction, fire or other ignition sources
R3 Very high explosion risk by shock, friction, fire or other ignition sources
R4 Form very sensitive explosive metal compounds
R5 Explosive when heated
R6 Explosive with and without air contact
R7 Can cause fire
R8 Inflammable when in contact with combustible substances
R9 Explosion risk when mixed with combustible substances
R10 Inflammable
R11 Very inflammable
R12 Extremely inflammable
R14 Intensive reaction with water
R15 Reacts with water forming extremely inflammable gasses
R16 Explosive when mixed with oxidising agents
R17 Spontaneous ignition in air
R18 Possible formation of ignitable sasses/explosive gas-air-mixtures
R 19 Can form explosive peroxides
R30 Can become very inflammable in use
R44 Explosive when kept in closed rooms
Part B: Classification of substances and mixtures that have health effects
R20 Dangerous when inhaled
R21 Dangerous through skin contact
R22 Dangerous when swallowed
R23 Toxic when inhaled
R24 Toxic through skin contact
R25 Toxic when swallowed
R 26 Very toxic when inhaled
R 27 Very toxic through skin contact
R 28 Very toxic if swallowed
R29 Develops toxic gas in contact with water
R31 Develops toxic gas in contact with acid
R32 Develops very toxic gas in contact with water
R33 Can accumulate in the body during lasting use

R34 Corrosive

R35 Strong corrosive

R36 Eye irritating

R37 Irritating for respiratory passages

R 38 Skin irritating

R39 Risk for permanent health injuries

R40 Possible danger for health injuries

R41 Risk for serious eye injury

R42 Can give allergic reactions when inhaled

R43 Can give allergy by skin contact

R45 Can cause cancer

R46 Can cause heritable injuries

R48 Serious health injuries from longer time exposure

R49 Can cause cancer when inhaling

R50 Very toxic for water organisms

R51 Toxic for water organisms

R52 Harmful for water organisms

R53 Can cause unwanted long-term effects in water environments

R54 Toxic for plants

R55 toxic for animals

R56 Toxic for organisms living on the soil

R57 Toxic for bees

R58 Can cause unwanted long-term effects in the environment

R59 Harmful for the ozone layer

R60 Can injure the power of reproduction

R61 Can injure the foetus

R62 Can possibly injure the power of reproduction

R63 Possible risk for injuring the foetus

R64 Can injure babies fed mother’s milk

R 65 Can cause injury when swallowed

R215 Possible risk of cancer