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# Toward a Sustainability Indicator for Buildings

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## Abstract

Several approaches have already been made in order to analyze a building over its whole life-cycle, however, due to an inadequate description of the building and/or to poor quality of the material data, the spread of the results is very wide. Therefore, in order to get a better feeling of the relative effect of the different building elements, we have in a first step considered and analyzed, in a very detailed way, a typical residential building. The whole analysis is based on the life cycle assessment method.
The aggregation of the results remains a central question, therefore we have analyzed various approaches, a monetarisation approach, including the internalization of the external costs, looks promising and adapted for the needs of the practice.

## 1. Introduction

The building sector is characterized by substantial material flows (building materials, fluids...) as well as large energy flows (heat, electricity...). Its occupation of land has a notable impact on the environment (parceling out of land reserves, water drainage, disappearance of green spaces etc.) and it entails considerable amounts of polluting emissions.

In most countries, building operation is accountable for 25 to 40 % of the total energy demand, and the energy needed for the production of building elements should be added to this amount. This energy consumption induces considerable amount of emissions ; waste, due to building refurbishment and demolition, also has to be considered, specially when harmful for the environment.

Buildings also have a long lifetime and wrong concepts consequently produce durable damage ; this is why efforts have been made in order to increase the sustainability of the building sector. Our purpose is to contribute to the development of a « sustainability index » appropriate for the building sector. This index should constitute a useful tool in the decision and design phases.

## 2. Building Life Cycle

Following the Life Cycle Assessment method /SETAC 93/, the building has to be considered from its cradle to its grave. A building's life-cycle essentially includes the following phases :

## 2.1. Preceding phases

The preceding phases include all activities outside the system limits of the building itself : These are e.g. the extraction and production of building materials, production of final energy, preparation of transport services and also the treatment of waste. The sum of the environmental burdens along the production chain of these activities contributes indirectly to the total environmental burden of a building.

## 2.2. Construction

The inventory of the construction phase includes all activities up to the moment where the building can be used for its specific purpose. It includes the transport of the materials to the building site. Whether the transport of the workers to the construction site should be counted depends on the fixed system limits. Mostly in LCA the transport of workers to their permanent workplace is not counted.

In addition to the material incorporated in the mass of the building, auxiliary materials such as timber and metal for formwork, scaffolding etc... are also used. Their contribution to the total environmental burden seems rather small and for our purpose it might be appropriate to neglect them. Special care has however to be taken with regard to certain chemicals that are used. Another extra use of material, beside the material that can be found in the building mass, is due to losses and breakage during the construction phase.

For a really complete inventory, the infrastructure at the contractor's head quarters would also have to be inventoried and a proportion would have to be counted as induced by the building. As this is very difficult and the contribution to the total environmental burden is rather small, we tend to neglect it. This is also done in the LCA of most other products.

The energy used on the building site has to be estimated from data on existing building sites. It is difficult to allocate the total energy consumption to the different elements of the building. Further research has to be undertaken in this field. It is probable that just a few machines, such as cranes, consume most of the energy. An allocation proportional to the mass of incorporated materials would be suitable in that case. Special attention has to be paid to energy intensive activities like pumping of ground water to keep it out of excavations.

## 2.3. Operation

The inventory in this phase essentially includes the energy used for heating, air conditioning, hot water preparation, lighting and other technical facilities. We neglect the energy related to daily transportation of inhabitants, even if a considerable amount is used for this purpose, this energy depends very much upon local conditions and people behavior.

Concerning the maintenance, we do not include regular cleaning whereas building refurbishment is considered in the next paragraph.

## 2.4. Maintenance and renovation

The approach is in principle the same as for the construction phase. If we want to predict the whole life cycle of a building, we will have to make predictions on the lifetime of all units of the building structure and their renovation intervals. This inherently involves a large uncertainty as individual lifetimes can differ very much. In our case we adopt the assumptions based on practical observations /AFB 94, AMB 95/.

## 2.5. Demolition

This step is more difficult to estimate. Indeed it is almost impossible to predict the techniques and the requirements which will be valid in almost a century. Therefore, instead of establishing wrong hypotheses, we prefer to confine ourselves to an inventory of the quantities of the various materials which will have to be recycled, or eliminated, at the end of the building lifetime.

## 3. Case study

In order to gather practical and accurate data, a residential building, typical for Swiss standards, has been analyzed in a very detailed way.

Figure 1 « Les Friaudes » General view of the building.

The analysis has been made for the whole building lifetime :

a) For the construction phase, we had access to detailed documents such as tenders, shop drawings, reinforcement bar lists as well as to data related to the building site activities. Most of the data have been checked on site, and discussed with the contractors.

b) For the operation phase, annual heat requirements were calculated and compared with values as measured during the first periods of operation. These values are shown in table 1 which also contains the corresponding standard values according to SIA /SIA 380/1/.

| | Measured (MJ/m2) | Calculated (MJ/m2) | SIA 380/1 (MJ/m2) |
|---|---|---|---|
| Heating | 280 | 269 | 450 |
| Hot water | 40 | | 80 |
| Electricity | 120 | | 100 |
| Total | 440 | | 630 |

Table 1 Energy demand of the « Friaudes » building.

c) For the building maintenance and refurbishment, a detailed list of the interventions required during a lifetime of 80 years has been established. Interventions have been anticipated assuming 5, 10, 15, 20, 30 and 40 year intervals.

d) Table 2 shows the masses of the main building material families per square meter of heated floor area. At the end of the building's lifetime these materials will have to be either recycled or eliminated.

| Materials | kg/m2 |
|---|---|
| Cement-bound materials | 1524 |
| Other mineral materials | 234 |
| Ligneous & organic mat. | 14 |
| Metals | 79 |
| Glass | 3 |
| Insulating materials | 6 |
| Synthetic materials | 19 |
| Diverse | 2 |
| Total | 1881 |

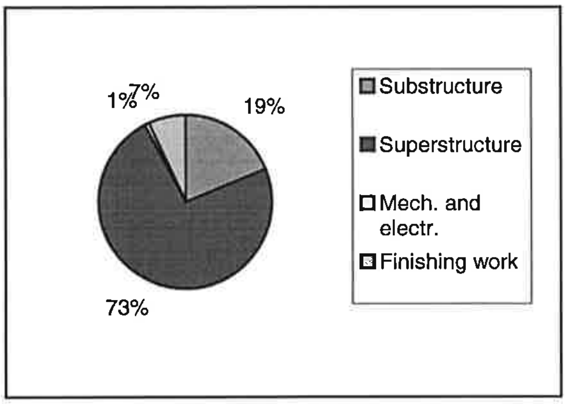


Table 2 Main building material families per m2 of heated floor area.

e) Finally, figures 2 presents the embodied energy for the various building elements and materials.

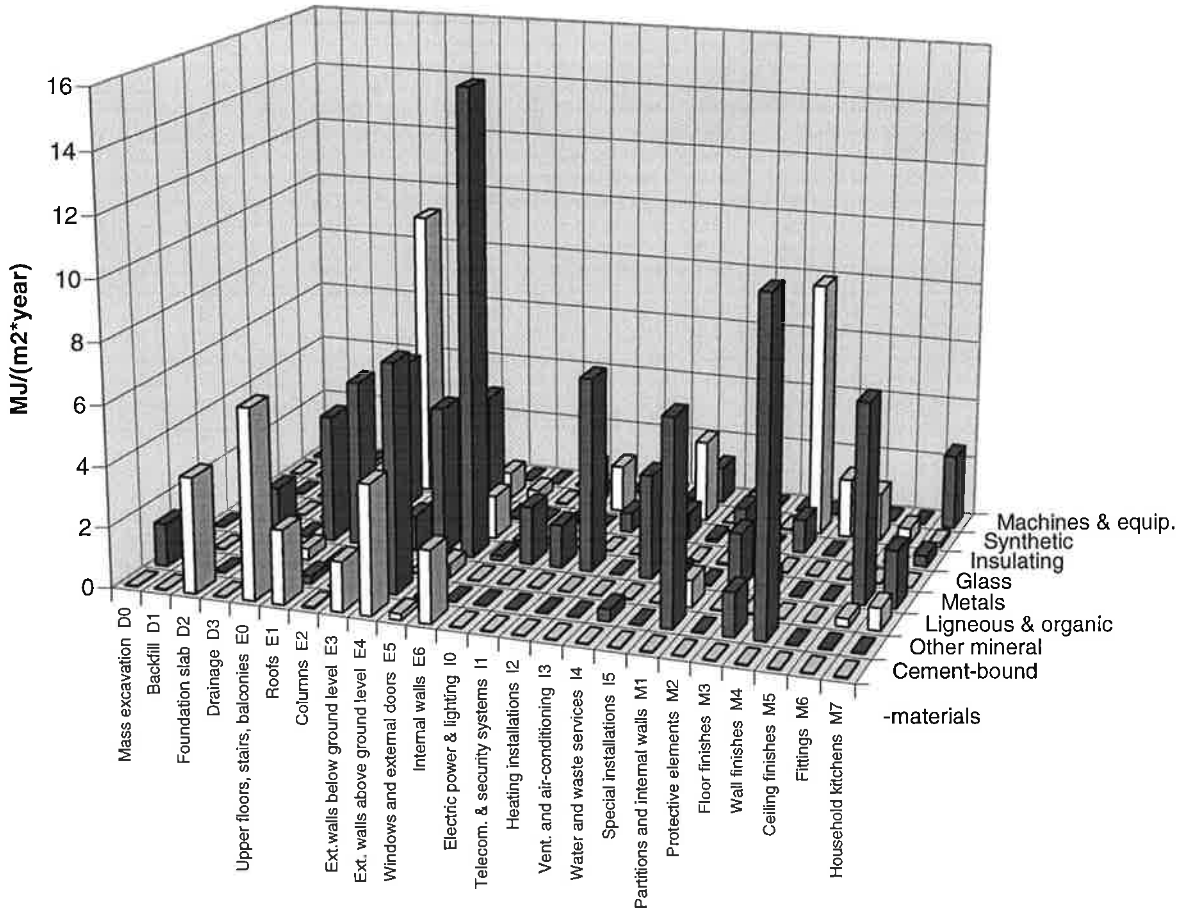


Figure 2 Embodied energy in the various building materials and elements.

## 4. Materials, waste and emissions

When analyzing a building, it would be misleading to consider only energy related aspects. In the context of building sustainability, all environmental aspects should be considered : they affect the air, the water, the soil and the natural livings.

An adequate approach is to follow the life cycle assessment method (LCA), as defined by SETAC /SETAC 93/. This method considers the fifteen factors which have the most impact on our environment. Amongst them, some have a local impact (land use, human toxicity, noise...), while others have a global impact (global warming potential, ozone depletion, resources depletion...).

At the building level, the approach may also be either sector based or global. In the first case, only building elements are considered (walls, slabs, roofs...), in the other case, the whole building has to be evaluated. A further step would be to also consider land use, various networks and local traffic.

## 4.1. Element based approach

The element based approach has been developed as a decision tool for architects : it adds criteria which include ecological aspects when selecting building elements. This approach is rather new in Switzerland, where a corresponding guide has been published, one year ago, by the Swiss Society of Architects and Engineers (SIA) /SIA D0123/. This guide analyses nine key elements of a building (foundations, external walls, slabs, partition walls, roofs), and for each element between 4 and 14 constructive variants are presented and analyzed. In addition to the usual technical data (mass, U-value, sound insulation...), the guide provides specific information about ecological aspects, such as embodied energy, global warming potential, acidification potential, expected lifetime of the element itself and problems related to its elimination. It should be noted that, the outcome of the study will not be the same depending on which of the environmental impact is given priority.

## 4.2. Building based approach

For the considered reference building, an extended analysis has been made using the life cycle assessment method. The whole building lifetime was considered, with the exception of its demolition. Indeed buildings have a long lifetime and it is therefore almost impossible to predict demolition and recycling techniques which will be used almost a century later.

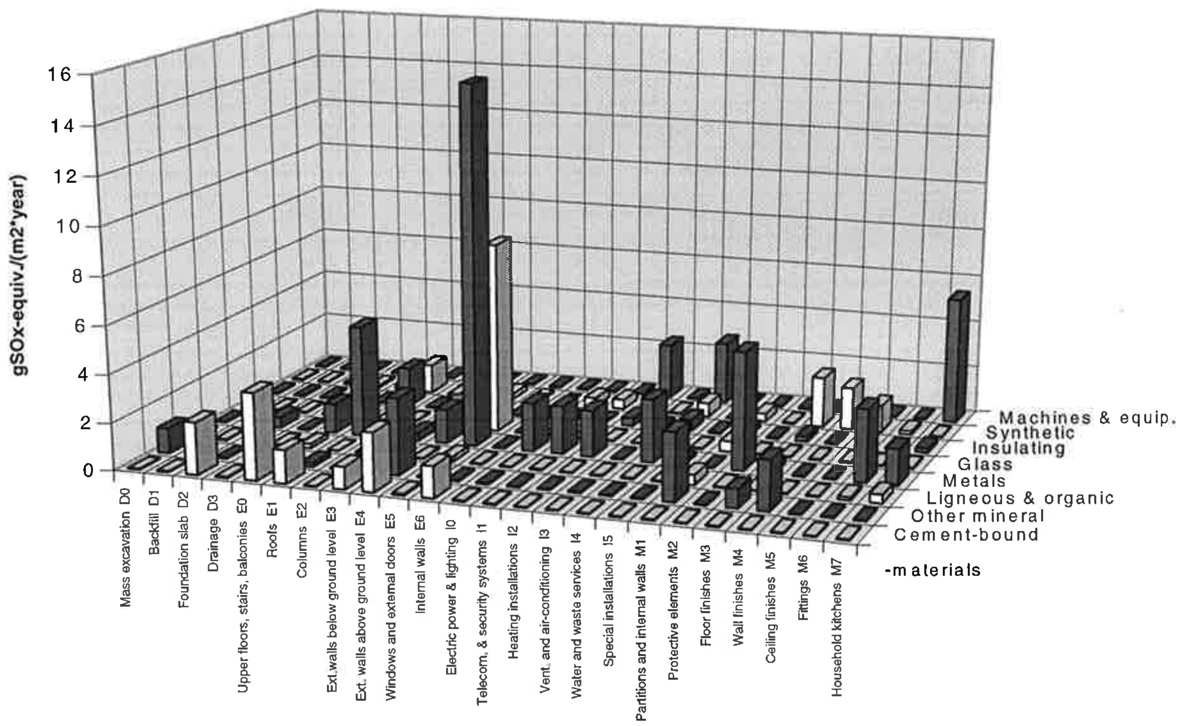


Figure 3 Acidification potential due to the various building elements and components.

The present article cannot discuss all environmental aspects. Therefore, as an illustration, our analysis will be focused on the acidification potential. This parameter is indeed more interesting than the global warming potential, the later being strongly coupled to energy consumption.

Figure 3 presents, for the various building elements and materials, the acidification potential resulting from the construction, the maintenance and the refurbishment of the building. The figure for the acidification potential is rather different from the figure for the embodied energy : when considering the acidification potential a strong contribution is due to extensive use of stainless steel in sheetmetal and other metal works as well as of aluminum in windows.

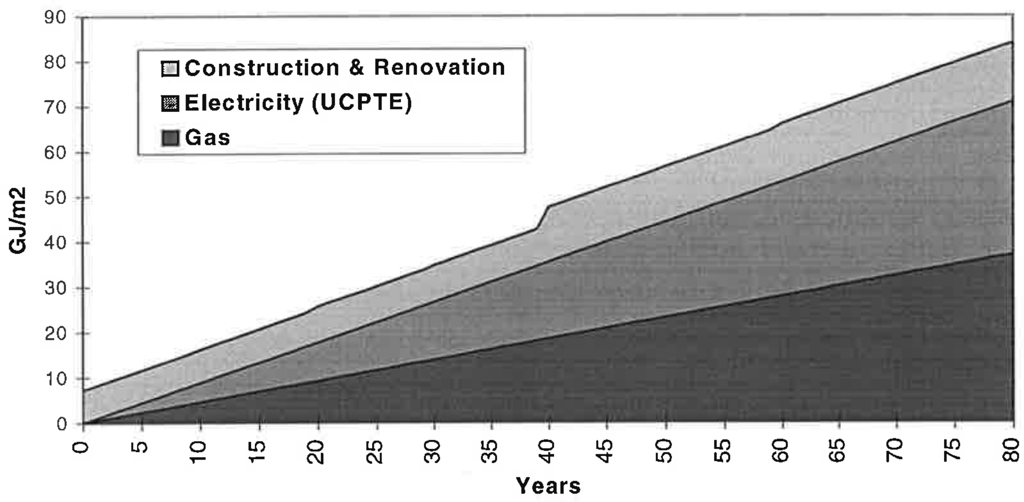


Figure 6 Cumulative energy demand including embodied energy (construction and renovation) and operation energy (electricity and gas).

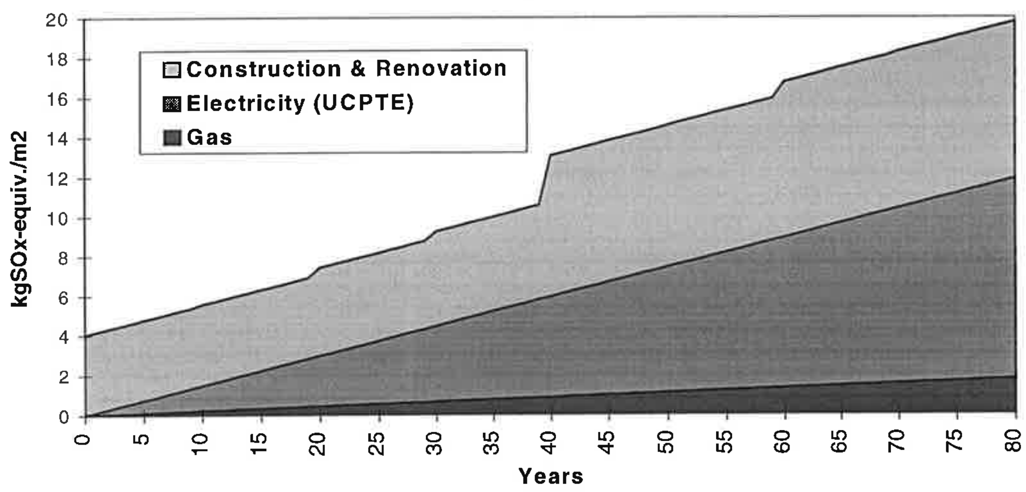


Figure 7 Cumulative acidification potential resulting from the construction, the maintenance and the building operation.

Figures 4 and 5 show the evolution, in time, of the global energy demand (including embodied energy), as well as of the acidification potential. These figures also include building operation. As outlined above, these two figures show different results when considering the energy, or the acidification potential. For the energy, the largest contribution is due to the building operation which, after 80 years, represents 84% of the total. For the acidification potential, the construction part becomes significant : 20% when limiting to the construction phase, twice as much if maintenance and renovation are included. The large contribution of the electricity : 6 times more than the natural gas, should also be pointed out.

## 5. Towards a sustainability indicator

As already mentioned, available approaches are either too limited, when they are focused only on building elements, or too complex, when all building materials and components are considered. Therefore, our study will determine those elements which are relevant in terms of environmental impact and propose target values as well as an adapted operating procedure.

As long as the results of the life cycle assessment contain10 to 15 factors, each characterizing a specific impact, the tool may indeed be complex and therefore practically unusable.

We will therefore have to adopt one of the following solutions :

a) Only consider some factors (up to 3) which are considered as representative of the global effect. This is the option which has been adopted by the SIA /SIA D0123/. This approach is questionable as potentially important effects may be fully neglected.

b) Utilize existing aggregation methods such as « Ecopoints » or « Ecoindicators » /Duijf 93/. However, these methods omit important factors such as resource depletion, energy and land use, as well as production of solid wastes. Moreover, the aggregation procedure is debatable and the final result is expressed in an arbitrary unit.

c) A third solution consist in expressing the effects in terms of external costs. These represent either measurable or calculable costs of direct impacts (health injuries, death of the forest...), or the costs of preventing these.

Even if the monetarization of the external costs is not an easy task, the application of this approach to the building sector has several advantages :

- the final result is expressed in a unit (e.g. $/m2 year) which is familiar to the target public : investors, architects...

- this result, which expresses the sum of external costs, may be added to the conventional construction cost allowing an easy comparison between different alternatives,

- in a later stage, assuming initial information is still available, the results may be updated by inclusion of new knowledge,

- such a procedure could easily be adapted to special conditions and claims,

- external costs, related only to energy consumption, have been determined /INFRAS 96/ and are already used in Switzerland by the Federal Office of Construction as well as by 3 cantons when optimizing HVAC installations for public buildings. In the Netherlands, the Ministry for Housing recently introduced a monetarisation procedure /NIU 96/ which is applied to the evaluation of public constructions.

## 6. Conclusion

The consideration of the environmental aspects of the building is a rather recent concern. It stands, however, to reason when considering the environmental impact of the building sector.

If the first countries which have adopted regulations in this direction, are essentially industrialized countries from the north ; in the future, southern countries, which are characterized by strong growth rates and exploding population, will be confronted with severe environmental problems. Soon, they will need practical tools in order to be able to evaluate and to control the sustainability of the building sector.

At the present time, investigation means exist already. They are, however, too complex either in their application or in their interpretation. Therefore, present research should allow to develop user friendly procedure and tools. In order to reach this goal, three aspects are specially important :

a) A standard and simplified procedure has to be found in order to facilitate the input of the relevant building characteristics.

b) A practical method has to be developed in order to aggregate the whole set of environmental impacts and to express them in an unambiguous form.

c) Existing data banks on building materials and components should be enlarged and updated. Data are in particular required for synthetic materials and for technical installations.

The sustainability indicator, as proposed in this paper, constitutes a step in this direction ; it allows to express most of the environmental impacts in a simple way. Such an aggregation method will, however, evolve either when better data are available, or when new impacts are added. Therefore, the final result should never be limited to a single number in any aggregation procedure. Individual impact data should also be preserved in order to allow future aggregation with other weighting procedures. The method should also be adaptable to other specific conditions such as climate, socio-economy, technology...

In this paper we have only considered the building itself. In a more global approach, other important aspects such as networks and traffic should also be evaluated in terms of impacts ; as they do have a strong impact on the environment.

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