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EVALUATION OF ENVIRONMENTAL IMPACTS OF BUILDINGS WITH LESOSAI 6

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ABSTRACT

This paper focuses on the environmental impacts assessment module recently implemented in an energy balance tool. It describes the data and the methodology used to evaluate these impacts. It is based on a life cycle approach and includes not only the energy consumption during the operation phase, but also the impacts of the contruction materials, from manufacturing to waste disposal. This tool has been used within the framework of a national projet to perform a life cycle assessment of 20 different buildings located in Switzerland. One of these case studies is presented in this paper.

KEYWORDS

Environmental impacts, life cycle impacts assessment, ecobalance.

INTRODUCTION

Buildings generate significant impacts on the environment during their lifespan. These impacts come from the energy consumed during the building occupation and from the materials used for the construction. It is possible to quantify these impacts in order to help optimize choices made during the planning phase.

Currently, new buildings in Switzerland have to be certified according to several standards, among them the SIA 380/1 standard, which calculates the energy demand of the building. This standard is based on the EN ISO 13790. In the framework of a project financed by the Swiss Federal Office of Energy and several Swiss cities and districts, the Laboratory of Solar Energetics and Building Physics (Anon) at the University of Applied Sciences of Western Switzerland (Anon A) has been working on adding an ecobalance module to a popular energy code compliant tool called Lesosai (Anon B). The result of this work is the release of Lesosai 6, which simultaneously provides energy balance as well as environmental impacts assessment. The LCA calculation is compliant with ISO14000 standards as well as to the new Swiss SIA 2032 recommendation in preparation.

ENVIRONMENTAL IMPACTS

Building life cycle

The environmental impacts of a building depend on two major contributions:

- The construction materials
- The energy consumed during the occupation phase

Figure 1 shows the different phases occurring during the building's life cycle.

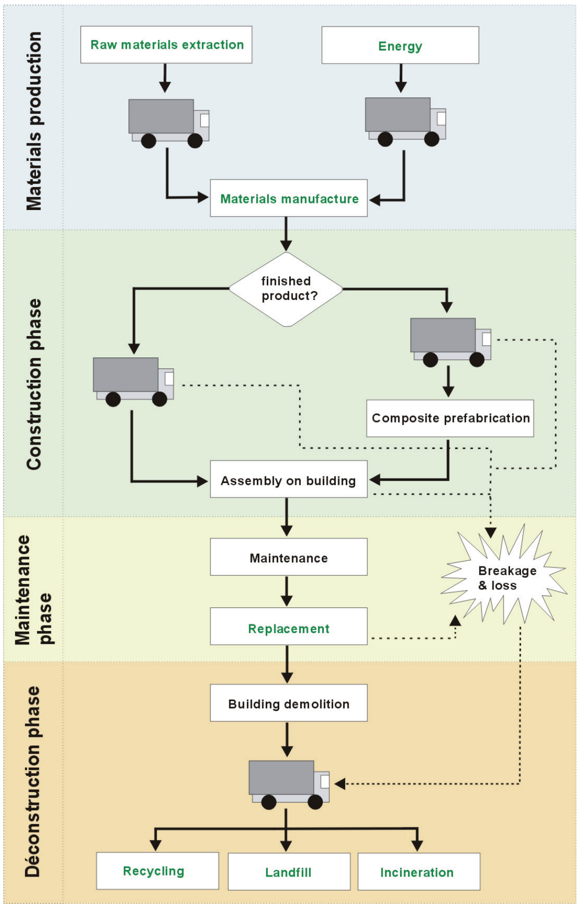

Figure 1 Life cycle of a building

The construction phase consists of raw materials extraction and their transformation into finished products that can be used on the building. A large part of the total impacts of a material comes from this manufacturing process. Materials have then to be transported to the building site. Although our studies have shown that transport impacts can be significant in some cases, they have not been included in this project, mainly because of the European policy in building construction regulations.

The impacts resulting from the building construction and deconstruction are not relevant when compared to the other impacts generated during the building life (Citherlet, 2001). During the occupation phase of the building, some materials have to be replaced, as they have a shorter life span than the building. The replacement materials are also taken into account in the calculation. Their manufacture and elimination impacts have been included.

At the end of the material life, the wastes (replacement materials and building deconstruction) are transported to facilities where they will be recycled, incinerated or buried in a landfill.

The energy consumed during the building occupation also generates environmental impacts. For existing buildings, the impacts related to the energy consumed are usually higher than impacts generated by the building materials. However, for low-energy buildings, it has been shown that the impacts of the construction materials can be similar or even higher than the impacts generated by the energy consumption (Citherlet, Defaux 2004). For such buildings, the reduction of their impacts is therefore connected to the selection of environmentally sound materials.

Impacts indicators

In the national project, it has been decided that the ecobalance module included in Lesosai 6 will display results for three environmental indicators:

Grey energy : Renewable and non-renewable primary energy consumed. It is an indicator of the resources depletion (at a human scale), such as fossil fuels. It is expressed in [MJ].

GWP : Global Warming Potential, which quantifies the emission of greenhouse gases. GWP is not measured in an absolute unity. As each gas has a different impact on the greenhouse effect, their potential is compared to CO_2. For instance, one kilogram of methane (CH_4) is equivalent to 23 kilogram of CO_2. The contributions of each gas can then be added. Results are expressed in [kg-CO_2-eq].

UBP : Umwelt Belastung Punkte. This is an endpoint indicator which takes into account the use of energetic resources, land and water as well as air and soils emissions and waste disposal. This methodology has been developed in Switzerland. UBP is evaluated in "Ecopoints" [pts].

Data

The environmental impacts data used in this project comes from the KBOB LCA recommendations. This is a document published by the Swiss Federal Office of Construction and Real Estate (Anon C). It regroups most of the materials used in the construction domain as well as transport means and energy production installations.

These materials are generic products. Environmental impacts values are given for the manufacture and for the elimination of 1 kg of the material. In the case of windows or doors, impacts values are given by square meter. The impacts of heat and electricity production installations are evaluated by MJ or KWh of useful energy.

This list has been elaborated using the Ecoinvent (Anon D) database, which is one of the most comprehensive in the world. Some materials come directly from Ecoinvent while some others are the results of calculations based on Ecoinvent data. The details of these calculations is not available to the general public.

CALCULATION

This chapter explains how the environmental impacts of a building element are calculated. For each phase, the impacts of the materials contained in each building element have to be added.

Manufacturing

Equation (1) explains how the manufacturing impacts of a construction element are calculated.

$$\overline{EI}_{j,imp}^{manuf} = \sum_{i \in j} \left(\overline{M}_i^{manuf} * IF_{i,imp}^{manuf} \right) \qquad (1)$$

Replacement

The replacements phase takes into account the manufacturing of the replacement materials. These impacts are calculated using equation (2).

$$\overline{EI}_{j,imp}^{replacement} = \sum_{i \in j} \left(Nr_i * \overline{EI}_{i,imp}^{manuf} \right) \qquad (2)$$

The number of times a material has to be replaced depends on its lifespan as well as the the lifespan of the building. Fixed lifespans have been set for each material of the database. This is not ideal as the lifespan of the materials sometimes also depends on where and how they are used. However, such considerations would require a lot of additional information for the user to input. The Laboratory of Solar Energetics and Building Physics is currently working on an update which takes these parameters into account.

Materials will not be replaced unless there is a sufficient number of years left in the building life. It has been assumed that a material will only be replaced when the new material will last at least half its lifespan. Equation (3) evaluates the number of material replacements.

$$Nr_i = Round\left(\frac{ls_i}{ls_{bat}}\right) \qquad (3)$$

Elimination

The elimination impacts of an element are calculated using equation (4). For each material, the data for elimination take into account the transportation to the waste disposal facilities and the elimination processes (recycling, incineration or landfill). In some cases, travel and treatment in a sorting plant is also included.

$$\overline{EI}^{elim}_{j,imp} = \sum_{i \in j} \overline{M_i^{e\lim}} * IF^{e\lim}_{i,imp} \qquad (4)$$

The mass of material eliminated represents the original material and all the replacement materials added to the building during its lifespan.

LESOSAI 6

User Input

Lesosai is a popular tool which is compliant with the SIA 380/1 swiss code. Previous versions of Lesosai were used to get an energy balance of a building in order to aquire the SIA 380/1 certification which is mandatory for every new building project in Switzerland. For this calculation, the user only had to input the characteristics of the building envelope (opaque and transparent elements).

Each building element is a multi-layer construction element created by selecting the materials in a local database. It consists of generic materials as well as a range of products from various manufacturers. In order to get envionmental impact values, these materials have been linked to the materials of the KBOB LCA list. Figure 2 shows the element editor included in Lesosai 6. Each layer is characterized by the material used and its thickness.

Following the approval of the EU directive entitled “Energy Performance of Buildings” (Anon E), Switzerland has examined the possibility of introducing an energy certificate for buildings. This has lead to the creation of the SIA 2031 technical book for which a calculation methodolgy has been developed. It is currently in use on a voluntary basis. It will be under review for a few years before it will be introduced into the swiss legislation.

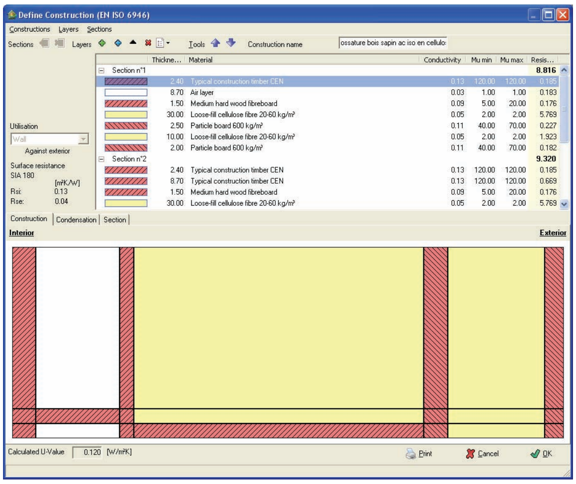

Figure 2: Element editor

The calculation require the input of all internal walls and floors. The energy consumptions and the technical installations used for heating, domestic hot water or cooling have to be described. Ventilation, lightning and other electrical equipment also have to be detailed. Solar thermal capacitors and photovoltaic panels can be added to decrease energy consumption.

The graphical user interface of Lesosai 6 has been enhenced to allow input of all these new parameters. The additionnal information is welcome from an LCA point of view. It is now possible to perform a comprehensive environmental analysis of buildings, including all energy consummers (heating, domestic hot water, cooling, ventilation, lighting, electrical equipment) .

The user also has to define other parameters such as the excavation volume, the heated floor area and the total floor area.

Life span

The lifespan of the building has to be specified in order to calculate the impacts of the energy consumption as well as the impacts of replacement materials. The lifespan of a building can vary depending on the type of the building and its context of use. Lifespans from 50 to 100 years are generally used for life cycle assessments [Erlandsson, 2003]. In Lesosai 6, the user can set the lifespan value before performing an assessment. A lifespan of 60 years has been used for the case studies. The lifespans of the materials are fixed values which are set in the database.

Displaying the results

Lesosai 6 is distributed with a free standard LCA module which displays the building global results as shown in Figure 3. Impacts related to the materials are evaluated for the three main phases of the life cycle (manufacturing, replacement and elimination) and can be compared to the impacts of the energy consumption and the excavation. Numerical and graphical results are provided.

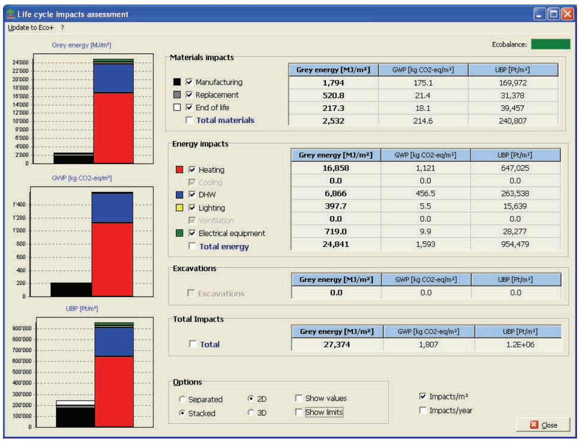

Figure 3: LCA module

In order to get detailed results, the user can install an advanced module named ECO+ (Anon F). This module provides graphical tools to compare building elements and materials. These additional features make materials optimization much easier.

CASE STUDIES

The methodology has been applied to twenty Swiss buildings which have very different characteristics. This has enabled us to establish a scale and set target values for environmentally-sound buildings in Switzerland. The results obtained for one of these case studies will be presented in order to illustrate the features of the ECO+ module.

Short description of the Building

The building used as an example is a three-storey office building which has been designed to have low energy consumption. An important effort has also been made with the choice of environmentally-sound construction materials that have low amount of grey energy.

Apart from the foundations and the basement walls which are made of concrete, the whole building is made of wood (walls, floors, roof, window frames and doors). In order to get good energetic performance, the building has been well insulated using mainly cellulose fibres. Coatings are made of eco-friendly materials such as clay plaster or natural paints.

A ground heating system with a wood pellets boiler is used. Solar thermal collectors have been installed to provide heat for the domestic hot water. The supplementary energy required comes from the pellets system. Low-consumption light bulbs coupled with movement detectors have been installed in an effort to minimize the electricity used for lighting.

Results

Figure 4 shows a screenshot of the main form provided by the ECO+ module. For each of the three indicators, the impacts of the whole building (energy + materials) are displayed on a chart. This form can be cutomized to display the required types of impacts in a number of different ways (stacked and separated bars, pie charts). Numerical and graphical results are provided by clicking on the respective tabs.

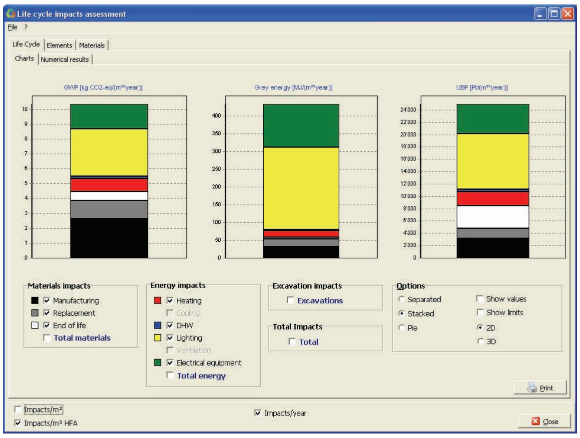

Figure 4: ECO+ global results

Compared to the standard module, ECO+ has additional features to refine the results related to the elements and materials of the building. For instance, the "Elements" tab presented in figure 5 shows the total impacts of the elements defined in the project.

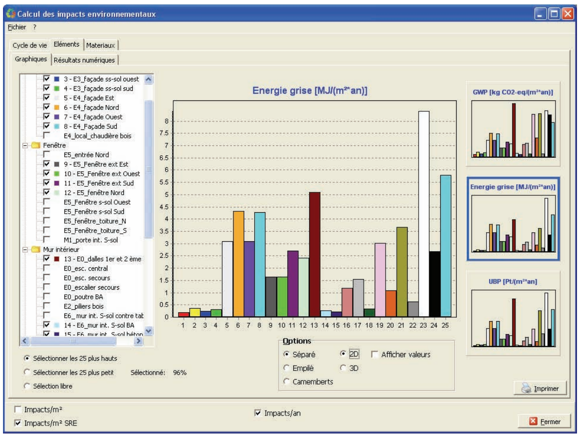

Figure 5: elements comparison

All building elements are classified by element type (external walls, roof, windows, etc.) and can be selected in the list on the left hand side of the form to have their impacts displayed on the charts. It is also possible to automatically select the 25 elements that have the highest or the lowest impacts.

The three little charts on the right hand side of the form are related to the three indicators (Grey energy, GWP and UBP). Clicking on one of them opens a bigger version of the chart on the centre of the screen. Analysing the impacts by elements allow to rapidly spot the building component(s) that should be analysed in first place in a building optimization.

It is also possible to display the impacts of the construction materials used in the building, independently of their use in one or several elements. Figure 6 illustrates this possibility.

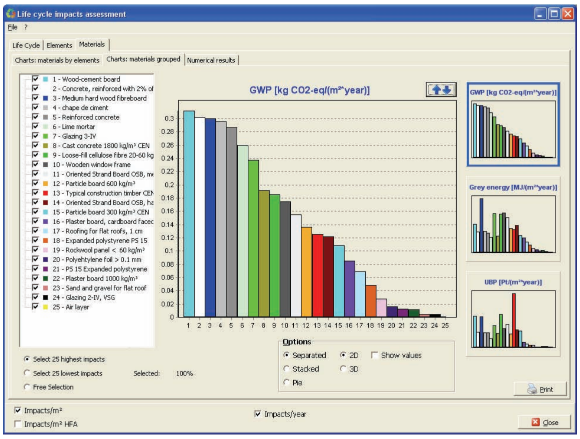

Figure 6: materials comparison

The user can sort materials by any of the three impacts indicators and instantly see on which materials an effort could be made to improve the environmental performance of the building.

CONCLUSION

This paper has presented the ecobalance module implemented in Lesosai 6, a code compliant tool for energy balance in Switzerland. The ecobalance includes the energy consumption and the material manufacturing, replacement and elimination used during the whole building life span.

Two versions of this module have been developed. The standard module ECO, which gives a synthetic display of the ecoblance results of the building, and the advanced ECO+ module, which displays much more details at elements and materials levels.

The addition of the ECO and ECO+ modules in Lesosai now offers a tool which can perform simultaneously a comprehensive ecobalance assessment of a building from an energetic and ecological point of view.

Some improvements still have to be made to be able to assess the impacts of all Lesosai materials. For some entries of the Lesosai database, it was impossible to find a matching material in the KBOB list. Some wishes have been expressed about the addition of new materials and hopefully these will be included in the next release of the document. While the materials data can be applied to most European counties, the KBOB list currently only offers the Swiss and UCTE electricity mix. To be able to use this tool in other countries, their respective mix will have to be added.

The management of materials replacements can still be improved. Fixed lifespans are currently used for each material, which is not realistic. We are already working on a new method which takes into account the type of element that contains the material as well as the position of the material inside the element. The only downside is that the user will have to input additional parameters which will make the whole input process a bit longer.

A later version of the ECO+ module will allow the user to transfer the building data to LCIA software Eco-Bat 3.0 (Anon G), which will be release in 2009. Eco-Bat is a user-friendly tool developed to assess the building ecobalance at design stage. This will provide the user with a gateway to obtain very detailed results as well as additional functionalities such as buildings comparison or impacts yearly evolution. The user will also have to possibility to precisely describe materials transports and to take them into account in the evaluation.

NOMENCLATURE

j	Building element identifier
i	Material identifier in the element *j*
imp	Impact indicator (NRE, GWP, etc).
$\overline{EI}^{manuf}_{j,imp}$	Impact value of indicator *imp* generated by the manufacturing of element *j*
$\overline{EI}^{replacement}_{j,imp}$	Impact value of indicator *imp* generated by the replacement of materials inside element *j*
$\overline{EI}^{e\lim}_{j,imp}$	Impact value of indicator *imp* generated by the elimination of element *j*
$IF^{manuf}_{i,imp}$	Impact value of indicator *imp* generated by the manufacture of 1 kg of material *i* [impact/kg]
$IF^{e\lim}_{i,imp}$	Impact value of indicator *imp* generated by the elimination of 1 kg of material *i* [impact/kg].
ls_i	Lifespan of material *i* [years]
ls_{bat}	Building lifespan [years]

$\overline{M}_i^{manuf}$ — Mass of material i manufactured [kg]. Takes into account all losses occuring during transport and assembly.

$\overline{M}_i^{e\lim}$ — Mass of material i to be eliminated [kg]. Includes the original material manufactured as well as all the replacement materials.

Nr_i — Number of times material i has to be replaced during the building lifespan.

$Round(v)$ — Function that takes a floating point number as parameter v and returns the closest integer value

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