COMPARING ENVIRONMENTAL IMPACTS OF BUILDINGS WITH ECO-BAT

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ABSTRACT

This paper presents the features of Eco-Bat, a computer program developed to assess the environmental impacts of buildings, including construction materials and energy consumed, during its life cycle.

The methodology used to evaluate environmental impacts based on a life cycle assessment (LCA) approach, compatible with ISO 14040 standards, is detailed. The data are mainly extracted from Ecoinvent (Anon A).

Two applications are presented to illustrate the possibilities offered by Eco-Bat. The first one is a comparison of different variants of building facades. The second example shows the analysis of a whole building including its energy consumption.

KEYWORDS

Environmental impacts, life cycle impacts assessment, ecobalance.

INTRODUCTION

For low-energy buildings, the environmental impacts due to energy consumption are of the same order of magnitude as the impacts generated by the construction materials during the building life span. Therefore, the reduction of environmental impacts on low-energy buildings should not only focus on the reduction of its energy consumption but also on the use of environmental-friendly construction materials.

Unfortunately, the calculation of these impacts is a long and painful exercise. Therefore, it is important for planners, architects and engineers, as well as students, to have access to a user-friendly tool that can perform a detailed assessment of the environmental impacts of buildings.

A new computer program, named Eco-Bat (Anon), has been developed at the Laboratory of Solar Energetics and Building Physics (Anon C) at the University of Applied Sciences Western Switzerland (Anon B). Eco-Bat allows evaluating the environmental impacts generated by a building or part of it during its life cycle.

ENVIRONMENTAL IMPACTS

Building life cycle

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

- The construction materials
- The energy consumption (use phase)

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

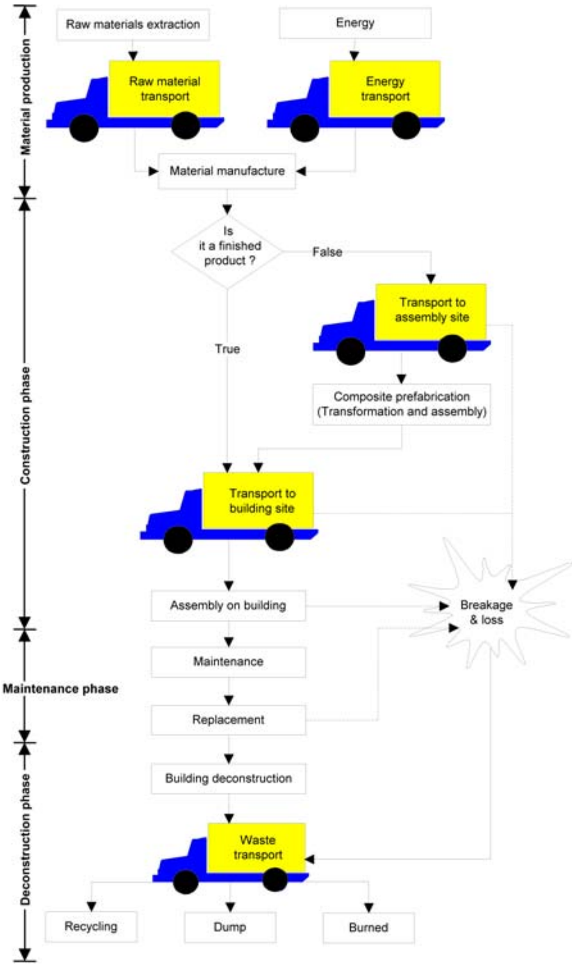

Figure 1 Life cycle of a building

Each stage of the building life cycle represented on *Figure 1* has a negative effect on the environment.

The construction phase consists of raw material 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 the manufacturing processes. Most materials are then transported directly to the building site. Some pre-fabricated elements (window frames for instance) have to go through an assembly process and therefore have to be transported to a specialized facility before to be send to the building site. Environmental impacts related to the transportation can change depending on the construction site and the factories locations. Eco-Bat makes the assumption that the construction site is in Switzerland. Average distances are used for inland-found materials as well as imported ones. As the transport impacts account for a small percentage of the total impacts of a material, this approximation is adequate.

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 use 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 fabrication, transport 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.

For each material, information such as life span, transport distances, vehicles used and elimination rates is stored in the Eco-Bat database. It has been obtained through practitioners and cannot be modified by the user without special access.

The energy (heating, cooling, domestic hot water, lighting, electricity for equipments) consumed during the building occupation also generates environmental impacts. For standard buildings, the environmental impacts related to the energy consumed are much higher than the 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. Eco-Bat has been developed to help designers to optimise the building's environmental performances.

Impacts indicators

Currently, Eco-Bat uses the following four environmental indicators which are compliant with the well accepted CML classifications.

NRE : Non-Renewable Energy, which represents the non-renewable primary energy consumed. It is an indicator of the depletion of non-renewable sources (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. We can then add the contribution of each gas. Results are expressed in [kg-CO_2-eq].

AP : Acidification Potential. Gas emissions that contribute to acidification. For instance, SO_2 or NH_3, mix with water molecules in the atmosphere to create acids. The effects can affect water, vegetation and living species. AP is given in [kg SO_x-eq].

POCP : Photochemical Ozone Potential. Some substances contribute to photochemical ozone production. Ozone has oxidizing properties and can lead to breathing problems or irritations on human beings. POCP is compared to ethylene and is expressed in [kg C_2H_4 –eq].

Building life span

Each material has its own life span. Some, like concrete will last until the building is decommissioned. Some others, like mineral wool insulation, will have to be replaced after a number of years. Eco-Bat takes the material life span into account. Therefore, the number of material replacements will depend on the building's life span. The latter can easily be changed which allows to quickly assess its effects on the results.

In order to illustrate the possibilities offered by Eco-Bat, two application examples are presented hereafter. The first one details the comparison of 4 variants of building facades. The second one presents the analysis of a whole building, including construction materials and energy consumed during its life cycle.

EXAMPLE A: BUILDING ELEMENT

This section presents the analysis of three different variants of a light weight building facade and a heavy weight element (brick). We also made the assumption that they will be integrated into a building whose life span is estimated to be 50 years.

Description of a building element

In order to evaluate the environmental impacts of a construction element in Eco-Bat, the user has to define its composition as a multi-layer construction.

First, the user has to give the element surface area. Then, for each layer of the construction element, the material used has to be selected in a list and the layer thickness has to be specified.

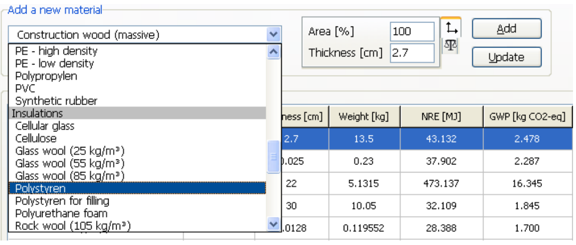

Figure 2 Description of a building element

Variant 1 (Brick)

Variant 1 is a heavy weight envelope element. It has a structure made of terra cotta bricks with external polystyrene insulation. Its composition is given in *Table 1*.

Table 1 Variant 1 composition

MATERIAL	AREA [m^2]	THICKNESS [cm]
Internal roughcast	1.0	1
Clay brick	1.0	15
Polystyrene	1.0	22
External roughcast	1.0	2

Variant 2, 3, and 4: Identical layers

Variants 2, 3 and 4, have the same light structure, made of wood and are insulated with glass wool (25 kg/m^3) including an air-tight layer and a vapour barrier in polyethylene. The external layer is different on each variant. However, in each case it is fastened with nine stainless steel screws per m^2. Each screw weights 31.5 grammes.

Variant 2 (wood)

The outer surface in variant 2 is made of small wooden beams of different cross sections (average 5 cm). These elements are placed horizontally and are painted with three layers of varnish on each side before assembly.

Table 2 Variant 2 composition.

MATERIAL	AREA [m^2]	THICKNESS [cm]	WEIGHT [kg]
Acrylic varnish	5.83	0.012	-
Wood (average)	1.0	5	-
Screws	-	-	0.2835
Rain barrier	1.0	0.0128	-
Glass wool	0.933	22	-
Massive wood	0.067	30	-
Vapour barrier	1.0	0.025	-
Wood panel	1	2.7	-

We assumed that every 12 years, 2 layers are applied on the external surface during the refurbishment process. *Table 2* summarises the construction materials used in Variant 2.

Variant 3 (flat fibre panel)

The outer layer of variant 3 is a flat panel made of fibreglass reinforced plastic with a polyester resin. The manufacturer has provided the basic data (composition, density, dimensions, etc.). A transportation distance of 600 km between the panel factory and the building site has been used. *Table 3* gives the composition of this variant 3.

Table 3 Variant 3 composition

MATERIAL	AREA [m^2]	THICKNESS [cm]	WEIGHT [kg]
Fibreglass panel	1.0	0.5	-
Screws	-	-	0.2835
Rain barrier	1.0	0.0128	-
Glass wool	0.933	22	-
Massive wood	0.067	30	-
Vapour barrier	1.0	0.025	-
Wood panel	1	2.7	-

Variant 4 (corrugated fibre panel)

The outer surface of variant 4 is made of the same fibreglass panel as variant 3. But in the latter, the panel is flat, while in variant 4 the panel is corrugated and, for the same rigidity, has a lower thickness. Its composition is given in *Table 4*.

Table 4 Variant 4 composition.

MATERIAL	AREA [m^2]	THICKNESS [cm]	WEIGHT [kg]
Fibreglass panel	1.0	0.186	-
Screws	-	-	0.2835
Rain barrier	1.0	0.0128	-
Glass wool	0.933	22	-
Massive wood	0.067	30	-
Vapour barrier	1.0	0.025	-
Wood panel	1	2.7	-

Results

Eco-Bat allows displaying many results. Hereafter, only some of the diagrams relevant for the analysed case study are shown. These figures are extracted from the results forms generated by Eco-Bat.

Figure 3 shows the total environmental impacts for each variant over 50 years. For all four indicators, the heavy weight variant shows the highest impacts. It can also be seen that the flat fibreglass panel (variant 3) always has higher impacts than the corrugated panel (variant 4). This result is related to the fact that the flat panel has a higher mass per unit area. Thus, for each phase of the panel life cycle (fabrication, transport, elimination), more impacts will be generated.

Eléments	NRE [MJ]	GWP [kg CO2-eq]	AP [kg C2H4-eq]	POCP [kg SOx-eq]
Variant 1 - Brick	1'758.935	104.659	0.415	0.067
Variant 2 - Wood	884.140	44.745	0.190	0.013
Variant 3 - Fiber flat	1'299.172	80.860	0.293	0.015
Variant 4 - Fiber undulated	900.309	47.465	0.192	0.011

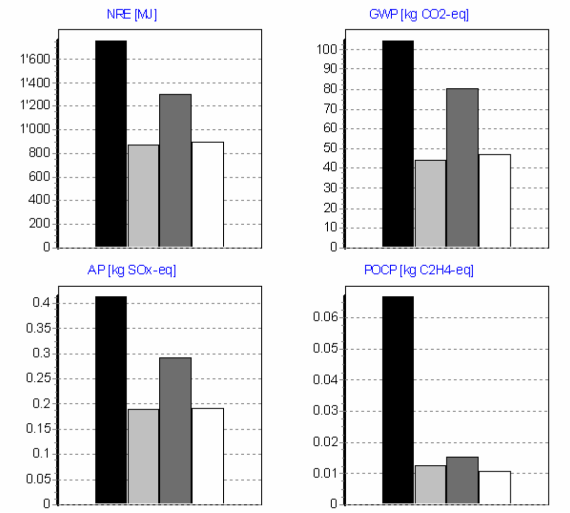

Figure 3 Variants comparisons

Figure 4 shows impacts related to each major phase of the life cycle of variant 4. The construction phase (black area) which includes the manufacturing process is predominant. However, the GWP shows a high elimination contribution due to the incineration of the fibreglass panel. This is also the case for variant 3.

Phases	NRE [MJ]	GWP [kg CO2-eq]	AP [kg C2H4-eq]	POCP [kg SOx-eq]
Construction	584.052	27.298	0.131	0.008
Replacement	295.064	10.474	0.053	0.003
Elimination	21.201	9.692	0.008	0.000

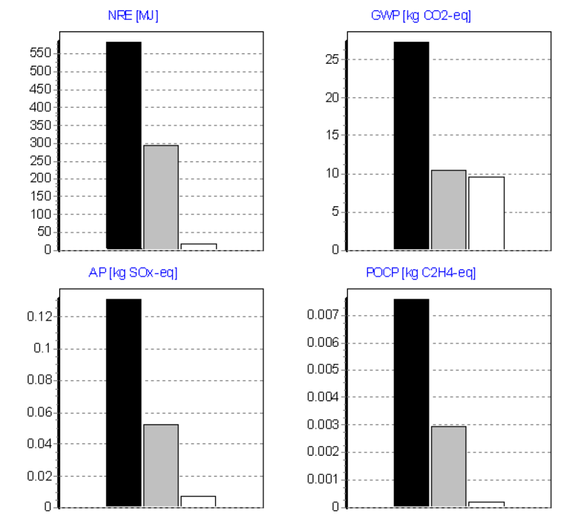

Figure 4 Variant 4: phases comparison

Variant 1 (brick) has the highest environmental impacts. Among the materials, terra cotta bricks and roughcast have a great influence on the results, as the energy consumed to manufacture these two materials is high.

A priori, variant 2 would have been intuitively the best solution, as it is based on wood material. Despite the fact that the wood is protected by an acrylic varnish, the impacts are very close to those of the corrugated fibreglass panel. NRE, GWP and AP impacts are slightly lower and POCP is slightly higher. *Figure 5* shows the analysis of material impacts inside the wood variant. These impacts are stacked on the charts to show which proportion of the element total impacts they account for.

Materials	NRE [MJ]	GWP [kg CO2-eq]	AP [kg C2H4-eq]	POCP [kg SOx-eq]
Construction wood	43.132	2.478	0.015	0.001
Vapour barrier PE	37.902	2.287	0.007	0.000
Glass wool (25 kg/m^3)	473.137	16.345	0.075	0.005
Construction wood	32.109	1.845	0.011	0.001
Polypropylen	28.388	1.700	0.008	0.000
Construction wood	79.874	4.589	0.028	0.002
Acrylic varnish	140.256	12.472	0.030	0.002
Stainless steel	49.380	3.027	0.017	0.001

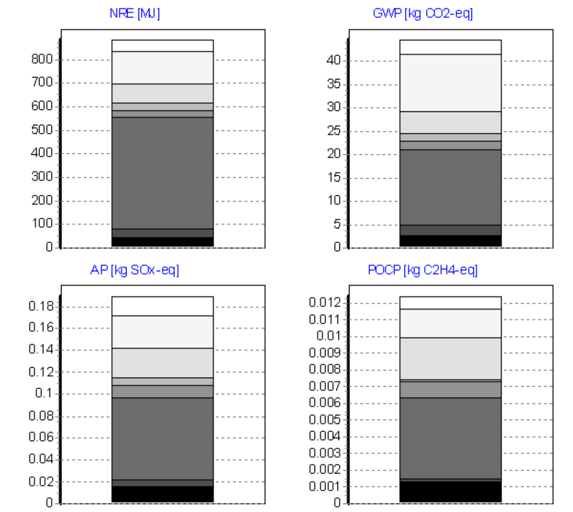

Figure 5 Variant 2 at material levels

Some materials, such as the glass wool insulation, have a relatively high contribution as they are replaced several times during the building life span. In this example it accounts for half of the element NRE and more than a third of all other impacts. In an environmental impact assessment of construction materials, it is important to take into account the replacements. If the impacts are calculated only with the materials initially on the building, it can lead to erroneous results.

Figure 5 also shows the varnish's importance. It participates to approximately 30% of the GWP and 15% of the NRE, AP and POCP. We could reduce the impacts by increasing the time between each refurbishment or by applying fewer layers each time. However, such measures would not guarantee the element's durability. Therefore, it would be better to use a more ecological kind of paint.

EXEMPLE B: A WHOLE BUILDING

The previous example has shown how Eco-Bat can be used to compare material variants of an element. But Eco-Bat was initially designed to analyse the environmental impacts of a whole building during its life cycle, including the construction materials and the energy consumption.

In order to achieve this goal, the user needs only to define:

- The construction elements (as explained in example A).
- The energy consumption and the corresponding energy vector for each consumer (*Figure 7*). The energy consumption can be given either in absolute value (MJ or kWh) or in relative value (MJ/m² or kWh/m²). In that case, the building heated area has to be set by the user.

The flexibility of Eco-Bat also allows the user to add any other object in his project. For instance, sinks or bath tubes can be defined by selecting the corresponding material type and by giving the material mass.

The time required to define a whole building depends on its complexity. As an example, for a family house, it takes only a few minutes to create the project, assuming that all the data are known. This rapid building description process is well suited for educational and for consultancy purpose.

For a whole building, the results can be displayed in various formats, such as:

- by construction materials
- by building elements (roof, facade, etc.)

The impacts of the construction materials can also be compared to the impacts of the energy consumption (*Figure 6*).

Phases	NRE [MJ]	GWP [kg CO2-eq]	AP [kg C2H4-eq]	POCP [kg SOx-eq]
Construction	17'356'007.400	1'554'871.310	4'901.182	401.855
Replacement	12'062'150.500	749'546.168	2'994.779	214.651
Elimination	3'012'549.620	327'186.076	996.385	29.757
Heating	24'034'378.600	1'403'077.920	1'418.891	169.410
DHW	5'880'900.000	339'264.000	372.384	40.714
Lighting	19'226'900.000	333'106.667	1'078.887	34.097
Electr. equipment	8'240'100.000	142'760.000	462.380	14.613

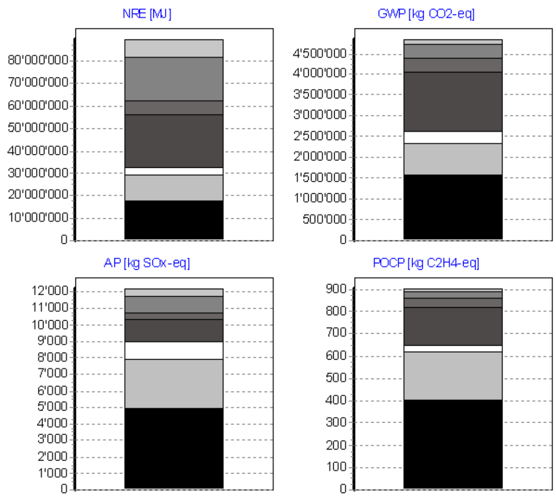

Figure 6 Results comparing materials and energy.

These different possibilities of displaying the results help to point out which are the materials, elements or energy consumers with the highest environmental impacts.

Comparing the relative contribution of the construction materials vs. the energy consumption, allows determining where the effort must be put to reduce the environmental impacts of a building. It has been shown (Citherlet 2004) that construction materials can have higher environmental impacts than the energy consumed, depending on the energy vector used (oil, wood pellets, etc.), energy consumption and the building location. This latest has an influence on the environmental impacts of the electricity.

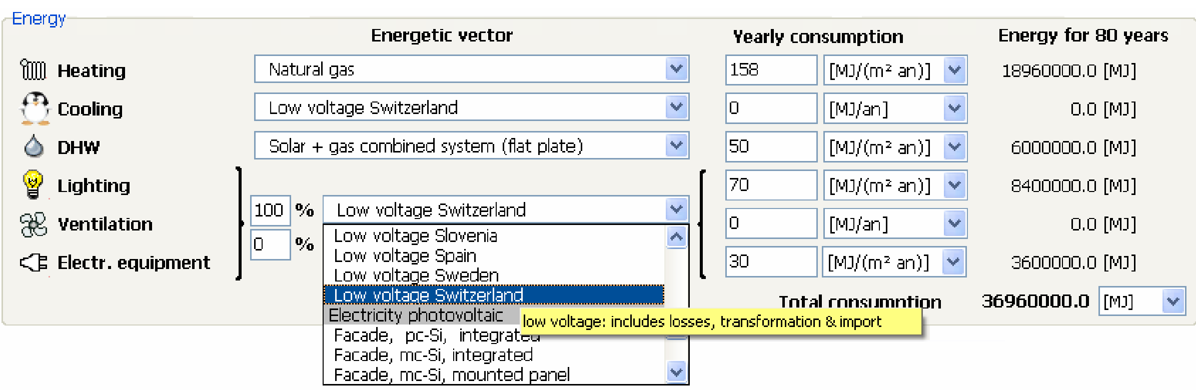

Figure 7 Energy consumption input

Therefore, Eco-Bat provides electricity data for all European countries, which include local production mix with electricity importation. It also provides the electricity data for the UCTE-mix (average of European countries).

Eco-Bat also provides data for many other energy production systems, such as:

- Fossil fuels (various oil and gas system)
- Heat pumps (various)
- Wood (logs and pellets)
- Solar thermal and Solar photovoltaic

Therefore, it is very convenient to evaluate the environmental impacts of different heating systems.

CONCLUSION

Eco-Bat is a computer tool used to calculate the building's environmental impacts, including construction materials and energy consumed during its life cycle. Complete building or single element analysis can be performed.

Around 60 construction materials (minerals, metals, plastics, insulations, etc.) are available. The impacts data come from the ECOINVENT (Anon A) database and additional information, such as transport distances and elimination rates, has been obtained through practitioners.

To evaluate impacts related to energy consumption, the user must define the energy vector used as well as the consumption for each category (domestic hot water, heating, ventilation, lighting, cooling, and electrical equipment).

Detailed results analysis is available at different levels: the building, the elements and the materials as well as the energy consumed.

Currently Eco-Bat is used by architects, engineers, students and practitioners. Its user-friendly, multi-lingual (English, French and Italian) interface and its graphical representation allow a quick comparison of building elements or a whole building. Therefore, identifying materials, or energy consumers responsible of generating high impacts, is an easy task with Eco-Bat.

The next developments will be:

- to include the Swiss label for eco-buildings
- to add new indicators (EPS, Eco-indicator, etc.)
- to develop the concept for refurbishment
- to add a German interface (soon)

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