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, eco-balance.

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 lifespan. 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 environmentally 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.
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 prefabricated 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 CO₂. For instance, one kilogram of methane (CH₄) is equivalent to 23 kilogram of CO₂. We can then add the contribution of each gas. Results are expressed in [kg-CO₂-eq].

**AP**: Acidification Potential. Gas emissions that contribute to acidification. For instance, SO₂ or NH₃ mix with water molecules in the atmosphere to create acids. The effects can affect water, vegetation and living species. AP is given in [kg SOₓ-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 C₂H₄ –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

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>AREA [m²]</th>
<th>THICKNESS [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal roughcast</td>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td>Clay brick</td>
<td>1.0</td>
<td>15</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>1.0</td>
<td>22</td>
</tr>
<tr>
<td>External roughcast</td>
<td>1.0</td>
<td>2</td>
</tr>
</tbody>
</table>

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/m³) 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 m². Each screw weighs 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

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>AREA [m²]</th>
<th>THICKNESS [cm]</th>
<th>WEIGHT [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic varnish</td>
<td>5.83</td>
<td>0.012</td>
<td>-</td>
</tr>
<tr>
<td>Wood (average)</td>
<td>1.0</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Screws</td>
<td>-</td>
<td>-</td>
<td>0.2835</td>
</tr>
<tr>
<td>Rain barrier</td>
<td>1.0</td>
<td>0.0128</td>
<td>-</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.933</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>Massive wood</td>
<td>0.067</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>Vapour barrier</td>
<td>1.0</td>
<td>0.025</td>
<td>-</td>
</tr>
<tr>
<td>Wood panel</td>
<td>1</td>
<td>2.7</td>
<td>-</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>AREA [m²]</th>
<th>THICKNESS [cm]</th>
<th>WEIGHT [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibreglass panel</td>
<td>1.0</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Screws</td>
<td>-</td>
<td>-</td>
<td>0.2835</td>
</tr>
<tr>
<td>Rain barrier</td>
<td>1.0</td>
<td>0.0128</td>
<td>-</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.933</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>Massive wood</td>
<td>0.067</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>Vapour barrier</td>
<td>1.0</td>
<td>0.025</td>
<td>-</td>
</tr>
<tr>
<td>Wood panel</td>
<td>1</td>
<td>2.7</td>
<td>-</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>AREA [m²]</th>
<th>THICKNESS [cm]</th>
<th>WEIGHT [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibreglass panel</td>
<td>1.0</td>
<td>0.186</td>
<td>-</td>
</tr>
<tr>
<td>Screws</td>
<td>-</td>
<td>-</td>
<td>0.2835</td>
</tr>
<tr>
<td>Rain barrier</td>
<td>1.0</td>
<td>0.0128</td>
<td>-</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.933</td>
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<td>Massive wood</td>
<td>0.067</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>Vapour barrier</td>
<td>1.0</td>
<td>0.025</td>
<td>-</td>
</tr>
<tr>
<td>Wood panel</td>
<td>1</td>
<td>2.7</td>
<td>-</td>
</tr>
</tbody>
</table>

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.
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 fiberglass panel. This is also the case for variant 3.

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 fiberglass 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 total impacts they account for.

Figure 4: Variants comparisons

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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).

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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.
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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