Environmentally-conscious design and life cycle assessment

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Abstract

The use of Life Cycle Assessment (LCA) for materials/product design is raising in relevance also at European building industry level. The possibility to investigate the environmental burden of materials and products for building construction, either for civil or industrial use, is a practice that can help the designer in the selection of solutions able to provide lower environmental impacts during construction and use phase. Taking into account the wide availability of different materials, their selection in the case of buildings is a particularly difficult performance issue because a single building results from the combination of many possibilities. First of all the designer has to select functions that can be realised with the use of different materials and this constitutes the basis for the application of the LCA methodology, with particular regard to the comparison and simulation stage. The passage from a subjective choice of ecological materials, based on the perception of natural characteristics, to an objective identification and absolute measure of environmental burden, linked to the specific material production in a life-cycle perspective, constitutes the main feature of the revised bio-architectural approach that foresee sustainability as a key element for a successful project. This paper reports the application of eco-design methodology to an Eco-Industrial Park (EIP) situated in a rural area in the North-West of Italy for which a project has been financed by the European Commission (CRAFT 1999-70125; 2001-2003).

1 Introduction

The project “Optimisation of Resource use and waste Management in an Eco Industrial Park” (ORMA), financed by the EC for the period 2001-2003, aims to develop the concept of sustainable development in the construction and management of an Eco Industrial Park (EIP) which will be located in the northern part of Italy. The choice of eco-materials and related technical solutions is the specific goal of the first part of the project that will be here briefly presented. The preliminary design of the eco-campus foresees the analysis from an environmental life cycle perspective of the production of all the materials involved in the project and a classification from an eco-efficiency point of view. All technical solutions (“technical packages”) have been outlined in co-operation with the EIP designer in order to propose different options of building materials which have the same function, thus allowing the designer to select from a set of environmentally-conscious alternatives. The point is to move from an environmentally-friendly personal perception of the designer to the identification of the objective information concerning eco-efficient material performance for the selected candidate materials and processes.
As a consequence of these activities, an eco-design software tool is going to be implemented on the basis of Cambridge Engineering Selector (CES) system to provide designers with a standardised and automatic method of selecting materials and processes on the basis of their technical and environmental properties.

2 The approach to the project

Building materials initially chosen by the EIP designer have been catalogued and the LCA approach has supported the definition of a set of information cards (“LCA cards”) describing the environmental burden in terms of energy and raw materials consumption as well as emissions to the environment from the cradle to the construction of the campus, transportation included.
The LCA cards have been organised in order to summarise the following information:

- **production process:** qualitative description of the system from raw materials extraction to construction operations, detailing system boundaries, functional unit and data quality. A flow chart of main operations is included and some hypotheses on end of life are proposed too;
- **main technical properties,** such as density [kg/m^3], thickness [m], thermal conductance [also known as heat transfer coefficient, W/m^{2}K], thermal conductivity [l, W/mK], thermal resistance [R, m^{2}K/W] and number of functional units per square meter or cubic meter.
- **environmental load** of the functional unit, in terms of gross energy consumption [MJ], gross raw materials consumption [kg], classified environmental effects (global warming, acidification, etc).

The organisation of this information was necessary to build a model of different possible solutions, the so-called technical packages, proposed by the designer. These technical packages represent the basis upon which it is possible to compare solutions from the point of view of environmental performance and to provide suggestions for the final choice, by means of a simulation stage. For instance, four different solutions for bearing walls have been proposed and analysed [4] each of them composed of different materials such as bricks, cement, insulation layer and so on. A similar approach was proposed also for floor (heavy), floor (light), roof covering and floor slabs as later described. The present report aims to evaluate technical and environmental performances of insulating materials available for one solution proposed for roofing.

2.1 Data origin and inventory phase

LCA cards are made up by primary and secondary data. Secondary data comes from the Boustead Model data base, the Italian Data Base on LCA (I-LCA, developed by the Italian Environment Protection Agency - ANPA) [2] and previous researches made at Politecnico di Torino [5]. With regard to primary data, it is interesting to note that information about hard floor coverings production (ceramic tiles, concrete paving units, terrazzo tiles, agglomerated stones, clay tiles and natural stones) comes from a recent project made again for the EC about the development of the ecological criteria for the award of the EU Eco-label for the Hard Floor Coverings (HFC) product group [3].

LCA results for the selected building materials are then included in the CES database and this stage allows integration of technical information about a material (such as Young's modulus, density, and so on, already included in CES database) with environmental life-cycle information. The CES software consists of graphical selection functionality and a material properties database [1]. The database itself includes a full range of materials (ceramics, composites, metals, natural materials, polymers) and a range of mechanical, electrical, thermal and other properties. The inclusion of LCA information into CES led to the development of a database including environmental properties such as:

- Resource and consumption data: annual world production, reserves, average concentration in earth's crust / sea water, economic ore grade;
- Energy and emission data: production energy, recycling energy, energy to melt / vaporise / deform (ie different processing energies for polymers, ceramics, metals) , CO_2, NO_X, SO_X creation;
- End of life: recoverable energy, suitability for recycling, reuse, incineration, landfill
- Aggregated measures: EPS value and eco-indicator.

After the first year of activity within the ORMA project, some main aspects can be highlighted:

- Only the materials specified by the ORMA project architect are at present available (about 50) but further improvements are going on;
- Many environmental properties have been calculated and introduced into the CES database;

- Environmental properties are peculiar to the ORMA project (for example, they include transportation effects for each material to this particular location).

This data-gathering phase will result into a specific version of CES designed for the ORMA project, able to integrate environmental and design technical parameters in a simulation tool to optimise the selection of technical components with all the environmental life-cycle information about the considered materials.
The result of this activity will be an iterative selection of materials on the basis of their technical and environmental properties starting from the building functions selected by the campus architect.
The following example shows how the initial Life Cycle Inventory results have been used for the simulation phase on selected technical solutions as aforementioned. To move from static LCA cards to a dynamic approach, a simulation of several technological solutions is to be performed for the eco-campus project. CES and the Boustead Model are to be used in parallel, because of a friendly interface is not at present available between the two models.

3 The roof case

In order to measure the environmental load of the different solutions proposed for each of the possible packages, which are intended to fulfil the same function, the LCA methodology is applied to select the proposed solutions from an environmental point of view. Hence, LCA integrates other considerations, such as technical or economic ones, to suggest to the designer the best eco-compatible and financially sustainable solution for construction. This approach is hereafter explained referring to a case-study, the roof selection case.
The selection of the eco-compatible roofing system started from the analysis of one of the three solutions proposed by the designer, made of the following main components (Figure 1 shows the design of one solution for the roof together with the starting values of thickness for each layer):
- Main beam;
- Wood boarding panels;
- Kraft paper;
- Insulating cork panels layer;
- Wood boarding panels;
- Gaiter;
- Wood strip;
- Flooring bricks.

Apart from considerations of the roof static behaviour (in this context, no mention of mechanical performance of the roof is given) the main function here assumed for the roof is its thermal insulation, which is measured by its thermal resistance R. Hence, the work aims to identify the most eco-compatible solutions for roofing and specially for insulating purposes, whereas the analysis was performed focusing the attention on materials representing the insulation, whereas the proper insulation material is the only degree of freedom.

- Wood boarding panels (22 mm, λ = 0,12 W/mK);
- Insulating cork panels layer (75 mm,0,038 λ = 0,12 W/mK);
- Wood boarding panels (22 mm, λ = 0,12 W/mK).

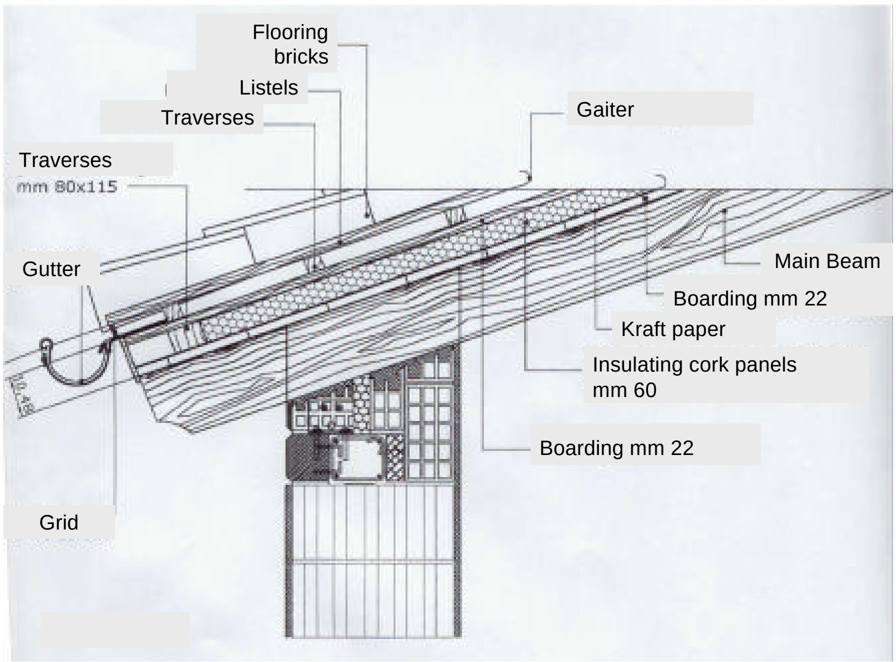

Figure 1: The starting technical package considered for one roofing solution.

In detail, the work takes into account not only the insulating material but also the wood boarding in order to weight the relative importance of contributions.
According to this point of view, many materials were considered as possible alternatives for the insulation function: Figure 2 shows the characterisation of different materials in terms of their thermal resistivity and density.
Among the various possibilities, three materials were selected because of their technical aspects and diffusion (labelled bubble). Main characteristics are reported in table 1.
Since the possible alternative solutions (adopting different materials) proposed for this duty could not have the same thermal insulation factor, a first normalising step was necessary. Appropriate calculations have been performed to vary the insulation layer in order to obtain exactly the same value of thermal resistance. An ad hoc Excel model has been prepared to simplify the calculation procedure: starting from the roof basic configuration (as above reported, Figure 1) that has a thermal resistance R = 2,027 m^2K/W and a K = 0,493 W/m^2K, a new K1 (“Imposed K”)

has been set at 0,4 W/m^{2}K, which is the value used to compare the three solutions proposed for the roof configuration. On the basis of this value, the new thickness of the insulation panel for each alternative solution was therefore calculated and the quantity (per m^2 of roof) necessary to obtain the appropriate K1 (or R1) obtained for each candidate material. These values were then used to integrate the EIP model into the Boustead Model to calculate the environmental load of the proposed solution.

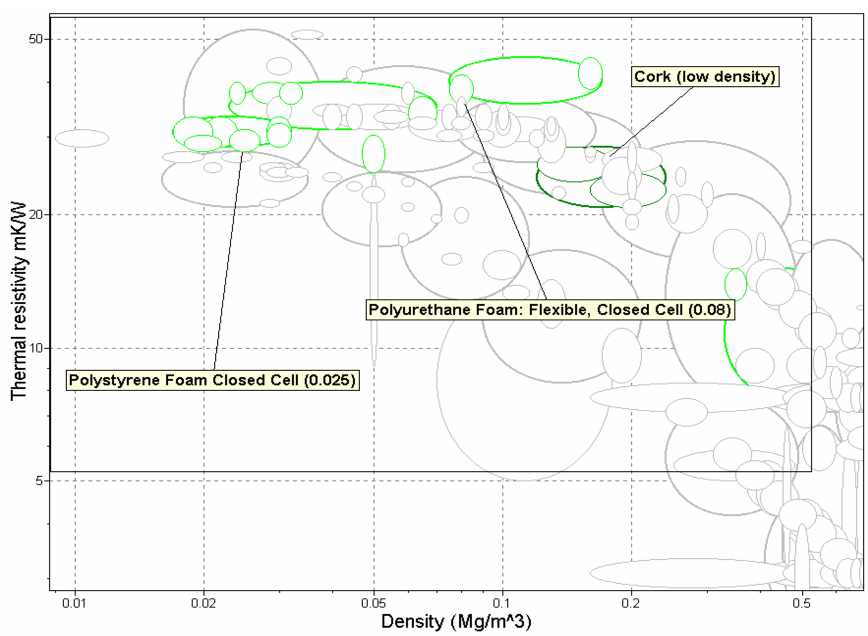

Figure 2: the screening stage with Cambridge Engineering Selector.

Table 1. Physical properties of some materials used for the technical package.

	Cork	Polyurethane foam (PU)	Polystyrene foam (PS)
Density ρ [Mg/m^3]	0,16	0,080	0,025
Thermal conductivity λ [W/mK]	0,04	0,026	0,034

Results arising from the LCA are summarised in Figure 3 for the three alternatives (here defined on the basis of the insulation function only) where the Gross Energy Requirement (GER) is subdivided into main energy items (direct energy, indirect energy, transport energy and feedstock energy). Energy results should be completed considering the opportunity to avoid the accounting of the feedstock energy because of it is potentially recoverable by burning and energy recovery systems; a further comparison could take into account contributions due to the irreparably lost energies (the same of Figure 3 without the feedstock contribute).

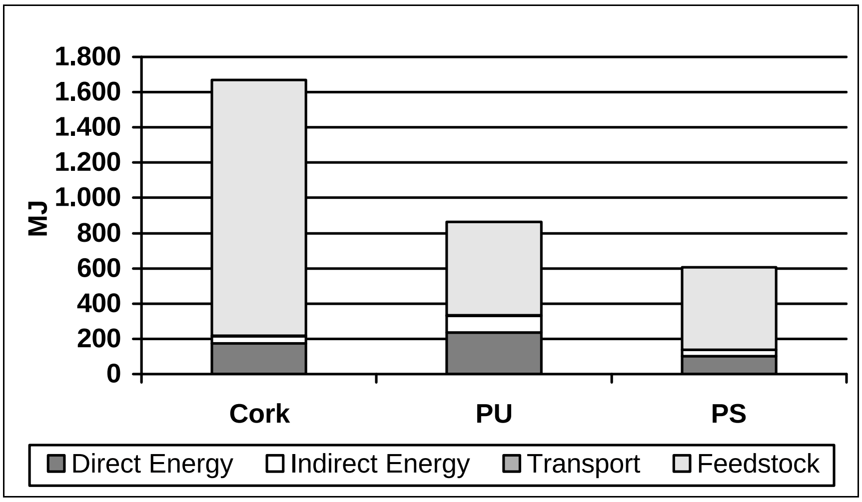

Figure 3: Gross energy requirements (GER).

Moreover it is possible to balance the contributions to GER from proper insulation material and wood boarding as shown in Figure 4 where the differences are due to the reduction of insulation significance.

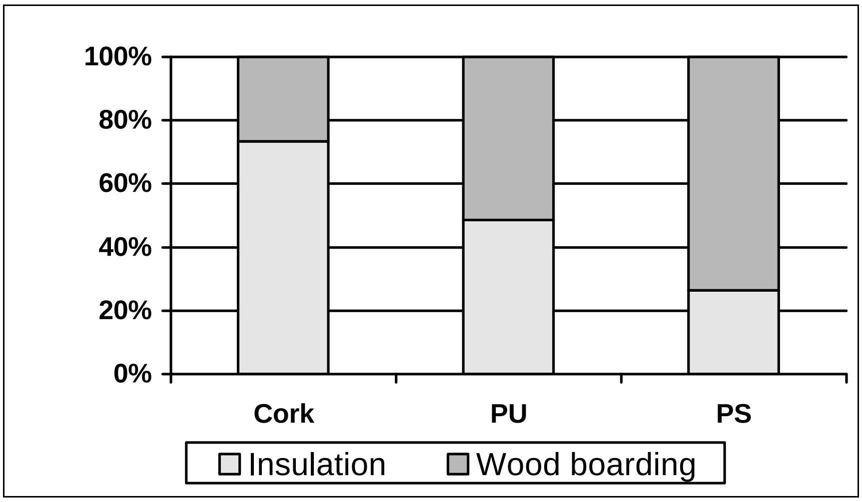

Figure 4: Contributions to GER.

To provide also a measure of other environmental indicator, Figure 5 shows the Global Warming Potential (GWP_{100}) for the three alternatives. Negative values depend on CO2 credit for wood (or bio-mass) to which the positive value for polymers is added.

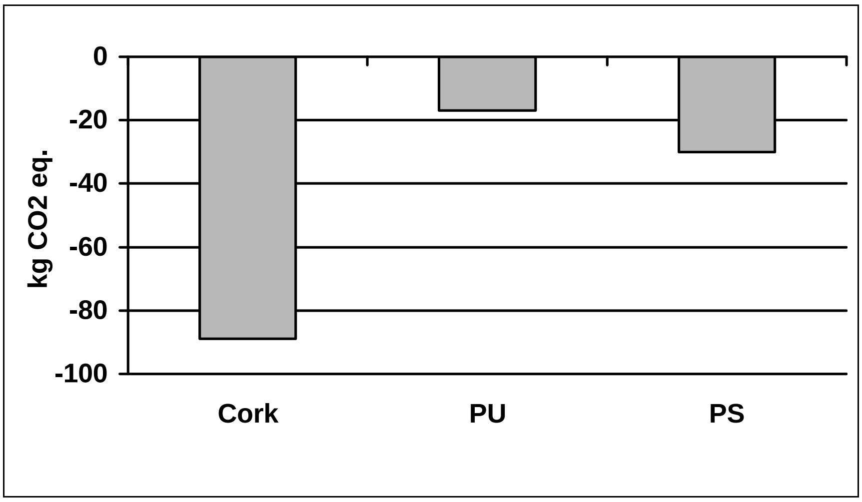

Figure 5: Environmental results – Greenhouse effect in terms of GWP_{100}.

4 Final remarks

The performed analysis allows integrating different criteria to optimise buildings performances. The example demonstrates how the same insulating degree can be reached by using materials which provide different environmental burdens.
Cork presents high energy consumption even if mainly stored in the material (feedstock energy) and available for energy recovery at the end of useful life. Polyurethane presents the highest value of lost energy. Polystyrene has the lowest energy demand, especially feedstock (because of the low density), therefore it represents the optimal selection from a supply chain energy consumption point of view. From a global warming indicator point of view, CO_2 from polymers is from fossil resources hence not sustainable, while in the case of cork the emissions can be considered sustainable. Other indicators such as acidification, eutrophication and photo-smog don't influence substantially the choice among the three solutions.
The approach presented is now being used to develop an Eco-tool based on a "score method" which aims to evaluate the energy and environmental performances of technological components, in relation to a number of specific requirements.

As shown above, in addition to environmental considerations, other factors, such as economic costs, influence the choice and suitability of different building choices. For example, the businesses units that are going to be established in the eco-park and their building constructors will be able to take into account the costs and building specifications associated with selecting environmentally friendly materials.

The LCA methodology together with the CES approach aims to analyse trade-offs between performance and environmental-impact of the alternative solutions identified.

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