Influence of LCA procedure on the green building rating tools outcomes

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Influence of LCA procedure on the green building rating tools outcomes

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Abstract. Building energy performance has a key role in the international energy scenario. Labelling procedures have been developed in several countries for certifying the environmental sustainability of buildings, aiming at reducing energy consumptions and environmental impacts.

In this study, the impacts of the insulating materials on the energy and environmental performance of a residential building have been analysed. From previous studies developed by the same authors, it emerged that the sustainability protocols LEED and ITACA take into account the thermal properties of the insulating materials but their impact on the environment is not adequately considered. Starting from these considerations, in this work a life cycle analysis was carried out on the four insulating materials in order to highlight if and to what extent they differ in terms of environmental impacts. What emerged from the results is that the balance between nature, origin and amount of input materials strongly influences the results and the natural materials are not always the most sustainable and eco-compatible.

1. Introduction

World energy demand is growing in the next 20 years due to the increase of urbanization and urban population. As a consequence, high environmental impacts have occurred in terms of local and global pollution. Energy policy have been implemented at international level in order to minimize these impacts [1]. The building sector is responsible of about 40% of the global energy consumption so the reduction of building energy needs is one of the main targets for administrators [2]. In order to reduce energy consumptions many solutions have been implemented aimed at improving energy performance of buildings, measuring their impact on the environment and reducing emissions [3,4]. European Standard introduced new requirements for obtaining energy savings in buildings: according to the EPBD Directive, new public buildings from 01/01/2019 and new private constructions from 01/01/2021, have to reach the Nearly zero energy buildings (NZEB) targets **Errore. L'origine riferimento non è stata trovata.**. Certification procedures have been developed in accordance to the EPBD directive, which allow to evaluate the energy performance of buildings [6-7]. In addition to the energy aspects, also the environmental performance of buildings should be evaluated to assess the impact of the building sector from a global perspective. This issue is even more relevant for NZEB and ZEB (Zero Energy Buildings) which aim to reduce as much as possible building energy needs: the concept of energy performance is strictly related to the environmental aspects and should not be considered separately. In fact, the responsibility of all the parties which collaborate to plan, build, operate and dispose of Nzebs is to ensure that all these phases are managed in an energy-efficient and resource-saving way [8]. Sustainable protocols are available to determine the grade of sustainability of buildings based on specific characteristics, objectives and standard at national level [9]. The application of sustainability rating tools to high performance energy buildings (Nzebs) would certify the lowest possible environmental impact during their life cycle and the minimization of resources, energy consumption and land use [8]. These procedures calculate the level of efficiency of buildings taking into account the impacts on environment and the effects on human health. Differently from the energy certification schemes, these are not mandatory. Many studies have been developed to compare the international sustainable protocols [10-13]. In these studies, the weights, criteria and credits of the protocols have been analyzed with the aim of highlight similarities, differences and lack of these schemes. Among these researches, in [14] two macro-categories of protocols were defined: in the first group the schemes based on a multidisciplinary approach are included, while the protocols focused on the Life Cycle Approach (LCA). The definition of these two groups highlights that the assessment of LCA aspects is missing in the first group, and, in the other, there is a lack in the multidisciplinary approach. The need of integration between these two methods was observed by the authors in previous researches [15-17]. In two of these studies [15,16], ITACA and LEED protocols were applied to a residential building to assess if there were differences in the sustainability scores as the insulating materials of the envelope varied. Four insulating materials were used with the same thermal conductivity but different environmental features. Results demonstrated that despite materials were characterized by different embodied energies and different structural features, the final scores were the same for both the protocols. In [17] a methodological analysis of five international protocols (LEED, ITACA, CASBEE, Green Star, BREEAM) was developed to highlight the positive and negative aspects of these schemes. It emerged that big variations do exist among these protocols and important aspects are currently considered only by a few of them. In particular, the missing of LCA and LCC aspects in many protocols is an outstanding result, considering how important they are for a complete environmental analysis. In fact, the analysis of the direct (construction, operation, rehabilitation, demolition, disposal of components) and indirect impacts (production of building materials, embodied resources of building envelope and technical systems) in the life cycle of a building plays a fundamental role in the assessment of the building performance from a global perspective. It is especially relevant for Nzebs: with conventional buildings, the operation phase was the more consuming, causing the largest energy and environmental impact compared to the other building life phases; now that Nzeb Standards require to cut to a minimum the energy consumption in the operation phase, all the other life stages of the buildings become much more relevant. According to this, the assessment of the embodied impacts involved in the all phases of the building construction cannot be avoided anymore. Basing on these considerations, the aim of this work is to develop an LCA analysis of the four insulating materials used in [15] to assess the difference among them in terms of environmental impacts within their entire life cycle. In this work the analysis was focused on the “cradle-to gate” phase. This evaluation will allow to understand the differences among the insulating materials, which did not emerge from the application of the protocols. Future developments of this work will be the definition of LCA indicators to be included in the sustainability protocols to evaluate in a complete and accurate way the environmental impact of the building materials.

2. Objective and methodology

This study aims at demonstrating the influence of the physical nature of insulating materials on the entire life cycle of buildings, highlighting that many factors should be considered in the choice of the building elements and components. The four insulating materials are: glass wool, EPS, rock wool and cellulose fibre.

2.1. The Model

The LCA was developed using the software SimaPro [18]. SimaPro is a professional tool for assessing and monitoring the environmental performance of products and services. It allows to use data from the database or to create new items, for creating complex life cycle according to the relevant Standard ISO 14040.The database includes information regarding materials, processes and operations. The first step is the definition of the Assembly, where all the information regarding the components of the process are collected. In order to adequately develop this phase, data regarding materials (type and quantity), processing, energy use and transport must be considered. The Disposal scenario is the block where all information about the end-of-life stage of the components. Lately, the life cycle block takes into considerations all the aforementioned steps, including also Processing, Energy and Transport. The starting hypotheses of the model are the following:

- The database Ecoinvent 3.0 included in the software was used;
- In the calculation the unit of mass of each insulation material was considered to assess and compare the production processes
- The analysis was carried out taking into account 1 m^2 of external wall and calculating the mass of each layer of the envelope, with the aim of guiding the choice of the insulating material basing also on the amount of material needed.
- A comparative analysis was also carried out considering the EPS obtained with recycled plastic
- The materials of the envelope (bricks, gesso and concrete) are the same for all the configurations of wall.

2.2. The LCA indices
The environmental impact has been evaluated by means of the following indices:

- Global Warming Potential – This indicator estimates the greenhouse effect and it is calculated considering air substances which contribute to global warming.
- Photochemical Oxidation – It includes all the volatile organic substances that contributes to the photochemical development (in the presence of solar radiation) of tropospheric ozone.
- Acidification - The acidification indicator calculates the emissions of particular acidifying substances, such as nitrogen oxides and sulfur oxides. Abiotic Depletion, non-fossil – This impact is related to the extraction of minerals. The calculation consists in identifying the amount of consumed materials, considered as rare, and convert them into an equivalent mass of a mineral whose exhaustion is expected in a near future. Despite it refers to the abiotic part of the ecosystem, it affects also the biotic.
- Abiotic Depletion, fossil fuel - This index is similar to the previous one, but it refers exclusively to the consumption of fossil fuels. It takes into account the energy aspect of the production process. It is measured in MJ / kg of product and can quantify the embodied energy of the material. The distinction of these two sub-indicators of Abiotic Depletion is justified by the preponderance of the depletion of fossil resources over other types of resources.
- Eutrophication - This indicator evaluates the effect of eutrophication, the increase in the concentration of nutrients in aquatic environments.

3. Case study
The case study building is located in Terni, Umbria. It is placed in a high-density residential area, characterized by different ways of transport (bus lanes, trains) which connects the area with the neighborhoods. The nine-floor building is east-west oriented and includes: the underground level which hosts parking, thermal power plant, video surveillance system and rainwater tank; the ground level, occupied by shops and residential entrances; 7 residential floors (6 floors + 1 attic).

The characteristics of the insulating layers are shown in Table 1. The underground floor and the residential floors are connected by a common staircase. There are 38 apartments: 6 flats for each floor and 2 bigger apartments on the attic floor. The lot around the building is characterized by 811 m^2 of green area and 750 m^2 of paved area. An underground tank for rainwater recovery is installed, 164 photovoltaic panels are located on the parking roofs and 25 solar water heating panels are placed on the pitched roof. Natural and local building materials were used to limit the environmental impacts of the building construction.

Table 1. Characteristics of the insulating layers

Materials	*Density [kg/m³]*	*Thickness [cm]*	*Area [m²]*	*Mass [kg]*	*Thermal conductivity [W/mK]*	*Specific Heat [J/KgK]*	*Density [kg/m³]*	*Embodied Energy [MJ/kg]*
EPS	30	8.5	1	2.55	0.039	1000	20	17.12
Glass Wool	25.2	8.5	1	2.14	0.038	1400	25	99.05

Rock Wool	100	8.5	1	8.50	0.036	1030	100	16.20
Cellulose Fiber	50	8.5	1	4.25	0.040	2100	50	4.33

4. Results

In this work a life cycle analysis was developed for the production process of four insulating materials. The calculation has been performed using the EPD method [19] and the outputs are the impact indicators. Two types of analysis were developed: in the first one (Figure 1) the indicators are expressed for mass unit of each insulating layer is shown; in the second one (Figure 2), the indicators are expressed in terms of surface unit of the wall. It highlights that the differences in the materials density imply a variation in the amount of product to be used. Results are shown in Figure 1 and 2.

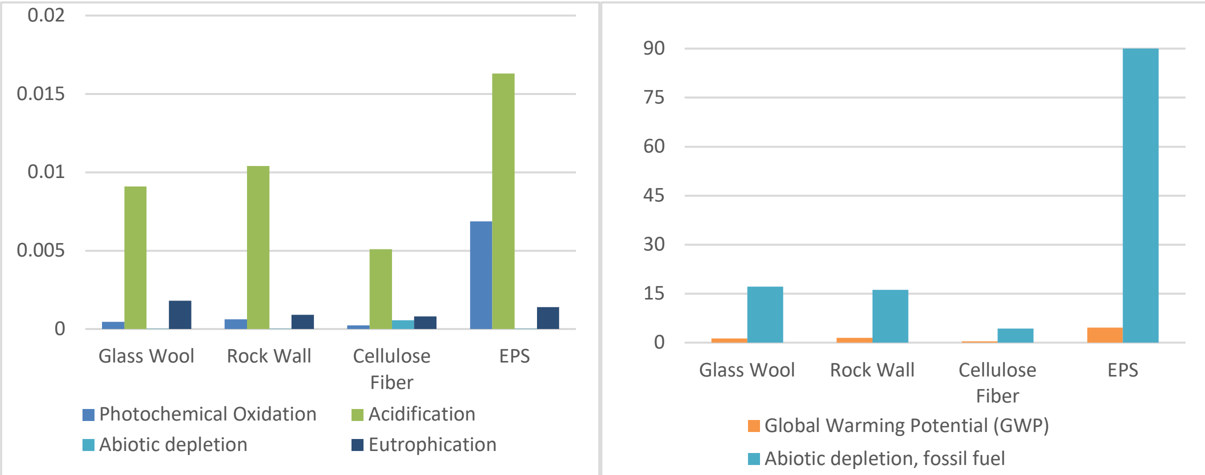

Figure 1. Results of the LCA analysis “cradle to gate” (mass unit)

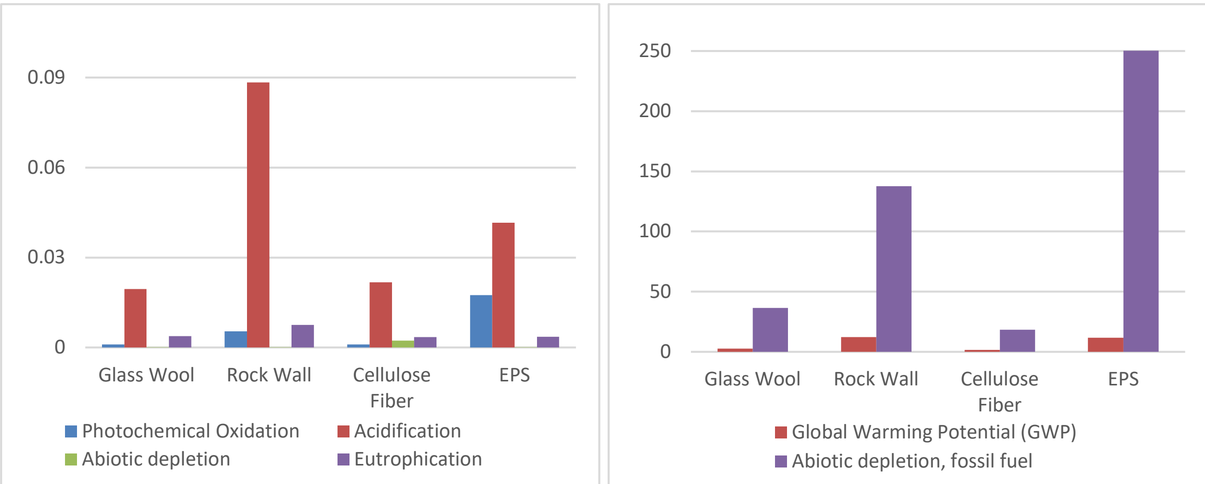

Figure 2. Results of the LCA analysis “cradle to gate” (surface unit of the wall).

Concerning the Global Warming and the Photochemical Oxidation indicators, the most polluting is the EPS, due to its synthetic origin from fossil fuel. The rock wool and glass wool have a lower impact; the results are very similar between these two, little differences are attributed to the melting temperatures of the respective production processes. Temperature for rock wool is 1600°C while for glass wool is 1400°C. The same results are obtained for Acidification and Abiotic Depletion for Fossil Fuels (embodied energy). Cellulose fiber presents the lower value of Abiotic Depletion of fossil fuels, due to its natural origin, but on the contrary it has the highest impact in terms of Abiotic Depletion of other sources. It also presents the lowest values of Global Warming Potential and Acidification. Glass wool has the highest potential of Eutrophication: during the extraction process of silica sands, other components are produced (i.e. phosphorus) which increase the concentration of nutrients for the proliferation of plant organisms in water. Regarding the analysis per surface unit of the wall, density of the insulating materials becomes influential. The rock wool, with a density of 100 kg/m^3, turns out to be the densest: with the same surface area, it requires the largest quantity of product. According to this, concerning the Global Warming Potential, the Acidification and the Eutrophication, the rock wall has the highest impact, even exceeding the EPS. This analysis allows to differentiate the environmental behavior of Rock Wool and Glass Wool both, especially in terms of Abiotic Depletion of fossil fuels, revealing that the rock wool has a lower environmental impact compared to the Glass Wool.in terms of photochemical oxidation and Abiotic depletion of fossil fuel, EPS is still the worst: the greater quantity of rock wool does not compensate for the synthetic nature of EPS.

4.1. Application of recycled EPS

Results of this analysis (Table 2) highlights that the use of recycled materials is very effective in terms of impact reductions. Two type of simulations have been performed: EPS 100% recycled and 45% recycled. As noticed in figures 1 and 2, the EPS resulted to cause very high environmental impacts especially in terms of Global Warming Potential and Abiotic Depletion of fossil fuels. In Table 2 it can be observed that the 45% recycled EPS allows to obtain good improvements compared to the standard EPS; with the 100% recycled EPS, results obtained are the best among the four materials, apart from the embodied energy (Abiotic depletion of fossil fuels).

Table 2. Results of the LCA using recycled EPS (mass unit)

Indicator	*Unit of measure*	*Glass Wool*	*Rock Wool*	*Cellulose Fiber*	*EPS*	*EPS, 100% recycled*	*EPS, 45% recycled*
Global Warming Potential (GWP)	kg CO2 eq	1.25	1.43	0.39	4.62	0.36	3.29
Photochemical Oxidation	kg C2H4 eq	0.00046	0.00063	0.00023	0.00686	6.94E-05	0.00356
Acidification	kg SO2 eq	0.0091	0.0104	0.0051	0.0163	0.001	0.008
Abiotic depletion, fossil fuel	MJ	17.12	16.21	4.33	99.06	5.46	69.07
Abiotic depletion	kg Sb eq	6.47E-06	2.91E-06	0.00056	7.25E-07	4.5E-07	8.31E-07
Eutrophication	kg PO4 eq	0.0018	0.0009	0.0008	0.0014	0.0001	0.0007

5. Conclusions

In this paper the impacts of the insulating materials on the energy and environmental performance of a residential building have been analysed. From previous studies developed by the same authors, it emerged that the sustainability protocols LEED and ITACA take into account the thermal properties of the insulating materials but their impact on the environment is not adequately considered. Starting from these considerations, in this work a life cycle analysis was carried out on the four insulating materials in order to highlight if and to what extent they differ in terms of environmental impacts. It was assessed that the most critical phase in the life cycle of these materials is the production. According to this in this work only the cradle to gate process have been shown. What emerged from the results is that the natural materials are not always the most sustainable and eco-compatible. What strongly influences the results is the balance between nature, origin and amount of input materials. It was observed the dual and contemporary influence of the density connected to the embodied energy of the materials. From calculations per unit of wall surface, it was possible to notice how the denser material (rock wall), implying a greater mass, generates impacts even higher than the material with higher incorporated energy (EPS), in terms of Global Warming Potential, Acidification and Eutrophication. The study also revealed that using recycled materials, the embodied energy of the most impactful material (EPS) becomes comparable with the most sustainable one (cellulose fibre). In the choice of the insulating layers it should be preferred to use low-density materials with low embodied energy and to take into consideration not only the natural origin but also the level of recycling. This analysis should hopefully result in a modification of the sustainability protocols, aimed at paying more attention on life cycle aspects, which are partially overlooked in the current versions of some sustainability schemes. According to this, future developments of this research will be the complete life cycle analysis (from cradle to grave) of the insulating materials and the proposal of new indicators and parameters to be included in the sustainability protocols for assessing the environmental impact of the materials in a more complete way.

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