Green or ecological roofs?

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Abstract Long-term sustainability represents a challenging goal for the construction industry. Green roofs can be used to create more environmentally sustainable buildings. However, up-to-date environmental data are needed to allow the comparison of green roofs with conventional solutions. In this work, the importance of green roofs related to the environmental impact of the life cycle of a building is assessed with both Ecoindicator 99 and CML 2000 methodologies. Energy consumption during the use phase is shown to be responsible for the main environmental impacts in a building's life cycle. The results show a significant improvement in the environmental performance when the green roof strategy is applied (50% to 85% reduction, with the exception of the category of ozone layer depletion).

1 Introduction

The construction industry consumes 40% of the materials entering the global economy and generates 40–50% of the global output of greenhouse gases and acid rain agents. The United Nations Environment Programme (UNEP) Sustainable Building Initiative (SBCI) explains that the building sector is the main producer of greenhouse emissions in most countries and that the greenhouse emissions are due to the energy used during the use stage of a building's life-cycle [1]. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report (AR-4) concludes that the building sector has a huge potential for reducing greenhouse gas emissions, an estimated 30-50% without a noticeable increase in costs. Thus, building energy consumption minimization became one of the basic principles of the European Environmental Legislation and Strategy [2].

Several efforts have been made to identify ways to reduce the environmental impacts of housing. The report "Environmental Improvement Potentials of Residential Buildings" (IMPRO-Building) of the Joint Research Centre has identified the reduction of heat losses through the roof as one of the more suitable strategies to reach that goal [3]. Considering this, the benefits provided by green roofs appear to make them a good option. They reduce thermal fluctuation on the outer roof surface and increase thermal capacity; help to mitigate air pollution; reduce urban heat island effect and noise propagation; reduce runoff peaks of rainfall events; and increase biodiversity [4-7].

The use of green roofs has increased noticeably in recent years in many countries, but relevant up-to-date environmental data is needed to allow the environmental comparison of green roofs with conventional solutions. This will help to assess their behaviour and analyse if, in addition to merely having vegetation, they can be called truly ecological roofs.

There are examples of Life Cycle Assessment (LCA) studies of some construction materials; however, no comprehensive Life Cycle Inventory (LCI) data for green roofs is available in the literature. The scope of this study is to deepen the knowledge of green roofs by studying the environmental performance of green roofs along their life cycle.

In a previous work, LCA methodology has been applied to analyse the environmental profile of the materials involved in the construction of green roofs. That work considered how the environmental impacts of green roofs are affected by adaptation to climatic conditions [8]. Varying the thickness of the thermal insulation was the chosen way to make this adaptation. Conclusions of this previous work are that the effect of the thermal insulation is not significant from an environmental point of view. When the structure is excluded the surface layer creates the most impact. The structure can be seen as the common element in a comparative analysis.

2 Goal and scope

The main goal of this study is to assess how the use of a green roof affects the environmental impact of a building. To reach this goal, a comparative LCA was performed of the same building covered with a green and a conventional roof.

2.1 Functional unit description

The functional unit studied is 1m2 flat inverted pedestrian with tiles supported by pedestals for private use roof, installed in a commercial building with a life span of 30 years. The features of the functional unit determined elements of the roof: the flat roof will determine the shape of the structure that supports it, an Inverted roof will have its thermal insulation in a certain position, and the use of this surface by pedestrians for a private use will decide the kind of tiles and pedestals.

2.2 System description and boundaries

The analysed green and conventional roofs are described in Fig 1 and Fig 2 respectively. They both have characteristics that allow them to meet all the requirements of the functional unit. The roof systems in both cases have some similar elements that have been studied as subsystems in the previous work. These subsystems correspond to the different functions of the layers that compose the roof. The following subsystems have been studied for the green roof system: surface finish, thermal insulation, water basin, waterproofing and structure. For the conventional roof the subsystems are: surface finish, thermal insulation, waterproofing, drainage and structure. The materials composing the subsystems will be addressed in the inventory analysis.

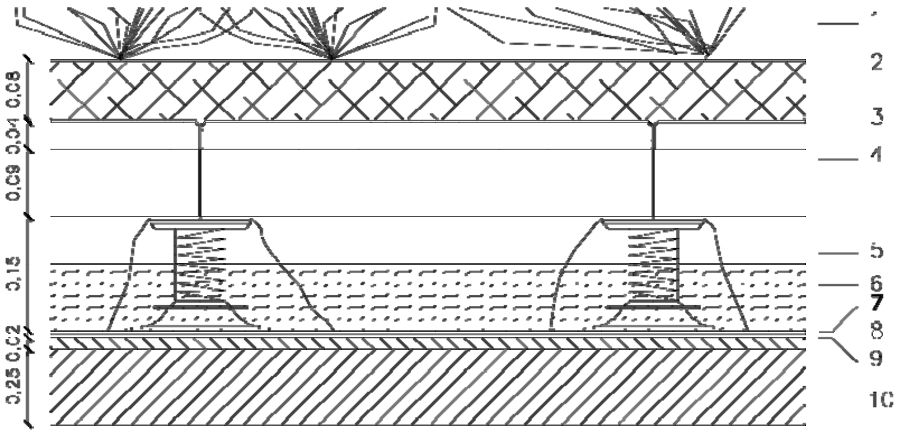

Fig.1: **Description of the green roof. 1. Vegetation. 2. Soil. 3. Felt sheet 150. 4. Concrete tile with extruded polystyrene. 5. Pedestals. 6. Water basin. 7. PVC membrane. 8. Felt sheet 300. 9. Cement mortar. 10. Concrete slab.**

The use phase has been studied in a commercial building considering a life span of 30 years. This typology was selected because many green roofs can be found on commercial buildings and they are usually flat and have a big area. Taking into account their ‘building envelope’ – which is the area consisting of the roof and the facades - the proportion of the roof in these buildings is larger than that of other types of buildings. Hence it is easier to measure the changes produced in the thermal behaviour of the building when the configuration of the roof is modified.

The scope of the study covers the entire life cycle of a commercial building built in 5 different cities corresponding to the 5 climate areas in Spain. The roofs have been adapted to reach the limitations imposed by the Technical Code [9] for each climate area by increasing the thickness of the insulation layer. Construction and disposal phases are beyond the scope of the study. Lighting, water supply and water heating, in the use phase, have been excluded according to the principle of excluding identical activities for comparative assessments.

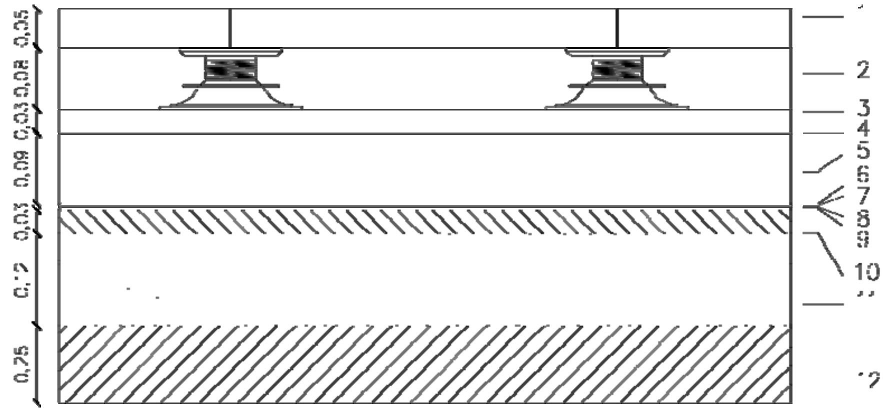

Fig.2: **Description of the conventional roof. 1. Terrazzo tile. 2. Pedestals. 3. Protection cement mortar. 4. Geotextile sheet. 5. Extruded polystyrene. 6. Geotextile sheet. 7. Asphalt sheet reinforced with polyester felt. 8. Asphalt sheet reinforced with fiberglass felt. 9. Bitumen primer coat. 10. Surface regulator cement mortar. 11. Slope formation concrete. 12. Concrete slab.**

3 Inventory analysis

3.1 Origin of data and data description

A company that installs green roofs provided the data for the green roof. The data for the conventional roof were taken from commercial information. Technicians related to building construction sector supervised the final design of both roof solutions. Tables 1 and 2 show respectively the inventory of the materials analysed for the green roof and the conventional roof.

Tab.1: Inventory table of green roof materials

Green roof composition		Roof data	
Function	Element	kg/m²	Element kg/total roof kg (%)
Surface finish	1. Vegetation	1.00	0.13%
	2. Soil	47.87	6.11%
	3. Felt sheet 150	0.26	0.03%
Thermal insulation	4. Concrete tile with extruded polystyrene	69.71	8.90%
	5. Pedestals	1.41	0.18%
Water basin	6. Water basin	140.00	17.88%
Waterproofing	7. PVC membrane	1.55	0.20%
	8. Felt sheet 300	0.30	0.04%
	9. Cement mortar	50.17	6.41%
Structure	10. Concrete slab	470.72	60.12%
	Total (kg/m²)	782.99	100%

The energy consumption during the use phase (Table 3) was estimated with the Design Builder energy simulation software [10]. This software can examine the material characteristics of the building and the energy consumption due to different subjects related to the use of the building. The software has recently implemented an “eco-roof” into their materials database. The parameters of the material were adjusted to make the thermal behaviour of the “eco-roof” fit with experimental data.

The Spanish mix production profile has been used to assess the environmental impact of the power consumption. The power generation characteristics of the Spanish stage show a distribution where electricity from renewable resources with 22%, combined cycle plants 21%, and nuclear power 20% are the main suppliers. Hydraulic power also has a notable contribution that reaches 14% [11].

4 Impact assessment

Ecoindicator 99 and CML 2000 methodologies have been applied to detect the critical elements of the system. Endpoint and midpoint methods coexist in LCA case studies. In this work the aim was, on one hand, to have different data to give comprehensible information to the different stakeholders and, on the other, to analyse whether the results with both methods were coherent.

Tab.2: Inventory table of the conventional roof materials

Conventional roof composition		Roof data	
Function	Element	kg/m²	Element kg/total roof kg (%)
Surface finish	1. Terrazzo tile	100.40	11.70%
	2. Pedestals	1.88	0.21%
Thermal insulation	3. Protection cement mortar	100.34	11.29%
	4. Geotextile sheet	0.20	0.02%
	5. Extruded polystyrene	2.31	0.26%
Waterproofing	6. Geotextile sheet	0.15	0.02%
	7. Asphalt sheet reinforced with polyester felt	3.00	0.34%
	8. Asphalt sheet reinforced with fiberglass felt	3.00	0.34%
	9. Bitumen primer coat	0.40	0.04%
Drainage	10. Surface regulator cement mortar	100.34	11.29%
	11. Slope formation concrete	102.56	11.54%
Structure	12. Concrete slab	470.72	52.96%
	Total (kg/m²)	888.90	100%

Tab.3: Energy consumption used for thermal conditioning of the building, in 5 different climate areas with conventional and green roof. Conv.: Conventional roof. Green: Green roof

Energy consumption										
City	Cadiz		Valencia		Vigo		Madrid		Soria	
Roof	Conv.	Green	Conv.	Green	Conv.	Green	Conv.	Green	Conv.	Green
Air conditioner (kwh/m²)	6.82	0.30	10.05	.093	3.06	0.00	11.03	0.74	2.70	0.00
Heating (kwh/m²)	24.24	21.35	28.82	26.03	32.44	30.03	38.92	36.11	47.41	44.33

4.1 Life cycle phases and their relevance

Figures 3 and 4 show the characterisation results with CML 2000 and Ecoindicator 99 methodologies for the green roof adapted to the climate conditions of Madrid.

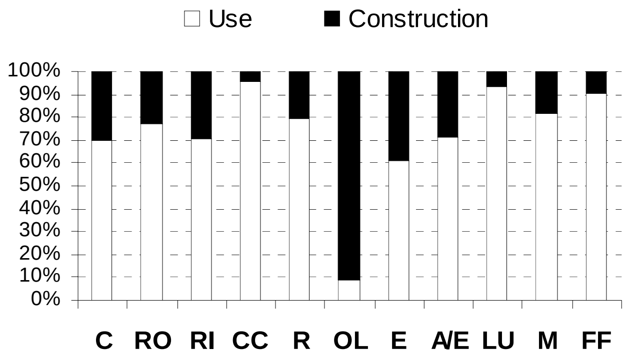

Fig.3: **Characterisation results with Ecoindicator 99 for the green roof adapted to Madrid climate conditions. C: Carcinogens; RO: Respiratory organics; RI: Respiratory inorganics; CC: Climate change; R: Radiation; OL: Ozone layer; E: Ecotoxicity; A/E: Acidification/Eutrophication; LU: Land use; M: Minerals; FF: Fossil fuels.**

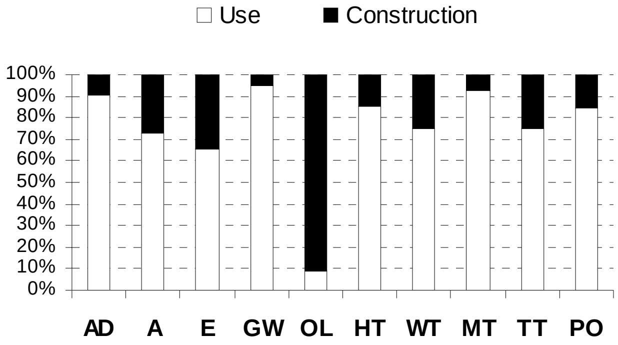

Fig.4: **Characterisation results with CML 2000 for the green roof adapted to Madrid climate conditions. AD: Abiotic depletion; A: Acidification; E: Eutrophication; GW: Global warming; OL: Ozone layer depletion; HT: Human toxicity; WT: Fresh water aquatic ecotoxicity; MT: Marine aquatic ecotoxicity; TT: Terrestrial ecotoxicity; PO: Photochemical Oxidation.**

The environmental profiles that results from the assessment with CML 2000 and Ecoindicator 99 methodologies are very similar. The contributions to the categories dealing with the same subjects are analogous, such as in the case of abiotic depletion and fossil fuels contribution that reaches 90% for the use phase, the 90% contribution of the construction phase to the ozone layer and ozone layer depletion categories, and 95% contribution of use phase to the climate change and global warming categories. The use phase presents the highest contribution in almost all impact categories, with the only exception of the categories related to the ozone layer depletion. The high contribution of the construction category to the ozone layer depletion categories is due to the fabrication stage of the extruded polystyrene, in particular to the refrigerant R134a used in the expansion of the polystyrene.

4.2 Comparison between conventional and green roof use phase

It has been seen that use phase presents the most notable contributions. Then it is necessary to make a comparison between the environmental impacts associated to the use phase for both roofs. Figure 5 shows the normalisation results for the use phase of the building, adapted for the Madrid climate conditions, with CML 2000 methodology.

The figure evidences the higher contribution of the building with the conventional roof in all impact categories. The categories where the difference in environmental impact is the greatest are: fossil fuels, climate change and respiratory inorganics. High contributions to fossil fuel category are due to the production of gas onshore. This gas is used to supply gas fuel for heating boilers and to produce electricity in combined cycle power plants and cogeneration plants.

5 Discussion

5.1 Construction vs. use phase

The results of this work agree with those from several studies that have addressed this issue [3, 12-14]. Most of the previous results have concluded that the use phase is responsible for the most impact during the life cycle of buildings and that the impact of this phase is due to the energy consumption. The contribution to the impact categories of the use phase in European housing is higher than 50%, in all cases, and even reaches 97% and the contribution is related to the high environmental burden emitted to the atmosphere. In recent years the number of low energy buildings has increased and so has the number of studies related to their energy performance and savings [15-16].

The conclusions obtained in these works show that in low-energy buildings where the chosen way to reduce energy consumption is by using passive strategies, even though embodied energy of materials increased noticeably, the operating energy represents by far the largest part of energy demand in a building during its life cycle. Therefore it has also been concluded that usage phase has to be taken into account when choosing products in the building sector.

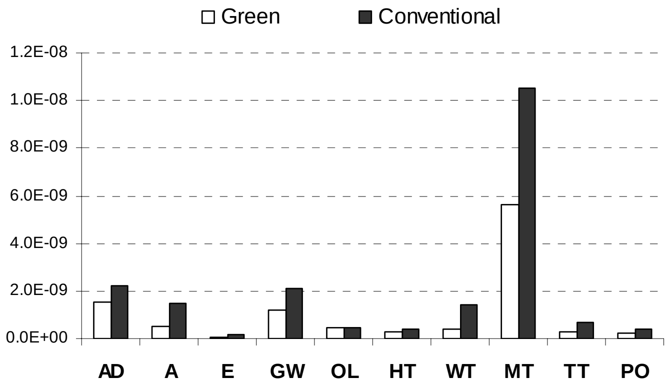

Fig.5: **Normalisation results with CML 2000 metodology for the use phase of the two roofs adapted for the Madrid climate conditions. AD: Abiotic depletion, A: Acidification; E: Eutrophication; GW: Global warming; OL: Ozone layer depletion; HT: Human toxicity; WT: Fresh water aquatic ecotoxicity; MT: Marine aquatic ecotoxicity; TT: Terrestrial ecotoxicity; PO: Photochemical Oxidation.**

5.2 Use phase: conventional vs. green roof

The benefits of green roofs, from the point of view of their thermal behaviour, have already been addressed in different works [13, 17]. In these cases the thermal conductivity of green roofs was always lower than the conductivity of conventional roofs and these results were influenced by both for the effect of thermal insulation capacity of the roof as well as for evapotranspiration.

In this work both green and conventional roofs have the same thermal conductivity, and so reduction in energy consumption is entirely the effect of plants and soil. This reduction occurs mostly in summertime, when the evapotranspiration effect of the vegetation creates a fresh air barrier between hot air and the surface of the roof.

The environmental performance during the use phase is closely related to the power consumption. The assessment of the environmental impact of the power generation was made using yearly average production data for the Spanish stage. As Saiz points out, the generation profile of power during peak demands, that occurs in extreme climate conditions like summertime, can be noticeably different from the average profile. A sensitivity analysis should be made to see whether the impact reduction could vary due to this difference.

5.3 CML 2000 and Ecoindicator 99 results

¿Which method should I use to assess the impacts? ¿Endpoint or midpoint?

These questions nowadays, even though there have been several tries to solve them [18-20], do not have a single answer.

In this work the results with both methods show that, for the categories with the main contributions in this process, the scores are broadly consistent. This can be seen in the impact categories like those related to the climate change and abiotic resource depletion.

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