Environmental impact of thermal insulations: How do natural insulation products differ from synthetic ones?

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Abstract: As the environmental awareness of the public is rising and at the same time contemporary buildings are becoming more and more energy efficient, the focus is shifting towards the usage of environmentally friendly building products. Human decisions are often driven by emotions and perceptions. Consequently, there exists a strong tendency towards preferring “natural” constructional products to the synthetic ones, especially in the case of thermal insulations. Life cycle assessment (LCA) has enabled an opportunity to widen the meaning of the word “environmentally friendly”, giving researchers and building designers an objective decision making tool to determine the environmental impact of building products, building components and buildings as a whole. The purpose of this study was to compare the environmental impact of various thermal insulations for the cradle to gate life cycle stages, based on a unified functional unit. Overall, 15 most commonly used thermal insulation products were analysed and classified into natural and synthetic groups. Based on the differentiation, we compared the impact in the selected environmental categories and identified the most influential environmental drivers. The results show that in some environmental categories natural thermal insulations perform better (i.e. global warming potential), while in others (i.e. eutrophication potential) they underperform. However, environmental impact trends can be identified, specifically for the natural and the synthetic materials.

1. Introduction

The building sector is responsible for a major share of global material consumption and energy use. Consequently, it has a profound impact on the environment [1]. During the last decade, the European Union has been pushing on its member states to implement energy efficiency measures in buildings and promoted the use of renewable energy [2]. Since buildings are getting more and more energy efficient and thereby the environmental impact related to the operational phase of the buildings life cycle is ever smaller, other phases of the buildings life cycle are becoming significant from the environmental perspective [3]. Decisions about choosing the environmentally most appropriate building materials and products are increasing their role in the building design process. Thermal insulation products are among the most detrimental parts of the building envelope, directly affecting the energy use by reducing the heat flow through the opaque building envelope and thereby contributing a major role in providing comfortable living conditions [4]. Despite the fact that a myriad of different insulation types can be considered as equally efficient in reducing the heat flow and providing suitable thermal comfort, when appropriately incorporated in the building envelope, their environmental impact can vary substantially.
Life cycle assessment (LCA) has been proven as a useful tool in evaluating the impact on the environment and human health of various goods and services [5]. The presented study focuses on the environmental impact of various thermal insulation materials in the cradle to gate life cycle stages. However, the goal of this study was not to determine the type of insulation material with the lowest environmental impact. Rather, the goal was to elaborate a comparative analysis of thermal insulations and obtain a sense of impact that different insulation materials have on the environment. The analysed insulation materials were separated in three groups; inorganic-synthetic, organic-synthetic and organic-natural. Based on this classification we will try to pinpoint typical drivers that influence the environmental impacts in each group and emphasize the differences between them.

2. Methodology and materials

2.1. Environmental data
The LCA data of the analysed insulation products were collected through EPD-s from the program operators Institut Bauen und Umwelt e.V. and Bau EPD GmbH, members of the ECO Platform (http://www.eco-platform.org/). This approach enabled us to evaluate LCA data of widely used building products that are sold on the EU market.

The LCA results reflect the cradle to gate life cycle stages (A1 – A3). We are focused on the environmental categories defined in EN 15804 [6]: Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP), Eutrophication Potential (EP), Abiotic Depletion Potential of Elements (ADPE) and Abiotic Depletion Potential of Fossil resources (ADPF). The defined functional unit is 1 m$^2$ of the insulation material with its thickness adapted to the thermal transmittance of 0.25 W/(m$^2$K).

For each insulating material as many as possible EPD-s were collected. Each EPD had to be ISO 14025 [7] and EN 15804 compliant, and the EPD-s that lacked the results interpretation were excluded. The results interpretation in the EPD-s is of vast importance for us, as it provided information about the most important factors that determine the environmental impact of a certain environmental category. The LCA results used for each insulation in the study are the average values of the insulation products. These values can be considered as average environmental characteristics of insulation products sold on the EU market.

The described methodological approach has its flaws, which need to be accounted for. The life cycle inventory (LCI) of the insulation products is usually a combination of manufacturer provided data from the production plants and generic data from an LCI database. Two databases are commonly used, the GaBi and Eco invent database. Although the first one is used in the majority of the analysed EPD-s, using different databases can lead to disparate LCA results. Another aspect to consider is the fact that EPD-s do not provide information about which midpoint life cycle inventory method (LCIM) was used to perform the LCA study. Using different midpoint LCIM methods (e.g. CML2010, ILCD) can also affect the LCA results [8]. This is the main reason why we will focus on identifying those drivers that influence the environmental impact, rather than evaluating which insulation materials are less or more preferable from the environmental perspective.

2.2. Insulation materials

Altogether 15 insulation products were analysed. The inorganic-synthetics are glass wool (GW), low and high density stone wool (LdSW, HdSW) and foamed glass (FG). The organic-synthetic group consist of expanded polystyrene (EPS), expanded polystyrene with infrared reflectors (EPSir-r), extruded polystyrene (XPS), polyurethane (PU), polyisocyanurate (PIR) and phenolic boards (PHE). The insulations in the organic-natural group are low and high density wood fiber boards (LdWF, HdWF), cellulose fiber (CF, loose cavity insulation) and straw bales (SB). Also the environmental impact of vacuum insulation panels (VIP) is analysed, but based on its specific characteristics (composite insulation product consisting of the core material, in our case fumed silica, and vapour resistant barrier foil) we observed it separately as it did not fit in any of the defined groups.
3. Results
A brief overview of the results (figures 1–7) shows that VIPs are the most impactful in almost all the categories, except the POCP one. Although for other insulations the impact in each category is influenced by various factors, for VIPs the majority of the environmental burden (over 90%) can be contributed to processes related to extraction and production of the core material, namely fumed silica. In the GWP category (figure 1), we can notice that all the organic-natural insulations show a net negative impact. That is due to the CO₂ sequestration in wood and straw. This means that there is more CO₂ stored in the materials, than CO₂ equivalent greenhouse gases are released during the defined life cycle phases.

![Figure 1. GWP of the analysed insulation materials.](image)

Besides VIP, the PU and PIR insulations stand out in the ODP category (figure 2). This can be assigned to the production processes related to the basic raw materials (A1) methylene diphenyl diisocyanate (MDI) and polyol.

![Figure 2. ODP of the analysed insulation materials.](image)

Due to the pentane emission in the production process of EPS and EPSir-r (A3) they show the largest impact in the POCP category (figure 3).

![Figure 3. POCP of the analysed insulation materials.](image)

The AP potential (figure 4) is closely related to the emissions during the production process (A3) and the processes of raw material acquisition and processing (A1). Besides VIP, HdSW has the largest AP.
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7) due to the energy part of the basic raw material and in CF boric acid – something in common, shifting from the ADPE in figure 5. The major contributor is the use of farming machinery (diesel) – for sowing, harvesting and fertilising – and the use of fertilisers and pesticides.

Figure 4. AP of the analysed insulation materials.

Interesting to note is that SB has a profound impact in the EP category compared to other materials (figure 5). The major contributor is the use of farming machinery (diesel) – for sowing, harvesting and fertilising – and the use of fertilisers and pesticides.

Figure 5. EP of the analysed insulation materials.

Surprising is the high ADPE score (figure 6) for CF and GW insulation. However, they have one thing in common, that is the use of boron compounds: in GW borax pentahydrate (Na₂B₂O₇·5H₂O) as part of the basic raw material and in CF boric acid (H₃BO₃) for the protection against fire and insects.

Figure 6. ADPE of the analysed insulation materials.

Besides VIP, the FG insulation boards show the largest contribution in the ADPF category (figure 7) due to the energy usage for melting the raw materials in the electric furnace (up to 1300°C) and the curing in the cellulating oven at 850°C.

Figure 7. ADPF of the analysed insulation materials.
4. Discussion

Inorganic-synthetic materials: Their production process (A3) strongly determines their environmental impacts, as a great amount of energy is needed and emissions are released when melting the mineral materials (up to 1300°C for GW and FG and approx. 1500°C for SW). In the case of GW and SW the added binders (usually phenol formaldehyde resin) also contribute a notable part to the environmental impact, although they present only a small percent of the mass share (3%–9%).

Organic-synthetic materials: Processes related to the provision of raw materials (polystyrene for EPS, EPSir-r and XPS, MDI and polyol for PU and PIR and phenolic resin for PHE) determine their environmental impact in all the categories except the POCP one. In this category, emissions during the production phase are detrimental. For EPS and EPSir-r it is the pentane emission and for the othersthe emissions of the used blowing agents (e.g. CO₂, HFO 1234 ze, etc.).

Organic-natural materials: Basic raw materials (wood, cellulose, straw) have a minor environmental impact compared to the impact of the production process and the one related to other additives (binders, fire retardants, insecticides). Although different factors determine the environmental impact of WF insulation (production process, additives), the conclusion regarding the environmental impact of CF and SB insulation is straightforward. The environmental impact of the former is defined by the mineral fire retardants and boric acid, and of the latter by the activities related to sowing (use of farming machinery – diesel), harvesting, fertilising (fertiliser) and pest control (insecticides), which is most notable by the high impact of the EP category (figure 5).

5. Conclusion

This study investigated the environmental impact of different insulation materials (products) in the cradle to gate life cycle phases. They were separated in three groups: inorganic-synthetic, organic-synthetic and organic-natural. The drivers which influence the environmental impacts were highlighted and based on the grouping, conclusions regarding their environmental impacts were made. The study showed that there are parallels concerning the factors that influence the environmental categories between the insulations in each group and that for each of the defined groups, specific drivers influence the environmental impact.

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