ОЦЕНКАТА НА ЖИЗНЕНИЯ ЦИКЪЛ НА СТРОИТЕЛНИТЕ ПРОДУКТИ (LCA) КАТО КРИТЕРИЙ ЗА ПРИЛОЖЕНИЕТО ИМ В СТРОИТЕЛСТВОТО

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LIFE CYCLE ASSESSMENT (LCA) – BASED SELECTION OF CONSTRUCTION MATERIALS

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Abstract:
Nowadays, there is an increased concern about the environmental burden of construction sector. A lot of measures are taken to reduce the energy, water and resource demand of buildings throughout their life cycle. Efforts are normally focused on the use stage of a building as it is of longest duration. However efficient this approach, attention need also to be paid to the other life cycle stages, e.g. manufacturing of construction materials and products, processes on the building site and end-of-life stage. Some products are of increased interest, e.g. ETICS (External Thermal Insulation Composite System) due to their contribution to the energy efficiency during the use stage of buildings. The article presents a life-cycle oriented approach to estimate the different variables that have impact on ETICS' environmental footprint. The main environmental impacts of ETICS system using expanded polystyrene (EPS) boards as a thermal insulation are analysed. The effect of different thicknesses of EPS and of different renders is discussed. These issues are actually part of Environmental product declarations (EPDs), which are specified by Regulation 305/2011 for substantiating the sustainable use of construction products. EPD is based on a detailed life cycle analysis (LCA). Therefore, LCA can be regarded as an important source for estimating the initial environmental burden of a building and thus, at a design stage, it can serve as a tool for appropriate choice of construction products.

Keywords:
Construction Products, environmental footprint, EPD, ETICS, LCA

1. INTRODUCTION

Nowadays, sustainability of construction sector is among the key fields of industrial innovations. In order to assess the achieved level of sustainability a large number of parameters need to be considered. A modern building is required to provide technically safe, energy efficient and healthy environment at reasonable cost with little or no stress on environment. A variety of

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evaluating tools, standards and building certification systems are available to assess building's performance with respect to its social and economic dimension as well as ecological impact. The categories under evaluation are differently prioritized depending on regional factors, e.g. availability of resources, industrial and machinery advances, established practices, etc.

Construction products and materials, being an irrevocable part of a building's life cycle, are among the key factors to be analysed. A building has three interrelated stages of existence: construction, operation and demolition. Construction forms the input flows for the operation stage of the building, operation in turn forms the potential for reuse, recycling and landfill waste. Building materials are part of all three stages; they serve as an input and form the output of a building at the end of life stage.

The sustainable approach for buildings has identified lifecycle-based Environmental product declarations (EPDs) of construction products as an important certificate of their environmental performance. Despite their voluntary status more and more manufacturers recognize EPDs as a way to improve their products and to declare responsibility for energy and resource efficiency.

2. METHODOLOGY

2.1. Life cycle assessment (LCA) and EPDs of construction products

An EPD is "an independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products" [1]. There are three types of EPDs. *Type I* is an eco-label approved by a third- party organization (governmental or non-profit organizations) indicating environmental advantages in a common sense based on parameters of the life cycle of products. *Type II* is a self-declared non-verified environmental claims, graphs, symbols by manufacturers used for marketing and advertising purposes. *Type III* is a disclosure of the life cycle environmental performance of products using pre-determined parameters. *Type III EPDs* are built upon *Life cycle assessment (LCA).*

The LCA is a relative quantitative approach for evaluation the environmental impacts of a certain product, process or system. It accounts for all input and output flows and can have different scope (fig. 1).

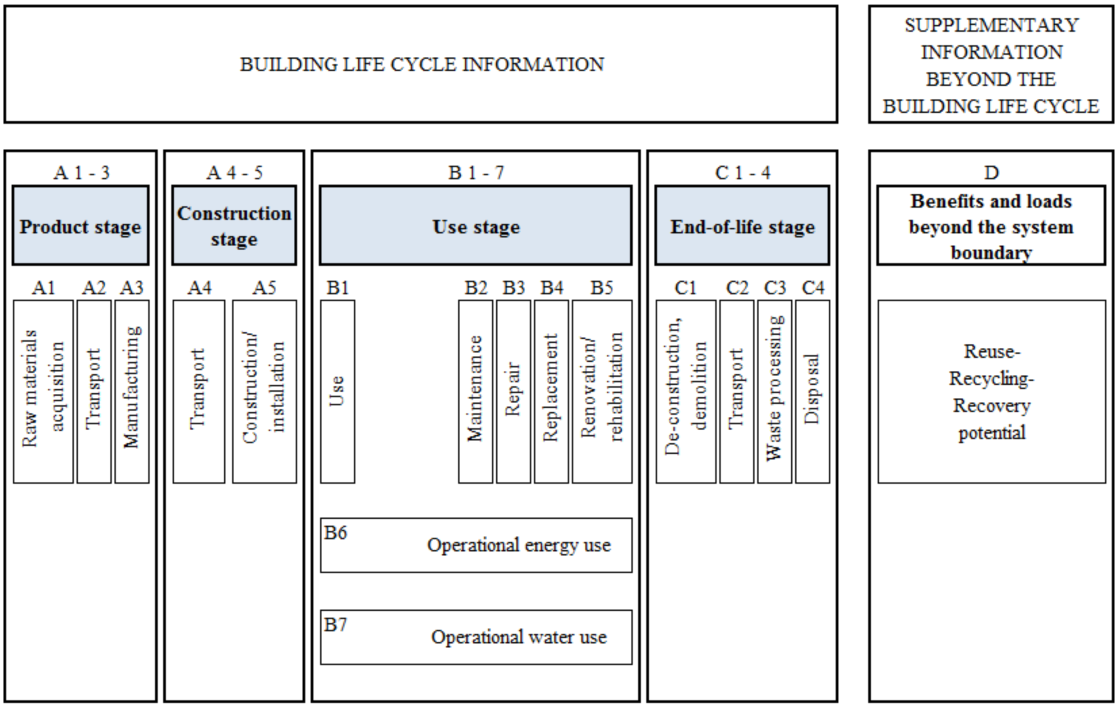

Figure 1. Life cycle stages and modules [2].

The scope of LCA depends on the purpose of the study – cradle-to-gate (Product stage), cradle-to-gate with options (Product stage plus modules from the Construction, Use or End-of-life stages), cradle-to-grave (the whole life cycle of the product) and cradle-to-cradle (the whole life cycle plus recovery processes and end-of-waste state).

The content and format of EPDs are equivalent for groups of products that fulfill equivalent functions (e.g. 'thermal insulation') and are determined by *Product Category Rules (PCR)*. These EPDs are independently verified by third-party experts and can serve as a basis for comparison of construction products in terms of environmental impacts.

Development and publication of Type III EPDs is a subject of a number of CEN and ISO standards among which EN 15804, 15941 and 15942 [2, 3, 4] and ISO 14040, 14044 and 21930 [5, 6, 7].

2.2. Product description and field of application

This study provides a closer look at the Product stage of an External Thermal Insulation Composite System (ETICS).

The ETICS is intended for installation on external walls of various building types (offices, residential buildings, public and commercial buildings, etc.). It is composed of the following layers: a) Bonding (adhesive) layer, which serves to ensure the adhesion of the thermal insulation (b) to the insulated wall. Usually this mortar is based on cement and polymer-modified cement bonder; b) Insulation layer is usually of expanded polystyrene (EPS) or mineral wool. Other materials with low thermal conductivity such as cork, expanded polyurethane, etc. can also be applied. The thickness of the thermal insulating layer varies according to the requirements for the thermal conductance coefficient (U-value) of the insulated wall; c) Coating layer is also a cementitous mortar and serves to coat the thermal insulation layer and to receive the (d) reinforcing layer of fibre mesh (typically glass fibre mesh); e) Primer serves to improve the adhesion of the last, finishing layer – the Render (f). Primer is a very thin layer and its chemical composition depends on that of the Render; f) Render can be acrylic, silicate, mineral or silicone. It is a fine grained mortar. It is white, but can be coloured (prior or, rather, after its production) by small amount of pigments. Mechanical fixings as anchors are also used for the attachment of the insulation layer. They are usually plastic or of combination of steel and polymers.

2.3. Case study of External Thermal Insulation Composite System (ETICS)

The study is based on the EPDs of two ETICS systems.

The *first EPD* is for an ETICS product "weber.therm Family", offered by Weber, Saint-Gobain Construction Products, Bulgaria. The Bulgarian branch of the company produces the dry mix for the bonding and coating layers. The system will be referred further as "Weber ETICS"[8].

The *second EPD* is on ETICS "CERESIT CERETHERM CLASSIC" issued by the Building Research Institute (ITB), Poland under ref. No. 032/2016. The manufacturer is the Polish branch HENKEL Operations Sp. Z o.o. of another leading construction products producer [9]. The system will be referred further as "Ceretherm ETICS". It is also based on EPS boards which thickness varies as 10, 12, 15, 20 and 25 cm respectively. Five types of render have been evaluated – acrylic, silicate, mineral, silicone and silicate-silicone.

2.4. Goal and scope of the study

The purpose of this study is to present the main environmental impacts of ETICS system using expanded polystyrene (EPS) boards as a thermal insulation and to analyse the relative share of ETICS components on the environmental impacts and the contribution of different processes (supply of raw materials, transport, manufacturing, packaging). The effects of different thicknesses of EPS and of different renders are assessed.

The impacts on GWP and ODP of each ETICS component is evaluated on the base of its average composition and a typical production line and supply chain for ETICS.

The input and output flows in LCI and LCIA procedures are calculated for declared unit 1 m^2 of the Weber ETICS with specified ingredients and technical performance. The same declared unit is used in the EPD of Ceretherm ETICS.

The life cycle analysis of the examined products covers "Product Stage", A1-A3 modules (Cradle to Gate) in accordance with EN 15804+A1 and ITB-PCR A.

Details on Ceretherm ETICS systems limits are provided in product specific report. All materials and energy consumption inventoried in factory are included in calculation. In the assessment, all significant parameters from gathered production data are considered, i.e. all material used per formulation, utilised thermal energy, internal fuel and electric power consumption, direct production waste, and all available emission measurements.

The modules included in the LCA for the Weber ETICS are presented in table 1. Since the Bulgarian manufacturer of the Weber ETICS has no control and influence on the manufacturing processes of the EPS plates, mechanical fixings, glass fibre mesh, primer and plaster, these constituents are considered in this study by their substantial composition and transport to the Weber ETICS manufacturer.

Table 1. Modules covered in the LCA report for the Weber ETICS

Weber ETICS elements	**Life cycle modules covered in the study**		
	A1 Raw materials and pre-products	**A2 Transport to factory**	**A3 Manufacturing (ETICS)**
Bonding (adhesive) mortar	☒	☒	☒
EPS	☒	☒	☒
Coating mortar	☒	☒	☒
Mechanical fixings	☒	☒	☐
Glass fibre mesh	☒	☒	☐
Primer	☐	☒	☐
Render	☒	☒	☐

2.5. Life cycle inventory analysis for the Product stage of Weber ETICS (A1-A3 modules)

As presented on figure 1, the *Product stage* includes modules *A1*, *A2* and *A3* together with all materials, products and energy, packaging processing and its transport, as well as waste processing up to the end-of waste state or disposal of final residues during the product stage. Figure 2 shows the processes in A1-A3 modules for the bonding and coating mortar.

Data collection and calculation procedures for Ceretherm ETICS are summarized in the EPD [8]. Factory-prefabricated boards made of EPS, mesh glass fibre and anchors are not produced by HENKEL [8]. The impacts of those products were included from databases *Ecoinvent, EMPA, Ullmann's, Plastic*-*Europe, ITB-Data, SPC and CML ver. 4.2* based on EN 15804:2013+A1 version.

For the Weber ETICS, all relevant inputs and outputs related to the products or product systems are identified and quantified. The typical production process of the bonding and coating mortar is presented in Figure 2. Generic data from *ecoinvent v.3.3* database is used to model the ETICS components that are delivered by external suppliers and the manufacturer does not have influence on their production processes.

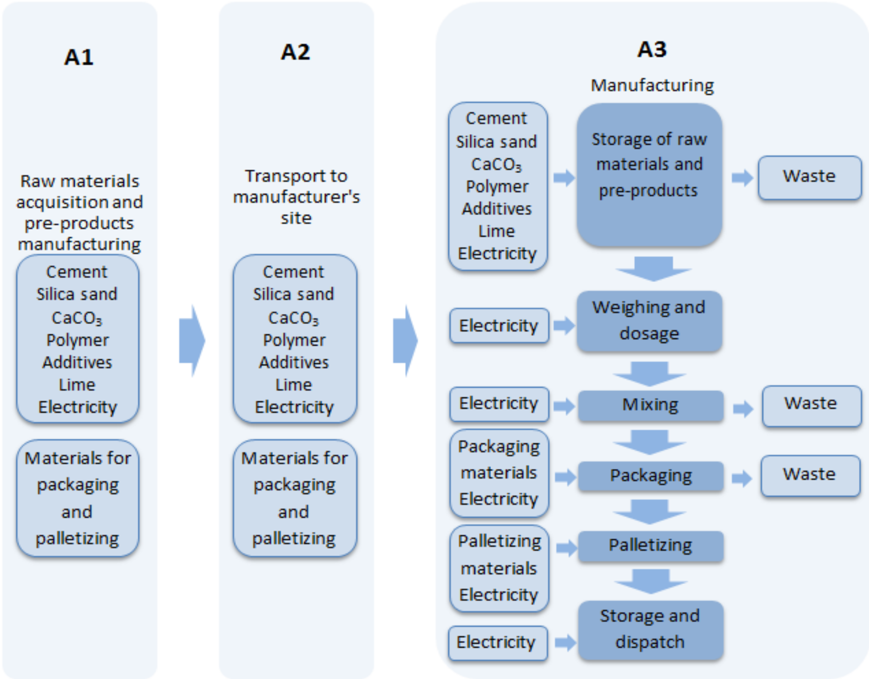

Figure 2. Modules A1-A3 (Product stage) of the bonding and coating mortar at Weber ETICS

2.6. Life cycle impact assessment

The assessed impact categories are in accordance with the provisions of EN 15804. The herein made analysis includes the impact categories listed in table 2.

Table 2. LCA impact categories

Impact category	**Unit**
Global warming potential – GWP	kg CO_2–eq.
Depletion potential of the stratospheric ozone layer – ODP	kg CFC 11–eq.
Acidification potential of soil and water – AP	kg SO_2–eq.
Photochemical ozone creation potential – POCP	kg Ethene–eq.
Eutrophication potential – EP	kg $(PO_4)^{3-}$–eq.
Abiotic depletion potential (ADP-elements) for non-fossil resources	kg Sb–eq.
Abiotic depletion potential (ADP-fossil fuels) for fossil resources	MJ
Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials) – RPERM	MJ
Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials) – NPERM	MJ

3. INTERPRETATION OF THE RESULTS

The environmental impacts increase with the increase of the EPS thickness (from 8 to 12 cm) as the material quantities are higher and, therefore, form higher environmental impacts (fig. 3). As shown on Figure 3 the increase varies for the different impacts from less than 1% for ADP-elements to 10-20% for GWP, POCP (20%) and ADP-fossil fuels (12-14%). The increase of ODP, AP (10-12%) and EP is on average 5–10 % per every 2 cm EPS added. On average, the increase in the total use of renewable energy resources around 4% per every 2 cm of EPS and for the total use of non-renewable resources the increase is within the range of 12-14 %.

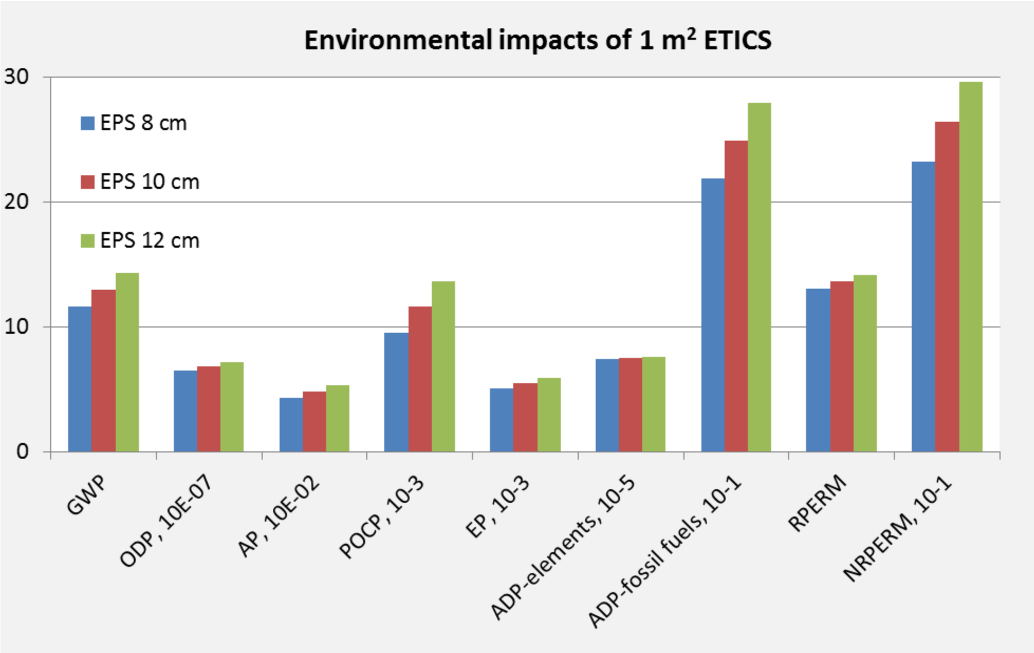

Figure 3. Increase of the environmental impact values of the Weber ETICS with increasing the thickness of the EPS board [8]

LCA results of multi-component products and building elements, like the ETICS under study, can sometimes be difficult to predict when changes are made in the proportions of constituents. In this case, EPS holds for around 10-15% share of the total mass of the ETICS, but its contribution on some impacts is significant, so even small increases in the amount (additional 2 cm in thickness) can cause 10-20% increase of the environmental impacts.

For example, based on other author’s studies, the major share (around 50%) of the ETICS’s CO_2 emissions originates from the manufacturing of the EPS (the expanding polystyrene process) — figure 4. The reason is that the production process for EPS is energy intensive and the raw material (polystyrene) requires specific chemical treatment. Around 30 % of the GWP comes from the Bonding mortar, namely from its ingredients acquisition, especially from highly energy intensive cement production process, and from the transport of these ingredients.

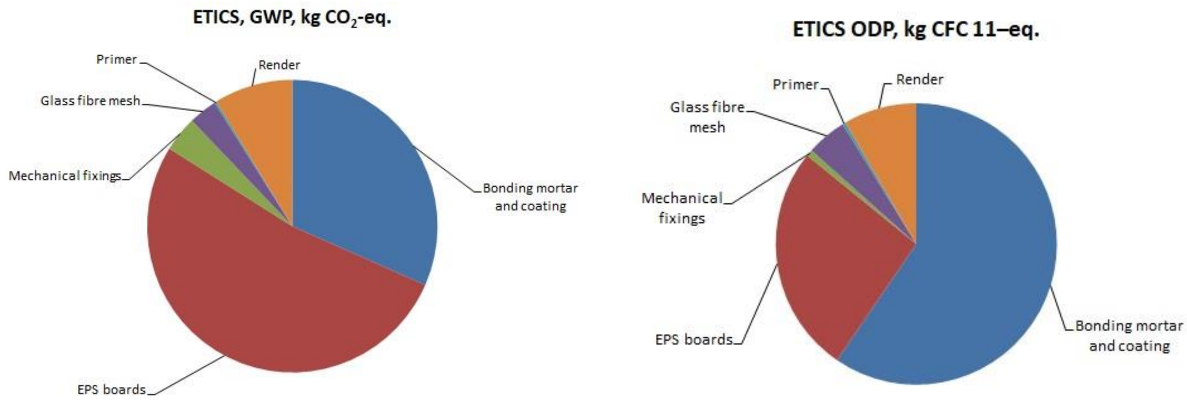

Figure 4. Contributions of different components of EPS-based ETICS to GWP and ODP.

The same ETICS’s compounds are responsible for the depletion of the stratospheric ozone layer (ODP), but in a reverse order – due to the composition and manufacturing process of the bonding mortar, its share is around 60% in the overall ODP, while EPS layer forms around 25 %

(fig. 4). Such detailed assessment and interpretation of the results is crucial for identification of the harmful potentials of a product or product system.

The great impact of the EPS on the overall environmental impact of ETICS has been confirmed by the EPD on Ceretherm. A linear relationship can be established between the GWP of the system and the thickness of EPS boards (fig. 5). The relationship is similar for all types of renders, because the render itself has a relatively limited contribution to the GWP of the whole system. However, at a constant thickness of EPS (10 cm), the type of Render has a significant effect on the environmental impact of ETICS – the GWP increases by up to 20% when the acrylic render is replaced by a mineral render and by about 10% when silicate, silicone and silicate-silicone are used instead of acrylic (fig. 6).

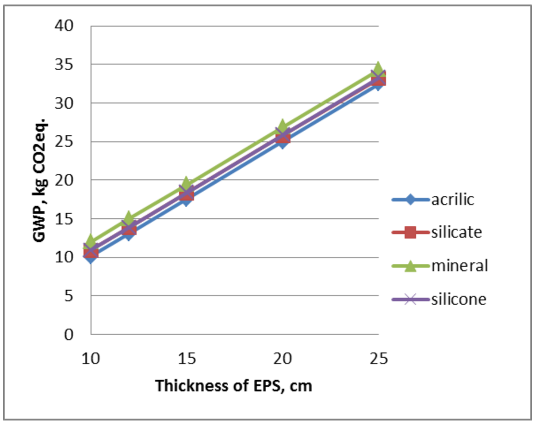

Figure 5. Impact of EPS thickness on the GWP of Ceretherm ETICS [9]

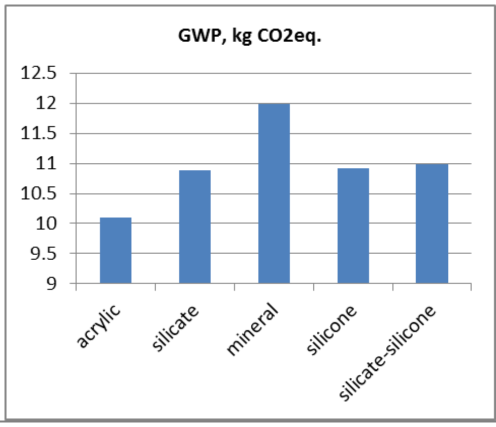

Fig. 6. Impact of the Render’s type on GWP of Ceretherm ETICS (EPS=10 cm) [9]

As mentioned above, the impact ADP-fuels is formed mainly the manufacturing of the EPS board. It is then expected that the impact of the render’s type will be unsignificant – fig. 7. However, the impact of mixed silicone-silicate render on ADP-fuels is bigger by approximately 50% compared to the other types of renders. .

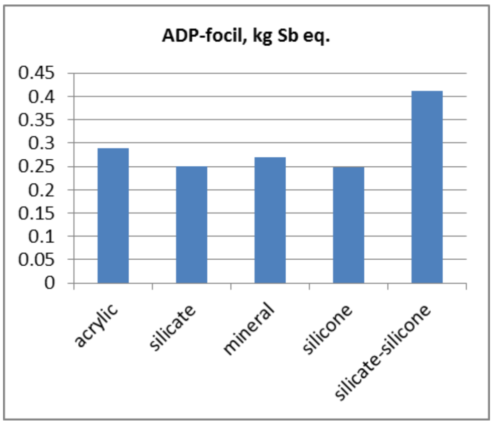

Figure 7. Impact of the Render’s type on ADP-fossil of Ceretherm ETICS (EPS=10 cm) [9]

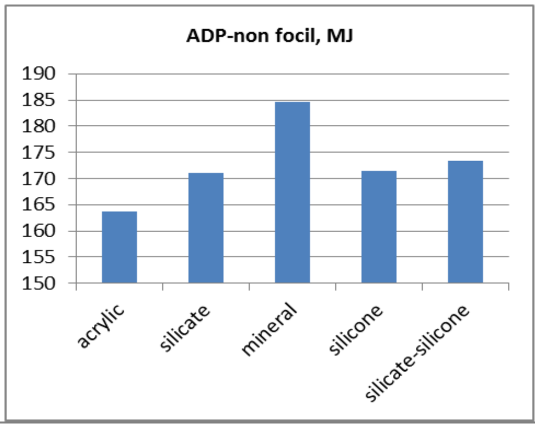

Figure 8. Impact of the Render’s type on ADP-elements of Ceretherm ETICS (EPS=10 cm) [9]

The range of ETICS in terms of ADP-non-fuels (ADP-elements) is quite different –the ETICS based on silicate, silicone and silicate-silicone renders have similar environmental impact, the mineral render leads to a greatest impact, while the smalest impact can be identified with acrylic render (fig. 8).

Although a certain difference in renewable primary energy ressources consumption of different ETICS can be identified, the small absolute values do not allow to draw a certain conclusion (fig. 9). In terms of non-renewable energy ressources, the use of acrylic render ensures the smallest value of that indicator, while the mineral render involves the biggest ressource consumption (fig. 10).

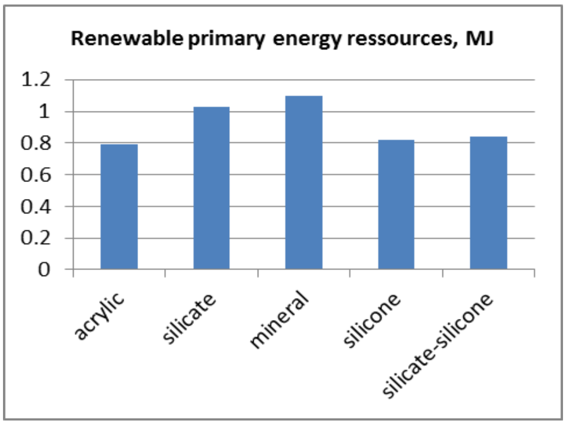

Figure 9. Impact of the Render’s type on RPERM of Ceretherm ETICS (EPS=10 cm) [9]

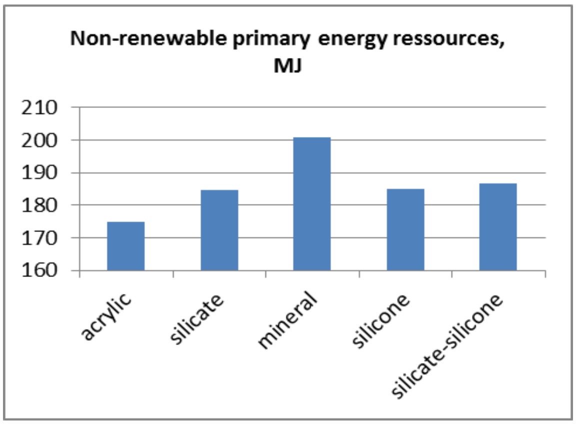

Figure 10. Impact of the Render’s type on NPERM of Ceretherm ETICS (EPS=10 cm) [9]

4. CONCLUSIONS

The benefits from using the LCA approach in the construction sector has already been recognised in building certification schemes, EPDs, national strategies for sustainable construction and criteria for green public procurement of roads and office buildings, etc. This study illustrated the advantages of LCA not only for quantifying and assessing the environmental impacts, but also for a more sophisticated analysis regarding contributions of constituents (EPS) in more complex construction elements and systems (ETICS).

It is clear from the examples in this paper that interpretation of the results from the impact assessment must be carefully done regarding the significance of the individual sources. This is particularly important for the case of multi-component systems like ETICS where the additional analysis confirms that contributions vary across the different indicators and identification of general trends is not always possible. The case with the ETICS examples is interesting as there can be various combinations with multitude of product types, e.g. the insulation layer can be from EPS or mineral wool or cork; the rendering mix can be of acrylic, mineral, silicate or other types, etc. It is within the potential of LCA to cover such variables in a transparent and objective manner.

As a result, the LCA assessment can serve for a starting point for optimizations of the manufacturing of ETICS in terms factory processes and better supply chain of the products, including resources delivered by external companies. LCA provides methodology for evaluation of varying quantities and compositions of components, which can serve as a basis for comparison between different options and can be helpful for the decision making process during design and construction of buildings and construction works.

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