TÉCNICO LISBOA

Extended Abstract

Environmental impact of thermal renders

Isabel Filipe Silva dos Anjos Pinto

Master Dissertation in

Industrial Engineering and Management

Supervisor: Prof. José Dinis Silvestre (IST)

Co-Supervisor: Prof. Jorge Manuel Caliço Lopes de Brito (IST)

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1. Introduction

The European Union (EU) has established climate and energy policies in order to reduce the carbon footprint of this region. In October 2014, new policies were established to reduce greenhouse gases emissions by 80-95% (compared to 1990 levels), so that the Earth's temperature does not increase by more than 2 ºC. One of these policies involves improving energy efficiency by 27%. The construction sector accounts for about 40% of the EU energy and 25% of water consumption, and 1/3 of greenhouse gases emissions (Pinheiro, 2006; Bragança et al., 2013). Thus, it becomes evident that there is a need for change and new solutions must be found, both in the raw materials used in the construction of buildings and corresponding production processes (of raw materials and finished products), and in the end-of-life processing of the buildings components.

This dissertation was developed within the scope of a research project entitled *Nanorender: Performance of nanoaerogel silica-based renders*, funded by "Fundação para a Ciência e Tecnologia" (FCT). The main objective of this dissertation is to determine and evaluate the environmental impacts of the life cycle of three versions of a silica-based aerogel that is used as aggregate in mortars for wall renders. These aerogels are produced using a subcritical drying process, which is more economical and secure than supercritical processes (Julio et al., 2013). The environmental assessment was carried out through the Life Cycle Assessment (LCA) methodology, according to ISO 14040 standards series and using a cradle-to-gate approach. These life cycles were: modelled using the information on their production collected in the Chemistry laboratory of *Instituto Superior Técnico* (IST), Lisbon; built in the LCA software SimaPro. Additionally, the environmental impacts of reference mortars, and industrial and laboratorial thermal mortars (the later with those aerogels in their composition), were analysed.

2. Research methodology

The evaluation of the three versions of the silica aerogel was carried out using the LCA methodology, which can be described as a "compilation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (NP EN ISO: 2006). LCA evaluates each stage of the life cycle of a product or process and enables a more rational choice of materials according to their environmental impacts throughout the life cycle of buildings, paving the way for a more sustainable policy.

According to ISO 14040 and 14044, the LCA process includes four phases: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA) and (4) interpretation. These phases are described below:

(1) Goal and scope definition - at this LCA phase, the objectives of the study are identified, as well as the functional unit, system boundaries, assumptions and limitations;

(2) Life cycle inventory - data regarding the system under study are collected and processed in order to identify and quantify the inputs and outputs of materials and energy (e.g. emissions to the atmosphere, disposal of solid waste, effluent discharges);

(3) Life cycle impact assessment - in the third phase of LCA, a quantitative assessment of the effects of the inputs and outputs of materials and energy on the environment and human health is made. Inventory results are subsequently transformed into environmental impacts grouped into categories;

(4) Interpretation - the interpretation of the life cycle is the last stage of the LCA process. The results of stages 2 and 3 (life cycle inventory and impact assessment) are discussed and evaluated, allowing conclusions and recommendations to be drawn, which can lead to a decision being taken in accordance with the objective and scope of the study.

SimaPro software was used for the life cycle assessment. Environmental impacts were assessed in two impact categories using cumulative energy demand impact assessment method, and in six other impact categories using CML 2001 impact assessment method, including abiotic depletion (ADP), acidification (AP), eutrophication (EP), global warming (GWP), ozone layer depletion (ODP) and photochemical oxidation (POCP) potential.

For the evaluation of the environmental impacts of wall rendering mortars, impacts have been quantified for each category of environmental impact and raw material, and were multiplied by the corresponding amount in each mix.

3. LCA study

The LCA study involved the analysis of three types of silica aerogels - Inorganic Aerogel (IA), and two hybrid aerogels in different forms - powder (HYB-A) and monolithic (HYB-C). These aerogels are synthesized using subcritical drying in the Chemistry laboratory of IST.

3.1. Functional unit

The functional unit of the present LCA study is defined as 1 kg of aerogel produced. For thermal renders, the functional unit is 1 m^2 of mortar 4 cm thick applied in a wall.

3.2. System boundaries, assumptions and limitations

The system boundary intends to define the unit processes to be included in this LCA study. Figure 1 shows a life cycle of a construction material from cradle-to-grave.

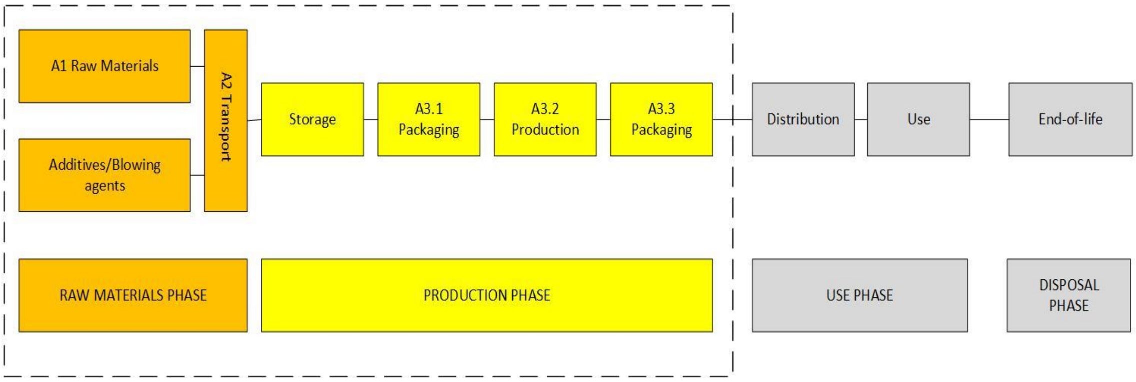

Figure 1 - Life cycle of a construction material form cradle-to-grave (adapted from Pargana, 2012)

The boundaries in the life cycle of the three aerogels and of the mortars studied are:

- (A1) - extraction of raw materials and processing phase;
- (A2) - transportation to the place of production;
- (A3) - production, and waste from production and from raw materials packaging;

  - (A3.1) - packaging;
  - (A3.2) - production flows;
  - (A3.3) - waste generated in production, including packaging waste.

In this study, only the raw materials and production phases were considered (A1 to A3). The use and disposal phases were not considered in the comparison of aerogels and of mortars because they are identical for all the solutions compared.

Some limitations of the LCA study have been identified:

- In the inventory phase, data regarding the amount of raw materials and packaging consumed, and of waste from production and packaging, were obtained through questionnaires answered by the person in charge of the production of aerogels in the Department of Chemistry of IST. However, data on the extraction and production of raw materials, transports and production of electricity were obtained using existing databases in SimaPro software (e.g. Ecoinvent);
- The environmental impact assessment is expressed only in six environmental impact categories and two environmental indicators;
- The study is limited to the system boundaries;
- The study refers to the production at a laboratorial scale;
- Regarding the modelling of the production of the three aerogels, consumables (bottles used for the synthesis of aerogel) were not considered since they are reused.

3.3. Life cycle inventory (LCI)

The production stages of the aerogels analysed are: 1. Reception of raw materials; 2. Transportation and storage of raw materials; 3. Aerogel production; 4. Mixing, packing and transportation of the aerogel. Figure 2 details the production of IA. The production of HYB-C is similar to the production of IA (Julio et al., 2014).

In SimaPro, these processes were modelled into three categories: 1. Mixing; 2. Drying and 3. Packing. Table 1 details the raw materials used in each aerogel and the corresponding processes used in its modelling in SimaPro.

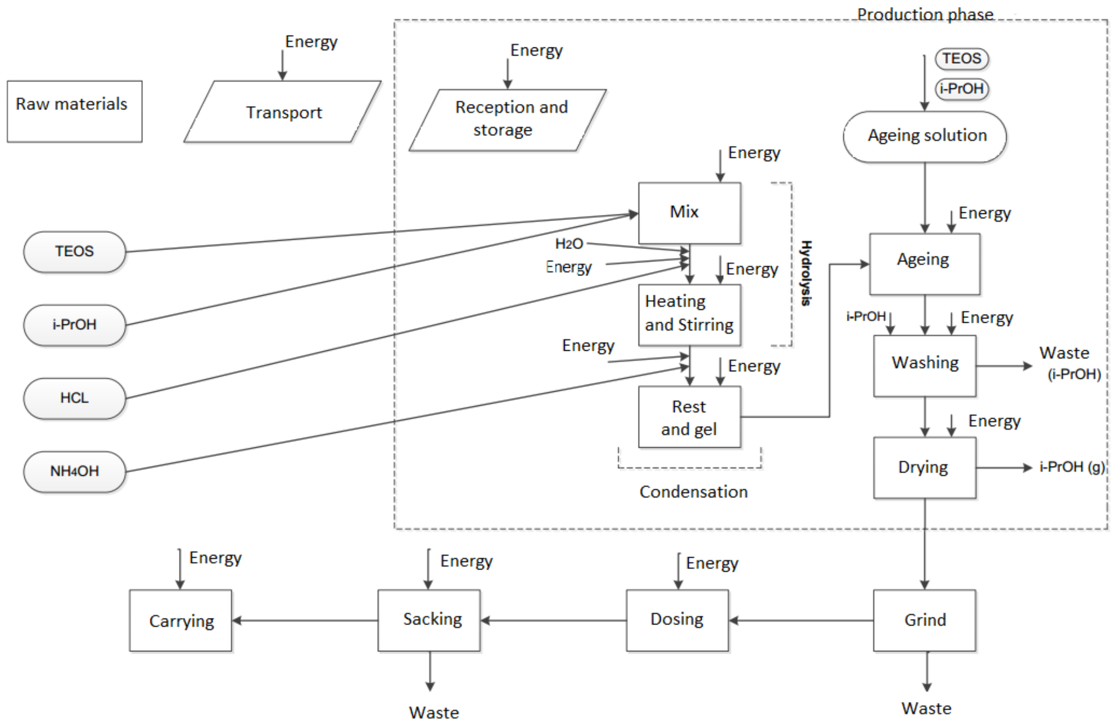

Figure 2 - IA life cycle

Table 1 - Raw materials used in each aerogel and corresponding process used in its modelling in SimaPro

Raw materials		**Aerogel**		
Raw materials	**Processes in *SimaPro***	**IA**	**HYB-C**	**HYB-A**
TEOS	*Tetrachlorosilane [Ecoinvent]*	X	X	
i-PrOH	*Isopropanol [Ecoinvent]*	X	X	
HCl	*Hydrochloric acid [Ecoinvent]*	X	X	
NH_4OH	*Ammonia, liquid [Ecoinvent]*	X	X	
HMDZ	*Hexamethyldisilazane [Ecoinvent]*		X	X
Sodium silicate	*Sodium silicate [Ecoinvent]*			X
HNO_3	*Nitric acid [Ecoinvent]*			X
n-hexane	*Hexane [Ecoinvent]*			X
H_2O	*Water, ultrapure [Ecoinvent]*	X	X	

4. Results

4.1. Aerogel

After the environmental evaluation of the aerogels produced in the laboratory, a comparison was made between them (Table 2).

As shown is Table 2, HYB-A aerogel has the lowest environmental impact in all impact categories. For A1-A3 phases, IA has the highest environmental impact in ADP, GWP, POCP, PE and PE-NR-Re indicators, while HYB-C has the largest impact on the remaining indicators. This difference is due to the raw materials used for the synthesis of each aerogel. IA and HYB-C have a similar composition and therefore have identical impacts. HYB-A does not have TEOS in its composition, the raw material responsible for most environmental impacts, and requires less time to dry which justifies its best environmental performance.

Table 2 - Environmental impacts of IA, HYB-A and HYB-C for the stages A1-A3 (for 1 kg of aerogel)

Indicator	Unit	A1-A3		
		IA	HYB-A	HYB-C
PE-NRe	**MJ**	7,86E+03	1,15E+03	7,42E+03
PE-Re	**MJ**	1,16E+03	5,74E+01	1,15E+03
ADP	**kg Sb eq**	3,83E+00	5,47E-01	3,66E+00
AP	**kg SO_2 eq**	1,36E+00	5,51E-01	1,43E+00
EP	**kg PO_4^{3-} eq**	3,25E-01	1,17E-01	3,29E-01
GWP	**kg CO_2 eq**	4,54E+02	5,60E+01	4,42E+02
ODP	**kg CFC-11 eq**	5,01E-05	7,08E-06	5,08E-05
POCP	**kg C_2H_4 eq**	1,16E-01	2,65E-02	1,02E-01

It was also concluded that IA has the highest environmental impact in A1 phase, followed by HYB-C and HYB-A. In the production phase, A3.2, HYB-C has the highest environmental impact, followed by IA and HYB-A.

4.2. Thermal insulating mortars

Aerogels produced in the IST laboratory were incorporated in mortars. 31 different versions of this construction material were produced in the Construction Laboratory of IST, differing in the amount of binder, aggregates and additions (Soares et al., 2015). The environmental impacts of a commercial thermal mortar was also studied (Patent PT 105937, 2013). Five environmental impact categories were selected for the LCA of mortars: AP, GWP, POCP, PE and PE-NR. The results per kg were converted to the impact of a square meter of mortar with 4 cm thickness, taking into account the respective density.

It was found that mortars with aerogel in their composition have a worse environmental performance. For instance, in mortars # 29 and # 30, aerogel HYB-C is responsible for 97% of the environmental impacts. The environmental impacts of aerogels concern their laboratorial production, which influences the environmental performance of the mortar. This data were also used to calculate the environmental impacts of mortars with commercial aerogel and, therefore, the impact results of such mortars were biased in this way. However, at an industrial scale, these impacts can be mitigated by increasing the batch size and using a continuous production. The use of more efficient equipment also reduces electricity consumption, the main cause of the impacts during the production phase of aerogels and mortars.

The mortars with better environmental performance are the same for the five environmental impact indicators. Mortar #5 is the one that performs better and is composed of cement, lightweight aggregate and water. The main lightweight aggregate used is an industrial by-product and therefore does not have a significant environmental impact associated with its production. In these mortars, the raw material that causes more impact is cement, with a contribution greater than 98%.

Figure 3 shows a comparison between an estimative of the thermal insulation provided by each mortar and the environmental impacts for PE-NRe and GWP categories.

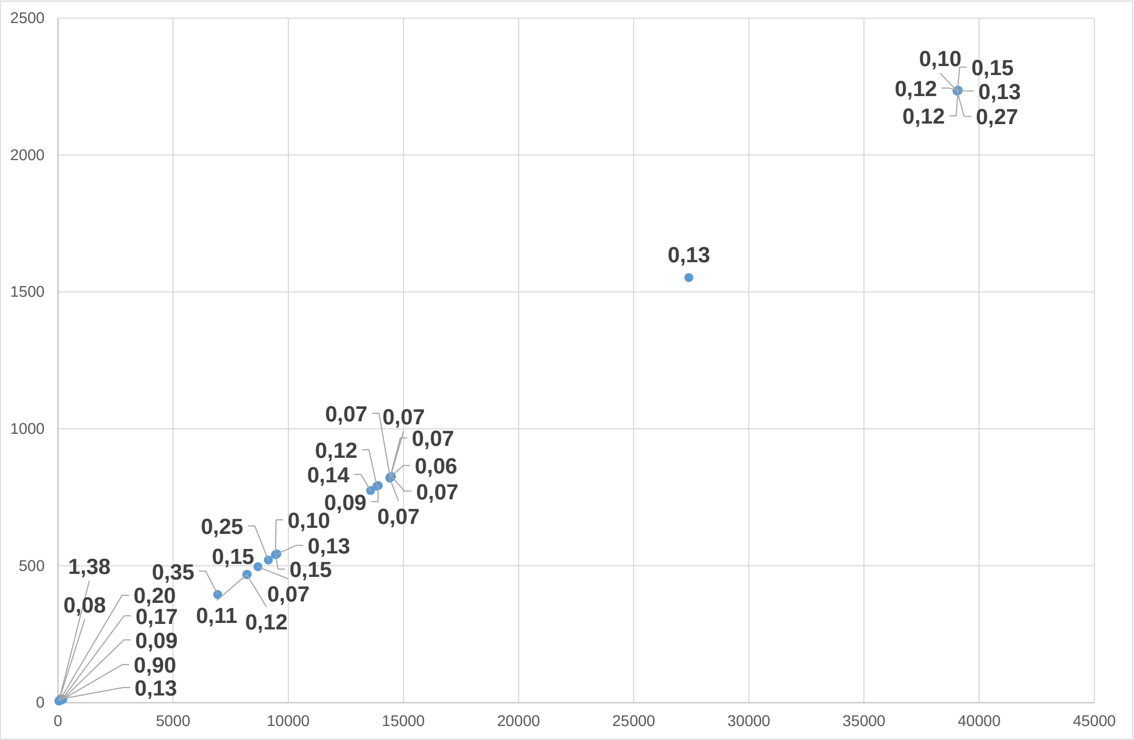

Figure 3 - PE-NRE (in abscissa, MJ), and GWP (on the ordinates, kg CO_2 eq) for commercial mortar and mortars produced in the laboratory where each point corresponds to the thermal conductivity (W/m.ºC)

Mortars # 1, # 2, # 3, # 4, # 5, # 6 and # AC (commercial thermal mortar) have the best environmental performance in all impact categories (Figure 4).

Reference mortar # 1 has the worst thermal performance (λ = 1.38 W/m.ºC), which is an expected result since it does not have lightweight aggregates. Mortar # 2 has a similar composition to that of the reference one, and therefore also has a high thermal conductivity (0.90 W/m.ºC). Mortars # 3, # 4 and # AC have lower thermal conductivity values, but still high (0.20, 0.17 and 0.16 W/m.ºC, respectively), since they have a reduced amount of lightweight aggregates. Mortars # 5 and # 6 have lower thermal conductivity (0.08 and 0.09 W/m.ºC, respectively) but # 5 has lower environmental impacts. These mortars include lightweight aggregates that are by-products of the industry and that give them insulating properties.

Mortars with aerogel in its composition (# 26, # 27, # 28, # 29, # 30 and # 31) have higher environmental impacts. It is important to point out that the aerogel used in these mortars was produced in the laboratory, which negatively influences the outcome of their environmental impacts. However, these mortars do not have the best thermal conductivity values (between 0.10 and 0.27 W/m.ºC). The composition of these mortars is very similar, differing only in the percentage of each raw material, which explains the similar thermal conductivity values.

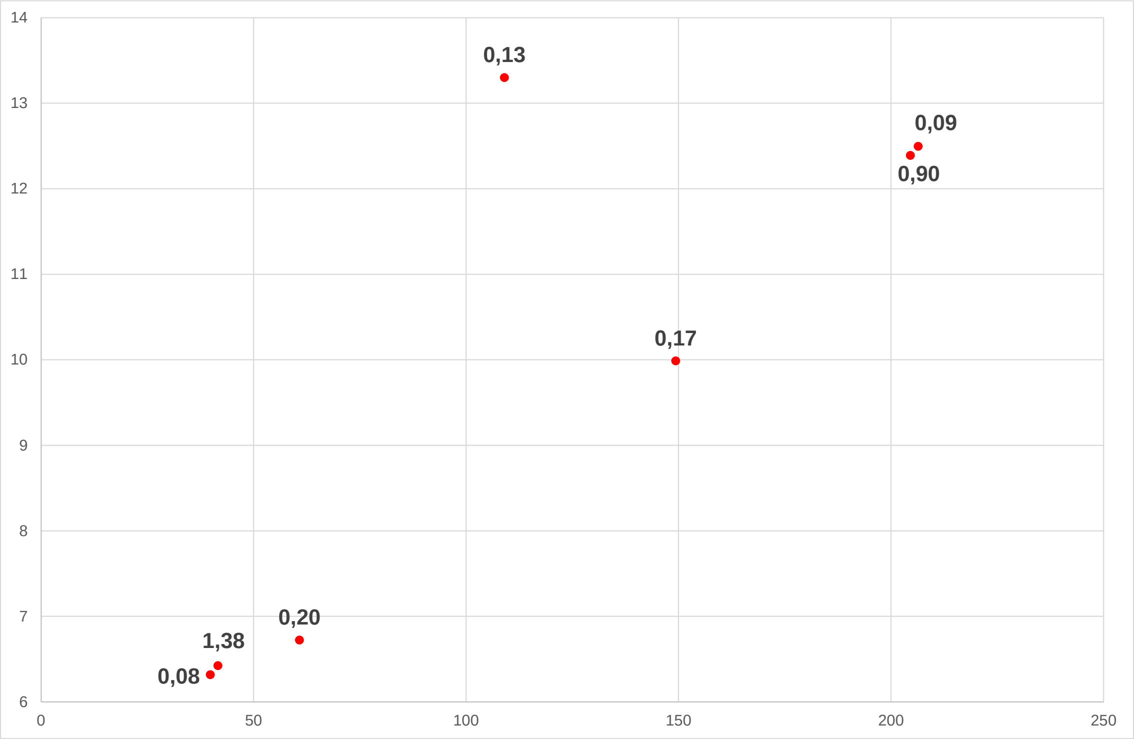

Figure 4 - PE-NRE (in abscissa, MJ), and GWP (on the ordinates, kg CO_2 eq) for mortars with the lowest environmental impact and where each point corresponds to the thermal conductivity (W/m.ºC)

Mortar # 18 features the best thermal performance (λ = 0.06 W/m.ºC) but has relatively high environmental impacts in all impact categories. This mortar was produced in the laboratory with insulating materials that confer thermal properties such as a commercial aerogel (about 19.7%) and hydrated lime (about 79.8%).

5. Conclusions

A Life Cycle Assessment was completed for three versions of a silica-based: Inorganic Aerogel (IA), and HYB-A and HYB-C aerogels. Results regarding the different stages of the life cycle showed that HYB-A aerogel has the lowest environmental impact in all categories, followed by HYB-C and IA. These differences are related with the raw materials used in the synthesis of each aerogel and with the drying time during their production. IA and HYB-C have a similar composition and therefore have identical environmental impacts. TEOS is the raw material that causes more environmental impacts. The amount of packaging used for the final product (A3.1) is very low and therefore hardly contributes to the total environmental impact of each aerogel.

In the production phase, A3.2, HYB-C aerogel has the highest environmental impact, followed by IA and HYB-A. HYB-A aerogel requires less drying time, using less energy, which makes their environmental impacts lower in this phase.

Data about the environmental impacts of aerogels are related to its production in laboratory. To expand to production at an industrial scale, it is estimated that these values can be reduced, although it is difficult to make an estimative of the corresponding reduction.

Results showed that mortars with aerogel in its composition have a worse environmental performance. The environmental impacts of commercial aerogels were calculated based on the average impacts of the aerogels produced in the laboratory, which conditioned the environmental performance of the mortars using this raw material.

On the other hand, mortars with best performance are those with lightweight aggregates in its composition. These aggregates are an industry by-product and do not have a significant environmental impact associated. In these mortars, the raw material that causes major environmental impacts is cement, with a contribution greater than 98%.

When comparing the thermal performance of the mortars with the respective environmental impact, it was found that reference mortar (# 1), made with cement, sand and water, has the worst thermal performance (λ = 1.38 W/m.ºC). Mortars with aerogel have medium values for thermal conductivity.

However, mortar # 5 (λ = 0.08 W/m.ºC), made with cement, lightweight aggregate and water, is the one that offers a better relation between thermal and environmental performance.

As a further development for this study, it would be interesting to carry out a detailed LCA for commercial aerogels, since the data used to calculate the environmental impacts of these aerogels were based on the results of aerogels production in laboratory. Another aspect that could be improved is the adaptation of the aerogel production in laboratory to an industrial scale, making a more realistic quantification of the environmental impacts of these insulation materials.

6. References

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