Long-Term Performance of Super-Insulating Materials in Building Components and Systems

1) Introduction

- Since not all product-specific environmental impacts are currently available, illustrative datasets can play an important role, for both manufacturers and building designers to improve the estimate of the environmental impact of a building and its constituent materials.

2) Status quo of Life Cycle Assessment, Embodied energy and Life Cycle Cost Assessment

- Table 2 shows a summary of LCA studies on VIP's (different products, document type and the building life cycle information) (**Page 4**).

- International projects: Most international LCA studies on VIP were made after 2010, one investigating the reduction of energy consumption in existing buildings (Clear-up) and another looking at state-of-the-art and innovative technology for district heating pipes (FC-District).

- Environmental Product Declarations: **Since several VIP products are out in the market as construction materials, there are a few EPDs publicly available.** As of February 2016, there were 3 EPDs of VIP from 3 different manufacturers, which were declared for Belgium, the US and Germany. The 3 declarations were published in 2013 and 2014, 2 of the declarations included C modules (Cradle-to-grave) based on the Life Cycle Module from EN 15804.

- LCA on SIM applications: Among the collected studies, two scientific articles reported an LCA of VIP application in buildings.
    - One study was from Norway (Lolli & Hestnes, 2014) on retrofitting a residential building, which looked into the carbon emissions of the building with different scenarios of electricity grid mix, as well as the energy demands that depend on the retrofit option. The retrofit option for insulation materials includes aerogel, VIP and Rockwool.
    - Another study from Sweden (Karami, Al-Ayish, & Gudmundsson, 2015) conducted an LCA of residential buildings with a broader scope of environmental impacts. The study investigated the application of VIP to residential buildings compared to traditional insulation materials, including mineral wool and expanded polystyrene (EPS).
    - **The conclusions from both studies were that the life cycle carbon emission of the building using the VIP did not outperform the building with conventional insulation material when the thermal performance of the materials was aligned (the functional unit of the two insulation materials have been brought to the same thermal performance level to make the comparable).** Both studies investigated A1 to C modules for carbon emission, which considers the operational phase.

- Figure 2. Shows the mapping of GHG-emissions from various insulation materials with aligned thermal performance: **the competitiveness of VIP was higher than that of aerogel in terms of cradle-to-gate carbon emission (Page 7).**

- Life cycle cost calculation: The study from (Alam, Singh, & Limbachiya, 2011) investigated the payback time of four material alternatives (glass fibre, foams, perlite and fibre/powder composites) on the achieved insulation performance with VIP and EPS in the UK. **The payback time of installing EPS was less than a year for all cases while the payback time of installing VIP for all cases were more than 7 years when the value of space savings was disregarded. When the effect of space saving was included, the case with VIP installation had a shorter payback time than that of EPS in the scenario with the highest insulating performance requirement.**

3) Life cycle inventory of SIMs

- LCI of Aerogel blanket: Figure representing two drying methods, which are ambient and supercritical drying **(Page 13)**.

- LCI of Hollow silica nanosphere **(Page 14).**

- The fumed silica VIP LCI was based on mass produced data. The LCI data of aerogel blanket was considered to be on pilot-scale. Hence, large-scale production data will very likely result in lower environmental impacts. In the case of hollow silica nanosphere, the data was based on laboratory-scale which also implies an optimization potential for the production processes, e.g. on resource consumption during manufacturing.

4) Life cycle impact assessment of the SIMs

- In order to judge the environmental performance of the SIMs when applied in buildings, the impact was assessed and compared with conventional insulation materials by the GHG emissions. It has to be noted that better data for conventional insulation materials were available when conducting an LCIA thanks to its common use.

- Fumed silica VIP: For fumed silica VIPs to improve their environmental performance, **measures to reduce the GHG emissions generated during the manufacturing of the core material are essential.** However, with the current profile of fumed silica VIP's improvement potential of its performance through process optimization is **rather limited as the largest share of the environmental impacts stems from the fumed silica itself and not the other processes, such as transportation, packaging etc. (Page 15)**

- Aerogel blanket, 2 different manufacturing procedures:
    - For the ambient dried aerogel, the impact of the material used is dominant, representing more than 60% of the impact. While the impact of electricity contributes 30% of the ambient dried aerogel embodied energy, it is responsible for 80% of the aerogel made by supercritical drying. **This highlights the significant improvement potential of the environmental performance of aerogel made by supercritical drying, for instance by sourcing the electricity from renewable energies (Page 16**).

- Hollow silica nanosphere: For the improvement of the environmental performance of the hollow silica nanosphere, **further improvement on silica coating would be necessary (Page 16).**

- Figure 11. Shows the updated mapping of GHG emission from various insulation materials with aligned thermal performance **(Page 17).**

- **The LCIA result of fumed silica VIPs with a mass-based allocation is in relatively good accordance with the values of published EPDs, which was less than 10kg CO2eq. The result with an economic-based allocation showed higher values than any of the published EPD results.**

- This fumed silica, the hotspot for the embodied emission of fumed silica VIPs is created via a multi-output process together with Hydrochloric Acid (HCl). While HCl is rather a ubiquitous chemical for various applications, **fumed silica is considered more of a value-added chemical, which tends to have higher economic value.** With such a difference, the environmental impacts of such multi-output process-based products being allocated based on mass could be questionable. Nonetheless, the LCI result from the subtask allows such considerations to take place transparently and allows fair comparison among different product categories with differences in assumptions. This allows conducting sensitivity analysis for various assumptions that would not be possible for the existing EPDs that do not disclose all inputs and production steps.

- Hotspot analysis provides a good basis for potential improvement opportunities for the aerogels environmental performance, **such as producing in a country with a more carbon-friendly electricity grid mix, such as France or Sweden.**

5) Case studies on LCA and LCC

<u>Hypothetical case building for 2 retrofitting options:</u>

- Table summarising the resulting payback times for the investigated cities **(Page 21):** The result of the economic payback time for **fumed silica VIP suggests that cities with high renting price or high heating demand and gas price can have around 4 years of payback time.** Meanwhile, the economic payback time of **aerogels was longer than 10 years** except in Gothenburg. This is **due to the rather thick layer being applied on the wall**, which may call for an optimization based on the cost and the thermal insulation performance.
- The payback time of **CO2was less than 5 years for VIP in Gothenburg**, where the highest heating demand was seen. Since the case study took the embodied emission of VIP with economic allocation, the payback time calculated with the embodied emission of it with mass-based allocation **could result in shorter time.**

<u>Real Case buildings:</u>

- <u>Traditional house renovation in Thun, Switzerland (VIPA case)</u>: The vacuum insulation panels contribute to an aged thermal conductivity of 0.0061 W/m*K.”. **With the traditional insulation materials, neither the performance nor the architectural design requirement would have been met.**

- <u>Renovation of a school building to meet passive house standard in Freilassing, Germany (VIPA Case):</u> The value of VIPs was specially recognized by the fact that the **VIPs achieved high insulating performance without compromising the room height.**

- <u>Office building renovation in Rheinfelden, Switzerland:</u> The renovation increased the insulation performance of the building, which the façade U-value improved to 0.18 W/m2K or below. **This performance improvement of the façade is expected to reduce the energy consumption of the building by 143 MWh per year.**

6) Conclusion on SIM LCA

- The LCIA result of the LCI of **VIP showed a good level of coherency with the published EPDs, which normally do not contain fully transparent LCI information.** The result creates a solid basis for comparison with the conventional insulation materials for other LCIA studies.

- Meanwhile, the LCIA result of the created **aerogel LCI showed a large difference between the published EPDs**. This was presumed to be because **the available LCI information only represented pilot scale**.

- A hypothetical case of renovation, which looked into the economic, and the environmental payback time showed **SIMs have very high simple payback times in most of the northern European cities.** However, **places with high land price or high heating demand can affect the competitiveness of the SIMs, both economically and environmentally.** In reality, various limitations may affect the decision of insulation material selection. Cases where space limitations are given or preservation of the architectural design was seen as the reasons for implementing the SIMs in the existing building renovation projects.