LONG-TERM PERFORMANCE OF SUPER INSULATING MATERIALS IN BUILDING COMPONENTS & SYSTEMS – IEA-EBC ANNEX65

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ABSTRACT

For households, heating and mobility are the two main loads of their energy burden. A large amount of the energy used for heating air and water is wasted through heat leaks of building envelopes and tank walls. For new building, it's possible to reach very low energy consumption thanks to a good design of building, a good airtightness, some solar gains in winter and efficient solar protections in summer but mainly and above all a good thermal insulation. In new building, the thickness of the insulating layer is ranking between 15 to 30 cm, with traditional insulating materials. This thickness in not acceptable for retrofitting and there is a growing interest in the so-called "super-insulating materials" (SIM), especially for internal thermal insulation. Except for a few types of cellular foams, all traditional insulating materials rely on still air embedded in cavities, pores or cells which prevent any convection. This is why the thermal conductivity of such materials reaches a minimum value, of about, 29 $mW.m^{-1}.K^{-1}$.

To go beyond this limit and achieve superinsulation, three main principles can be applied to reduce thermal conductivity:

- 1: Removing the gas : this technique is used for Vacuum Insulation Panels (VIP)
- 2: Entrapping the gas in tiny pores with a size lower than the mean free path of the entrapped gas in order to limit energy transfer between molecules: this technique is used for aerogel or other Advanced Porous Materials (APM).
- 3: Changing the gas : this technique is similar to the one use for double glazing filled with argon or krypton

Using one of these three options, the thermal conductivity of SIM is generally below 15 $m.W.m^{-1}.K^{-1}$ and can reach very low values (close to 5 $mW.m^{-1}.K^{-1}$). Only VIP and APM are now available on the market and integrated in building products but there is still a lack of information about long-term performances and installation techniques in order to foster the use of SIM in the building sector. The challenges of the IEA-EBC Annex 65 entitled "Long-Term Performance of SIM in Building Components & Systems" is to provide answer to these questions.

Keywords: building, energy, thermal insulation

INTRODUCTION

In the Building Sector, Space Heating (SH) and Domestic Hot Water (DHW) remain the most important energy users. Moreover, refrigeration & freezers (RF) account for around 25% of the whole household appliances. Finally, SH, DHW and RF represent about 80 % of the total energy consumption of household used to fulfil their needs for comfort, sanitary conditions and food storage and unfortunately most of this energy is wasted through heat losses and not used on purpose. Since the first oil crisis, the implementation of Building Regulations [1]

through a combination of higher efficiencies of equipment's and improved thermal performance of building envelope leads to a significant reduction in the per capita energy requirement for SH. Unfortunately, these efforts do not balance the increasing of energy consumption of appliances (especially small ones) and air-conditioning in a few countries.

The potential of energy saving has been estimated to be close to the energy consumption in the transport sector [2] and the current challenge is to make this potential a reality. The first target is to ensure that new buildings do not place additional strain upon energy resources. This goal should be reached by developing NZEB (Net Zero Energy Building) [3] and promoted in the new EPBD. But in most industrialized countries new buildings will only contribute between 10 % to 20 % additional energy consumption by 2050 whereas more than 80% will be influenced by the existing building stock and 75% of current buildings in OECD will still be standing in 2050. Accordingly, the big challenge is the renovation of existing buildings as these represent such a high proportion of energy consumption and they will be with us for many decades to come. According to the IEA BLUE map scenario, two-thirds of the energy savings come from the residential sector and the improvements in the building envelope coupled with energy savings in electrical end-uses dominate total CO_2 reductions. Furthermore, several studies [4,5] have shown that the most efficient way to curb the energy consumption in the building sector (new & existing) remain the reduction of the heat loss by improving the insulation of the building envelope (roof, floor, wall & windows).

A step beyond the current thermal performance of building envelope is essential to realize the world wide intended energy reduction in buildings. For example, in Europe, it appears [6] that the optimum U-values lie between 0.15 W/m².K to 0.3 W/m².K, with an average value close to 0.2 W/m².K. Using traditional insulating materials such as mineral wool or cellular foams, it means a thickness from 15 to 20 cm. For retrofitting and even for new buildings in cities, the thickness of internal or external insulation layers becomes a major issue of concern. For systems (DHW or RF) the reduction of thickness is essential. Therefore, there is a growing interest in the so-called super-insulating materials (SIM), such as VIP or APM.

The former Annex 39 HIPTI [7] have shown that VIP's products have reached a level of quality that customers can trust in for specific applications under well-defined conditions. However, there is still a need for test methods and evaluation procedures to characterize the suitability of SIM for wider applications in praxis. Actually, overall performance and durability of SIM must be investigated when the working life conditions are more severe (high/low temperature, high humidity, mechanical load …). Moreover, new types of SIM appear on the market and their durability and applicability needs to be answered on a scientific level.

OBJECTIVES AND SCOPE OF THE ANNEX

Objectives

An extensive renovation of existing buildings & the development of NZEB appear as the future tracks for 2050, in the building sector. To make both objectives a success, the thermal performance of the envelope is a top priority and SIM should greatly contribute to this challenge if reliable data (properties & durability) and secure implementation techniques are provided to the supply chain (designers, engineers, builders & workers on site).The sustainability of SIM (LCA-Life Cycle Assessment, LCC-Life Cycle Cost as well as EE - Embodied Energy) will be complementary aspect of the study.

Therefore, the current research proposal of Annex 65 has the following objectives:

- to make a state of the art of a decade of development of SIM by the industry and of applications in the building sector
- to develop experimental & numerical tools in order to provide reliable data (properties & durability) for manufacturers and designers.
- to write guidelines for secure installation
- to support standardization and assessment procedures
- to improve knowledge and confidence of the supply chain regarding SIM, thanks to sustainability analysis
- to foster a wider public acceptance of SIM in the future by communication

Scope of the Annex 65

The scope of the Annex65 will cover two types of SIM: the Vacuum Insulation Panel (VIP) and the Advanced-Porous Materials (APM), such as Porous Silica & Aerogel

Figure 1: Vacuum Insulation Panel (VIP) Courtesy: Porextherm

Figure 2: Aerogel Fibre Mat - Courtesy: Aspen Aerogel

Three scientific and technical issues will be addressed during this Annex:

- The performance & durability of SIM through the performance testing in laboratories, coupling with ageing procedures and the measurement on site.
- The installation techniques, indeed there is a high risk of degradation during handling and installation on site.
- The sustainability which is crucial for SIM as the raw materials used to produce them are very specific (TEOS, TMOS, aluminum …) and the manufacturing processes remains sophisticated (super-critical conditions, vacuum process …).

ORGANIZATION OF THE ANNEX

The Annex is organized in four subtasks.

Subtask 1: State of the Art on Materials & Components - Case Studies

The main objective of this task is to provide an up-to-date catalogue of commercially available materials & components. This catalogue will provide technical description of each product with technical data and information about the application domains and the implementation rules.

Furthermore, during the last decade, basic research and first demonstration projects [8] have shown that SIM can be applied in buildings. First European Technical Approvals [9,10]

(ETAs) have been issued for VIP and Aerogel for the use in buildings in the recent years. However, a large use of these components is still hindered by scepticism on the reliability in practice. In order to improve the confidence in these new components, this task will make a detailed analysis of these components offered by manufacturers. An overview on all the application areas such as external & internal wall insulation, roofs, floors, ceilings …will be investigated through a few case studies.

Subtask 2: Characterization of materials & components at the laboratory scale

As their structure and microstructure are completely different, SIM cannot be compared directly to traditional insulating materials, but worldwide acceptance of these materials will be improved, if the hygro-thermal and mechanical properties of SIM can be declared clearly and reproducible. In particular, nano-structured materials used to manufactured SIM are characterized by a high specific area (a few hundred of m^2/g) and narrow pores (smaller than 0.1 µm) which make them very sensitive to gas adsorption (H_2O, VOC …) and capillary condensation can occur in narrow and generate very high pressure. Both phenomena are responsible of drastic changes of the microstructure. Therefore, the methods of characterization must be adapted and even in some cases; new methods have to be developed to measure microstructural, hygro-thermal and mechanical properties of materials and barrier films.

In parallel, modelling methods to describe heat, moisture and air transfer through nano-structured materials and films will be developed (adsorption and desorption models, diffusion models, freezing-thawing …).

Of course, a few methods will be common to all SIM, for example the core materials of VIP can be an APM. But due to their completely different manufacturing process some specific methods have to be developed. For VIP, the durability depends strongly of the performances of the barrier film, such gas permeability (H_2O, N_2, O_2) which can be degraded by the manufacturing process (folding of the film and sealing) [[11]].

SIM can offer considerable advantages; however potential drawback effects should be known and considered in the planning process in order to optimise the development of these extraordinary properties and to prevent negative publicity which could be detrimental to this sector of emerging products. It's why ageing tests will be defined according to the conditions in use (temperature, moisture, pressure, mechanical load …).

One objective of artificial ageing is to understand potential degradation processes that could occur, such as densification of the porous materials due to water vapour adsorption for a long period [[12]]. The durability of the hydrophobic treatment will be also subject of discussion and investigation to prevent premature degradation.

At the component scale, additional characterizations are needed as in general panels or rolls are sold by manufacturers. In particular, thermal bridges will be carefully investigated, as the extraordinary thermal performance of SIM is sensitive for the influence of thermal bridges resulting for the film seam around VIP, as well as thermal bridges at the components and walls scales.

Subtask 3: Practical Applications – Retrofitting at the Building Scale – Field scale

The objective of this task will be to define the application areas of SIM and to describe the conditions of the intended use of the products. Indeed, it's clear that the requested performances of the SIM will strongly depend on the temperature & humidity and load

conditions. The local climate will play a great role as well as the application: terrace, roof, wall, floor, water tanks and refrigerator.

For on-site applications, requirements for storage, handling and installation will be also well defined as these three concerns appear to be pivotal for quality insurance.

Common and specific modelling methods will be also developed at the building scale in order to understand the impact of SIM on the performance of wall, roof and floors an even the whole envelope with regards mainly to thermal insulation, airtightness and risk of condensation as VIP can be considered as a vapour barrier and APM as a permeable layer.

Subtask 4: Sustainability – Risk & Benefit

The goal of this task is to assess the overall sustainability of SIMs through the evaluation of LCA and LCC, as well as EE of superinsulation materials over the entire life (production, use and end-of-life).

Life Cycle Inventories for the production step will be established relying on input from material and component producers. The in-use phase will be modelled in various climatic contexts and several building types, taking into account results from Task 2 and 3 alongside taking into account the fact that SIMs are expected to allow larger living or commercially usable areas in a building whilst achieving a lower or equivalent U-values. Current and potential future end-of-life treatment processes will be analysed and corresponding inventories established.

Inventories for all three phases will not only include material and energy flows but also economic flows, thus allowing evaluating the environmental profile of the materials, components and systems at the same time with costs over the whole life cycle. For example the impact of SIM on the living space saving should be considered in the LCC analysis.

DISCUSSION

As the core materials of VIP and APM are highly porous materials (porosity > 95%), two mains concerns need to be addressed in order to evaluate the long-term performance of SIM: the thermal conductivity of the gas entrapped in the porous media and the solid conductivity of the skeleton.

The thermal conductivity of air (λ_g) in a confined porous media which can be written as follows:

$$\lambda_g = \frac{\lambda_{g0}}{1 + C.\frac{T}{\delta \cdot P_g}} \tag{1}$$

C is a constant, λ_{g0} is the air conduction in normal condition and δ is the pore size.

The equation 1 emphasizes the great role of the term $\delta.P_g$ on the gas conduction λ_g.

On one hand, for long-term performance of VIP, it means that the low pressure of the entrapped gas mixture P_g must be kept for 20 to 50 years. Consequently, the gas-tightness (H_2O, O_2, N_2) of the film and the quality of the seams are the key drivers of the durability of VIP. Of course, if δ is small (lower than 0.1 µm), with a very low manufacturing pressure (about 0.001 bar) the expected life-span will be longer as the internal pressure can increase without any change of the thermal conductivity.

On the other hand, for VIP using micro-nano-porous core materials and APM, two ageing processes have been identified [13,14]:

- the water-vapour adsorption which can modified the connexion between silica grain,
- a densification effect resulting from microstructural change similar to Ostwald ripening when a hydrophilic nano-porous media is exposed to high humidity for a long time.

CONCLUSION

The SIM appear as very promising insulating materials, especially to tackle the renovation challenge but their long-term performance is still questionable, especially when exposed to high temperature and humidity. The IEA-EBC Annex 65 has gather the main actors of this sector (industrials, institutes …) and working together, they will brought answers by understanding basic phenomena, improving materials, measuring performances and providing guideline for secure application on site.

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