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Long-term performance of glass fiber Vacuum Insulation Panels exposed to severe operating conditions in buildings

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Abstract

Vacuum insulation panels (VIPs) provide an effective solution for retrofitting building envelopes, particularly when space for conventional insulation is limited. However, certain conditions can accelerate the ageing of VIPs. Roofs, in particular, represent the largest exposed area to outdoor thermal stresses (rain, solar radiation, temperature fluctuations). This study examines the long-term thermal performance of glass-fiber VIPs in building applications, with a focus on attic space conversions and energy retrofits. Specifically, glass fiber VIPs incorporating integrated getter technology were investigated. These panels, which offer lower thermal conductivity than traditional fumed silica VIPs, can extend service life by adsorbing permeated gases. A full-scale roof test room was used to monitor the long-term performance of these panels under natural exposure conditions over four years, assessing their thermal and hygrothermal behavior over the time. The primary objectives of the study were to evaluate the improvements of the thermal performance achievable by retrofitting an attic space with glass-fiber VIPs. Analyses were extended to cover both summer and winter period and were aimed at: analysing the risk of hygrothermal stress on the panels, validating models for the prediction of their service life, with real-world data, and detecting possible changes in thermal conductivity over time due to ageing. The results showed that the VIP-retrofitted roof significantly reduced heat losses in winter and enhanced thermal insulation in summer, keeping thermal conductivity below 2.7 mW/mK after four years of real life usage. The monitored boundary conditions—temperature and humidity at the panel surfaces — revealed that VIPs were exposed to severe operational conditions. Despite this fact, the observed values remained within acceptable limits, ensuring long-term service life without rapid degradation. The data from this study are significant for validating ageing prediction models and improving the knowledge about the use of glass fiber VIPs in real building envelope applications. In conclusion, glass fiber VIPs offer significant potential for improving the thermal efficiency of roof attics, providing a durable and effective solution for energy retrofits. The data gathered from four years of exposure to severe environmental conditions will be instrumental in validating ageing prediction models, that can be extensively used for demonstrating the conditions under which glass-fibers VIPs can guarantee an acceptable service life and supporting their adoption in sustainable building practices.

Keywords: Vacuum Insulation Panels; Glass Fibers; Roof; Service Life

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1. Introduction and aims

This paper present the results of a long term monitoring campaign on glass fiber core Vacuum Insulation Panels (VIPs) containing getters, installed in a roof component. The study began in November 2020, when three 600x750mm VIPs were installed in the TRIS test room (Testin Roofing Innovative System) in Torino, Italy (see Fig.1 and Fig.2). Initial results of the first year monitoring campaign has been presented in 15th International Vacuum Insulation Symposium (IVIS2021) [5]. Centre of panel thermal conductivity was measured on both pristine and one-year naturally aged panels, revealing a negligible increase of approximately 2–3%, which falls within the range of measurement uncertainty. As the data collected during the first year were insufficient to draw significant conclusions or to experimentally validate the degradation prediction model developed in [4], the monitoring campaign was extended for an additional four years, until November 2025.

The objective of this study is to present the evolution of the thermal conductivity of the VIPs after four years of natural aging (November 2020 to November 2024). Additionally, the study investigates temperature and water vapor pressure conditions at the panel boundaries and evaluates the potential for reduced heat losses during winter and decreased heat gains during summer, in comparison with a conventional insulated roof of the same thickness.

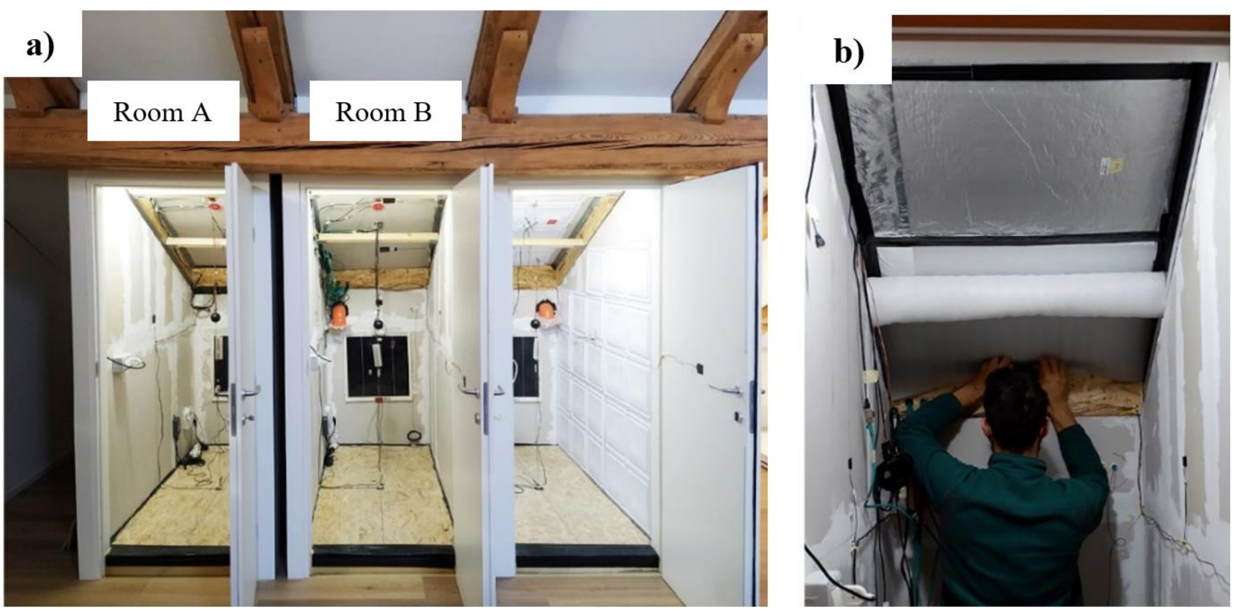

Fig. 1. TRIS experimental setup. a) TRIS test rooms; b) The VIP installation in room B. Picture source [5].

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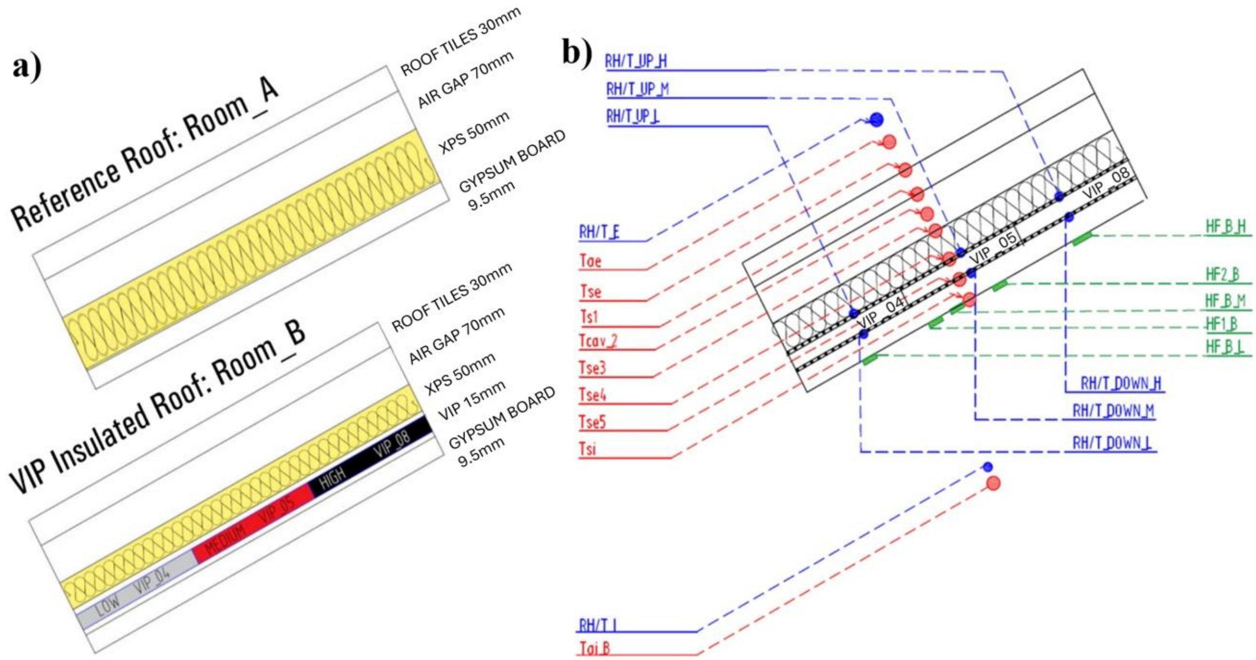

Fig. 2. TRIS experimental setup. a) The roof stratigraphy installed in room A and B; b) the installed sensors. Picture source [5].

2. Test room experimental campaign results

The monitored temperature and water vapour pressure (Fig.3) show that the VIPs are exposed, on their top surface, to a temperature exceeding 50°C for about 0,4% of the time. However, the critical threshold temperature of 60°C – defined as maximum service temperature condition for long term exposure according to Annex 39 [2]) – was never reached. Similarly, although water vapor pressure levels were elevated during the summer months, they never exceeded critical values. These findings suggest that, while high temperature and humidity conditions may contribute to accelerated aging mechanisms, they do not reach levels considered critical for long-term performance degradation. An additional consideration should be given regarding the relative humidity results, which reach peak values as high as 85% during winter. As demonstrated in [6], films containing ethylene vinyl alcohol copolymer (EVOH) exhibit increased water vapor transmission (WWT) rate under high humidity conditions. To mitigate the ageing mechanism associated with WWT, [6] suggests incorporating additional desiccant when VIPs are exposed to high relative humidity.

Similar VIPs boundary conditions results were reported in [1] for a flat roof installation in Swizerland, indicating that the environmental conditions observed in this study are likely representative of typical roof applications across Europe.

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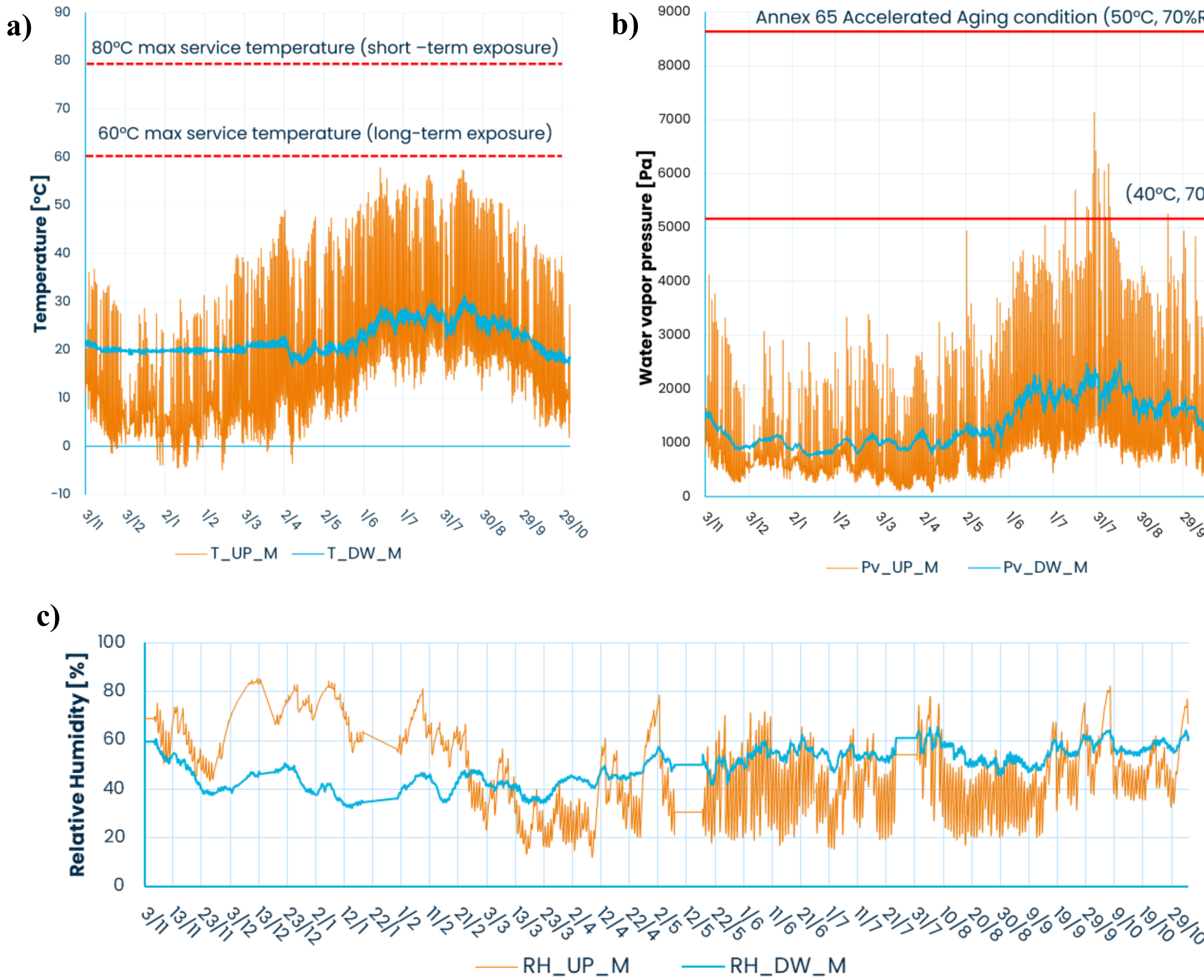

Fig. 3. a) Temperature; b) water vapour pressure; c) relative humidity. ("UP" indicate the upper VIP side and "DW" the bottom VIP side). Picture redrawn from [5]

Fig.4 highlights the indoor surface temperature of roof components A and B. Data from a cloudy winter week in January 2021 shows an average surface temperature ~1°C higher in the VIP insulated roof, with peak difference of up to 2°C. This temperature increase resulted in a substantial reduction in peak heat losses wich turn in a reduction of the peak heat lossess of about 75%, from 14 W/m^2 to 4W/m^2 in the conventional roof and in the VIP insulated roof respectively (see Fig.5).

Analysis of the monitored data from the warmest week in July 2021 further demonstrates the benefits of VIPs during the summer period. During daytime, the roof is subjected to substantial solar heat gains, leading to indoor surface temperatures of up to 32 °C in room A and corresponding peak heat gains of approximately 15 W/m² (Fig.6 room A). In room B, the application the VIPs reduced the peak surface temperature of ~2.4°C, with a maximum surface temperature of 29.6°C. Detailed weather conditions of the analysed weeks are presented in [5].

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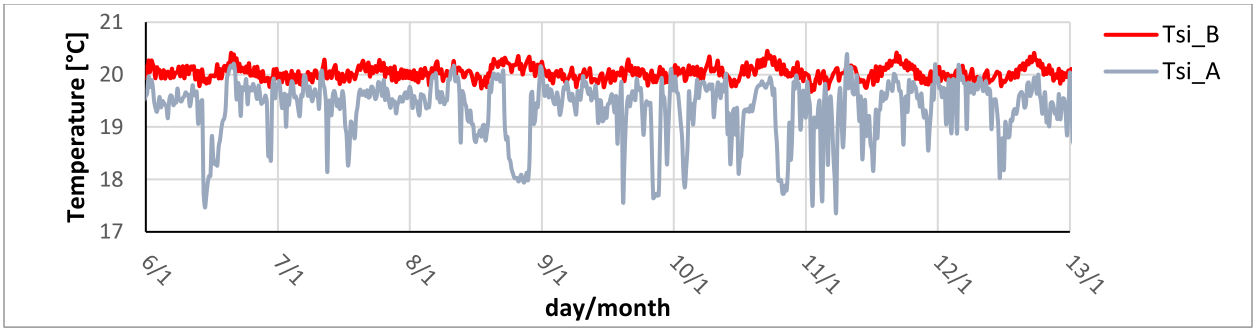

Fig. 4. Indoor surface temperature in a winter week in room A (reference) and room B (VIP insulated).

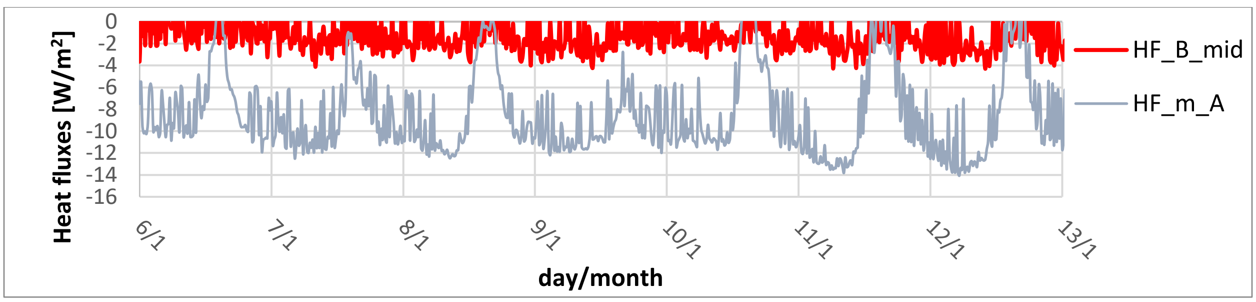

Fig. 5. Heat fluxes in a winter week in room A (reference) and room B (VIP insulated).

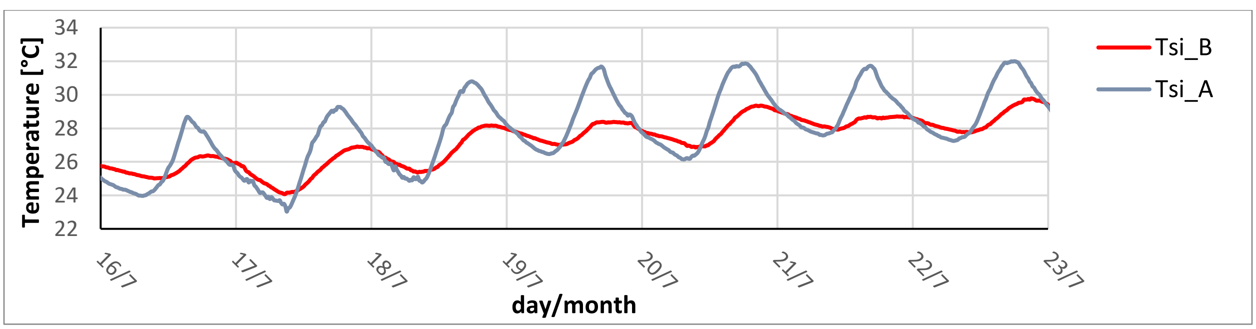

Fig. 6. Indoor surface temperature in a summer week in room A (reference) and room B (VIP insulated).

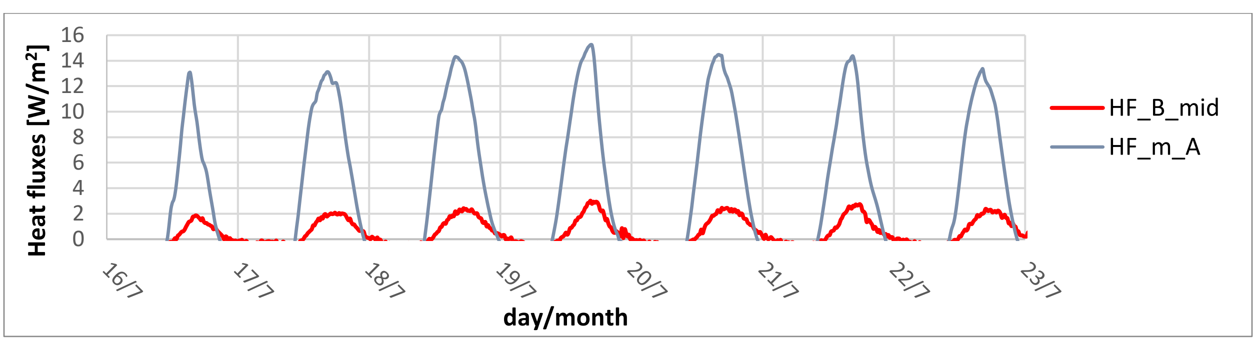

Fig. 7. Heat fluxes in a summer week in room A (Reference) and room B (VIP insulated).

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3. Thermal conductivity over time

The centre of panel thermal conductivity of the three VIPs samples, namely VIP_04, VIP_05; VIP_08, installed in the bottom, middle and top section of the test room, respectively, was assessed under pristine condition prior to installation. The tests were conducted in accordance with EN 12667 standard making use of a Heat flow Meter device (TA instrument - Fox 600) (Fig. 8 left). The temperature conditions of the two plates were set at 10°C (upper plate) and 30°C (lower plate), resulting in a temperature difference of approximately 20°C. Moreover, it is worth mentioning that the getters were positioned outside the metering area of the experimental device.

Initial test results revealed thermal conductivity values ranging from 1.53 ± 0.05 mW/m·K to 1.58 ± 0.05 mW/m·K. These measurements were compared with those obtained prior to shipment to Italy by ASAHI Fiberglass, which reported consistent values in the range of 1.55 ± 0.05 mW/m·K to 1.63 ± 0.05 mW/m·K.

Each year in November, the three VIPs were removed from the test setup and transported to the Politecnico di Torino laboratory to repeat the center-of-panel thermal conductivity measurements. Fig.8 (right) shows the evolution of thermal conductivity over time—from the pristine condition to the fourth year of aging—with the exception of VIP_05, which was punctured during installation or transportation. As a result, data for VIP_05 are only available for years 1st and 2nd. In the 3rd year, the measured thermal conductivity for VIP_05 increased dramatically to approximately 32 mW/m·K, indicating a loss of vacuum that was confirmed by the visual inspection.

Regarding VIP_04 and VIP_08 differences in aging behavior were observed. After the first two years, both panels showed a modest increase in thermal conductivity—approximately 7% for VIP_08 and 12% for VIP_04. However, from the third year onward, their thermal performance began to diverge. After four years, VIP_04 exhibited a thermal conductivity of 2.7 ± 0.08 mW/m·K, representing an increase of about 70% from its initial value. In contrast, VIP_08 reached only 2.03 ± 0.06 mW/m·K, corresponding to a relative increase of approximately 32.5% over the same period.

The differing trends in thermal conductivity evolution can be partially attributed to the initial performance of the VIPs. Specifically, sample VIP_04 showed slightly lower performance from the start of the experimental campaign, with an initial thermal conductivity approximately 3% higher than that of VIP_08 and VIP_05. This may indicate a higher internal core pressure present from the beginning.

An additional factor contributing to the accelerated aging of VIP_04 could be the presence of microscopic damage to the envelope surface, which may have facilitated increased permeation of water vapor and gases

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into the panel, thereby reducing its effective lifetime. Future analyses using microscopic inspection techniques are planned to identify any damage not visible through standard visual inspection.

The main explanation of the different trend evolution can be partially explained by the initial performance of the VIPs. Indeed, the sample 04 slightly underperform since the beginning of the experimental campaign, with an initial thermal conductivity that was 3% higher than sample VIP_08 and sample VIP_05, suggesting a potential higher core pressure from the beginning of the experimental campaign.

Moreover, an additional explanation of the more rapid VIP_04 thermal conductivity evolution, could be searched in the presence of microscopic damaging at the envelope surface, which determine a more rapid water vapour and gas permeation in the VIP, hence reducing its lifetime. Future inspection using microscopy will be done to determine the presence of damaging that were not possible to be determined with a simple visual inspection.

Finally, it is worth noting that—excluding the punctured VIP_05—the remaining VIPs continue to exhibit excellent thermal performance after four years. Their thermal conductivity remains in the range of 2.0 to 2.7 mW/m·K, well below the commonly accepted threshold of 8 mW/m·K used to define end-of-service life.

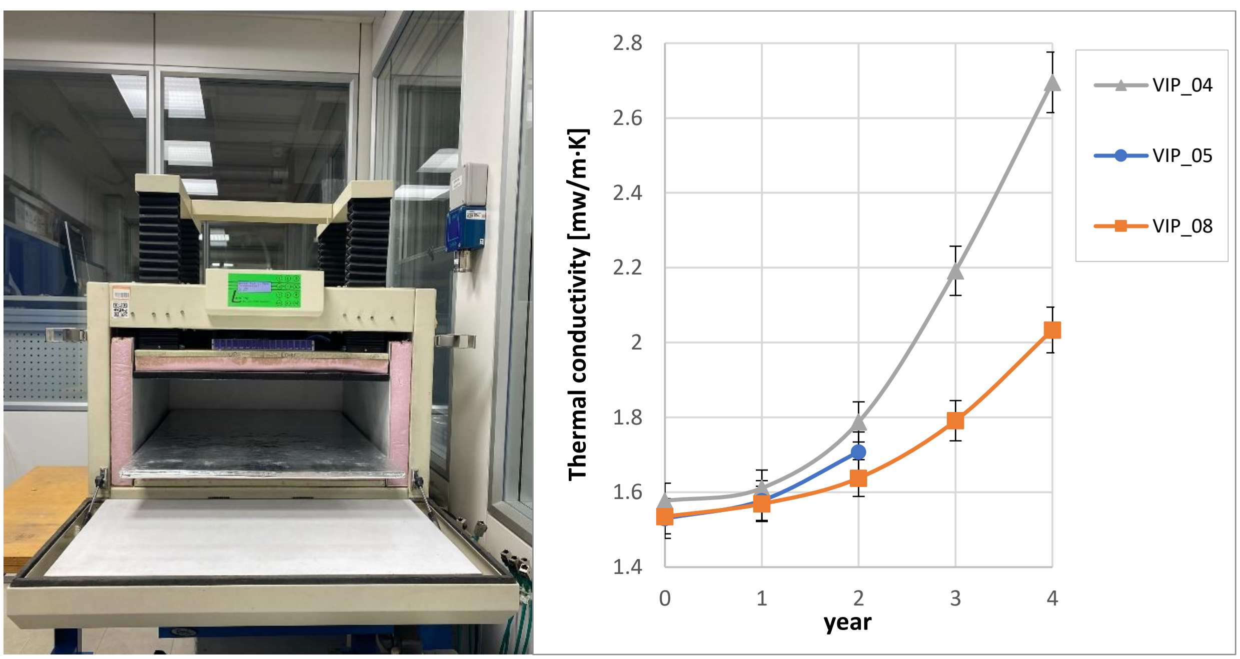

Fig. 8. Left) The Heat flow meter device; right) centre of panel thermal conductivity over time.

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4. Conclusions

This paper presents the results of a long-term experimental campaign aimed at monitoring the performance of glass fiber core vacuum insulation panels (VIPs) containing getters. Three VIPs, each with an initial thermal conductivity below 1.6 mW/m·K, were installed in the roof of a parallel test room system and compared with a reference roof insulated using conventional insulating materials of the same thickness. The results show that the VIPs were subjected to severe boundary conditions (e.g., temperatures exceeding 50 °C), but only for a limited number of days each year. In contrast, high relative humidity conditions (up to 85% in the winter period) were monitored, highlighting a potential risk of increased water vapour permeation in films containing EVOH.

Monitoring of indoor surface temperatures and heat fluxes revealed a substantial reduction in thermal loads: peak heat losses in winter and peak heat gains in summer were reduced by up to 75% compared to the conventionally insulated reference roof.

After four years of natural aging, the VIPs still demonstrated low thermal conductivity values, with one panel measuring approximately 2.7 mW/m·K and the other around 2.0 mW/m·K, indicating varying degrees of performance degradation. These findings suggest that while some aging has occurred, the panels largely maintain high thermal performance. Future work will focus on assessing the thermal conductivity after the fifth year of aging. These data will be used to further validate the aging model for fumed silica core VIPs containing getters, as proposed by H. Yamamaoto and D. Ogura 2022 [4].

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