Thermal and Acoustic performance of superinsulated façade spandrel modules embedding Glass-Fiber Vacuum Panels

Stefano Fantucci[a][1], Louena Shtrepi[a], Farid Jafari[a], Giorgia Autretto[a], Elisa Fenoglio[a],

Hideya Yamamoto[b]

[a]Politecnico di Torino - Department of Energy, C.so Duca Degli Abruzzi 24, Torino 10129, Italy.
[b]Asahi Fiber Glass Co., Ltd. Samukawa-machi, ichinomiya, 6-11-1, 2510111, Japan.

Abstract

The development of highly performant pre-fabricated slim spandrel façade systems represents nowadays an important step to minimize the energy consumption of curtain wall buildings, towards the Zero Energy Building targets. In this context, the Powerskin Plus project is aimed at developing a new multifunctional slim façade spandrel modules that implement different functionalities i.e Solar Energy Harvesting by integrating Perovskite PV solar cells, energy storage by means of Phase Change Materials activated by an embedded heating systems and second life Li-ion batteries, and
In this work, the thermal and acoustics performance of the systems has been analysed to support the design decision process. The thermal performance (U-value) and the sound reduction Level (Rw), were analysed by processing the physical properties (thermal conductivity and elastic modulus) of Glass Fiber based Vacuum Insulated Panels that were assessed in laboratory conditions.
Results show a thermal transmittance ranging from 0.098 to 0.193 W/mK depending on the VIP thickness, and an Rw ranging between 25 and 45 dB, depending on the functional protective skin layers surrounding the VIPs.

Keywords: Vacuum Insulation Panels; Spandrel, Sound Reduction Level; Thermal Transmittance;

1. Introduction

Non-residential buildings represent about 25% of the EU building stock [1]. However, even if the quota is significantly lower compared with the other building typologies, their energy consumption is about 40% higher than the one of the other buildings (residential) [2]. So, the non-residential sector represents a priority in setting energy retrofit interventions to move toward a decarbonization of the whole building stock.
The majority of non-residential buildings make use of the Curtain Wall System (CWS). CWS is represented by a non-load-bearing external Façade anchored to the building structure. They are generally made by framing system that host “visual” transparent panels alternated with “non-visual” opaque spandrel insulated panels.
The CWS is very popular in modern non-residential mid/high rise buildings, because the relatively high rate of pre-fabrication allow minimizing the construction time while having a certain level of quality control (main assembly are made in factory environment).
To meet the building insulation requirement, opaque spandrel elements are generally made, in a second construction phase, by a non-prefabricated element embedding a thick insulation layer (such as mineral wool) that require additional construction time and internal space reduction. For this reason, the potential of integrating Vacuum Insulation Panels in façade spandrel has been recently explored by several research studies [3], [4].
In this context, the Powerskin Plus project is aimed at developing a new multifunctional slim façade spandrel modules for the deep energy retrofit and for the new nZEB oriented non-residential buildings. For this sake, a truly innovative spandrel system that implements different functionalities i.e Superinsulation, Solar Energy Harvesting by integrating Perovskite PV solar cells, energy storage by means of Phase Change Materials activated by an embedded heating systems and second life Li-ion batteries is under investigation.
One of the key-drivers in the technology development is the superinsulation, a target U-value in the range of 0.1 W/m^{2}K has been set as priority constrain. Moreover, lightweight features and low thickness as been

[1] Corresponding author email address: stefano.fantucci@polito.it

also considered. Indeed, to be hosted in a conventional framing system, that are generally designed to host typical double/triple glazing unit having thickness lower than 60-64mm.
Super insulating materials such as Vacuum Insulation Panel (VIPs) represent a suitable solution to develop highly energy efficient spandrel modules by keeping low façade thickness and weight. Nevertheless, a number of technological integration challenges can potentially determine a decrease of thermal, mechanical and acoustic properties.
The aim of this study is to present the experimental and simulation process which allow identifying the thermal and acoustic performance of different spandrel design alternatives.

2. The spandrel module configurations

In this paper the standard lightweight opaque spandrel module configuration has been analysed. This spandrel module represents the simplest technology developed in the framework of the project, and it is composed by a commercial glass fiber VIP having nominal thermal conductivity of 2 mW/mK and density of ~200 kg/m^3. The VIP is sandwiched on the outer side and on the inner side by a protective skin panel. Three different configurations making use of different protective skins, and three different VIP thicknesses (9 design alternatives) were considered for the thermal and acoustic analysis. Table 1 summaries the analysed design alternatives.

Table 1. The analysed spandrel module configurations

Config.	Protective skin panel	side	Skin thickness	Module thickness [mm]			Surface mass density [kg/m^2]		
		Outer/ inner	[mm]	VIP 10	VIP 15	VIP 20	VIP 10	VIP 15	VIP 20
1	Stainless steel	outer	0.6	11.2	16.2	21.2	11.4	12.4	13.4
	Stainless steel	inner	0.6						
2	Lamin. glass	outer	6	20.0	25.0	30.0	26	27	28
	Tempered glass	inner	4						
3	Fiber-resin composite	outer	0.7	11.4	16.4	21.4	4.1	5.1	6.1
	Fiber-resin composite	inner	0.7						

3. Thermal performance

A first set of analysis was made to assess the nominal center of panel thermal transmittance (U-value) that has been determined according with the ISO 6946 standard calculation method. Results are summarized in Table 2 (U-value calc.).
To experimentally demonstrate that the center of panel U-value fulfill the initial target value (U<0.10 W/m^{2}K), A small scale prototype of 600 x600 mm^2 and 21 mm thickness has been fabricated making use of 20 mm VIP and protective stainless steel sheets on inner and outer side (config. 1 - 20mm).
The prototype U-value has been tested by means of a single sample Heat Flow Meter apparatus. To determine the U-value an additional upper and lower mats having the same thermal resistance of the standard (ISO 6946) surface heat resistance (upper side ~0.13 m^{2}K/W, lower side ~0.04 m^{2}K/W). The HFM testing condition and results are summarized in Table 2.

Table 2. Measured thermal transmittance

Measured thickness [mm]	Upper plate temperature [°C]	Lower plate temperature [°C]	U-value meas. [W/m^{2}K]	U-value calc. VIP 10 mm [W/m^{2}K]	U-value calc. VIP 15 mm [W/m^{2}K]	U-value calc. VIP 20 mm [W/m^{2}K]
21.30	17.52	32.53	0.094	0.193	0.130	0.098

4. Acoustic performance

The aim of this study was to characterize the sound insulation properties of the different spandrel design alternatives at the component scale and at the façade scale. To this end, in this study, a first experimental campaign to assess the VIP elasticity module (Young modulus) has been carried out, then the sound insulation properties has been simulation.

4.1 Determination of VIP Elasticity modulus

The Elasticity module (E) is determined as the ratio between the measured specific load σ [N/mm^2] and the measured specific deformation ε. Test results are summarised in FIgure 1 (right). Test has been carried out according to JOSK7171/ISO178 standards on Glass Fiber core VIP samples having 10, 15 and 20 mm thickness, width (w) and lenght (l) were 80 and 200 mm respectively. Figure 1 shows the test performed and the VIP conditions before (left) and after the test (center).

VIP thickness [mm]	E [N/mm^2]
10	0.061
15	0.130
20	0.169

Fig. 1. Left) VIP before test; center) VIP after test; right) test results

4.2 Acoustic performance simulation

All the simulations on the façade element scale have been performed with INSUL software to evaluate the weighted sound reduction index Rw. The simulations on the façade level scale, on the other hand, were done with the Echo software developed by ANIT (Italian national association for thermal and acoustic insulation).
The simulation results of the three spandrel configurations considering the different VIP thickness (10, 15 and 20 mm) are summarised in Table 3.
Among four different configurations, panels consisting of glass layers show higher acoustical insulation (≃37dB) and panels including Fibre Resins show the worst insulating performance (23-26 dB). Please note that increasing the VIP thickness does not contribute to a significant improvement (≤ 1dB).

Table 3. Results of Weighted Sound Reduction Index Rw [dB]

Configuration	VIP core 10 mm	VIP core 15 mm	VIP core 20 mm
1	31	32	33
2	37	37	37
3	23	24	26

As expected the acoustic performance Rw are highly dependent by the spandrel surface mass. Indeed the configuration having higher surface mass (glass as skin protection layers) show the higher Rw. Furthermore a slightly increse in the Rw can be observed by increasing the VIP thickness, this trend is evident in the config.1 and 2 (stainless steel skin and fiber resin composite), while is negligible in the configuration 2 (glass skin).

4.3 Simulation results for different façade combinations

This section aims to evaluate the standardized sound insulation capacity of the building façade $D_{2m,nT,w}$. The analysis has been applied to a reference building room (6m x 8m floor area) having only one external façade composed by six floor-to-ceiling panel modules having a width of 130 cm. For the framing system a conventional aluminium curtain wall stick system was considered.
Opaque (spandrel) and transparent (visual) modules were alternated to define four different façade design alternatives, having a Window to Wall Ratio (WWR) of 33%, 50%, 67% and 83% respectively (Figure 2 right). For the transparent (visual) modules an hypothetical triple glazing unit having a sound reduction index of 46 dB [5] was considered. Calculations have been performed with Echo software version 8.0. The façade was considered to be a plane type façade with a height less than 1.5 m and a balcony absorption coefficient αw less than 0.3. The estimated weighted standardized level difference $D_{2m,nT,w}$ of façade are presented in Figure 2.

Considering the Italian passive acoustic requirements, it can be observed that the config. 2 (glass skin) fulfills the office and commercial building requirements for WWR higher than 50%, while the config. 1 (stainless steel skin) fulfill the office requirements of buildings in case of VIP thickness higher than 15mm and 83% of WWR.

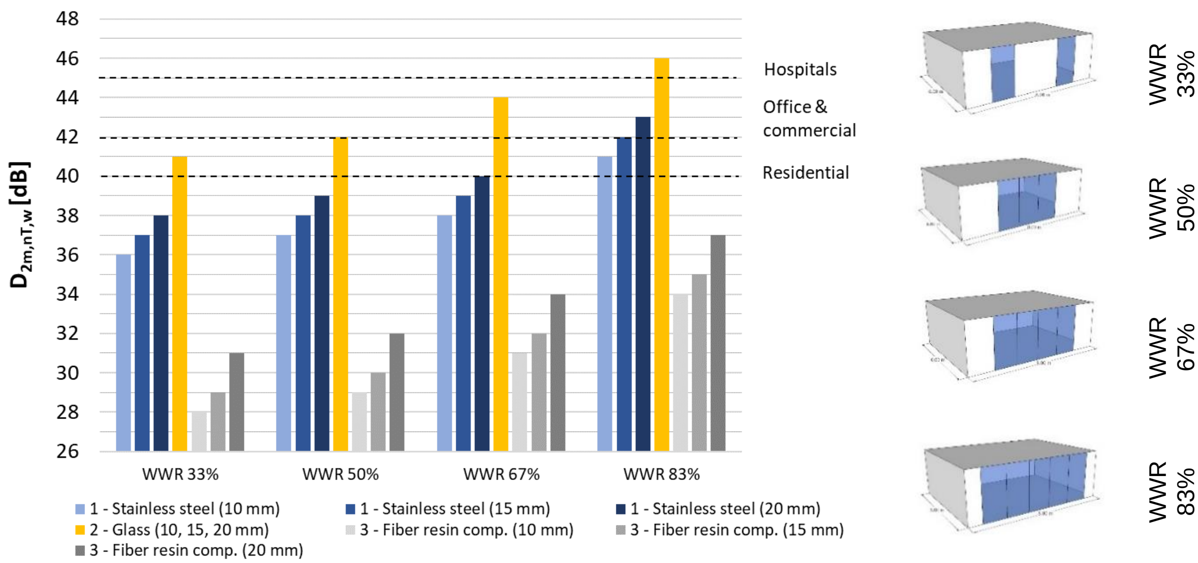

Fig. 2. $D_{2m,nT,w}$ for different modules configuration and façade WWR.

5. Conclusions and outlook

In this study the possibility of developing a high performing spandrel panel making use of glass fiber VIP has been explored. Different skin protection materials and different VIP thickness has been combined to support the best design option.

The study demonstrates that, while the use of VIP as insulating layer presents several advantages i.e. low thickness, low surface mass, and outstanding thermal insulation performance (measured U-value up to 0.94 W/mK), on the other side, the lightweight feature can potentially lead to underperforming acoustic properties. Indeed, the study demonstrated that the configurations in which VIP are protected by glass skin, that correspond to the design alternatives having higher surface mass density, represent the most acoustic-performing solution for the retrofit of non-residential buildings.

Since the study revealed that acoustic aspects could represent one of the key-driver in the design of high performing VIP-based spandrel modules, future analysis will be carried out on the definition of possible strategies to improve both thermal and acoustic performance by the addition of different functional layers.

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