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## Analysis of the temperature distribution in an SIP building envelope

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**Abstract:** The insulation performance of building envelopes is one of the areas with a significant impact on the building energy intensity. In Poland, 71 % of the energy demand of the entire building is used for heating households. Therefore, solutions are sought that will ensure the required thermal comfort and reduce the energy demand. The paper presents the testing of the temperature distribution inside an envelope made of structural insulated panels (SIPs) using state-of-the-art FBG sensors. Compared to classic temperature measuring devices, FBG sensors are characterized by high measuring resolution and reliability, reducing the testing invasiveness to the minimum. A composite structural insulated panel (SIP) and a traditional two-layer wall were tested. SIPs are modern building materials that are both a structural and an insulating element of building envelopes. The three-layer structure consists of a light core (EPS) skinned on both sides with magnesite boards which provide the panel with high strength, rigidity, fire resistance and resistance to biological corrosion. The knowledge of the actual temperature distribution inside the envelope can significantly improve the control of heating systems in buildings and reduce energy consumption.

**Keywords:** FBG temperature sensors, temperature distribution, thermo-modernization, structural insulated panel (SIP)

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## Introduction

The primary reason to start searching for ecological and energy-efficient building materials is to reduce greenhouse gas emissions and adapt to climate change in order

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to limit the negative effects of global warming. According to the Sixth Assessment Report of the IPCC (Intergovernmental Panel on Climate Change) of 2023, the air temperature rose by 1.1 °C compared to the global average temperature from the years 1850-1900, and it is still rising (IPCC, 2023). The emissions into the atmosphere of harmful gases, such as CO<sub>2</sub> and SO<sub>2</sub> produced in the process of thermal energy and electricity generation, cause negative changes to climate (Wieprzkowicz & Heim, 2022). Extreme, complex weather phenomena, e.g. parallel heat waves, droughts and floods, are more and more frequent, having an increasingly dangerous impact on man and the environment. Buildings account for 39% of global carbon emissions and 50% of global material consumption (Kietliński, 2015). Additionally, it is estimated that there will be a 50% increase in the demand for energy by 2050 (World Green Building Council, 2020). In Poland, 71% of the energy required by the entire building is used for heating households. The structure of building envelopes is usually multi-layered. Therefore, the knowledge of the actual temperature distribution enables adequate modernization of the envelope, thus providing a better comfort of life and reducing the demand for energy.

## 1. Layered structural insulated panel (SIP)

Structural insulated panels (SIPs) are simple three-layer composite elements consisting of a core, being a thick layer of expanded polystyrene (EPS) insulation, skinned on both sides as shown in Figure 1. They are mainly used as elements of the building envelope structure, creating a compact and energy-efficient body. The outer linings transfer bending stresses, while the core transfers tangential stresses and stabilizes the outer linings, protecting them from buckling and providing adequate rigidity. (Wawrzynowicz & Wojtkiewicz, 2024).

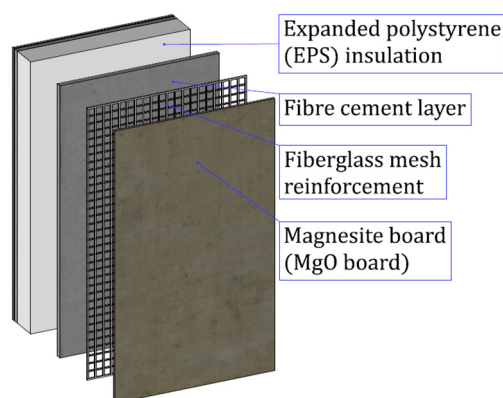


Fig. 1. Multi-layer SIP (*own research*)

The cement-magnesite boards themselves are composites made of special (magnesia) cement, fillers (volcanic sand), a fibreglass mesh layer, and some fibreglass material. Fillers significantly reduce weight and thermal conductivity, increasing noise insulation at the same time. Magnesite boards are a universal solution in terms

of ecology and safety, which is in line with the global trends in the development of construction. They are resistant to acids, fungi and mould, additionally demonstrating anti-allergic and antibacterial properties. Such boards are a durable, fire-resistant, waterproof and light material. Due to their advanced structure and use in layered walls, they are referred to as composite structural insulated panels (CSIPs) in the literature (Rajeev et al., 2024).

SIPs or CSIPs usually act as cladding elements, with the load-bearing structure located in the place of panel joints. A popular solution in construction is embedding a wooden frame in the core of panels, in the areas of joints. In addition, CSIPs can be reinforced with profiles placed on their edges. The result is a panel reinforced both on the edges and on the entire surface by layers of steel sheet. Such a panel is resistant to impact during assembly and disassembly and has better mechanical properties, which makes it a suitable load-bearing element (Smakosz et al., 2021).

## 2. Testing facility – measuring stand

The temperature distribution was tested for two different envelope structures. One measuring stand concerned a two-layer wall made of cellular concrete and extended polystyrene (EPS). The other measuring stand was an envelope made of a structural insulated panel (SIP), composed of an EPS core sandwiched between magnesite boards. The structures of the envelopes, along with the location of FBG temperature sensors (A1, A2, A3, A4, B1, B2, B3, B4), are shown in Figure 2. The temperature on the internal surfaces of the envelopes was measured using DS18B20 digital contact sensors, marked as A5 and B5 in the figures.

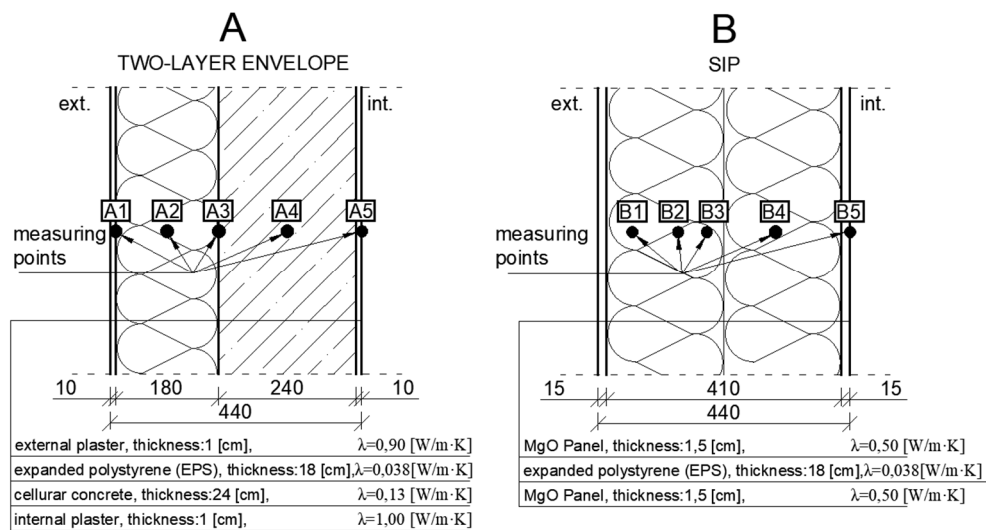


Fig. 2. Arrangement of the sensors in the tested envelopes (*own research*)

The boundary conditions on the outer surfaces of the analysed envelopes were identical, which means that the temperature and humidity on the inside of the tested

envelopes were the same, and the ambient conditions on the outside were identical for both the two-layer wall and the SIP.

The design of the measuring probe is a novel solution, purpose-made for a given thickness of the envelope, with FiSense FBG temperature sensors. A diagram of the adopted design solutions is presented in Figure 3. The measuring path was made of a string of fibre optic sensors with four Bragg gratings with a reference wavelength of 850 nm and a FiSpec FBG X100 interrogator. Before the probe was mounted on the test stand, the FBG sensor measuring path had been calibrated using a CTM9100-150 temperature bath calibrator. During the calibration, the actual value of the FBG sensor sensitivity to temperature was determined and the coefficients of the linear approximation function describing the temperature dependence on the reflected Bragg wavelength were calculated. The total measuring accuracy of the path determined in this way is  $\pm 0.3$  °C. The design of the sensor enables embedding it in a 6 mm hole drilled in the envelope (Juraszek & Antonik-Popiołek, 2021; Satława & Juraszek, 2024).

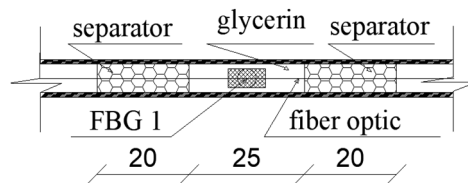


Fig. 3. Measuring probe design details (*own research*)

### 3. Results of temperature measurements in the envelope

Example results of the testing of the temperature distribution in the envelope in the period from 2.10.2025 to 8.10.2025 were recorded using a measuring system based on FBG sensors. The collected results were used to prepare graphs illustrating temperature changes over the analysed period (Fig. 4).

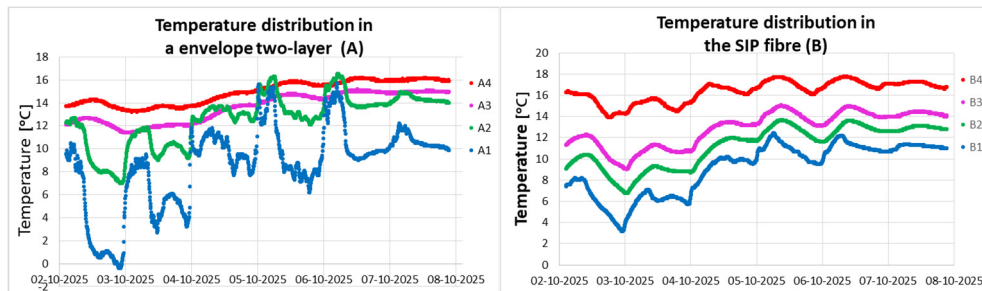
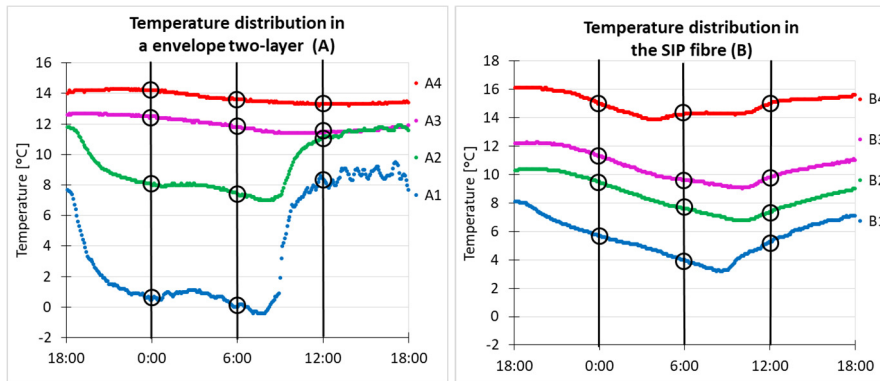


Fig. 4. Temperature changes inside the two-layer envelope (A) and inside the SIP (B) over the analysed period of time (*own research*)

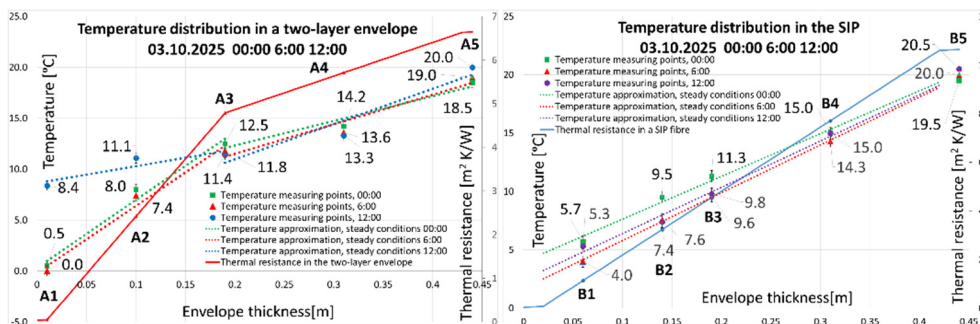
A comparative analysis of the temperature distribution in the tested envelopes was conducted based on the results of temperature measurements recorded between

2 October 2025 and 3 October 2025. Graphs A and B show the measured 24-hour temperature distribution for the two-layer envelope and the SIP. Marked on the graph are also selected points where a detailed analysis and a comparison of the temperature distribution inside the tested envelopes were carried out (Fig. 5).



**Fig. 5.** 24-hour temperature distribution in the two-layer envelope (A) and in the SIP (B) (own research)

The points corresponding to 00:00, 6:00, 12:00 hours were selected for further analysis. This selection makes it possible to trace the changes in ambient temperature over a 24-hour period and to conduct a comparative analysis of the impact of these changes on the temperature distribution in the tested envelopes (Fig. 6).



**Fig. 6.** Comparison of the temperature distribution in the two-layer envelope and in the SIP in selected measuring points (own research)

For comparison purposes, the graphs include curves illustrating changes in the thermal resistance values in the envelopes, with particular emphasis on the points where temperatures were measured. The thermal resistance values at these points are gathered in Table 1.

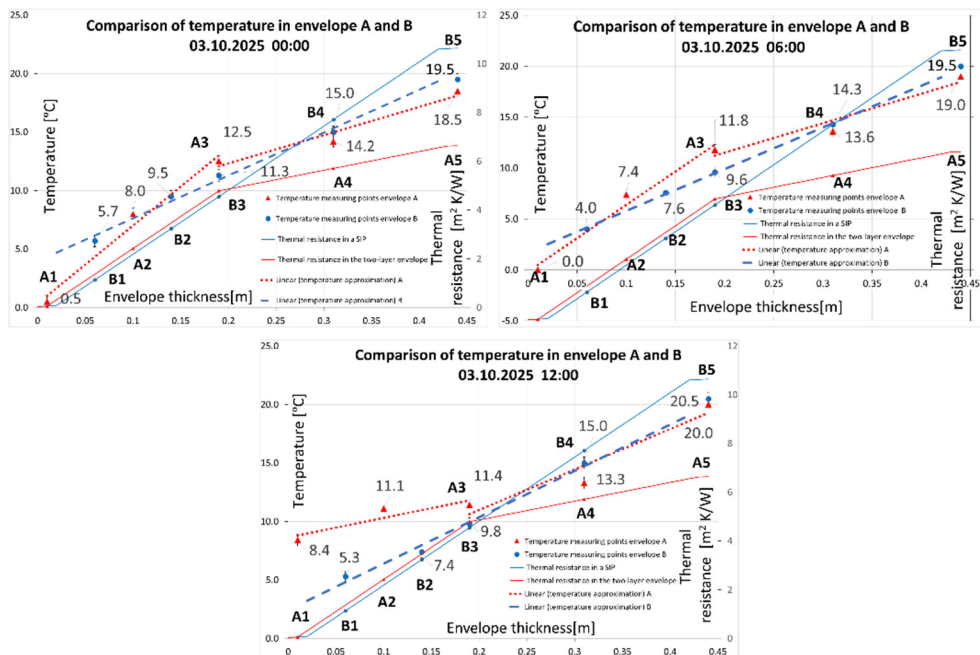
Due to high thermal resistance values above  $R = 5 \text{ (m}^2\text{K)/W}$ , the multi-layer envelopes that satisfy the thermal specifications of the WT (technical conditions) 2021 regulation are usually characterized by a linear distribution of temperatures inside them. A consequence of the high thermal resistance values is a low energy

flux density, due to which the temperature distribution inside the envelope proceeds in quasi-steady conditions. This regularity is maintained for all internal layers, including the insulation layer.

**Table 1.** 24-hour thermal resistance values for the points in the two-layer envelope and in the SIP (*own research*)

Thermal resistance R [m <sup>2</sup> K/W]									
two-layer wall (A)					SIP (B)				
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5
0.051	2.420	4.788	5.711	6.774	1.133	3.238	4.554	7.712	10.646

In the 24-hour period selected for the analysis of the temperature distribution inside the envelope, the temperature change amplitude was 8 °C. Despite the envelope exposure to such considerable changes in ambient conditions, the recorded temperatures in the internal load-bearing layers of the envelope varied only slightly in the range from 1 °C to 2 °C. Such small changes in temperature indicate a low value of the heat flux density and a low temperature gradient, which confirms the correctness of the above-accepted assumptions concerning quasi-steady heat transfer conditions in the envelope internal layers. The measured temperature values, within a measuring error of 0.3 °C, are in accordance with the approximated linear temperature distribution. The application of this rule for the calculation of the temperature distribution in load-bearing layers of envelopes made of cellular concrete is shown in the graphs using dashed lines connecting points A3 to A5 for the two-layer envelope (Fig. 7).



**Fig. 7.** Comparison of temperature in the two-layer envelope and in the SIP at selected measuring points (*own research*)

In the tested envelopes, the insulation layers were made of extended polystyrene (EPS) with a density of  $13.5 \text{ kg/m}^3$  and specific heat of  $1200 \text{ J/(kg K)}$ . This insulation layer type, which is usually 10 cm - 20 cm thick, is characterized by a low surface mass, and therefore low heat accumulation capacity and a high thermal resistance coefficient. For such parameters, the temperature distribution inside the layer is also linear and can be mapped as heat transfer under quasi-steady conditions.

In the case of a two-layer envelope, where the insulating layer is the external layer and thus exposed to changing ambient temperatures, the temperatures recorded during the tests indicate compliance with the linear nature of the temperature distribution. The temperature calculations for this layer are shown in the graphs using dashed straight lines approximating points A1, A2 and A3 (Fig. 7).

A similar method was used to determine the temperature distribution in the insulation layer of the envelope made of a structural insulated panel (SIP). In the graph it is the dashed line connecting points B1 and B4.

During the tested period, from 00:00 to 12:00 hours, the ambient temperature on the outside of the envelopes changed by approximately  $8 \text{ }^\circ\text{C}$ . During the same period of time, the temperature values on the external surface of the inner load-bearing layer (measuring points A3 and B3) change by  $0.7 \text{ }^\circ\text{C}$  for the two-layer envelope and by  $1.5 \text{ }^\circ\text{C}$  for the SIP-based one. Such small changes in temperature at these measuring points over a relatively long period of time (12 h) point to a low dynamics of changes in the heat flux density. It can be concluded that significant temperature changes in well-insulated envelopes occur over a period of several dozen hours. It should be noted that the temperature differences recorded over the tested period are often within the measuring accuracy of the temperature sensor. It is therefore essential that FBG sensors characterized by very high sensitivity and a low measuring error should be used for this type of measurements. This may be particularly important in the case of testing the temperature distribution inside collector-accumulation walls, for which the essence of operation is a correct use of the heat transfer direction.

The building envelopes currently in use have a multi-layer structure. Two- or three-layer envelopes are used the most often, with the inner layer always being the load-bearing one. (Satława & Juraszek, 2025). The outer layer, depending on the envelope structure, can be the insulating or the façade layer. If the outer layer is a façade layer, it usually does not make a significant contribution to meeting the required thermal characteristics of the envelope. A separate category are layered collector-accumulation envelopes, for which the outer layers of the so-called energy absorber are an essential structural element in the management of the heat transfer inside the envelope. The knowledge of the temperature distribution in such envelopes is absolutely necessary to make sure that they function properly.

## Conclusions

The determined actual temperature distributions in the two-layer wall and in the SIP indicate that compared to the two-layer envelope, the panel provides better thermal properties, which translates into lower demand for energy needed to heat

the same volume. In addition, attention should be drawn to the much lower cost of the SIP compared to the two-layer wall. The FBG temperature sensors mounted in the two tested envelopes are highly reliable compared to classic electrical resistance sensors. Further studies are planned which will focus on analysing the thermal comfort in rooms with these two different envelopes.

## References

- IPCC (2023) Climate change 2023: Synthetic Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. DOI: 10.59327/IPCC/AR6-9789291691647.
- Juraszek, J. & Antonik-Popiołek, P., (2021) Światłowodowe czujniki FBG do monitorowania temperatury przegród budowlanych. *Materials*, 14(5), 1207.
- Kietliński, W. (2015) Environmentally friendly and energy saving building engineering: the future. *Przegląd Budowlany*, 86, 2, 36-41. [bwmatal.element.baztech-a8541193-e6e7-4014-844a-234e22571cf3](https://doi.org/10.15199/33.2025.06.06).
- Rajeev, A., Ojha, S., Mathew, A.S. & Shelke, A. (2024) Smart composite structural insulated panels (CSIPs) with embedded piezoelectric sensors for damage localization. *Engineering Structures*, 322 (B). DOI: 10.1016/j.engstruct.2024.119118.
- Satława, A. & Juraszek, J. (2024) Analysis of the temperature distribution in an insulated reinforced-concrete building envelope using FBG sensors. *Construction of Optimized Energy Potential*, 13, 1, 210-217. DOI: 10.17512/bozpe.2024.13.21.
- Satława, A. & Juraszek J. (2025) Analysis of temperature distribution in a two- and three-layer partition using FBG sensors. *Materiały Budowlane*, 634, 06, 56-60. DOI: 10.15199/33.2025.06.06.
- Smakosz, Ł., Kreja, I. & Pozorski, Z. (2021) Zachowanie przy ścisaniu krawędziowym kompozytowych paneli konstrukcyjnych z okładzinami z płyt tlenku magnezu. *Materials*, 14, 3030. DOI: 10.3390/ma14113030.
- Wawrzynowicz, A. & Wojtkiewicz, T. (2024) New generation composite panels for military and civil applications: mechanical, thermal, fire, and acoustic properties. *Inżynieria Bezpieczeństwa Obiektów Antropogenicznych*, 63-70. DOI: 10.37105/iboa.238.
- Wieprzkowicz, A. & Heim, D. (2022) Badanie przewodnictwa zależnego od temperatury w celu poprawy charakterystyki energetycznej budynków. Konferencja BS2021 – 17. Międzynarodowa Konferencja IBPSA Building Simulation. Seria książek: Materiały z konferencji Building Simulation. 2022 r., [https://publications.ibpsa.org/conference/paper/?id=bs2021\\_30191](https://publications.ibpsa.org/conference/paper/?id=bs2021_30191). DOI: 10.26868/25222708.2021.30191.
- World Green Building Council, Our Strategy (2020-22).