

DEVELOPMENT AND APPLICATION OF ACTIVE THERMAL PROTECTION IN BUILDING FACADES

Veronika Mučková^{*1}, Daniel Kalús¹, Simon Muhič^{2,3}

^{*}veronika.muckova@stuba.sk

¹Slovak Technical University, Faculty of Civil Engineering, Radlinského 2766/11, 810 05 Bratislava

²Faculty of Industrial Engineering Novo mesto, Šegova ulica 112, 8000 Novo Mesto

³Institute for Renewable Energy and Efficient Exergy Use, INOVEKS, Cesta 2. grupe odredov 17, 1295 Ivančna Gorica

Abstract

This article explores integrating a facade with active thermal protection (ATP) into the Central Laboratories of the Slovak University of Technology in Bratislava. It covers the description of the building as well as ATP installation procedure, and presents preliminary results and recommendations. The study aims to implement ATP, conduct parametric analysis, and perform experimental measurements to assess the ATP performance under various energy functions.

Keywords

Active thermal protection, thermal barrier, heating, cooling

1 INTRODUCTION

The integrated energy-active component in the external wall construction is known as active thermal protection (ATP). It can serve a variety of energy functions, including thermal barrier, large-area radiant low-temperature heating/high-temperature cooling, heat/cool storage, solar and ambient energy capture and heat/cool heat recovery. The specific energy functions depend on the type of construction. For instance, a structure with high thermal conductivity is ideal for the thermal barrier function but would be ineffective for heating and cooling purposes. By utilizing active thermal protection, it is possible to eliminate the need for thick thermal insulation through controlled heat transfer. The thermal barrier function primarily relies on understanding temperatures between statically loaded, load-bearing structure and thermal insulation layer of the building. This temperature can be calculated manually and verified by computer simulation. In this paper, we present a design that is suitable for ATP in heating, cooling, and thermal barrier applications [1], [2], [3], [4], [5].

This study aims to implement active thermal protection, conduct a parametric study, and perform subsequent experimental measurements on the test object. The purpose of implementing the facade with ATP is to explore the role of active thermal protection in various energy functions. The research builds upon prior parametric studies and computer simulations. The design of this test facade is also suitable for further research opportunities or educational purposes. The experimental measurements obtained will be verified and compared with different calculations and computer simulations [6].

2 DESCRIPTION OF THE PRESENT STATE

Active thermal protection (ATP) is an area of active research, with numerous scientists and experts around the world exploring its potential. One notable contributor to the practical application of ATP, particularly in the field of thermal barriers, is Dipl.-Ing., Phys. Edmond D. Krecké. By harnessing solar energy through Energy (Solar) Roof technology and storing it in long-term ground heat storage systems, Krecké developed the patented ISOMAX system designed for residential buildings [7]. The implementation of this system started in the 1990s and continues to evolve today. The ISOMAX system applies ATP to the thermal barrier in three crucial ways, first, by placing it between the load-bearing structure and the thermal insulation; second, by incorporating it both between the load-bearing structure and the insulation and on the external side of the insulation to absorb heat from the ground at unfrozen depths; and third, by integrating it into the reinforced concrete core of the building's envelope, which is poured on-site using a special formwork made of EPS [8].

Some of the recent contributions to the research on active thermal protection are, for example:

S. Muhič, A. Čikić, and M. Perić, in their paper, introduce an active thermal protection system designed for both heating and cooling, applied to the envelope of a school building covering 5200 m². The system integrates renewable energy sources, such as thermal solar panels, direct cooling with underground water, and a heat pump, along with seasonal heat storage. Utilizing numerical simulations, the system's efficiency and sustainability were tested under varying environmental conditions. Measurements taken over several years showed that the system maintained low energy consumption, with average electricity use for heating, cooling, ventilation, and hot water preparation remaining below 8 kWh/m² from 2015 to 2019 [6].

A. Karanafti, T. Theodosiou, and K. Tsikaloudaki explore the growing interest in dynamic or variable thermal insulation systems, which offer more flexibility and efficiency compared to traditional steady-state thermal insulation. While thermal insulation has long been a standard method for improving energy efficiency in buildings, recent studies highlight the potential of adapting insulation to seasonal climate changes. The paper reviews various advancements in dynamic thermal insulation, analyzing their complexity, applicability, and limitations. It also discusses the challenges faced in implementing these systems widely within the construction industry and provides suggestions for future research to enhance their practical use in improving energy efficiency in buildings [9].

M. Fawaier and B. Bokor explore dynamic insulation, a method that adjusts heat transmission through building envelopes based on outdoor conditions. They focus on evaluating various dynamic insulation systems, particularly those using airflow, by reviewing existing literature on mathematical models, experimental studies, and numerical simulations. The paper compares different dynamic insulation structures, categorizing them by construction type, examined parameters, and research approaches. It highlights that dynamic insulation can achieve significantly lower heat loss and energy savings of over 40 %, compared to traditional static insulation. The article provides an overview of the development of this technology and suggests directions for future research [10].

3 METHODOLOGY

In this chapter, we present a fragment of the perimeter wall and the construction of the test facility at the Central Laboratories of the Slovak Technical University (STU) in Bratislava, Trnávka. Measurements and further research on various active thermal protection functions are planned for this building. The original perimeter wall, made of reinforced concrete panels, is covered with lime-cement plaster. A fragment of the perimeter wall is shown in Fig. 1.

Tab. 1 Thermal - technical properties of the structure.

	Material	Thickness	Density	Thermal Conductivity Coefficient	Thermal Resistance
	Symbol Unit	d m	ρ kg/m ³	λ W/(m·K)	R (m ² ·K)/W
1.	Lime-cement plaster	0.015	2000	0.990	0.015
2.	Reinforced concrete panel	0.400	2400	1.580	0.253
3.	Lime-cement plaster	0.015	2000	0.990	0.015
4.	System board	0.020	15.6	0.054	0.370
5.	EPS thermal insulation*	0.030	30	0.033	0.909
6.	Adhesive plaster	0.0025	1300	0.800	0.003
7.	EPS thermal insulation	0.040	30	0.033	1.212
8.	Adhesive plaster	0.0025	1300	0.800	0.003
9.	EPS thermal insulation	0.030	30	0.033	0.909
10.	System board**	0.020	15.6	0.054	0.370
Thermal resistance of the construction $R_{construction}$					3.690
Total thermal resistance $R_{100} = R_{si} + R_{construction} + R_{se}$					3.860
Total heat transfer coefficient $U_{100} = 1 / R_{100}$ W/(m ² ·K)					0.259

* EPS - Expanded Polystyrene

** this layer is not included in the thermal-technical assessment due to the contact with air (the layer is not closed)

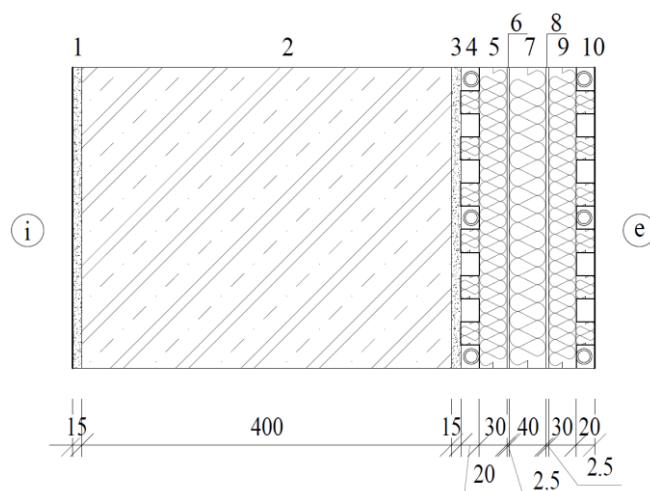


Fig. 1 Fragment of wall perimeter construction [Autor].

i – interior (interior temperature $\theta_i = 20\text{ }^{\circ}\text{C}$), e – exterior (exterior temperature $\theta_e = -11\text{ }^{\circ}\text{C}$). The composition of the structure is given in Tab. 1.

This construction, with a thermal insulation thickness of 100 mm, does not meet the standard requirements for thermal parameters:

- Standard value of thermal resistance:
 - $R_{\text{standard}} = 4.40\text{ (m}^2\cdot\text{K)/W} > R_{100} = 3.690\text{ (m}^2\cdot\text{K)/W}$,
- Standard value of heat transfer coefficient:
 - $U_{\text{standard}} = 0.220\text{ W/(m}^2\cdot\text{K)} < U_{100} = 0.259\text{ W/(m}^2\cdot\text{K)}$.

For this construction to meet the standard requirements for thermal parameters, the thickness of the thermal insulation would need to be 130 mm, with $R_{130} = 4.769\text{ (m}^2\cdot\text{K)/W}$ a $U_{130} = 0.210\text{ W/(m}^2\cdot\text{K)}$.

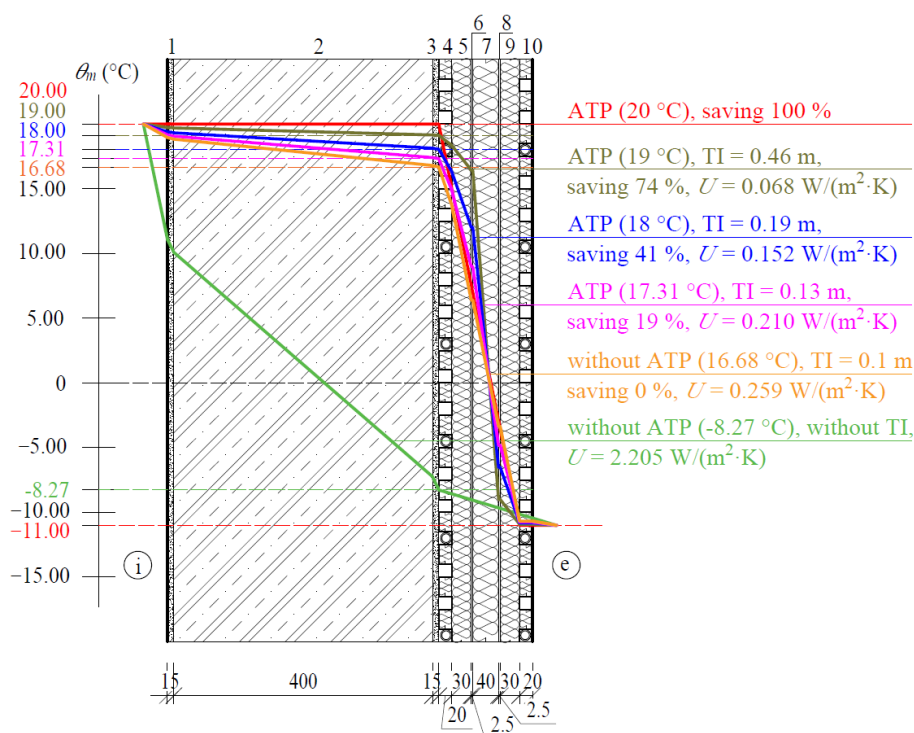


Fig. 2 Temperature profile and energy potential of the ATP in the perimeter wall in winter season [Autor].

i – interior (interior temperature $\theta_i = 20\text{ }^{\circ}\text{C}$), e – exterior (exterior temperature $\theta_e = -11\text{ }^{\circ}\text{C}$), θ_m – temperature in the structure ($^{\circ}\text{C}$), TI – thermal insulation, U – heat transfer coefficient ($\text{W/(m}^2\cdot\text{K)}$).

Fig. 2 shows the temperature profiles in the construction, along with the energy potential of the ATP and the heat transfer coefficient. The basic construction, which is insulated with the ATP turned off (indicated in orange), is presented first. The temperature in this construction is 16.68 °C, corresponding to a thermal insulation thickness of 100 mm and a heat transfer coefficient of $U_{100} = 0.259 \text{ W}/(\text{m}^2 \cdot \text{K})$. This serves as the baseline state for calculating energy savings (0 % savings). The state where the construction meets standard requirements is shown in pink. If a heat carrier fluid at 18 °C is supplied to the active thermal protection, the equivalent thickness of thermal insulation becomes 190 mm, and $U_{190} = 0.152 \text{ W}/(\text{m}^2 \cdot \text{K})$, representing 41 % savings. This means that by supplying a heat carrier fluid at 18 °C to the ATP, we save 190 mm – 100 mm = 90 mm of insulation thickness.

The construction and parameters behave similarly when the heat carrier fluid temperature is 19 °C. In this case, the savings are noticeably higher, up to 74 %. The temperature of 19 °C corresponds to a thermal insulation thickness of 460 mm. This means that by supplying a heat carrier fluid at 19 °C to the ATP, we save up to 460 mm – 100 mm = 360 mm of insulation thickness. At 20 °C in the ATP pipes, the system reaches an energy-balanced state with no heat loss from the interior to the exterior, meaning that the energy potential of the thermal barrier is 100 %. Circulation of the heat carrier fluid in the ATP is ensured by circulation pumps. In the future, electricity to power these pumps will be provided by photovoltaic panels installed on the facade and on the roof, thus further contributing to the building's energy potential.

The building in Trnávka is an older construction. We applied insulation with integrated energy elements on its facade, as shown in Fig. 3. The exterior wall is originally made of plastered reinforced concrete panels, 400 mm thick. The roof is flat, made from PZD panels, 240 mm thick, with levelling screed and bituminous membranes. The floor consists of linoleum and concrete, with a thickness of 100 mm.

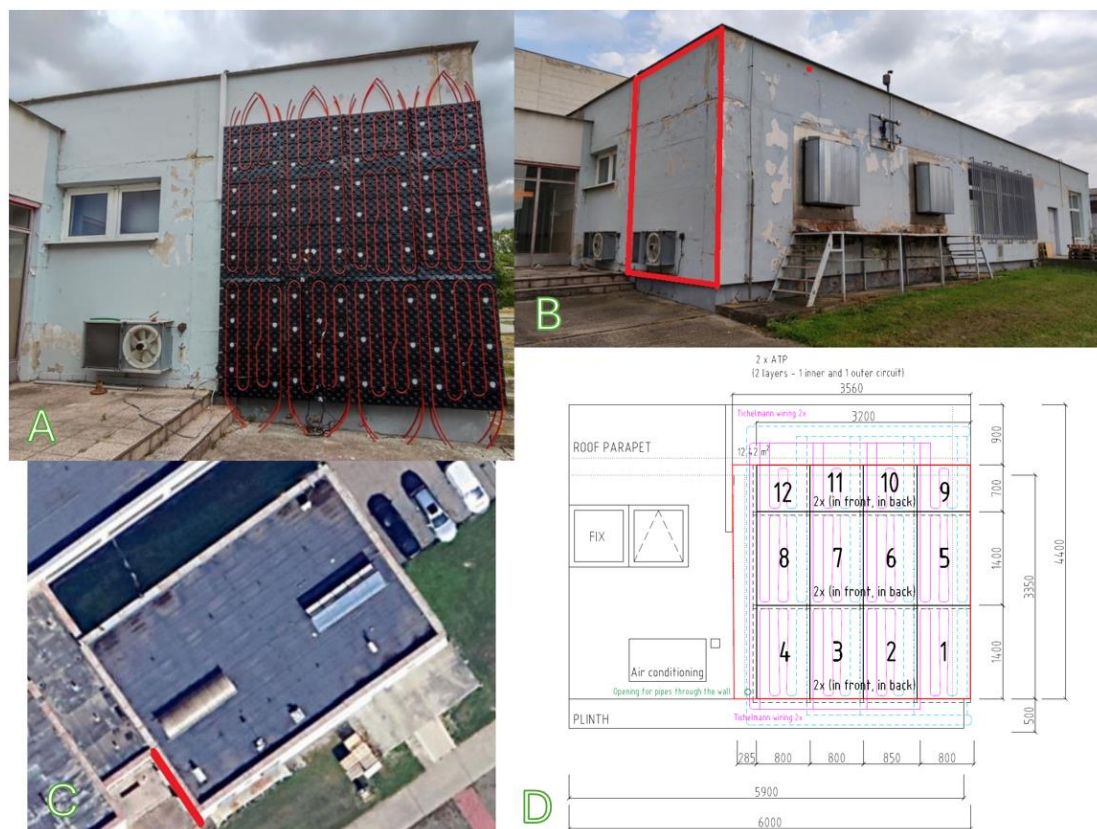


Fig. 3 Southwest facade with applied ATP panels [Author].

From the exterior side, the thermal insulation panels were attached, as shown in Fig. 3A. A detailed description of the panel construction can be found in Chapter 3. The ATP pipes (inner circuit) are fixed to the panel, while on the exterior side, pipes are installed for passive cooling during the summer (outer circuit). The panels are positioned on the southwest facade, as shown in Fig. 3B and 3C. Each basic panel measures 1400 × 800 mm, as shown in Fig. 3D.

4 IMPLEMENTATION AND DEVELOPMENT OF FACADE WITH ACTIVE THERMAL PROTECTION

In this chapter, we describe manufacturing of the panels and their application to the facade of the building at the Central Laboratories of STU in Trnávka.

In July 2024, we began assembling the panels. These panels are made from Varionova 30-2 Rehau system boards, designed for pipe mounting with integrated EPS (Expanded Polystyrene) thermal insulation, 30 mm thick. A 0.5 mm layer of adhesive plaster was applied to the board (Fig. 4A), and an EPS thermal insulation panel 40 mm thick, was glued on (Fig. 4B). Another layer of adhesive plaster was applied, and a second Varionova 30-2 system board was glued on (Fig. 4C and 4D). The finished panels are shown in Fig. 4E and 4F.



Fig. 4 Manufacturing of the Panels [Author].

The next step was to lay the pipes on both sides of the panel into the system boards, as shown in Fig. 5. It was important to ensure that the internal and external pipe circuits aligned correctly. Otherwise, it would not have been possible to securely anchor the panels to the perimeter wall construction. The pipes used were Rautherm S 17×2.0 mm. We chose a pipe spacing of 150 mm, based on previous parametric studies and computer simulations. The pipe placement was carried out according to the drawing, which outlined the panel laying procedure and the exact pipe locations, as shown in Fig. 3D. The pipes were then secured with straps with a spacing of 200 mm.



Fig. 5 Piping installation [Author].

After installing the pipes, a total of 8 temperature sensors were installed on the panels. Four sensors were placed for the inner circuit (upper circuit between the pipes, upper circuit on the pipe, lower circuit between the pipes, and lower circuit on the pipe). Similarly, sensors were placed for the outer pipe circuits, as shown in Fig. 6.



Fig. 6 Placement of temperature sensors: a) on the pipe, b) between the pipes [Author].

The panels were then attached to the southwest facade of the building. PUR foam was applied to the panels at six locations, as shown in Fig. 7A. Afterwards, the panels were glued on to the facade and anchored to the thermal insulation with anchors, as shown in Fig. 7B. Each panel was secured with six anchors to ensure that the pipes and sensors were not damaged. The panels were laid starting from the right bottom corner of the facade to maintain the overlap of the system board with protective film and protrusions on both sides of the panel, as shown in Fig. 7C. The upper circuit of the panels had to be connected before being placed on the facade, as it consisted of one and a half standard panels, as shown in Fig. 7D – 1 and 7D – 2. Once the panels were connected, the facade was completed, as shown in Fig. 8A to 8C.



Fig. 7 Application of ATP Panels to the Building Facade [Author].

The next step will be connecting the panels to the manifolds/collectors and subsequently integrating the entire system with the heat/cool source. The ATP panels must be connected to the Tichelmann system, as shown in Fig. 8C. There are four circuits:

- Top row of panels, inner ATP circuit,
- Top row of panels, outer cooling/preheating hot water circuit,

- Bottom row of panels, inner ATP circuit,
- Bottom row of panels, outer cooling/preheating hot water circuit.

The circuits will be connected to two manifolds/collectors (for heating and cooling), as shown in Fig. 8D. The heat/cool sources will be a monoblock heat pump and photovoltaic panels.



Fig. 8 Finalization of the Building Facade with ATP [Author].

5 DISCUSSION

Currently, the main system distribution is being installed, and the technical room is being constructed. The system is scheduled to be put into operation in the coming months. Experimental measurements were conducted during the winter season of 2024/25. These experimental results will be evaluated and compared with computer simulations and parametric studies [1], [2], [3], [4], [5], [6], [11].

- In the phase of implementing the facade with active thermal protection, the following points apply:
- By applying active thermal protection (ATP), we can reduce the thickness of thermal insulation by up to 360 mm (at an ATP temperature of 19 °C), thus saving on insulation costs.
- To meet the standard requirements for the heat transfer coefficient, the thickness of the thermal insulation can be reduced by 30 mm (at an ATP temperature of 17.31 °C).
- The ATP system has a high potential for energy savings and energy storage.
- The application of the ATP system results in energy savings compared to the composition of the outer wall construction.
- The temperature in the construction increases with the increasing thickness of the thermal insulation.
- The heat transfer coefficient in the construction decreases as the thickness of the thermal insulation increases.
- Active thermal protection at a heat carrier fluid temperature of 18 °C is sufficient when the indoor air temperature ($\theta_i = 20$ °C) and the outdoor air temperature ($\theta_e = -11$ °C) are considered. This heat carrier fluid temperature is equivalent to 190 mm of thermal insulation.
- The external pipe circuit will be active during the summer period and will serve as passive cooling or for preheating hot water.

6 CONCLUSION

We started implementing this facade in the summer of 2024. On some days, the outdoor temperature reached as high as 35 °C, and in direct sunlight, it was nearly 40 °C. The facade with ATP is oriented toward the southwest. After applying the ATP panels to the facade, we realized that the black colour of the system board was not suitable. A lighter colour would have been more appropriate, as it would absorb less solar radiation. Additionally, in the initial phase, it would be advisable to cover the facade with at least a geotextile to prevent excessive thermal

expansion of the pipes, which could damage them. In extreme cases, the high temperature in direct sunlight could cause the pipes to crack.

The goal of implementing the facade with ATP is to research the function of active thermal protection in various energy applications. Conducting this research has high potential. In addition to the planned experimental measurements, such as laboratory for active thermal protection, will also be suitable for further research and for students' education.

Acknowledgements

This work was supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic through the grant **VEGA 1/0118/23** and **VEGA 1/0229/21**.

References

- [1] MUČKOVÁ, Veronika, et al. Contribution to Active Thermal Protection Research—Part 1 Analysis of Energy Functions by Parametric Study. *Energies*, 2023, 16.11: 4391.
- [2] MUČKOVÁ, Veronika, et al. Analysis of the Dynamic Thermal Barrier in Building Envelopes. *Coatings*, 2023, 13.3: 648.
- [3] KALÚS, Daniel, et al. Contribution to the Research and Development of Innovative Building Components with Embedded Energy-Active Elements. *Coatings*, 2022, 12.7: 1021.
- [4] KRZACZEK, Marek; KOWALCZUK, Zdzisław. Thermal Barrier as a technique of indirect heating and cooling for residential buildings. *Energy and Buildings*, 2011, 43.4: 823-837.
- [5] YANG, Yang, et al. Thermal performances and invisible thermal barrier formation mechanism of arc-shaped metal-fin-enhanced thermally activated building envelopes with directional heat charging feature. In: *Building Simulation*. Beijing: Tsinghua University Press, 2024. p. 1461-1489.
- [6] MUHIČ, Simon; ČIKIĆ, Ante; PERIĆ, Mato. Building with an Active Thermal Protection in Combination with High Share of Renewable Energy Sources Use. In: *2024 9th International Conference on Smart and Sustainable Technologies (SpliTech)*. IEEE, 2024. p. 1-4.
- [7] @Isomax–Terrasol Building Technologies. Successor to Isomax–Solinterra. Available online: <https://www.solinterra.si/en/about-solinterra.html> (accessed on 27 March 2023).
- [8] KRECKÉ, E.; ULBRICH, R.; RADLAK, G. Connection of solar and near-surface geothermal energy in Isomax technology. *Proceedings of CESB*, 2007, 7: 622-628. Available online: <https://www.yumpu.com/en/document/read/4706674/connection-of-solar-and-near-surface-geothermal-energy-in-isomax-> (accessed on 15 March 2023).
- [9] KARANAFTI, Aikaterina; THEODOSIOU, Theodoros; TSICALOUDAKI, Katerina. Assessment of buildings' dynamic thermal insulation technologies-A review. *Applied Energy*, 2022, 326: 119985.
- [10] FAWAIER, Mohammad; BOKOR, Balázs. Dynamic insulation systems of building envelopes: A review. *Energy and Buildings*, 2022, 270: 112268.
- [11] KOENDERS, S. J. M.; LOONEN, R. C. G. M.; HENSEN, J. L. M. Investigating the potential of a closed-loop dynamic insulation system for opaque building elements. *Energy and Buildings*, 2018, 173: 409–427.