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THE IMPORTANCE OF USING ACTIVE THERMAL PROTECTION FOLLOWING RESTORATION WORK ON OLD BUILDINGS

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Abstract. The paper deals with the issue of humidity and the unhealthy environment of old buildings. Humidity is a very widespread problem not only in historical buildings, but also in newer buildings. This problem can be observed in various parts of the world and thus it can be said that it is a global problem. Humidity in these buildings causes an unhealthy environment, which has a negative effect on individual building constructions, but also on people's health. Humidity is also associated with the form of disruption of the individual layers of the construction and the disruption of the thermal resistance of these constructions. Buildings such as these subsequently have an unhealthy environment. After a part of the description of the known issue, the contribution follows on from this part by indicating possible remedial interventions and analyses the systems of additional thermal insulation (ETICS, ATP), ensuring the improvement of the internal environment. Finally, the article presents possible connections and extensions of this research and its application directly in practice. The results of the proposed research will significantly contribute to the approach to rehabilitated older buildings and their long-term sustainability from an economic point of view, as well as the possible use of them.

Keywords: Rising damp, anti-moisture technology, remediation interventions, additional isolation, ETICS, active thermal protection (ATP).

1. Introduction

A number of buildings suffer from the problem of structural wetness. This problem does not only concern Slovakia and its climate zone, but also affects buildings all over the world. It is interesting to mention that in Belgium, more than half of the remediation interventions belong to the removal of rising damp [1]. The problem of moisture in buildings has several causes. Humidity in these buildings is mostly caused by capillary rise, condensation of water vapour by absorption, transmission, etc. [2]. These problems are usually associated with insufficient maintenance of buildings and also with other usual causes of malfunctions – for example, corrosion of the original waterproofing or its absence, changes in the groundwater level, damage to water or sewage pipes, damage to gutters and rainwater waste, roofing, sheeting, etc. Condensation of water vapour is also an important source of wall surface moisture, which is subsequently manifestred in the higher parts of the walls [3]. These problems subsequently have a destructive effect on the buildings in which they occur, reducing the life of the materials. Damp walls also contribute to increasing the thermal conductivity of these buildings, resulting in high energy consumption for heating. It is therefore very important to focus on solving this problem.

In many cases, wetting of structures can be prevented by regular maintenance and inspection [4]. These inspections are often done visually and are not financially demanding. It is necessary to focus mainly on checking the roof, rain gutters, the condition of the masonry and the like. Often, however, only the consequence of the problem is removed, but the cause remains. This leads to the reoccurrence of faults and the cost of their elimination.

This article can be divided into two parts. In the first part, the authors deal with the removal of moisture from the structure and then follow up on this part with a proposal for the application of ATP to older buildings, based on the reduction of energy demand in older buildings. The individual steps are shown in Figure 1.

In this part, we will focus mainly on failures and wetting of structures due to rising humidity. The paper will also describe the possible methods to combat this problem and present the results presented directly from the research. These will help to improve the overview of the possible effectiveness of the selected technologies. Subsequently, the possibility of following up on this remedial intervention by the possible implementation of elements of Active Thermal Protection (ATP) will be described. A significant progress has also been made in this industry in recent years, as evidenced by numerous publications. As an example, the research of the physicist Edmond D. Krecke,

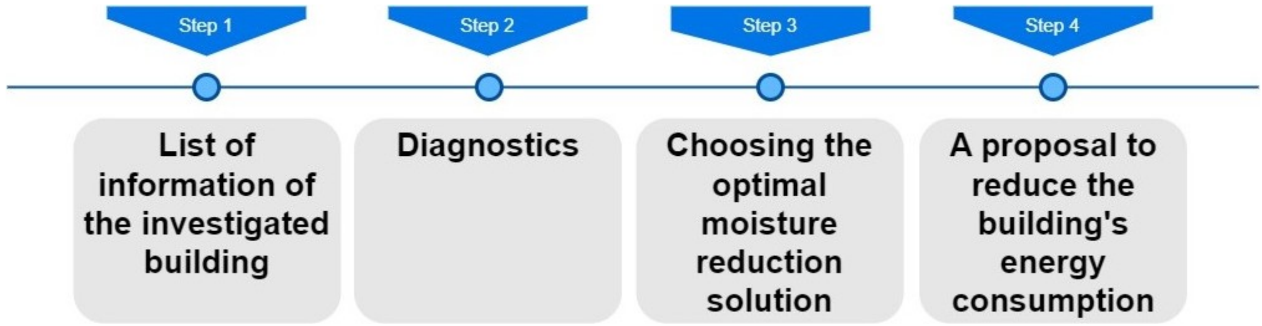


Figure 1. Development diagram of the successive steps of the dehumidification solution and the reduction of the building's energy consumption.

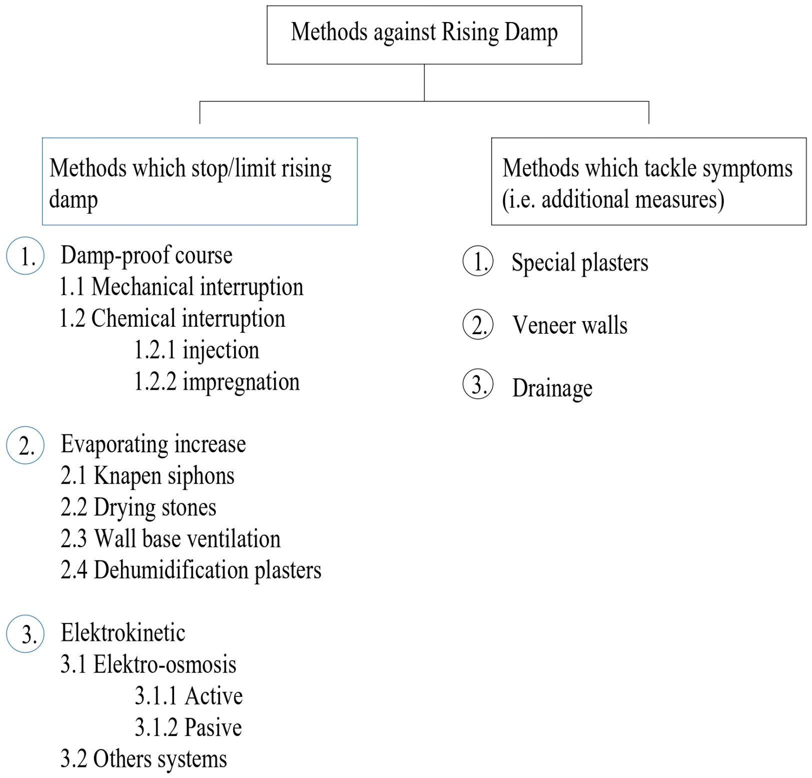


Figure 2. Division of methods intended for the rehabilitation of structures. According to [5].

who proposed the Solinterra system based on an idea already inspired by the medieval Romans, who used double wall systems [6], can be cited, but there are also many other scientists dealing with this issue [7, 8].

2. Anti-moisture repair technologies

There is a large number of individual technologies to combat rising moisture. As an example, the publication of the EMERSIDA project [5] can be cited, which divides these technologies into two main groups (Figure 2).

In this paper, we will focus only on the effectiveness of the first group of methods, specifically mechanical and chemical interruption, as they fall within the scope of the authors' current research. The principle of their application consists in the creation of an additional insulating layer, which ensures additional waterproofing insulation against rising groundwater infiltration.

The first thing to mention is the application of creating additional impermeable layers. Among these technologies, according to [3], the technologies of undercutting masonry and butting stainless steel sheets can be included. These technologies are implemented in successive steps.

The most commonly used undercutting technique is a diamond wire saw, which, with the aid of rollers, can create a storage layer for waterproofing in various types of masonry. Subsequently, the cut is cleaned, a waterproofing strip is inserted, wedged against settling, and the next shot is moved. The length of the shot depends on the type of masonry and various other factors. However, we can assume that a length of 0.5 m is usually carried out. Subsequently, wedges are applied to the joints against settling and the next shot is done. The last step is to fill the joint, for example, with the help of a mortar machine. The final plaster is applied last.

The technology of stopping stainless steel sheets is also commonly used. Sheets are made of very hard steel and often have a corrugated profile. In this case, a device is used, which, with the help of a high frequency, rams individual sheets into the masonry. They overlap in a certain length, or are connected by a lock. This principle guarantees the waterproofing functionality of the technology. However, there are implementations where the given system has not proven itself [9], mainly due to the inability of the given system to fight against pressurised water.

Other described technologies are the technologies of creating crystal screens [3], specifically, we will focus on injection technology. This technology does not need such a large working space as the technologies described above. From this point of view, it is therefore used in places where it is not possible to apply the technologies of additional impermeable layers. The principle consists in covering the original layers down to the masonry and marking the line of the boreholes. Subsequently, wells are drilled according to the type of applied substance, either horizontally or at an angle of 15–45°. Also, the distance between individual wells depends on the type of masonry and its porosity. For less porous masonry, a distance of approximately 10 cm is commonly used, for more porous materials, 20–30 cm is sufficient. After this step, the wells are cleaned with a compressed air, grout is applied, and the wells are sealed. After it has dried, the surface is finished when the masonry is completely dry and it is not necessary to re-inject some parts.

3. Collection of data from research on applied barrier repair technologies in situ

In this research, we will mention two buildings located in western Slovakia, on which the technologies described above were applied. In the case of these structures, initial research was first carried out, which determined the degree of dampness of the buildings. During this survey, samples were also taken to determine the level of salinity. Determining the degree of salinisation is an important element for the design of a suitable technology. The degree of dampness was determined according to the technical standard ČSN P 73 0610 [10]. Both buildings showed a high degree of dampness, according to ČSN P 73 0610, most places can be classified as wetting, as the moisture reached a value above 10 %. Subsequently, the relevant anti-wetting technologies were applied to the constructions.

In the case of building number 1, the masonry undercutting and grouting technologies were selected and then applied. Building number 1 is located at an elevation of 167.00 m.a.s.l. and its front forms a boundary with the street. It has two floors, a rectangular floor plan with a total built area of approximately 560 m^2, and is made of brick masonry. Building number 2 has a more complicated character and all 3 mentioned technologies were used, i.e. the technology of undercutting masonry, butting stainless steel sheets, and the injection technology. The building has two fllors and L-shaped floor plan with a total built-up area of 400 m^2. It is oriented on flat terrain near a small watercourse at an altitude of 144.00 m.a.s.l. From the local research destructive probes, it is clear that the building is built of brickwork, namely solid fired brick with a thickness of approximately 50 cm.

The data collection was recorded in the construction documentation. The individual places where the measurements were taken were marked. These measurements were carried out before and after the application of remedial measures. In the case of the investigated buildings, one measurement was made before the implementation and two measurements after the application of the rehabilitation intervention. Measurements carried out after the application were made several months apart, so that the individual values demonstrate the degree of effectiveness of the technology. Several measurements were made in the marked places to avoid possible inaccuracies. In building number 1, 49 measurement locations were selected due to the size of the building, where measurements were taken at two different heights. Building number two had 10 measuring locations. Here, the procedure was the same as for building number 1. Measurements were taken at a height of 30 cm from the floor and at a height of 150 cm from the floor. These values were recorded in tables, where a part of the table belonged to each measurement point. After the technologies were applied, several measurements were taken at different time intervals (usually several months), so the moisture behaviour could be observed after the application. The total duration of the research from the initial to the final measurement was 1.5 and 2 years for buildings 1 and 2, respectively. These results were recorded and evaluated and are shown in Tables 1 and 2.

The values given in the table were derived from the measured values. The average moisture was determined as the sum of all moisture values at a given height divided by their total number. The percentage difference before and after the rehabilitation was determined using the formula:

$$H_d = \frac{(H_a - H_b)}{H_b} x100, \tag{1}$$

where

H_a moisture content of the construction after the remedial intervention measured during the last inspection [%],

H_b moisture content of the construction before the remedial intervention measured during the first inspection [%].

	Building no. 1	
	30 cm	**150 cm**
Average moisture before remediation [%]	8.18	7.32
Average moisture after remediation [%]	2.99	3.57
% difference before and after rehabilitation [%]	−63.42	−51.28
Average moisture before remediation EXT [%]	8.19	
Average moisture after remediation EXT [%]	3.27	
% difference before and after rehabilitation (EXT) [%]	5.89	
Masonry type	Mixed	
Undercutting PE ins. (% moisture reduction) [%]	−44.71	
Undercutting stainless steel sheets (% moisture reduction) [%]	-	
Injection technology (% moisture reduction) [%]	−13.12	

Table 1. Display of the state and percentage of moisture reduction in the investigated building number 1.

	Building no. 2	
	30 cm	**150 cm**
Average moisture before remediation [%]	12.30	5.97
Average moisture after remediation [%]	1.83	3.03
% difference before and after rehabilitation [%]	−85.13	−49.28
Average moisture before remediation EXT [%]	9.14	
Average moisture after remediation EXT [%]	2.43	
% difference before and after rehabilitation (EXT) [%]	−73.42	
Masonry type	Brick	
Undercutting PE ins. (% moisture reduction) [%]	−54.20	
Undercutting stainless steel sheets (% moisture reduction) [%]	−74.95	
Injection technology (% moisture reduction) [%]	−82.82	

Table 2. Display of the state and percentage of moisture reduction in the investigated building number 2.

These two calculations are also used for the other data calculations in the table, but the input data for the calculation are changed according to the distribution of the type of technology, i.e. whether it is interior or exterior. This information was part of the protocol, in which the authors indicated individual measurement locations and the type of remediation technology used.

From the results presented in Tables 1 and 2, it is possible to evaluate the positive course of dehumidification of the buildings. By applying the remedial measures mentioned above, capillary moisture levels were reduced to 3 % or less under ideal implementation conditions. This finding is also supported by another research investigating injection remediation interventions on other structures [11]. These remediation technologies such as undercutting are discussed in an article by the German Professor Schmidt [12], who devotes a chapter to this technology and describes it on the one hand as radical and costly, on the other hand as very fast and effective. Kiesow also points to this technology in his book [13], where he evaluates it in terms of reliability and costs. It is also necessary to mention that the application of these measures also significantly reduced the humidity in the interior of these buildings. In order to ensure a hygienically optimal internal environment, it is possible to apply new rehabilitation plasters with the principle of releasing salts from the substrate, or thermal insulation systems to the building renovated in this way. Remedial plasters have a relatively short lifespan (10–15 years), as their pores become clogged very quickly due to residual moisture in the masonry and crystallisation of salts. With the rationale of ensuring an optimal internal environment, such plasters were also applied to the examined buildings after the measurements were completed. According to ETAG 004 [14] or EAD 040759-00-0404 [15], the basic lifespan of 25 years is set for insulation systems. The possibility of using ATP comes to the fore as one of the optimal solutions for such types of structures. The application of the ATP system for a given type of structure can optimise not only the costs of the operation of it, but also a suitable solution from the point of view of permanent sustainability. Therefore, this research will be followed by a proposal for the technology of additional wall insulation with the ATP system, which currently represents the theoretical level of this research, and a broader research is being prepared, which will monitor in situ the conditions achieved after the application of ATP to the investigated buildings.

4. Additional wall insulation technology with active thermal protection (ATP) in old buildings

As a result of the above-mentioned research, the question arose as to the possibility of applying a thermal protection system to buildings that do not meet the requirements for energy efficiency. The investigated buildings are older buildings whose energy consumption is relatively high. After the step of removing the rising moisture and drying the structure, it would be appropriate to apply the ATP system, which would significantly help reducing the energy demand of the buildings, which would significantly reduce, for example, operating costs. These gradual steps can also be considered the optimal solution from the point of view of the sustainability of buildings and their optimal use. This will fulfill directive no. 2002/91/EC of the European Parliament and of the Council of 16$^{\text{th}}$ December 2002 on the energy efficiency of buildings [16], and related directives. These directives establish the needs for increasing the energy efficiency of not only new, but also old buildings.

The contact insulation system is a composite construction that has been used in the central European latitudes since the 1970s to improve the properties of the outer shell, which represents a period of more than 50 years [17]. Contact insulation is mainly used as a rehabilitation of panel apartments and their ability to adapt to climate changes. This thermal engineering measure for prefabricated residential houses to reduce energy consumption creates healthy housing, a healthy indoor microclimate and a healthy surrounding macroclimate [4].

Insulation reduces heat losses through the building envelope and eliminates many of the deficiencies of exterior walls. The implementation of external heat-insulating contact systems (ETICS) also achieves the appearance of the outer shell comparable to a new structure.

The external thermal insulation contact system (hereinafter referred to as "thermal insulation contact system" or "ETICS") is directly an assembly of industrially produced elements for the outer wall built in on the construction site. It contains adhesive mortar, thermal insulation material, mechanical anchors, reinforcing layer and decorative plaster [18]. The ETICS specification results from the project documentation, where the exact composition, type, and thickness of the insulating layer, the type, number, and the distribution of mounting anchors, determination of accessories, and details of the solution are determined. The decisive technological stages in the application of a heat-insulating contact system are the preparation of the base, gluing and anchoring of the insulating material boards, the application of the reinforcing layer, and the application of the surface finish [18].

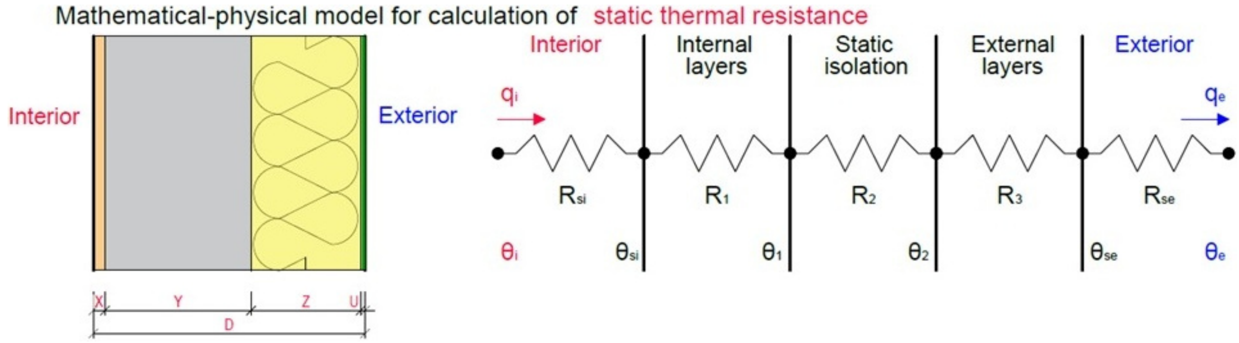
The purpose of the ETICS system is to ensure an efficient thermal and technical performance of the building, increase its energy efficiency, and to ensure the hygiene of the internal environment of older renovated buildings. It should be noted that, in this research, we do not consider these older buildings to be historical or heritage-protected buildings, to which it is necessary to apply the principles of monument protection or the principles of the Venice Charter [19]. The research is focused on buildings that, during their construction, did not yet fall under the energy certification and constructions that may have lacked moisture insulation. That is, buildings built approximately after 1950. Regarding insulation technology, it is also necessary to take into account the protection of health and the environment. In order to meet the conditions of thermal comfort in the room in winter and to meet the energy requirements, the walls, roofs, ceilings and floors of heated or air-conditioned residential and non-residential buildings in areas with a relative humidity of $\sim$80 % must have a construction heat transfer coefficient U smaller or equal to the normalised value. From 2020, the proposed insulation composition should comply with the required heat transfer coefficient of $0.15\,\mathrm{W\,m^{-2}\,K^{-1}}$ [20].

It is a technique whose output is static thermal resistance (Figure 3a). It is also reffered to as passive thermal protection. However, any wall thermal insulation design must take into account the moisture balance of the entire strcutre to prevent condensation of water vapour [20]. This can appear to be a problem in older renovated buildings.

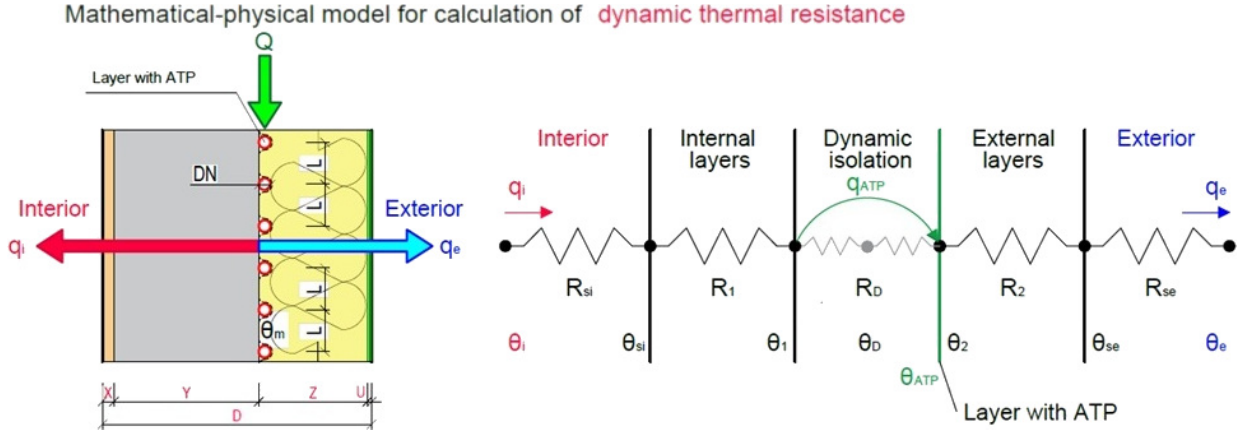
Residual moisture in the structure is a risk when additional insulation is applied to a restored and dehumidified building with a long term damp and saline envelope. By enclosing older and originally wet masonry in a contact insulation system with a relatively high coefficient of diffusion resistance, residual moisture and water vapour do not escape to the exterior and there is a risk of their accumulation on the surface of the walls in the interior. This promotes the formation of moulds and non-compliance with hygienic requirements for health protection.

The reduction of residual moisture in renovated older buildings can be achieved by using ventilated insulation systems. The ventilated system shows higher workability, it is not suitable for complex shapes of perimeter walls, and it requires high precision of installation of anchoring elements. Depending on the surface plate of the cladding, its implementation costs can be up to twice as high.

The principle of the ventilated system is an air gap in the composition of the layers and its primary function is to ventilate moisture from the thermal insulation layer. The air flow in the gap of the insulation system and its use to reduce the energy demand of the building has been investigated in the study Ventilated facade integrated with the HVAC system for cold climates [21]. The main task was the devel-



(A). Static.



(B). Dynamic.

D the total thickness of the building structure [mm],

L the spacing of ATP pipes [mm],

q_i the radiant flux density towards the interior [$\mathrm{W\,m^{-2}}$],

q_e the radiant flux density towards the exterior [$\mathrm{W\,m^{-2}}$],

q_{ATP} the radiant flux density in the ATP layer [$\mathrm{W\,m^{-2}}$],

Q the heat/cold [kWh] delivered to the ATP layer by a heat-carrying substance with an average temperature,

θ_m [°C] during time t [s],

θ_j the temperature in the j-th layer of the structure [°C],

R_j the thermal resistance of the j-th layer of the structure [$\mathrm{m^2\,K\,W^{-1}}$],

R_{si} the thermal resistance to heat transfer at the internal surface of the structure [$\mathrm{m^2\,K\,W^{-1}}$],

R_{se} the thermal resistance to heat transfer at the external surface of the structure [$\mathrm{m^2\,K\,W^{-1}}$],

θ_e the exterior temperature in winter [°C],

θ_i the interior temperature [°C],

DN pipe dimensions,

ATP active thermal protection.

Figure 3. Calculation of thermal resistance.

opment of the concept of a closed ventilation circuit with a convective heat flow, which will ensure the improvement of the building's internal comfort and at the same time reduce its operating costs. The experimentally developed system uses convection heat transfer in the ventilated facade for heat recovery in the buffer zone of the facade, which makes it possible to reduce ecological impact on the environment and the use of energy resources. However, this system does not allow the presence of moisture in the gap for the functionality of closing the ventilation circuit. Residual damp in rehabilitated older buildings would be undesirable in this case, and the incorporation of membranes would, again, threaten its accumulation on the inner surface.

The solution to reducing the risk of residual moisture in renovated older buildings could be the application of the so-called active thermal protection (ATP) on the dehumidified exterior wall. ATP introduces the so-called internal energy source understood as an energy system integrated in the zone between the static part and the heat-insulating part of the structure in the form of a low-temperature heat-carrying substance obtained from solar and geothermal energy, which is captured and accumulated. ATP is a controlled dynamic process characteristic of building constructions with integrated energy-active elements (distributions) that have one or more energy functions during various operations of energy systems and heat sources. Basic functions include:

- thermal barrier (TB),
- large-area radiant heating/cooling,
- accumulation of heat/cold,
- capture of solar energy and environmental energy,
- heat/cold recovery,
- various combinations.

That is why it is more appropriate to apply ATP to exterior wall structures after remedial action has been taken to cure the moisture load of older buildings.

Increasingly stringent EU energy legislation and the need to meet thermal energy criteria [22] mean that the thickness of thermal insulation is increasing over time. The ETICS composite, in accordance with the applicable legislation, reached a thickness of 180 to 200 mm after 2020, with a thickness of the peripheral wall panel of 270 to 300 mm [4]. The static thermal resistance of the exterior wall of a structure with a passive thermal protection therefore depends on the thickness and the coefficient of thermal conductivity of the j-th layer of the construction.

When designing the exterior walls of a structure with active thermal protection, we are talking about dynamic thermal resistance. The principle of ATP and dynamic thermal resistance is to maintain a uniform temperature in the layer of the structure, in which the active thermal protection elements are located. These elements (pipes, distribution systems) are usually placed between the statically load-bearing and heat-insulating layers of the exterior walls.

If we apply active thermal protection to the structure, the heat/cold Q [kWh] delivered to the ATP at time t [s] is also included in the thermal resistance calculation. This means that if we can affect the temperature in the structure with the heat supplied to the ATP pipe, we are talking about dynamic thermal resistance, Figure 3b.

In practice, ATP can be used not only during a construction of a new building, but also applied to existing buildings. To distribute the low-temperature heat-carrying substance, a pipe system is installed on the perimeter wall of the building, covered with levelling plaster, thermal insulation is glued on, and all layers of surface facade plaster are applied.

As an example of the application of active thermal protection, we present a fragment of a wall perimeter construction made of solid fired brick (Figure 4). In order for this structure to meet the standard requirements of static thermal resistance, the load-bearing part made of solid fired brick is insulated with 210 mm thick EPS thermal insulation. Before the application of the insulation, the internal temperature in the structure was $\theta_m = 18.04\,°\mathrm{C}$, after applying the 50 mm thick EPS thermal insulation, the temperature in the construction was $\theta_m = 13.27\,°\mathrm{C}$. We can change the temperature in ATP pipelines. If we set the water temperature to 18 °C in the ATP pipes, this temperature will be equivalent to a thermal insulation thickness of 210 mm. The result of such insulation is not only ensuring a constant temperature of the exterior wall, ensuring further drying and reduces the risk of mould growth in the interior, but by setting the correct temperature in the pipes, we can also reduce the required thickness of the thermal insulation by up to 160 mm. This has a high environmental impact.

The active thermal protection system has been applied experimentally to several research buildings (Figure 5). First structure was a prototype of the IDA I panel house built in Slovakia in the city of Bratislava (years 2005–2007). Subsequently, an experimental family house EB2020 was built in the village of Tomášov (years 2008–2014), and a mobile laboratory in Zochová chata (years 2015–2021).

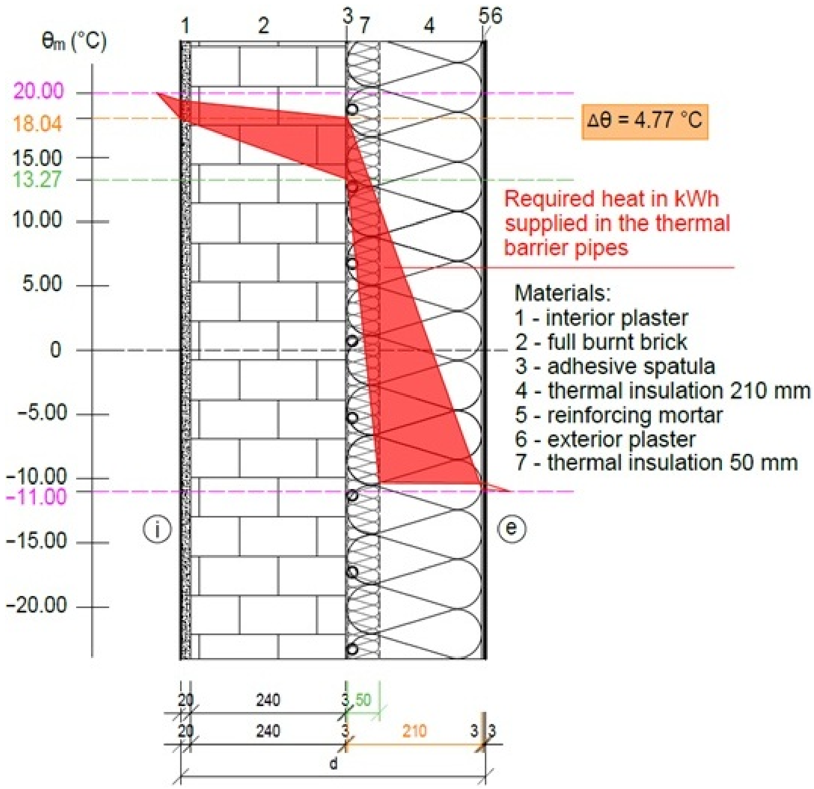
A study of the operation of ATP is currently being prepared on a fragment of a renovated building, on which anti-wetting technologies were previously installed, with the collection of moisture data after the implementation of barrier dehumidification technology. Two independent fields with contact insulation are placed on the building, so that they do not affect each other:

- on the monitored sample of the exterior wall of structure A, passive thermal protection will be applied;
- on the monitored sample of the exterior wall of structure B, active thermal protection will be applied.

Sensors for collecting moisture and temperature data will be placed on the inner surface of the walls. From the experimental research we expect:

- comparison of the design of thermal insulation thickness for static and dynamic thermal resistance in a renovated structure,
- comparison of temperature and moisture conditions in the renovated structures and on their inner surface.

The topic of active thermal protection is covered in various publications. In their research, Król and Kupiec [29] focus on the optimal placement of ATP in the shell of the building. On the contrary, steady-state analysis of authors [30] shows that at a design temperature of $-10\,°\mathrm{C}$, the 60 mm thick active insulation system has a performance equivalent to 110 mm of passive insulation. All these articles are useful and help to better understand this issue and the effectiveness of ATP, which in many cases may not only be used in new buildings, but also during a restoration of older buildings, which can subsequently meet certain elements of sustainability.



θ_m the interior temperature [°C],
$\Delta\theta$ temperature difference [°C],
d structure thickness [mm],
e exterior,
i interior.

FIGURE 4. Fragment of the wall perimeter construction: full burnt brick.

FIGURE 5. Research structures [23–28].

5. CONCLUSION

The use of the active thermal protection system has, in addition to the positive benefit of the thermotechnical properties of external walls, also an associated benefit in the form of keeping the originally wet walls in a dry state. We consider this a significant benefit for returning older buildings to use and ensuring their sustainability.

- A favourable moisture environment eliminates the disruption of the individual layers of the structures and the disruption of the thermal resistance. At the same time, it has a favourable effect on people working or living in them.
- When applying the method of active thermal protection, the requirements for thermal insulation and its thickness are reduced.
- Reduced requirements for the production of thermal insulation means less impact on the environment both during production and disposal at the end of its life.
- By using ATP technology, it is possible to regulate the well-being of the internal environment both in winter and in warm summer conditions, without negative effects on people.

Research on active thermal protection has not yet been carried out on isolated buildings where there is a risk of residual moisture in the exterior walls. We are currently evaluating the research on the active thermal protection systems applied in Slovakia so far. The evaluation requires a complex, interdisciplinary approach from both a thermal and a structural point of view. Temperature changes in distribution systems can lead to unacceptable loads on peripheral structures. Therefore, the interval of temperature changes and values during the annual cycle and their influence on the construction can be the subject of further interdisciplinary research.

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