Thermomodernization of Historical Buildings with Residential Facades

Dariusz Bajno*

UTP University of Science and Technology, Bydgoszcz, Poland

Abstract: Historic buildings, as well as much newer ones, with architecturally attractive facades, will not be thermomodernized from the outside, Because of their high value stands in the way. One such case is mentioned in this article, in which an analysis of external vertical partitions was carried out, in terms of heat and humidity in a small residential building located in southern Poland and built in 1930. The article describes a hygrothermal analysis of the above mentioned partitions, before and after thermomodernization, which should assess the legitimacy and effectiveness of using controversial methods of insulation of external building partitions from their internal sides. The article is a summary of a five-year observation and research of the object, after its thermomodernization in 2015. The analysis was focused on its vertical partitions.

Keywords: Thermomodernization, Historic buildings, Valuable facades, Insulation methods from the inside, Intra-layer condensation, Heat transfer coefficient.

1. INTRODUCTION

Climate warming and reduction of maintenance costs, forces building occupants to use solutions that limits, inter alia, the heat loss. This common procedure is thermomodernization of buildings regardless of their size and purpose. Regulations valid in Central Europe set out acceptable levels of heat emission, inter alia by imposing limit values of the heat transfer coefficients "U" [W/(m^{2}K)]. In Poland, monumental buildings and structures are currently excluded from this obligation, regardless of their size, function and appearance. Nevertheless, the owners (occupants) of such buildings carry out their thermo-modernization for economic reasons and due to increasing utility standards. However, it is not always possible to carry it out inappropriate technique (safe), i.e. from the outside because of their valuable facades. Thus, not only historical and historic buildings but also those much newer, with architecturally attractive facades, will not be thermomodernized from the outside, even though it is the most appropriate form of thermal modernization of external partitions. One of these cases has been mentioned in this article, where an analysis of external vertical partitions was carried out, in terms of heat and humidity in a small residential building located in southern Poland (temperate climate) and was built in 1930. The size of the object is not important here, because the problems concerns the principles of proper selection of additional layers limiting heat losses through building partitions and at the same time ensuring the safe migration of moisture inside them. The article carried out a hygrothermal analysis of the abovementioned partitions, before and after the thermomodernization process.

The goal set in the article is to overthrow the very common myth about the harmfulness of thermomodernization of buildings, using insulation techniques fixed from the inside of partitions, without any credible justification.

The article is a summary of a five-year observation and research of the object mentioned above, after a thermomodernization process of its vertical partitions in 2015, using the new Multipor technology made of light and easily machinable, diffusion-open, mineral materials. The performed tests of the facility have been verified by advanced hygrothermal calculations, which has shown that this type of technology, providing a certain amount of air exchange in rooms will not harm the construction of these objects and their partitions. It will even improve the microclimate and reduce heat loss through partitions even 4 to 7 times, as it has been shown in this article. Currently, the demand for thermal energy is almost three times lower in comparison to the period before thermo-modernization, and for 3 years has not exceeded the level of 50 kWh/m^2/year.

2. METHODS

The best research method will always be one that allows you to verify the "in situ" tests with the appropriate calculation model, and vice versa. The author, in the discussed case, conducted thermovision

---

*Address correspondence to this author at the UTP University of Science and Technology, Bydgoszcz, Poland; Tel: +48 502 187 898; E-mail: dariusz.bajno@utp.edu.pl

E-ISSN: 2409-9821/20

tests of the object and determined their moisture level in the period before and after thermomodernization. These studies have been numerically verified in support of advanced calculation programs and compared to each other. Such action allow us to determine the current technical condition of partitions and to forecast its propagation or stabilization after carrying out the rescue and modernization works. The culmination of tests and calculations mentioned above, should be the monitoring of such partitions, continued in the further period of exploitation, especially in places with high moisture condensation, that may periodically be in an environment of low (negative) temperatures. This stage of observation is briefly described in chapter “results” (pages 2-3), on the example of a historic building from 1830 year [2].

3. RESULTS

External walls of the building were made of ceramic facade bricks, laid down in layers, with an air gap inside: 25cm (brick) + 5cm (insulation gap) + 12cm (brick) (Figure **6**) [4]. The staircase external walls were made as a 25 cm thick, single-layer partition. New insulation techniques on the inside of partitions are constantly being researched using various materials (diffusion-open materials, VIP vacuum insulation panels, etc.) to improve thermal parameters, reduce the surface and between-layer condensation [9,11,12].

XELLA technology was chosen to to implement the new insulation layers, using "diffusion-open" materials, i.e. porous mineral plates, which are a variation of cellular concrete with a volumetric density, not exceeding 115 kg / m^3, and a thermal conductivity coefficient $\lambda \leq 0.043$ W / (mK). This is a non-flammable material with good thermal insulation parameters, resistant to biological corrosion and characterized by high "ability to release" moisture to the environment, which is the result of physical processes, that takes place inside the partitions.

The first tests were carried out at time when the building was undergoing thermal modernization and renovation works [4], when technological moisture in the partitions existed as a result of ongoing construction works (March 2015). For this reason, the newly laid layers of insulation have not reached full technical efficiency yet, which is also clearly demonstrated by the thermovision images (Figures **2-4,6,7**), for the case is shown in Figure **1b**. The rest of the article compares the insulation of external partitions of the ground floor before thermo-modernization (Figures **2-5a,5c**) with the same partitions after their

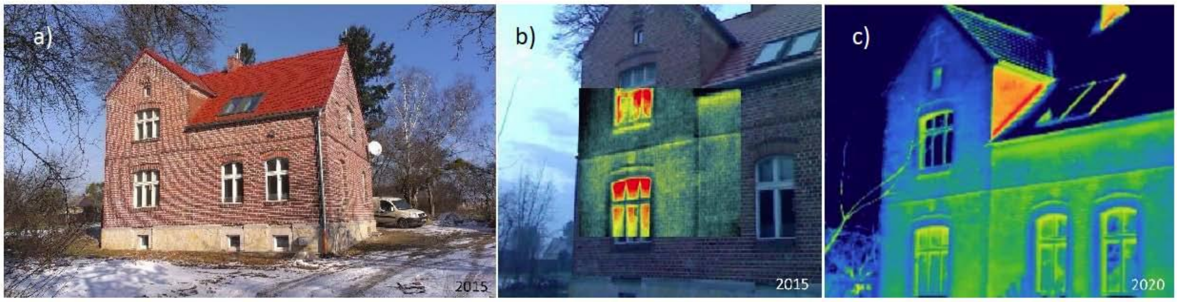


Figure 1: Southern elevation of a 90-year-old residential building: **a**) view, **b**) thermal image 2015 (outside temp. -3°C), **c**) thermal image 2020 (outside temp. -3°C).

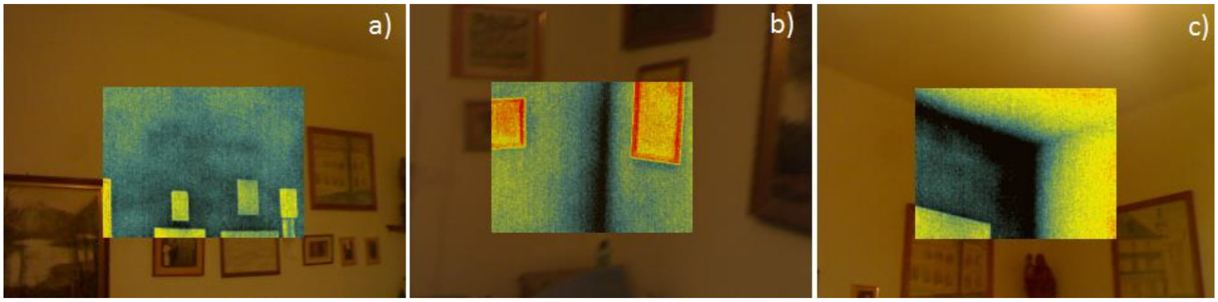


Figure 2: Thermovision map of uninsulated and wet ground floor walls: **a**) flat walls, **b**) 2D corner, **c**) 3D corner - closed from the top by a floor ceiling.

insulation (Figures **8-15**). These differences can already be clearly seen on the building facades Fig. **1**(**b** and **c**). Before thermo-modernization, the temperature level of internal wall surfaces has been in scope of +10,5°C to +13°C (Figures **2-4**).

Radiographic examinations were carried out at an external ambient temperature of -3°C and an internal building temperature of +16°C to +18°C. Calculations were made using Physibel Trisco 13.0 showed that if the outside temperature falls down to -20°C and inside the building remains + 20 °C (on φ=~45%), moisture could appear on the surface of wall: t_i=~7,5°C < t_s =+7,7°C (dew point temperature), temperature coefficient F_{Rsi} << 0.72 [7,13], (Figure **5**). This would create very favorable conditions for the development of mold fungi (Figure **2**) [3,4,8,10].

The graphic image of temperature distribution in the wall shown in Figure **2a** has been supplemented with temperature distribution lines (Figure **3**). It clearly indicates the heterogeneous thermal resistance of the wall, and thus its irregular surface and inside moisturizing (darker fields).

A similar situation is presented in the thermovision image and temperature diagram in Figure **4**. The calculations performed, simulating the existing condition, confirmed the possibility of lowering the temperature to +10,5°C in the inner corner of the room, which would further lead to the appearance of a further drop in the outside temperature moisture on its internal surface (Figure **5**).

As mentioned above, in 2015 building was under the renovation works, and at the same time it was insulated by the inside by the diffusion-open panels, 5 and 10 cm thick, in locations shown in Figures (**5b,5d,6,7**). Because, during the renovation works, an additional portion of technological moisture appeared in the walls, hence immediately after laying the mineral boards, their thermal resistance did not reach the required level yet. It was visible in the concave corners, where the temperature fall was about 4 °C in comparison to other flat surfaces. This condition could have been the result of a mismatch between the contacting mineral plates of thermal insulation boards, or the result of filling the gap between them, using supplementary material that was still moist/wet.

4. CURRENT CONDITIONS - MARCH 2020

The next research and calculations were carried after a 5-year building lifetime including performed thermomodernization. The obtained results indicated the correct selection of new heat-protective layers,

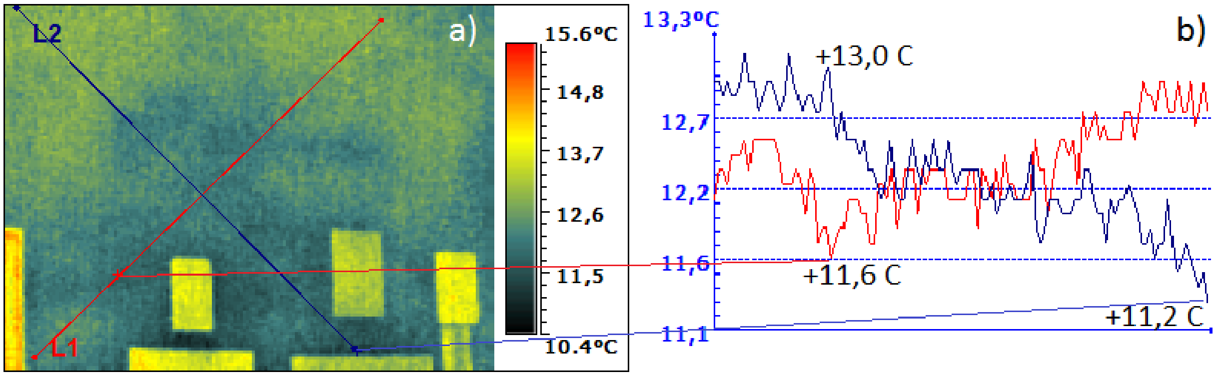


Figure 3: Insulated internal wall: **a**) thermal image, **b**) temperature distribution graph along lines L1 and L2.

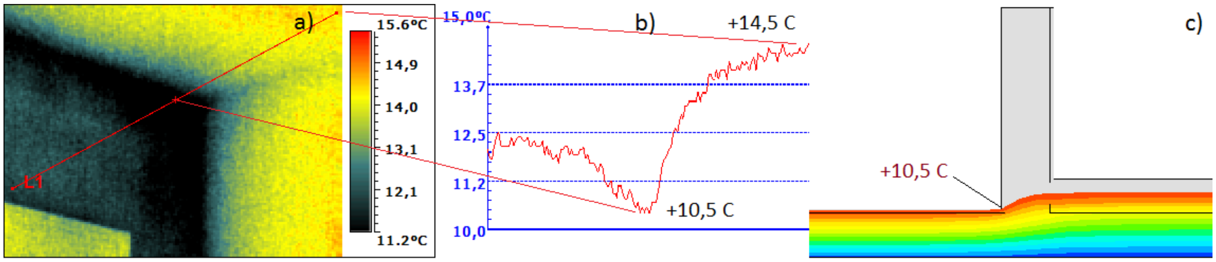


Figure 4: Corner of the ground floor walls: **a**) thermovision image, **b**) graph of temperature distribution along the L1 line, **c**) size of the corner temperature determined based on the calculation model.

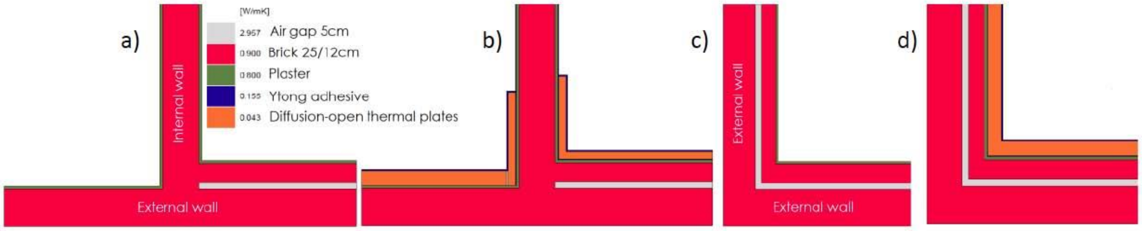


Figure 5: Current model of the outer partition: horizontal cross-section by connecting the gable wall with the inner one: **a**), **c**) not insulated, **b**), **d**) after thermo-modernization.

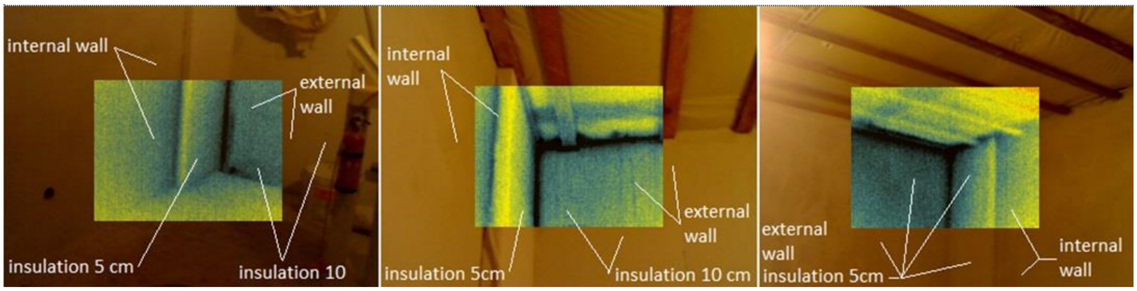


Figure 6: Thermal image of floor walls insulated with diffusion-open, mineral Multipor panels of the thicknesses given in the photographs above.

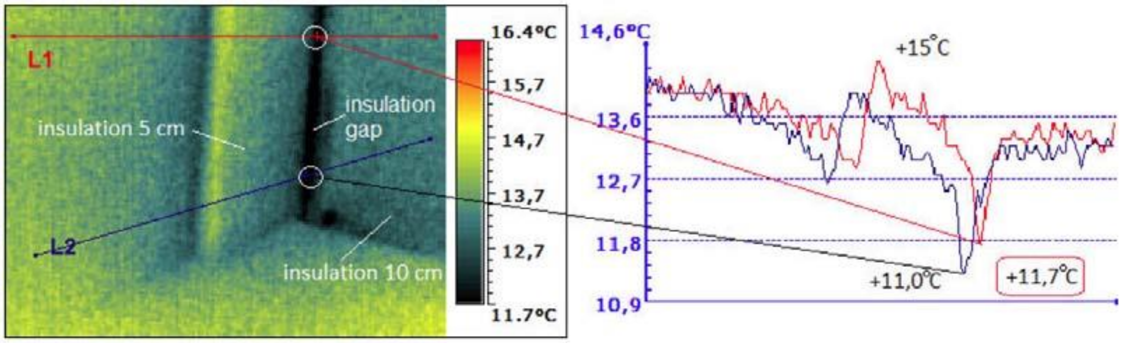


Figure 7: Diagram of temperature distribution at the interface between insulated external and internal walls.

because the lowest surface temperature at the contact point of the outer walls with inner wall did not fall below + 14 °C at the outside temp. -20 °C, and +17 °C at internal temp. -3 °C, while the temperature of remaining surfaces was close to the level of the indoor air temperature (Figure **8**). The zones of low (including negative) temperatures will mainly be located here at the junction of mineral plates and building walls insulated from the inside and in the structure of the plates themselves, which in these locations may cause periodic condensation of moisture, however their degradation has not been found. Walls have been made of ceramic (facade) bricks on cement and lime mortar. Thermal resistance of the analyzed partitions, after their insulation did not fit within the permissible range. The value of the heat transfer coefficient “U” determined as a result of calculations significantly exceeded its limit value, imposed in the current Polish regulations and for example German [7,13], where U_{gr} ≤ 0,23 W/(m^{2}K) - from January 1, 2021. U_{gr} should be ≤ 0,20 W/(m^{2}K). Nevertheless, the heat protection parameters of the partitions have been visibly improved.

The diagrams below show and compare the simulation of the temperature distribution in cross-sections of walls in their original condition (Figure **8**) and after the thermomodernization (Figures **9,11,13**). Calculations were made for two partition locations: in the corner (Figure **5c,5d**), and connection of the outer layered and homogeneous structured-wall with the inner wall (Figure **5a,5b**).

Figure **8** shows the temperature distribution in the outer wall before the thermomodernization, while Figure **9** includes a 5-year service life.

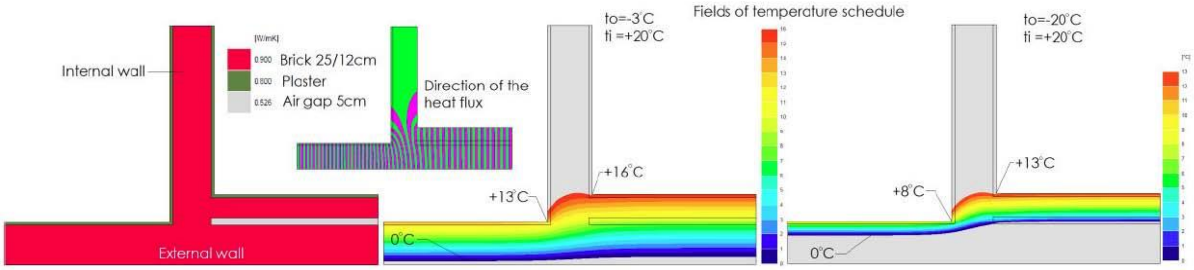


Figure 8: Model and computational simulation of temperature isotherms distribution and adiabat of heat fluxes in building envelope (without insulation) after 5 years of operation (outside temp. to -3°C and -20°C, internal temp. +20°C).

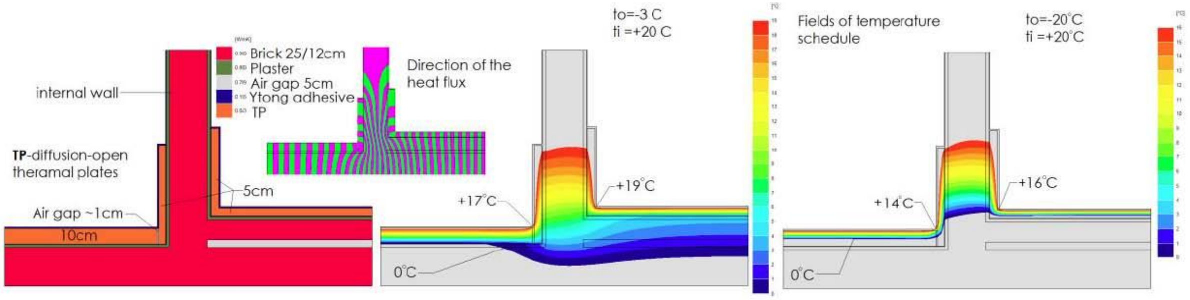


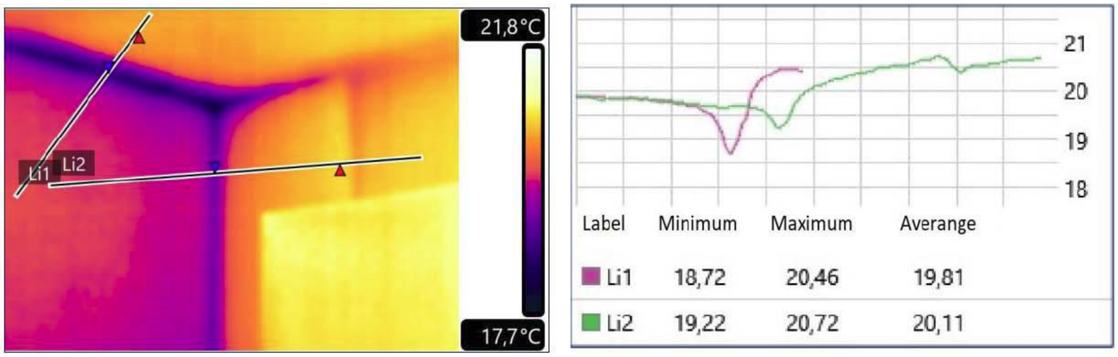
Figure 9: Model and calculation simulation of temperature isotherm distribution and adiabat of heat fluxes in external building envelope after insulation with 5 and 10 cm thick Multipor mineral boards (outside temp. to -3°C and -20°C, internal temp. +20°C).

Comparing the results of calculations presented in Figures **8** and **9**, a favorable temperature increase of Δt = +3°C to +6° C is noticed. These calculations were verified by thermovision testing of the abovementioned corners, which are shown in Figures **10-12**.

The following diagram (Figure **10**) presents a thermovision image of the temperature distribution at the contact point of walls insulated from the inside, shown in Figure (**9**, right side of the internal wall). The temperature drops in the inner corner by approx. 1 °C is clearly noticeable in comparison to the remaining wall surfaces. It should be considered that the test result is very similar to the results of calculations (Figure **9**), despite the fact that the calculations have used the indoor air temperature equal + 20 °C, and in fact it was 1°C to 2 °C higher.

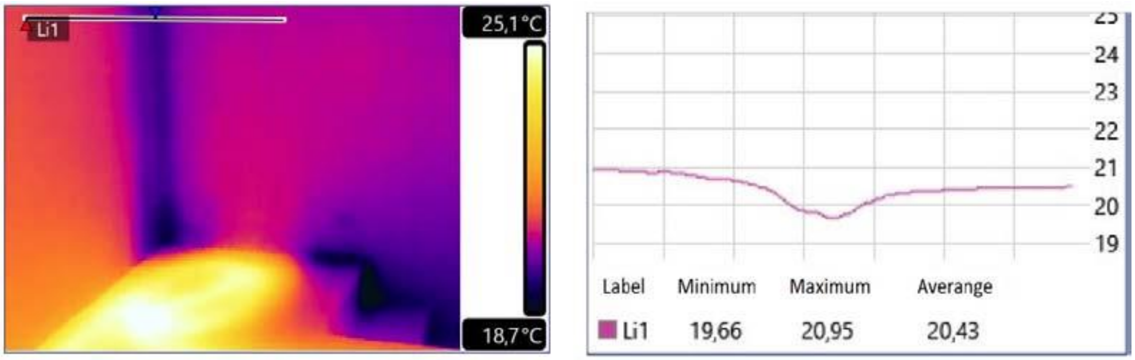
The next thermal image (Figure **11**) also shows a decrease in temperature in the corner by about 1 °C in relation to the remaining wall surface. In Figure **9** this concave corner is described at a temperature of +17 °C, which is 2 °C lower than thermovision indications. In fact, this may indicate that the defect in the gap between mineral plates has been filled with a material with similar heat protection parameters (Figure **7**), hence the same temperature level of the corner was obtained as on the other side of the inner wall.

Figures **12** and **13** show the wall corner before and after the thermal modernization. The temperature



Label	Minimum	Maximum	Averange
Li1	18,72	20,46	19,81
Li2	19,22	20,72	20,11

Figure 10: Current thermovision image of the inner wall corner - right side (Figure **9**) after 5 years of operation (outside temp. -3°C, internal temp. +21°C).



Label	Minimum	Maximum	Averange
Li1	19,66	20,95	20,43

Figure 11: Current thermovision image of the inner wall corner - left side (Figure **9**) after 5 years of operation (outside temp. -3°C, internal temp. +21°C).

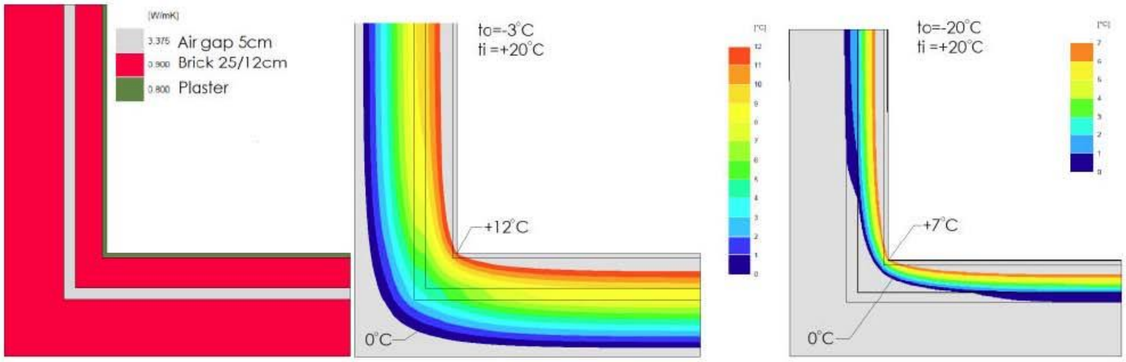


Figure 12: Model and calculation simulation of temperature isotherm distribution in an uninsulated corner of a building (outside temp. to -3°C and -20°C, internal temp. +20°C).

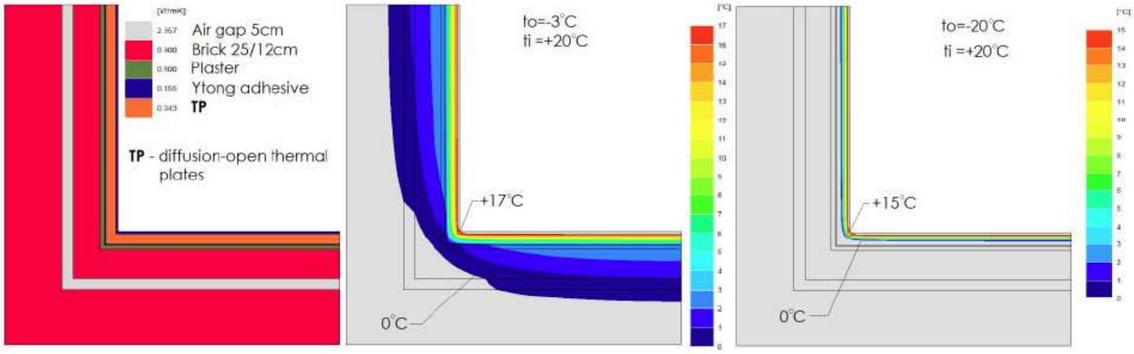


Figure 13: Model and calculation simulation of temperature isotherm distribution in the corner of a building after thermal insulation with 5 cm thick Multipor mineral plates (outside temp. to -3°C and -20°C, internal temp.+20°C).

differences in the concave corner are Δt= 5°C to 8°C, which clearly speaks for the root of the thermomodernization works carried out.

These calculations were verified by thermovision testing, which in fact showed even higher corner temperature by about 2.5 °C, than obtained on the basis of calculations made for similar ambient parameters.

Because, in fact, mineral boards, mainly 5 cm thick, were used to improve the thermal insulation properties of external walls (with one exception - Figure **9**, where a short layer of 10 cm boards was laid on a short section), that do not meet the requirements of applicable regulations (Table **1**). Below the same partition was modelled with two times thicker layer of thermal insulation. This solution also does not meet the requirements of Polish and European standards set out in regulations and slightly improves the thermal condition of the corner. Although globally, on flat wall fragments, it has a higher surface temperature, by approx. 2,5 ° C.

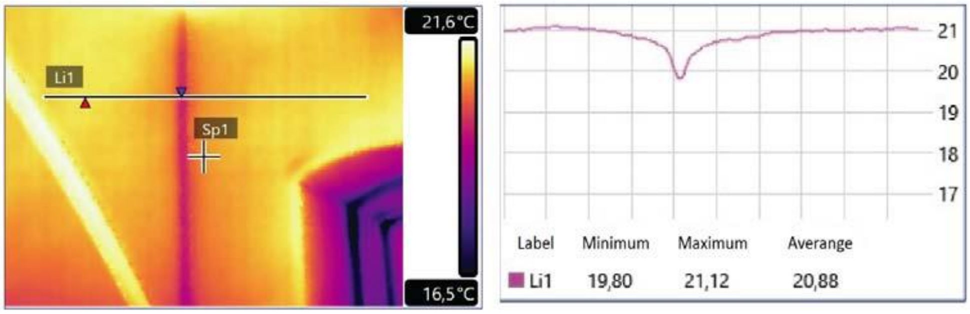


Figure 14: Calculation model of the floor walls (Figure **13**) (outside temp. -3°C, internal temp. +21°C).

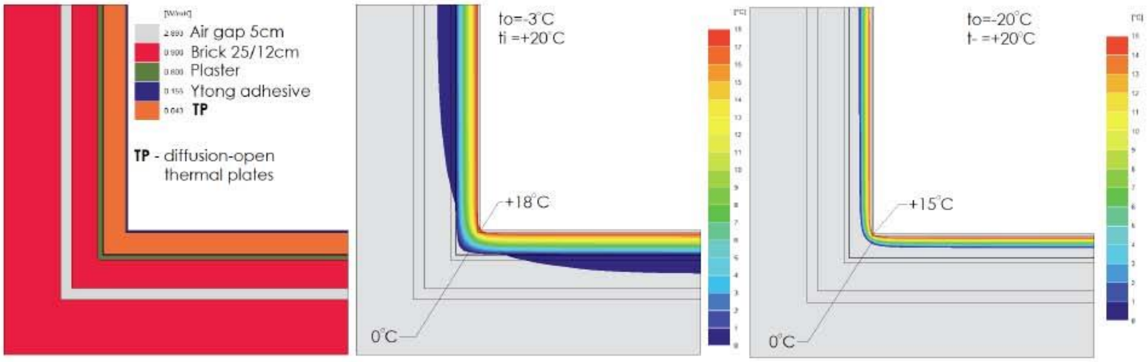


Figure 15: Model and calculation simulation of temperature isotherm distribution in the corner of a building after thermal insulation with 10 cm thick Multipor mineral plates (outside temp. to -3°C and -20°C, internal temp.+20°C).

5. ASSESSMENT OF THE CARRIED OUT CALCULATIONS AND TESTES

A computational analysis of the previous and current situation, taking into account the occurrence of a linear thermal bridge in insulation (Figures **6,7**) confirms here a manufacturing defect, revealed as a break in thermal insulation. This defect has been removed. The calculations indicated the validity of the thermomodernization, although it was carried out on the inside of the partitions, i.e. from the "center". It significantly improved their heat protection parameters, although it did not meet the statutory requirements. One of the two main disadvantages of using the so-called insulation from the "inside" is to reduce the floor space of the rooms, while the second possibility of frost and corrosion damage related to moisture condensation inside the partitions and limited possibilities of its evaporation. This applies to, inter alia endings of wooden ceiling beams in historical buildings [1]. This problem will be discussed in the next article. The thermal parameters of partitions before and after thermomodernization are presented in Table **1**.

Thermovision research of the walls and computer simulations of current condition of building partitions clearly showed an improvement of their heat protection parameters in comparison to their original conditions, which significantly reduced the heat loss and improved comfort of utilisation of the rooms, despite a significant reduction in the heat capacity of the walls. The type of material used for thermal insulation, which should be characterized by high thermal resistance, low sorption and high diffusivity, is irrelevant here.

6. ASSESSMENT OF THE MOISTURE CONDITION OF ANALYZED PARTITIONS AFTER 5 YEARS FROM THERMOMODERNIZATION

In walls subjected to thermomodernization on the inside, there is a problem of moisture condensation inside of them. A well-designed and constructed barrier should have the ability to remove excess moisture during spring and summertime [1,8]. A permanently dampened partition will not only fail to meet heat protection requirements, but will also be subjected to processes of corrosion, which can ultimately lead to irreversible degradation. Below, in Figures **16-20** are shown diagrams of moisture distribution in partitions, showing a slight increase in the first two years after insulation and then stabilization. Partitions can, and will seasonally accumulate moisture in their interior, but already during periods of higher ambient temperatures (mainly in the aforementioned spring-summer time)

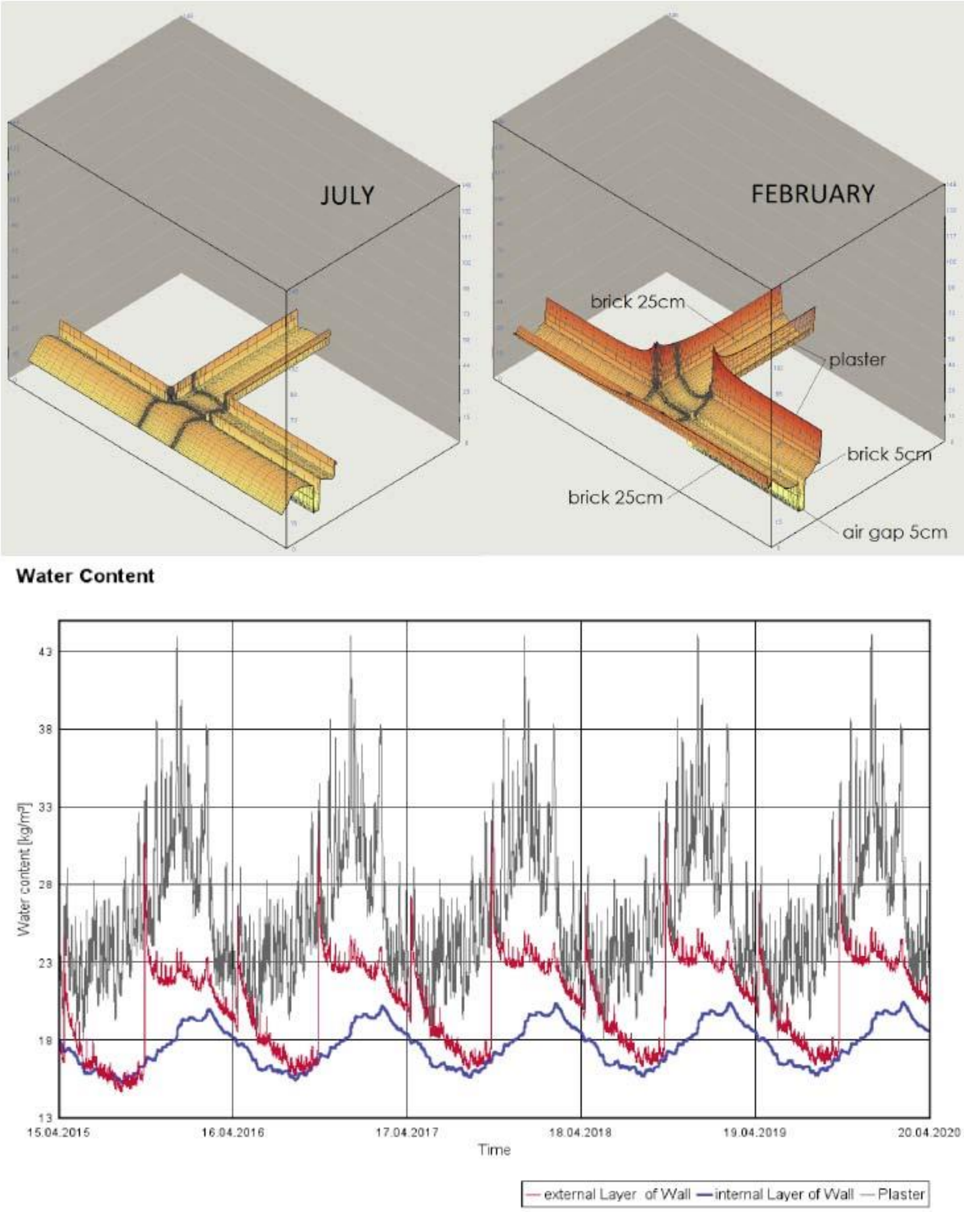


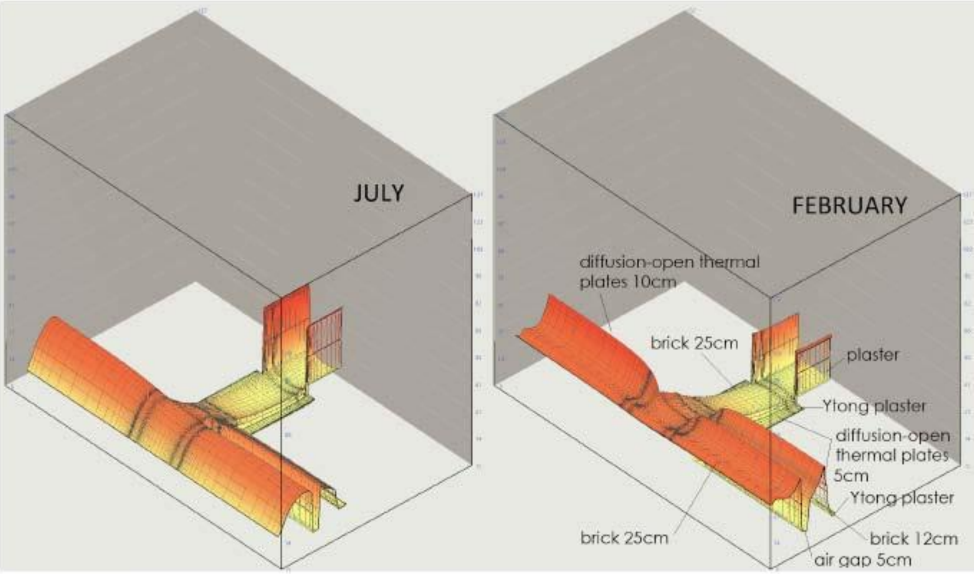
Figure 16: Diagram of moisture distribution in the partition (Figure **8**) over a period of 5 years, in w kg/m^3.

they will get rid of its excess and then maintain at an acceptable level, which is clearly shown in the graphs in Figures **16-20**, considering a period of 5 years of operation. Spatial models of partitions were presented for two months of the year, i.e. February, when the highest water accumulation occurs, and July, when its content is practically the lowest.

A summary of the amount of temporary and permanent moisture accumulation in analyzed partitions is shown in Table **1**, for all analyzed cases.

7. DISCUSSION

It is not enough to carry out only thermal calculations for the correct selection of the thickness and type of material to improve the thermal parameters of partitions. It is also very important to assess the effects caused by physical processes that have a significant impact on the chemical and biological corrosion of the partitions and, as a consequence, on the durability of the materials they were made of. Equally, consideration should be given to the results of thermal and humidity calculations, between which there is a causal relationship related to the durability of entire buildings, safety and comfort of exploitation. We should also remember about the very important role of efficient room ventilation [6], because the assumptions for calculations take into account its full effectiveness, guaranteeing the required air exchange rate. As a part of calculations, the technical condition of materials



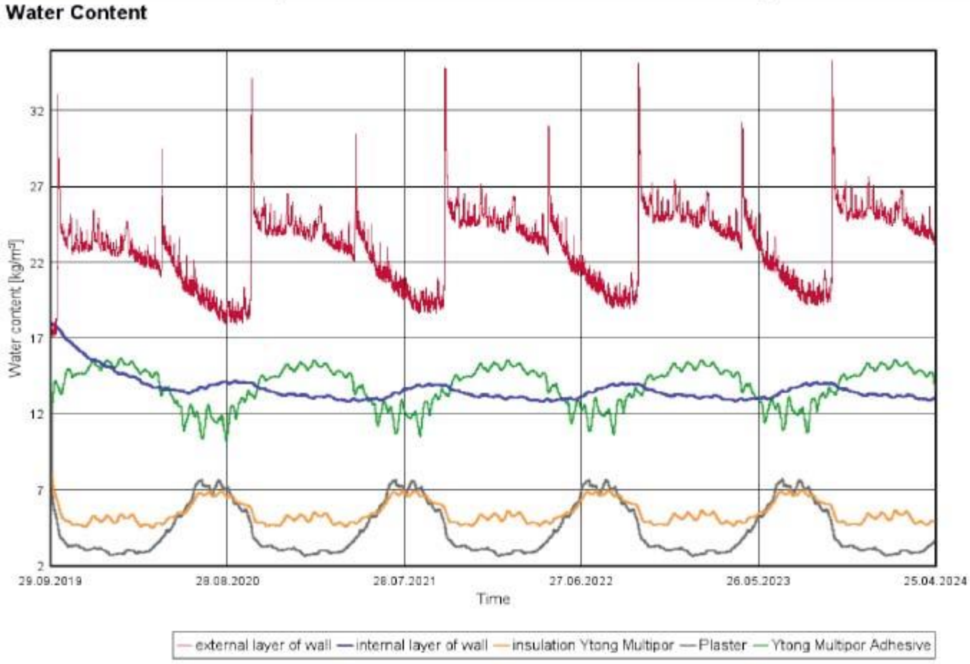


Figure 17: Diagram of moisture distribution in a partition (Figure **9**) over a period of 5 years, w kg/m^3.

embedded in the outer partitions, with relatively low corrosion resistance, is very often being forgotten. It regards for example the wood, which is part of the "half-timbered wall" structure. Also wood for roof trusses and especially load-bearing beams in closed ceilings. In the next article, the author will analyze the technical condition of wooden ceiling elements that are still parts of historical and historic buildings.

After the thermomodernization of the object, the technical condition of its partitions should be monitored [2,8], verifying this assessment, inter alia thermal imaging tests, in situ humidity measurement, for example by permanently embedded probes inside of them (Figure **21**). The author has already used this method in one of the historic buildings where he has been monitoring the temperature and moisture level of the adhesive layer for three years, between the historic brick wall and the diffusion-open insulation layer laid on the inside surface of the outer walls (Figure **21**).

The hygrothermal analysis of the external partitions of the building was carried out using two programs: Physibel Trisco 13.0w and WUFI2d 4.2 (Fraunhofer IBP), own research and measurements as well as experience acquired in other facilities.

Below, Table **1** compares the results of analyzes made for partitions in their original condition, as well as

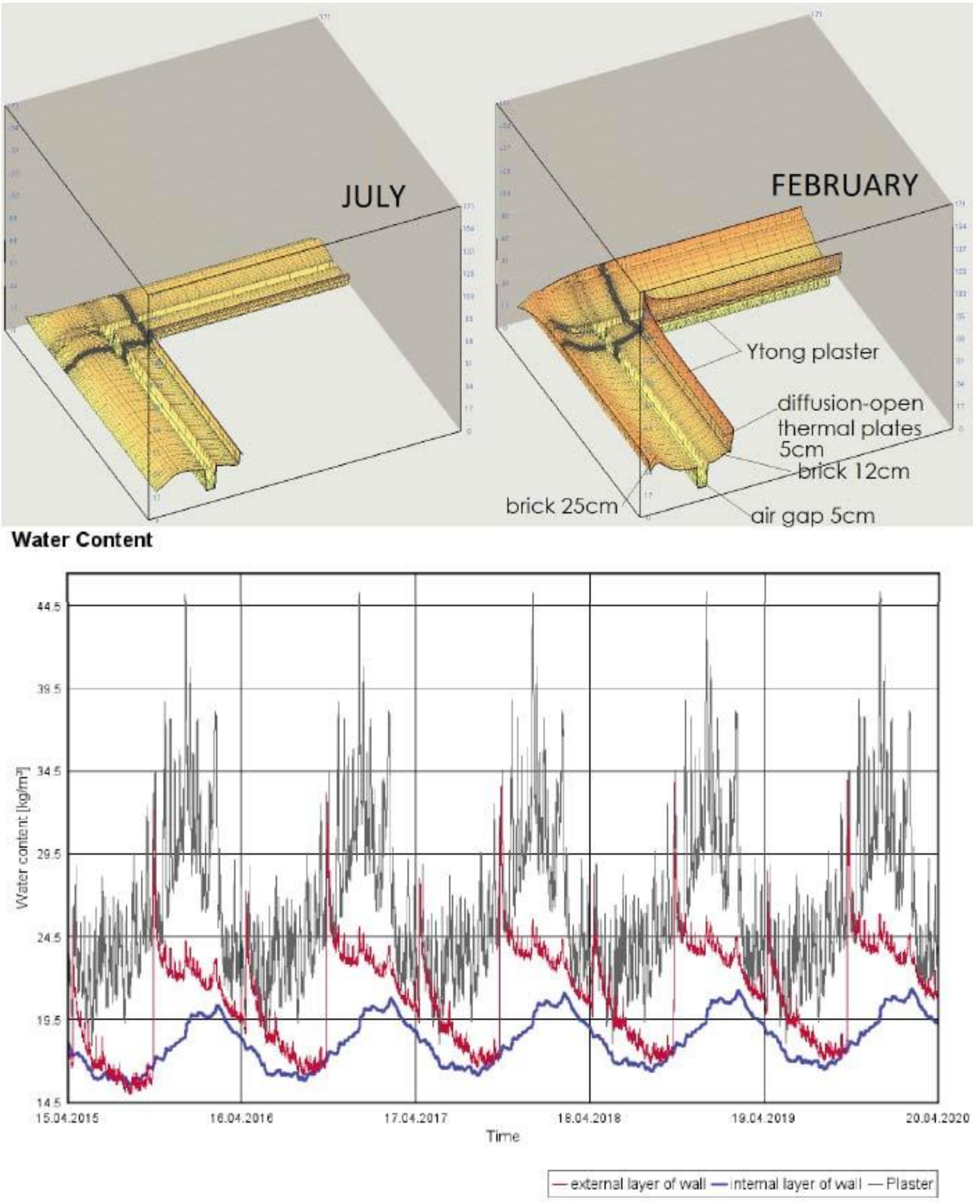


Figure 18: Diagram of moisture distribution in the partition (Figure **12**) over a period of 5 years, w kg/m^3.

after adding the insulation (current state), simulating the behavior of the wall corner after insulation from the inside with a 5 cm thick layer of thermal insulation (which was done) and 10cm/15cm (forecast).

Based on the obtained results, which are summarized in Table **1**, it should be stated that the walls insulation from the inside even with thin panels (in this case 5 cm) will allow more than 4 times reduction of heat loss in the case of walls No.1 and No.2, and 3 to 7 times for walls No.3, No.4 and No.5. High improvement of thermal parameters of these partitions will not cause deterioration of their moisture level, which shows high stability in diagrams (Figures **16-20**). The thicker thermal insulation layer is, moisture in each of the materials that build the layer will decrease during the period of lower temperatures, while it increases slightly during the summer, assuming a stable level. Insulation from the inside eliminates the risk of surface condensation of water vapor on opaque partitions. The increase in insulation thickness from the inside not only improves the thermal insulation parameters of the partitions but also does not increase their moisture content. The thicker thermal insulation is, the risk of surface condensation is significantly reduced.

The five-year service life of a 90-year building, after it has been thermomodernized, confirms the correctness of the chosen method, even if it is widely recognized as controversial (the so-called "from the

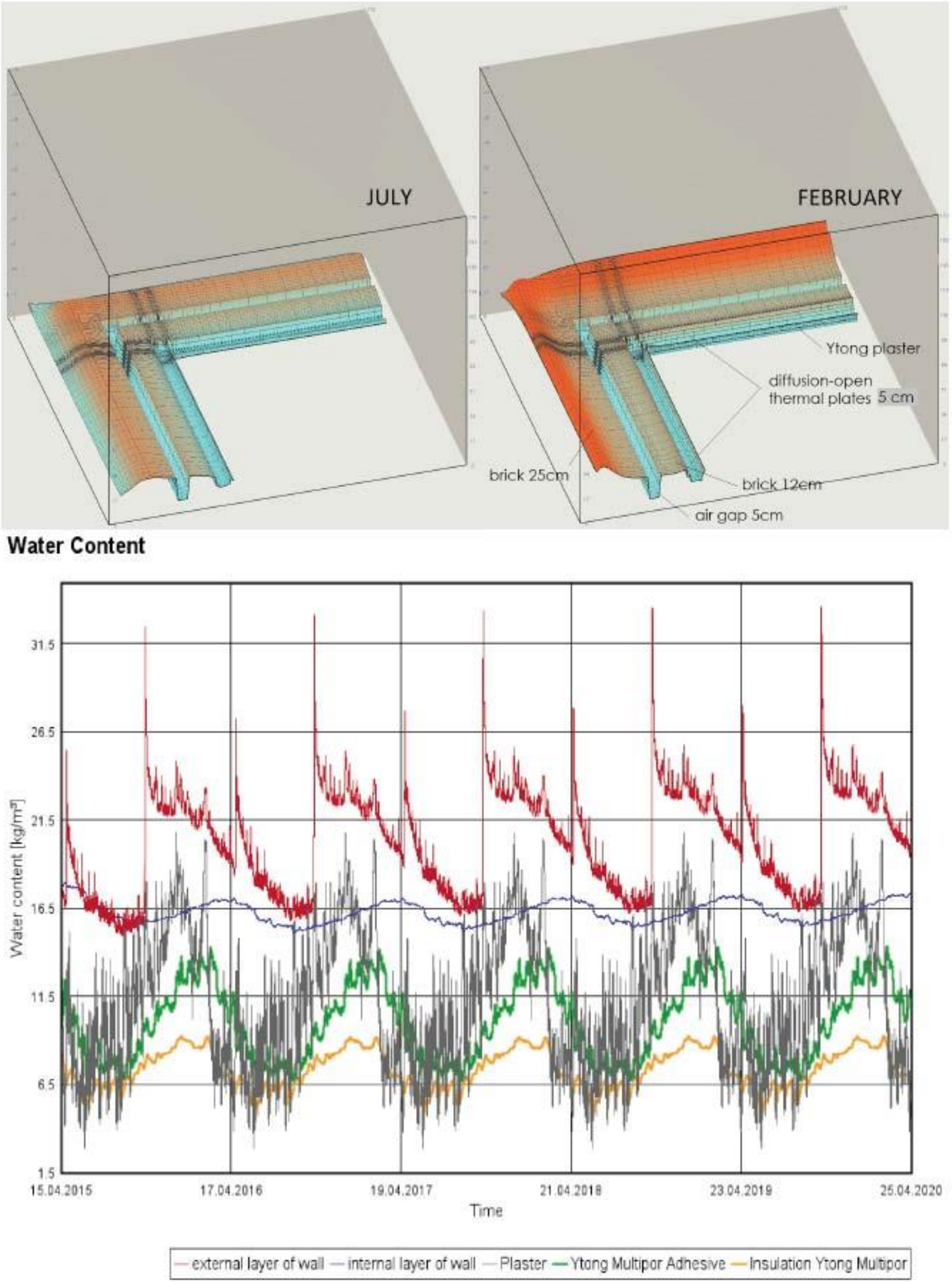


Figure 19: Diagram of moisture distribution in the partition (Figure **13**) over a period of 5 years, w kg/m^3.

inside"), it can successfully meet the tasks of building partitions, if it is properly implemented. As was mentioned, in some situations it will not be possible to lay the insulation on the outer sides, so it should be chosen second method, that contains a proper justification in calculation that can be successfully adopted. However, this should not be an obligatory and schematic issue, because as a consequence it may lead to opposite effects to expect, including degradation of the partitions and a significant deterioration of the internal microclimate. Also, it should not routinely approach any rescue and modernization works, depending on the size, function and age of each building.

Summing up the content of the article, it should be stated that the insulation of external partitions of buildings by "from the inside" method, using diffusion-open materials is the most acceptable and advisable when thermo-modernization from the outside is not possible. This solution will significantly improve the thermal insulation parameters of partitions without posing a threat to them, if it is carried out thoughtfully, supported by appropriate calculations and analysis of

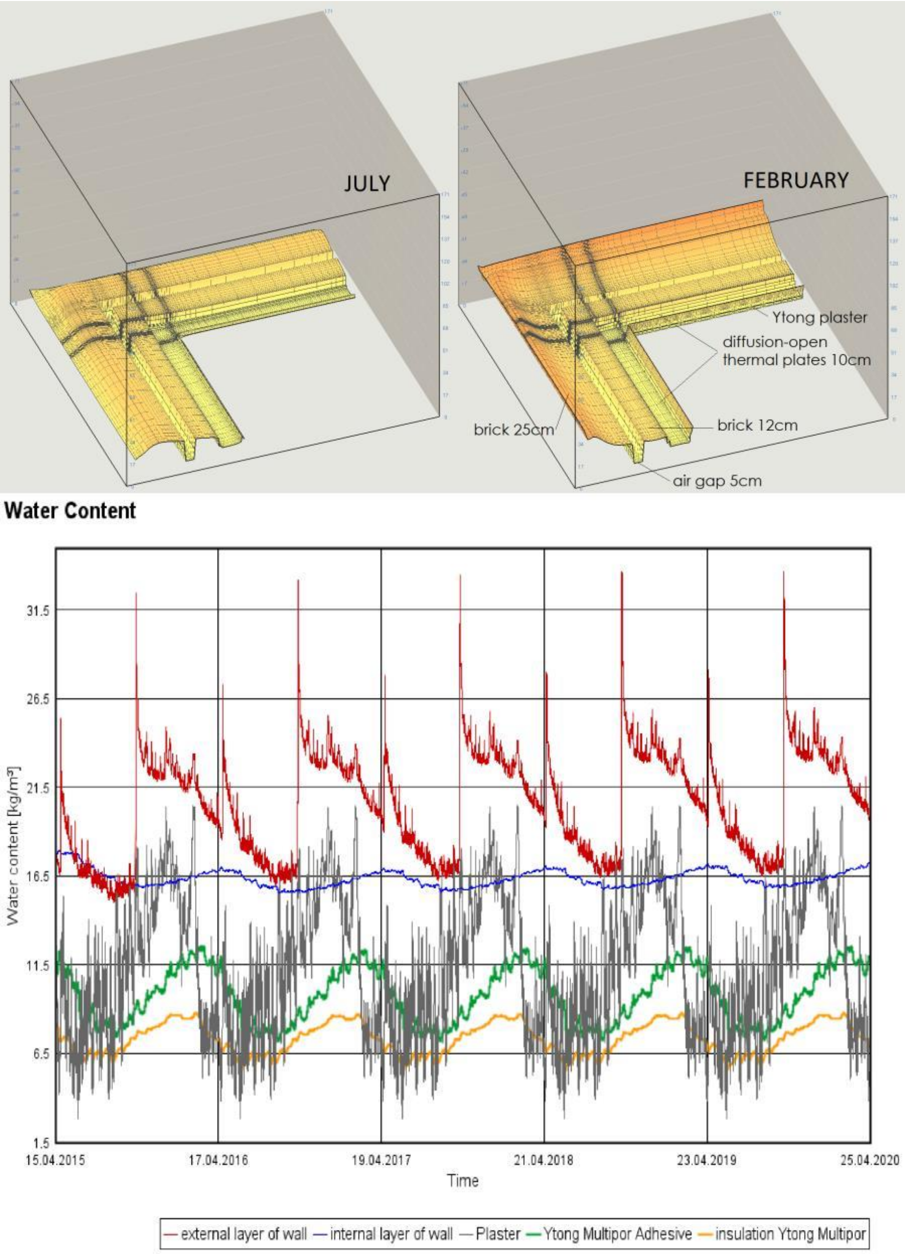


Figure 20: Diagram of moisture distribution in the partition (Figure **15**) over a period of 5 years, w kg/m^3.

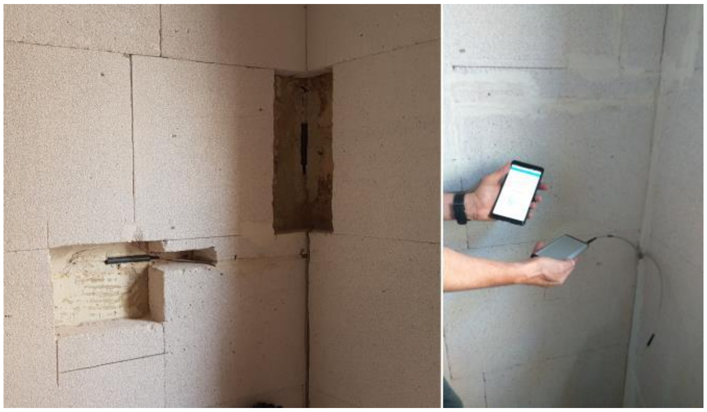
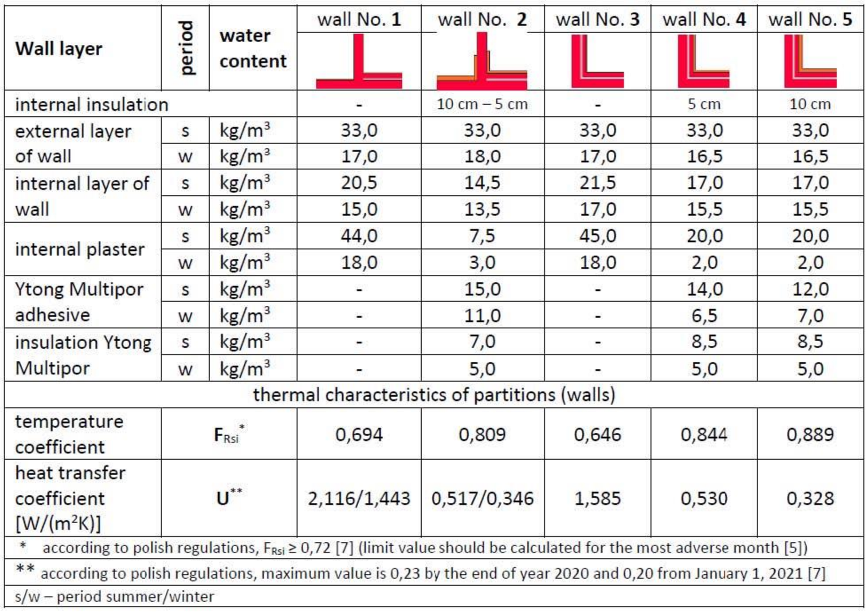


Figure 21: Monitoring of moisture content in permanently covered layers of partitions.

Table 1: Water Content and Thermal Characteristics of Partitions (Walls)



Wall layer	period	water content	wall No. 1	wall No. 2	wall No. 3	wall No. 4	wall No. 5
internal insulation			-	10 cm – 5 cm	-	5 cm	10 cm
external layer of wall	s	kg/m³	33,0	33,0	33,0	33,0	33,0
	w	kg/m³	17,0	18,0	17,0	16,5	16,5
internal layer of wall	s	kg/m³	20,5	14,5	21,5	17,0	17,0
	w	kg/m³	15,0	13,5	17,0	15,5	15,5
internal plaster	s	kg/m³	44,0	7,5	45,0	20,0	20,0
	w	kg/m³	18,0	3,0	18,0	2,0	2,0
Ytong Multipor adhesive	s	kg/m³	-	15,0	-	14,0	12,0
	w	kg/m³	-	11,0	-	6,5	7,0
insulation Ytong Multipor	s	kg/m³	-	7,0	-	8,5	8,5
	w	kg/m³	-	5,0	-	5,0	5,0
thermal characteristics of partitions (walls)							
temperature coefficient	F_{Rsi}^{*}		0,694	0,809	0,646	0,844	0,889
heat transfer coefficient [W/(m²K)]	U^{**}		2,116/1,443	0,517/0,346	1,585	0,530	0,328

* according to polish regulations, $F_{Rsi} \geq 0{,}72$ [7] (limit value should be calculated for the most adverse month [5])

** according to polish regulations, maximum value is 0,23 by the end of year 2020 and 0,20 from January 1, 2021 [7]

s/w – period summer/winter

results as well as experience transferred from other implementations.

Another direction of the author's activities will be the analysis of wooden elements permanently embedded in external walls, such as ceiling beams and skeletons of half-timbered and "Prussian" walls, in terms of their constant biological threat, affecting the durability and structural safety of entire buildings.

REFERENCES

[1] Bajno D. Selected thermal and humidity aspects related to the adaptation of historic buildings for utility in new conditions, 61 scientific conference of the Committee on Civil and Water Engineering of the Polish Academy of Sciences and the Scientific Committee PZITB "Bydgoszcz - Krynica" 20-25th of September 2015.

[2] Bajno D, Bendarz L, Matkowski Z. Monitoring of thermal and moisture process in varoius types of external histiorical walls. Materials (MDPI) 2019 vol.12.

[3] Bajno D, Bednarz Ł. Analysis of the effectiveness of insulation of external walls from the center: 5-13 Polish Association of Mycologists of Construction, Collective Work edited by Wojciech Skowroński – Wroclaw 2014.

[4] Bajno D. Thermomodernization of buildings with decorative facades. Kraków: Renovation and Monuments: 2015 pp 162-164.

[5] PN-EN ISO 13788:2003 Thermal and humidity properties of building components and building elements. Temperature of inner surface necessary to avoid critical surface humidity and interlayer condensation. Calculation methods.

[6] PN-83/B-03430:2003/Az3 Ventilation in apartment, residential and public utility buildings.

[7] Regulation of the Polish Minister of Infrastructure, dated on 12th of April 2002 (incl. changes) regarding technical conditions to be provided by the buildings and their location.

[8] Arbeiter K. Innendaemmung, Auswahl, Konstruktion, Audfuhrung. Rudolf Muller Publishing: Koln 2014.

[9] Capozzoli S, Fantucci F, Favorino M Perino. Vacuum Insulation Panels: Analysis of the Thermal Performance of Both Single Panel and Multilayer Boards. Energies, 6th International Building Physics Conference. Enery Procedia Turyn 2015, pp 2528-2547. https://doi.org/10.3390/en8042528

[10] Hartwig M, Kunzel H M. Bauphysik der Innendammung und Bewertungsverfahren. Internationaler Innendammkongress. Technische Uniwersitat: Dresden 2011.

[11] Johansson P, Time B, Geving S, Jelle B.P, Kalagasids A, Hagentoft C.E, Rongvik E, Interior Insulation Retrofit of a Brick Wall Using Vacum Insulation Panels: Design of a Laboratory Study to Determine The Hygrothermal Effect on Existing Structure and Wooden Beam Ends. Thermal Performance of the Exterior Envelopes of Whole Buildings XII International Conference. Clearwater: Florida 2013.

[12] Johansson P. Building Retrofit using Vacuum Insulation Panels, Hydrothermal Performance and Durability. Chalmers University of Technology: Gothenburg 2014.

[13] Scheffler G.A. Bauphysik der Innendammung. Fraunhofer: Verlag 2016.

Received on 29-04-2020 Accepted on 13-06-2020 Published on 30-07-2020

DOI: https://doi.org/10.15377/2409-9821.2020.07.3