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SELECTED PROBLEMS INVOLVING THE PRESERVATION OF HISTORICAL FRAME BUILDINGS IN SILESIA IN THE CONTEXT OF THEIR FUTURE THERMO-RENEWAL

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Abstract

The paper discusses the conservation state of selected examples of historical objects preserved in the Silesia Province, having a complex structure with the elements of Prussian wall. They can be found mainly in the so-called company towns created in the late 19th century. The work presents the structural and architectural details characteristic for such objects, with the emphasis on different technical condition of the structural and finishing elements. External envelopes were evaluated in terms of their thermal insulation and humidity condition, depending on their structure, type of material and location, using theoretical and calculation methods. Due to historical value of the buildings and special character of the façade, the paper suggests that the material values, thermal conductivity and humidity level of the envelopes should be closely identified to provide a basis for further analyses.

Keywords: **Prussian wall; insulation from inside.**

1. INTRODUCTION

The requirements involving the maintenance of buildings are defined in Poland by the Construction Law [1] and technical and construction regulations in the form of regulations [2, 3]. They ensure that the buildings are used in accordance with their intended purpose and environmental protection requirements and are maintained in a proper technical and esthetic condition. The above regulations specify the requirements for buildings and building envelopes, including such aspects as construction safety, fire safety, protection against moisture and corrosion as well as the issues of thermal insulation. With respect to historical objects with wooden frames, their maintenance is a complex issue which should allow for the selection of proper methods of repair and renovation of the existing structures, combining new materials with the old ones, taking into account their interaction and respect for historical substance. It is important to consider appropriate performance of wood as a construction material, hygrothermal condition of building envelopes (including also the adaptations of the objects to newly introduced utility functions) as well as their durability and quality of the façade. The performance of historical objects is significantly affected by the issues related to building physics: the influence of internal or external climate, the arrangement of envelope layers in terms of diffusive, thermal properties or tightness [4, 5, 6, 7, 8]. All plans to undertake repair, modernization or renovation works, also as part of comprehensive revitalization projects for areas with historical buildings, should be proceeded by a detailed examination of the existing condition, along with the assessment of humidity conditions of the envelopes. Planned corrective measures should be verified on the basis of available computer simulation methods, e.g. in terms of coupled heat and mass transfer, heat capacity and other [9, 10, 11, 12], taking into account the presence of construction salts in brick wall materials [13].

When considering objects which are subjected to renovation measures, a special attention should be given to buildings with inhomogeneous wall structures, e.g. frame structures, mullion-transom walls with clay filling of the frame and the so-called Prussian walls with brick filling.

The publication provides examples of historical buildings made from Prussian wall, found in the Silesia region, emphasizing diverse structure of their external envelopes and elements of architectural detail. Exemplary results of theoretical analyses and in-situ research involving the determination of preservation condition of building elements have been presented in terms of hygrothermal problems. Methods for their renovation have been proposed in order to reduce heat loss and the risk of surface condensation expressed by the factor f_{Rsi}.

2. SILESIAN EXAMPLES OF HISTORICAL BUILDINGS WITH WOODEN FRAMES

From among the existing examples of half-timbered houses preserved to date in Silesia, a great number of them are located in housing estates referred to as company towns. They mostly date back to the turn of the 19th and 20th centuries, and their formation was related to the development of industry in the region (e.g. the creation of railway lines, smelters or mines). The housing estates were developed as living quarters for local workforce, along with other building complexes and social facilities. The objects with Prussian walls can be found, e.g. in the districts of Zabrze, Bytom, Ruda Śląska and Pyskowice (Fig. 1–5). In the Zandka housing estate in Zabrze, in the years 1903–1927, about 40 residential buildings and public utility buildings were erected, including kindergarten, fire department, casino and department store. For workers, multi-family buildings were created with two or three residential floors, sometimes with apartments on the attic floors. There were also houses with better standard, intended for civil servants. Residential multi-family housing can be also found in the company town of Czerwionka-Leszczyny. The building complex was erected in the years 1898–1916 and was connected with the launch and dynamic development of the Dębieńsko mine. The wooden frame structure filled with ceramic bricks in company towns of Silesia was applied only in the upper parts of buildings, e.g. fragments of floors, tops of risalits, usable and non-usable attics, and also as an element of staircase enclosures. The structure of external envelopes and the thickness of walls depended on their locality. Residential and utility floors of multi-family buildings and public utility buildings were made with the thickness of one brick or one and a half bricks. The walls of attics and staircases were thinner (the thickness of 1/2 brick – 12 cm). The wooden frame, placed on the side of façade, was filled in with brickwork, sometimes covered with layered, textured plaster, also with glazed ceramic cladding (the housing estate with such cladding is at Czerwionka-Leszczyny). The geometry of the wooden frame depended on the building's size, location, the number and shape of window or door openings. The estates were characteristic of architecturally diversified building facades, reflecting different shapes of buildings, the coloring of bricks or cladding, but also wooden decorative elements, which included carved panels, balusters, cornice enclosures, gable planking, cantilever profiles and shutters.

3. CONDITION OF THE EXISTING BUILDINGS – SELECTED PROBLEMS

Buildings made of Prussian wall have been the subject of research studies carried out as part of the authors' scientific and research work as well as master's or bachelor's theses in engineering developed under their supervision. One of the objective of the research was to determine the condition of the existing objects as a starting point for further analyses and repair or renovation projects. The professional experience of the authors [4, 5] and information obtained from housing estate managers indicates that in some buildings modern modifications in the structure of historical envelopes have been introduced, usually individually adopted thermal insulation from the room side. Presently, we can observe cases of increased humidity of insulated in this way external building envelopes, e.g. visible fungi development from the inside of rooms, which, in effect, brings about the deterioration of technical condition of the envelopes and lowers the comfort of use of such apartments. The reasons underlying such a situation should be attributed to the fact that initial moisture conditions of the envelopes were not taken into

Figure 1–2.
Buildings in the housing estates Zandka in Zabrze, Wolności Street and Dębieńsko at Czerwionka-Leszczyny, Słowackiego Steet

Figure 3–5.
Wooden details in the apartment buildings of the housing estate Zandka in Zabrze, Wolności Street

account, the selection of material was incorrect, or the applied calculation methods were simplified. Before planning and implementing repairs, renovation or modernization works, it is necessary to examine, as part of the assessment involving the condition of the existing object, the actual structure of envelopes in terms of their geometry and used material, and to identify the level of moisture and thermal performance.

Envelopes made of half-timbered wall make up a special group of building envelopes due to their structure. Such walls are a combination of wooden elements, masonry, mortar, sometimes plaster and ceramic cladding. The materials have different thermal conductivity coefficients, thermal expansion and different diffusion resistance. In addition, it is characteristic for the envelopes that they have voids between the frame and the adjacent elements, allowing the penetration of rainwater into the wall. The development of such voids results, among others, from natural degradation processes of wood and mortar. The said process was described in the literature [14, 15], where aging processes and gradual losses in the cross-sections of wooden elements were addressed. Natural aging processes of wood, manifested as changes in its external appearance and in its technical properties, are caused by long-term impact of atmospheric factors (solar radiation, changes in temperature and humidity). According to the research [15], the changes may comprise: density, compressive strength along fibers, shrinkage and swelling of wood. The course and rate of changes depends, among others, on wood type and its use class [15]. With strong exposure to atmospheric factors, a gradual degradation of wood surface layers takes place. There are also changes in its chemical composition, when wood is subjected to the influence of strong solar radiation. It happens due to the absorption of UV radiation by lignin, making up approx. 20–30% of xylem, which results in its gradual degradation. This involves the deterioration of cellulose chains and the rise of their susceptibility to the changes of temperature or humidity. It is estimated that the cross-section thickness of a wood layer, which decomposes (disappears) as a result of aging in natural, external conditions, reaches about 6mm in 100 years [14]. The research was conducted for the wood of external use class, exposed to the impact of external environment, without any direct contact with the ground – use class 3 acc. [16]. The acceleration of wood degradation may be effected by the conditions enabling the development of biological corrosion. The place of wooden elements in the moistened zone, with no possibility of drying out, can contribute to the growth of fungi which facilitate the degradation of wood. Such examples can be observed when a wooden frame of a building is covered with a material of high diffusion resistance, with no ventilation gap ensured. As a result of moisture (due to the migration of water vapor from the inside, or the development of humidity through leaks) and hindered evaporation to the outside, structural elements may be subjected to severe damage.

Restricted water vapor migration due to the applied external diffusion barrier may bring about such consequences as the damage to façade layers or to brickwork filling the frame of the wall. With tight, secondary exterior paintwork, historical plasterwork and paintwork, originally made on the basis of lime, there is a risk of gradual delamination of their outer surface.

The emerging cracks at the place where the wood and brick surfaces meet as well as around wood studs facilitate the penetration of water into the envelope (e.g. during slanting rain). The gaps are also zones of heat flux density changes, which may adversely affect the durability of mortar in such parts of the envelope [7].

4. EXAMPLES OF EXAMINATIONS OF THE EXISTING STATE – THEORETICAL ANALYSES AND IN-SITU STUDIES

4.1. Accepted methods and assumptions

As part of the assessment involving the condition of the existing historical envelopes with Prussian wall (selected examples of buildings from company towns), the following works were carried out:

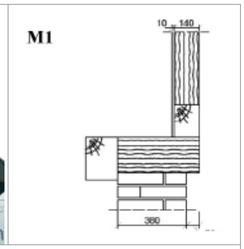
- theoretical studies involving temperature distribution in the envelopes (the use of 2D models analyzed in the THERM program, determined on the basis of the measurements of the actual structure of the envelopes),
- analyses of moisture transfer in the existing envelope, using the WUFI 2D program, carried out for the actual structure of the envelopes,
- in situ measurements of the thermal transmittance coefficient of the external envelope of one of the buildings with Prussian wall using a measuring setup.

The theoretical analyses concerning the determination of temperatures in the envelopes were made using the computer program THERM 7.4, based on FEM for the calculation of any two-dimensional model of building element. It allows to determine the distribution of temperature field in the envelope, to determine impact areas of heat flux density changes and to determine the temperatures at the selected cross-section within the range of the 2D model. The models were built in accordance with the instructions contained in [18], based on the actual structure of Prussian wall, for three buildings with brickwork risalits, with different solutions of roof peaks. In each case, the envelope was made of Prussian wall:

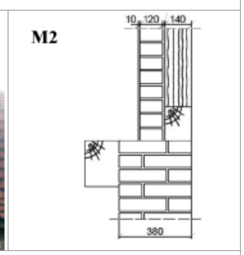
- model 1 (M1): 12 cm-thick wall, protruding outside the façade, supported on wooden cantilevers,
- model 2 (M2): 25 cm-thick wall, located in the plane of the facade,
- model 3 (M3): 25 cm-thick wall, placed on wooden, decorative cantilevers.

All facades were faced with glazed ceramic tiles. The material data accepted for analyses are presented in Tables 1–4.

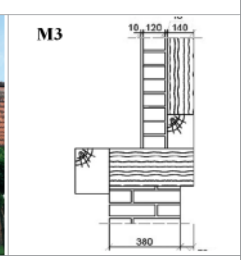
Table 1.
Structural details (models) – location on the facade, diagrams of cross-sections accepted for theoretical analyses carried out in the Therm program



The building is located among the buildings of the Patronacki Housing Estate in Czerwionka-Leszczyny, at. Mickiewicza Street no 1.



The building is located among the buildings of the Patronacki Housing Estate in Czerwionka-Leszczyny, at. Wolności Street No 34.



The building is located among the buildings of the Patronacki Housing Estate in Czerwionka-Leszczyny, at. Mickiewicza Street No 8.

The simulation tests were carried out for the envelope of the total thickness of 25 cm. The Prussian wall with the 12 cm-thick filling was on the side of façade. The façade was covered with ceramic tiles, and the interior was covered with 2 cm-thick lime plaster. The material parameters were adopted as presented in Table 1–4. The initial moisture content of the materials was accepted as for the equilibrium state. The parameters of the indoor climate were determined as for residential premises. The following sinusoidal conditions were assumed: (temperature t_i=20 +/- 2°C, humidity φ_i = 50+/-10%). The external climate conditions were adopted from the meteorological station in Katowice, including external temperatures, air humidity, atmospheric precipitation and insulation. A three-year period of hygrothermal simulations was adopted.

For the measurement of thermal transmittance coefficient U, the GreenTEG U-value measurement setup was used. It contained a heat flux plate meter and two temperature sensors: for the indoor temperature of the room and for the outside temperature. The setup was equipped with a stabilizing electronic system. The plate was placed on the surface of the brick wall of the thickness of 25 cm. The measurement time, according to the guidelines of the standard [17], should not be lower than 72 hours. In the investigated case, the total measurement time was 188 hours.

4.2. Design status – thermo-modernization methods for selected wall systems

In the course of insulation variants analysis, the choice of material thickness has been made with the adoption of two possibilities. In one case, the wood is 7 cm thick (variant II), which is half the size of the existing Prussian wall construction, while in the other, the wood is 14 cm thick. Having performed all the necessary calculations of the heat resistance R and the heat transfer coefficient U for variants with wood (presented in Table 2), the thickness of insulation boards based on light aerated concrete was established so that the thermal insulation value for variant three could be comparable to variant one and two.

Table 2.
Choice of thickness of insulation material for variant No. I, II and III

Selection of insulation materials thicknesses					
Lp.	Material	d [m]	λ [W/mK]	R [m²K/W]	U [W/(m²K)]
VARIANT II					
1	Larch boards	0.07	0.128	0.547	1.83
VARIANT III					
1	Larch logs	0.14	0.128	1.094	0.91
VARIANT I					
1	Light concrete	0.05	0.042	1.16	0.86

According to the calculations, the material thickness for variant I is 5 cm (the smallest offered by the manufacturer). The selected thickness of mineral plates gives the most similar value of heat resistance R and heat transfer coefficient U as for variant No. II and III.

Variant I

In variant one, where the partition walls are made of half-timber, mineral insulation boards were prepared

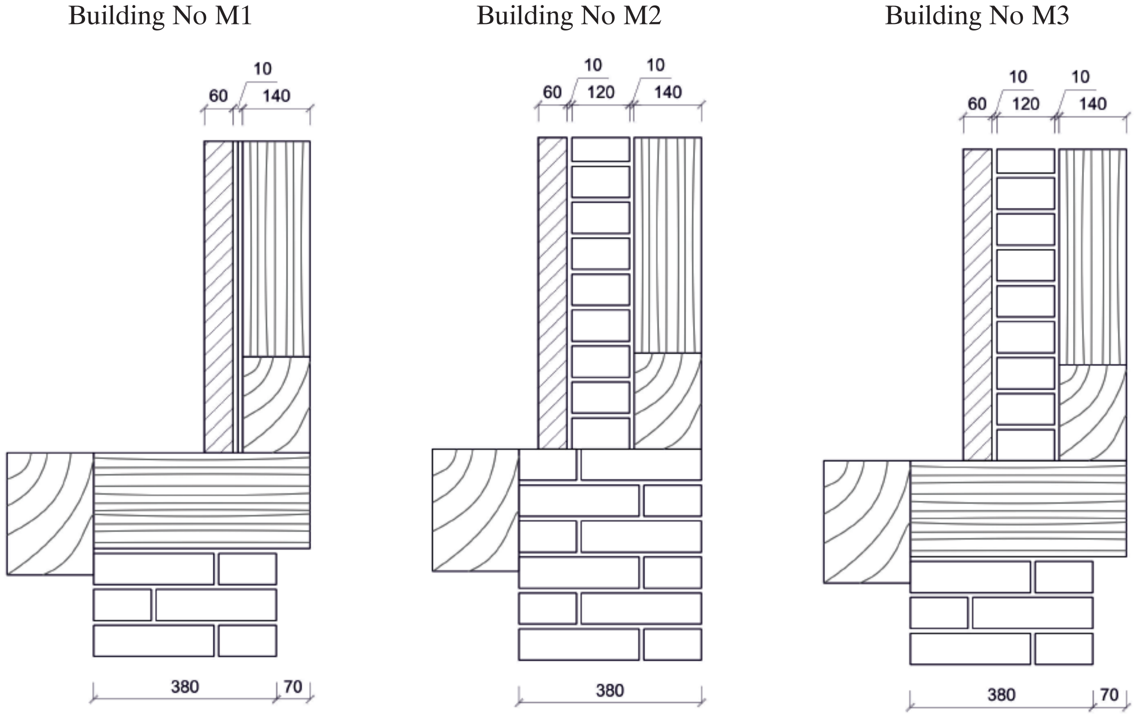


Figure 6.
Details of modification of buildings subject to analysis – Variant I (crosssection)

with the use of a light variety of aerated concrete. Details for individual objects are provided in the Figure 6.

Variants II and III

Variants II and III include insulation from the internal side of the analyzed partitions from the Prussian wall with the use of wood in two types of thickness. In variant two, 7 cm thick boards were used and in variant three – wooden logs 14 cm in diameter. The details are presented below, for variant II (Fig. 7).

4.3. Material parameters and adopted climatic conditions

The analyzed sections of partitions for individual buildings were modeled in the THERM 7.4 program assuming the values of thermal conductivity coefficient λ applicable for particular materials and emissivity values ε, which are presented in the following tables 3 and 4 referring to the condition of existing objects.

The material parameters applied for calculations above are presented in Tables 3, 4 and were taken from the technical data sheets of the materials used, standards, scientific articles and book publications included in item [10] of the bibliography.

Table 3.
Physical parameters of the analyzed partition in the existing state

No	Material	d [m]	λ [W/mK]	Emissivity ε
1	White glazed ceramic tile	0.01	0.68	0.90
2	Lime morta	0.01	0.7	0.91
3	Old brickwork wall 1810 kg/m^3	0.12	0.705	0.88
4	Pine wood, 550 kg/m^3	0.12	0.16	0.86
5	Cement-lime internal plaste	0.02	0.88	0.91

Table 4.
Material data for variant I ,II, III

No	Material	d [m]	λ [W/mK]	Emissivity ε
1	Light concrete	0.005	0.2	0.91
2	Mineral plates	0.05	0.042	0.90
3	Larch boards 400 kg/m^3	0.07	0.128	0.86
4	Larch logs 400 kg/m^3	0.14	0.128	0.86

In order to obtain the results of the temperature distribution and heat transfer coefficient U, concerning the analyzed details, in the THERM program, the parameters related to the climate as well as values related to the heat transfer issues have been adopted and are presented in Table 5.

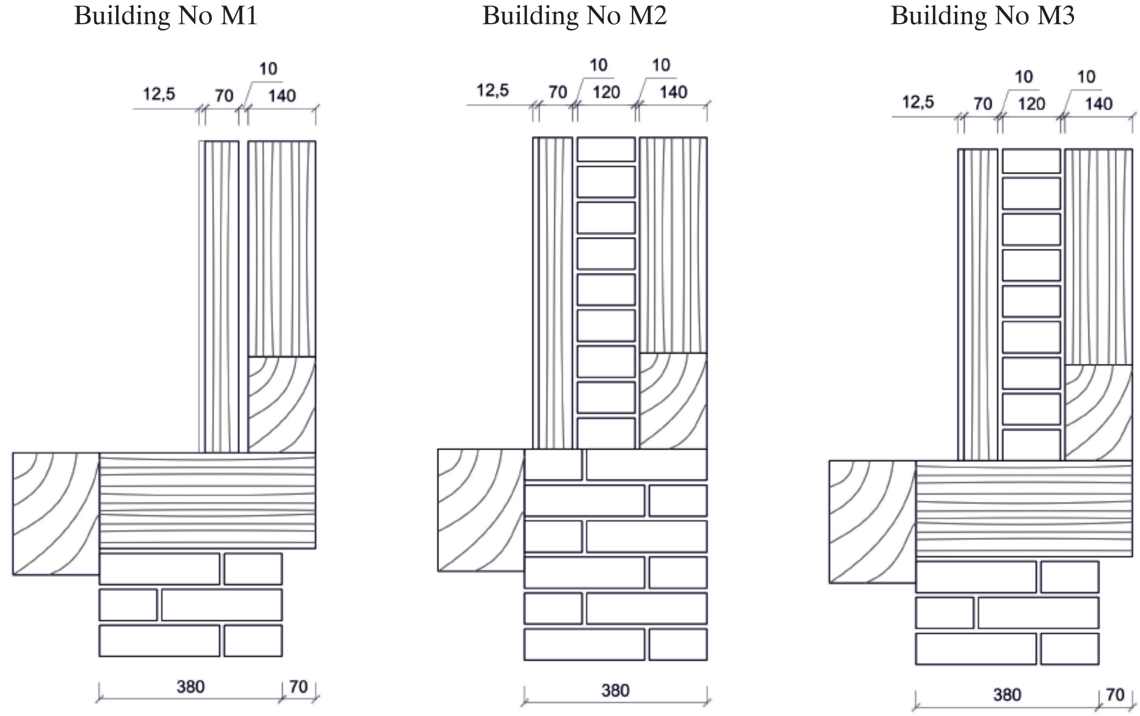


Figure 7.
Details of modification of buildings subject to analysis – Variant II (cross-section)

Table 5.
Climatic data and parameters related to heat transfer

No	Climatic data	
1	The outside temperature t_e	-2.4°C
2	The internal temperature t_i	20.0°C
3	Relative humidity φ	50%
	Heat transfer	
4	Coefficients of heat transfer h_e	25 W/(m^{2}K)
5	Coefficients of heat transfer h_i	7.69 W/(m^{2}K)
6	Coefficients of heat transfer (condensation of water vapour)	4.0 W/(m^{2}K)

The above values related to the issues of heat transfer were adopted on the basis of *PN-EN 6946 Standard Building components and elements of the building. Thermal resistance and heat transfer coefficient. Calculation method* [19].

As for the value of the outside temperature, it was obtained on the basis of climatic data referring to the average temperature of the coldest month for the meteorological station in Katowice. The internal temperature values, however, were adopted in accordance with the applicable Technical Conditions [2].

4.4. Temperature values on the surface of details

In studies using the THERM 7.4 program, the analysis of temperature in characteristic points as well as on the surface of the analyzed details in the existing state and after the performed modifications was also taken into account. The selected characteristic points of measurement are presented in Figs. 8, 9.

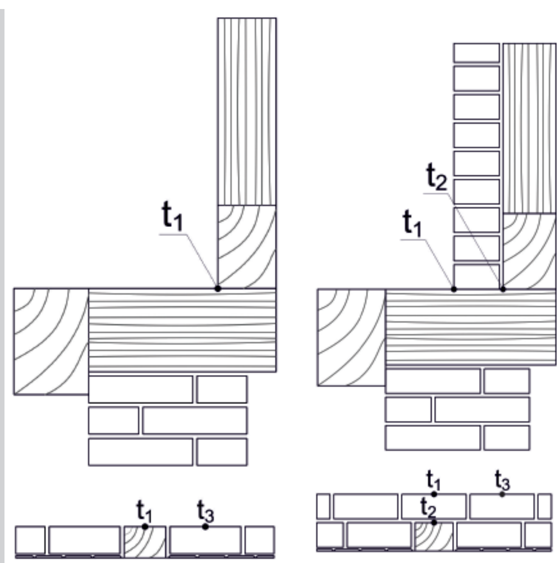


Figure 8.
Places of temperature measurement, for the existing state

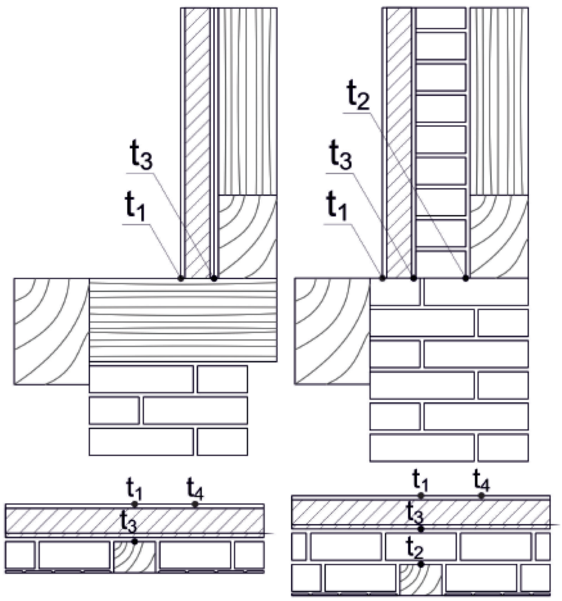


Figure 9.
Places of temperature measurement, for the state after modifications

The selected temperature reading locations marked on the drawings above refer to the following characteristic points:

- Details of the existing state

t_1 – temperature on the inside surface of the barrier,

t_2 – temperature inside the baffle layers at the half-timbered beam,

t_3 – temperature on the inner surface of the ceramic brick wall.

- Details of the state after modifications

t_1 – temperature on the inside surface of the barrier,

t_2 – temperature inside the baffle layers at the half-timbered beam,

t_3 – temperature at the interface between the insulation layer and the existing partition structure,

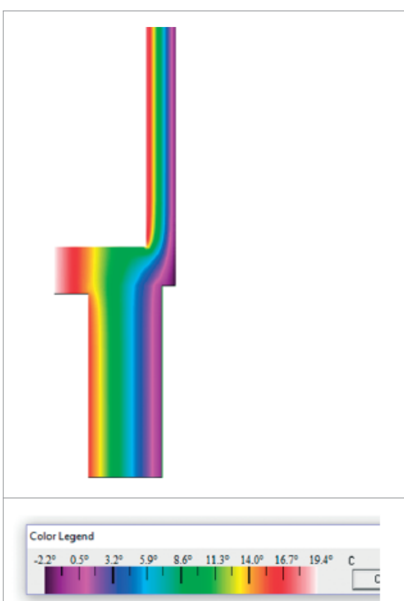
t_4 – temperature on the inner surface of the ceramic brick wall.

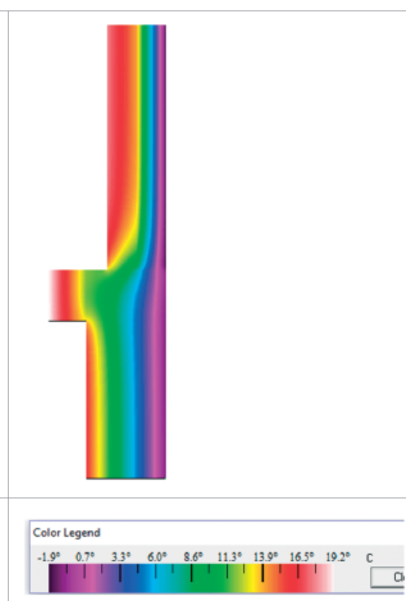
5. THE RESULTS AND THEIR ANALYSIS

5.1. Existing state

The calculation results in the Therm program are presented in the form of temperature distribution in the envelopes, with the indication of temperature values in selected places: on the inner surface of the external wall at the junction with the ceiling (for the wall 12 cm-thick) and at the contact place between

Table 6.
Analysis results in Therm – Distribution of isotherms for particular models, temperature values in selected places





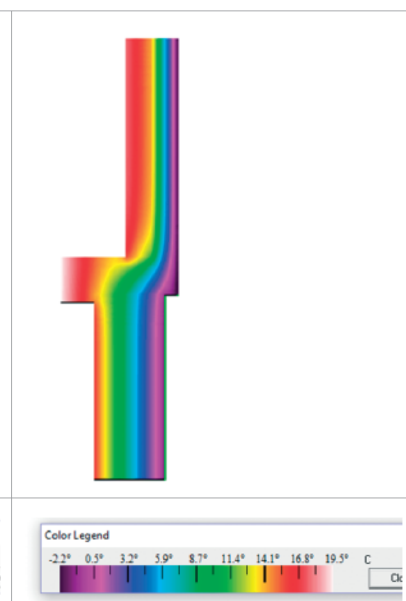


Table 7.
Temperature at selected points – existing condition

Temperature results for the state of existing objects			
	Building 1 1 Mickiewicza Street	Building 2 34 Wolności Street	Building 3 8 Mickiewicza Street
Cross-sections			
t_1	13.2°C	12.4°C	15.5°C
t_2	No data	7.6°C	10.9°C
t_4	14.5	14.1	16.8
Longitudinal section			
t_1	16.5°C	15.8°C	15.9°C
t_2	No data	10.7°C	10.4°C
t_3	12.4°C	15.1°C	15.2°C

the brick layer and the timber stud (for the 25 cm-thick wall). The obtained temperature values (Tab. 6) demonstrate that there is an impact of the construction method of Prussian wall on its thermal performance. If the wall is placed on wooden cantilevers, by supporting foundations on them, the impact of external winter conditions on the internal surfaces of the rooms is smaller. In this solution the temperatures for the 12 cm-thick wall are similar to the temperatures of the 25 cm-thick wall placed directly on the wall of the lower floor. For one-brick-thick walls, the temperature in the preset cross-section, at the contact place between the ceramics and the timber stud of the wall supported on wooden cantilevers, is 3.0°C higher as compared to the wall supported on the wall of the lower floor.

The modeling tests were carried out on the basis of hygrothermal simulations for transient boundary conditions, using the software WUFI 2D. From the described physical principles of heat and moisture transport a closed differential equation system can be developed with which the moisture behaviour of multi-layered building components can be calculated under natural climatic boundary conditions. They present the changes in the distribution of water content [kg/m^3], in the analyzed building envelope, in its particular layers (Figs. 10–13).

In the layer of inner plaster (Fig. 10), slight changes in water amount in annual cycles are noticeable. In winter, the level of water content increases from 25 kg/m^3 to 35 kg/m^3. This is due to the fact that the rooms are inhabited. The brickwork on the room side shows stability in terms of water increment, at the level of 18–19 kg/m^3 (Fig. 11). With the preset conditions, slight cyclical fluctuations in water content are noticeable, but in the analyzed calculation period this

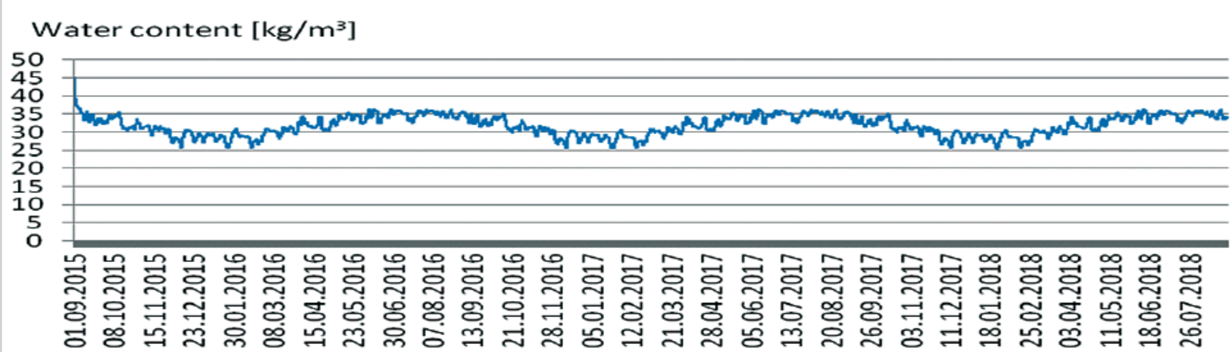


Figure 10.
Changes in water content in the internal plaster over 3 years

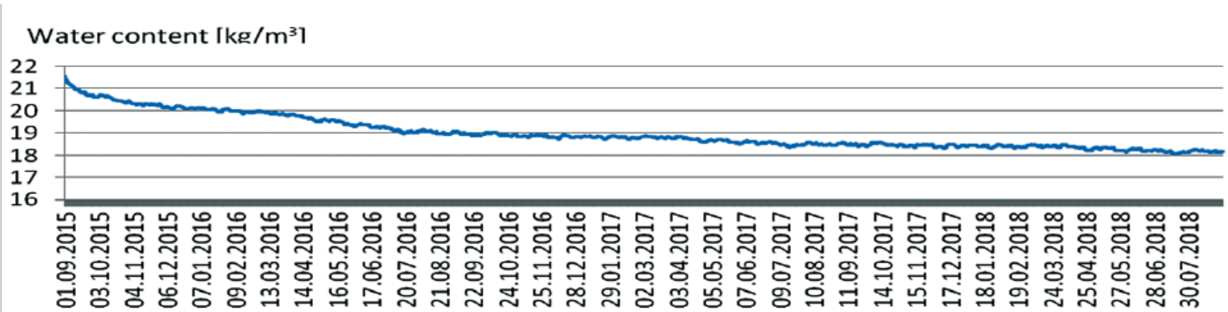


Figure 11.
Changes in water content in ceramic brick – the layer from the room side

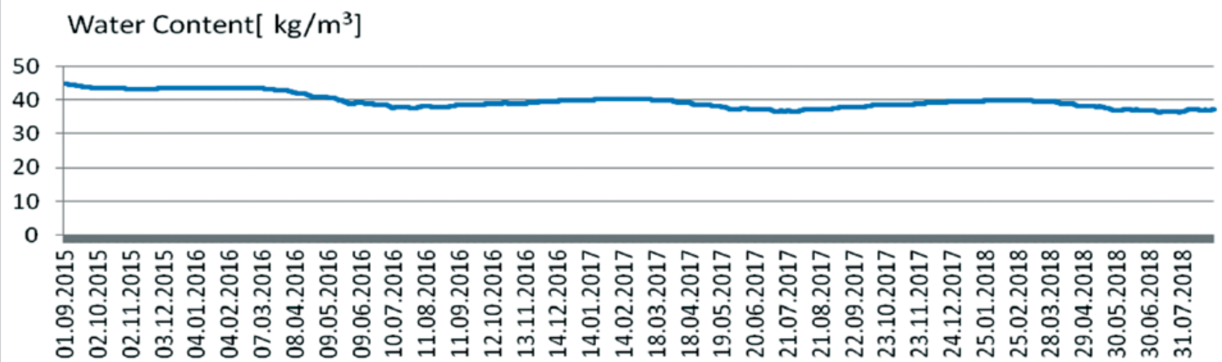


Figure 12.
Changes in water content under the ceramic tile

level decreases as compared to the initial values. Small differences in the annual cycles occur in the plaster layer under the ceramic tile (Fig. 12). The content of water increases in the autumn and winter period from 35 kg/m^3 to 45 kg/m^3. With respect to wooden studs, the level of water content in the three-year cycle decreases as compared to the initial preset value. Slight impact of weather conditions in annual cycles on the total humidity of wood can be seen.

Table 8.
Thermal insulation of bulkheads in existing state

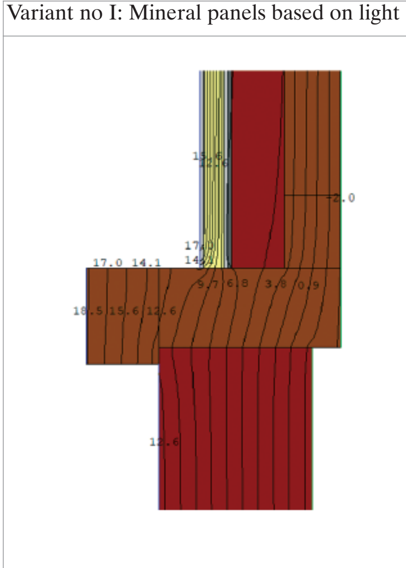
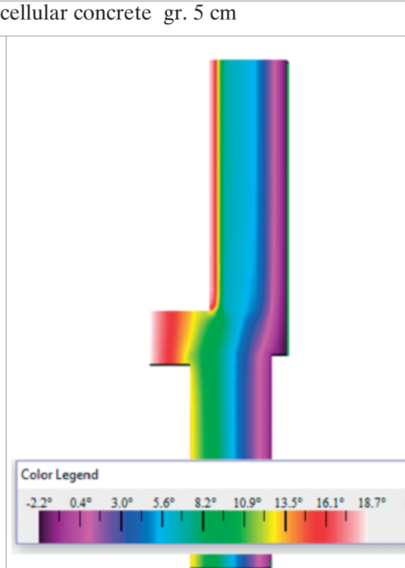
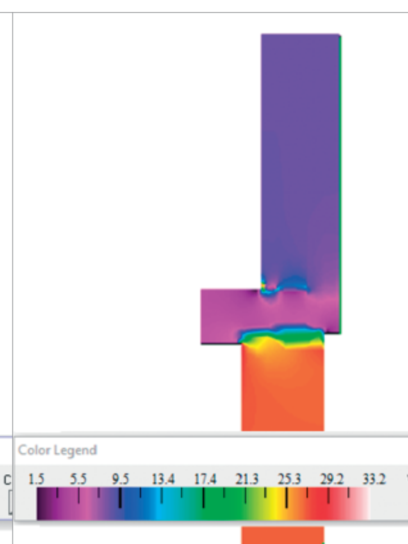
Building 1 1 Mickiewicza Street	Building 2 34 Wolności Street	Building 3 8 Mickiewicza Street
U = 2.3278 W/m^{2}K	U = 1.5961 W/m^{2}K	U =1.5603 W/m^{2}K

The measurements of thermal transmittance of the external envelope in the brickwork field were made using a measuring setup (Fig. 14). The averaged value U = 1.53W/(m^{2}K) (Fig. 14) (for building No 2). This value differs significantly from the obtained values yielded from the theoretical calculations, based on the tabular values (varied for bricks) of thermal conductivity coefficient of ceramic material [7, 19].

5.2. Design status

In the second stage of the research using the THERM 7.4 program, selected details of the modifications in individual variants of insulation from the inside were modelled. The analysis of the calculation results began by determining the state of thermal insulation after the modifications were made (Fig. 15).

Table 10.
Analysis results in Therm – Distribution of isotherms for particular models, temperature values in selected places for building 3: Mickiewicza 8 (example of calculations for a variant no 1)

Variant no I: Mineral panels based on light cellular concrete gr. 5 cm		
		

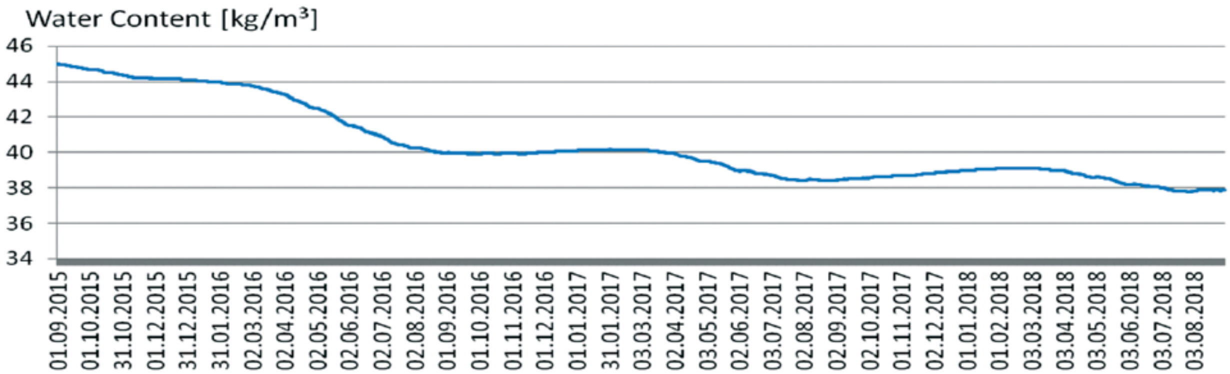


Figure 13.
Changes in water content in the timber stud

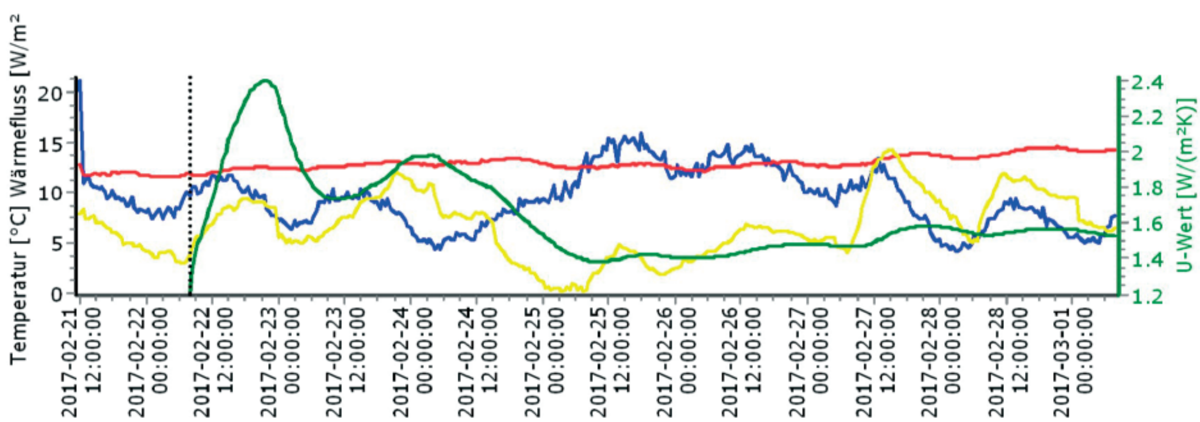
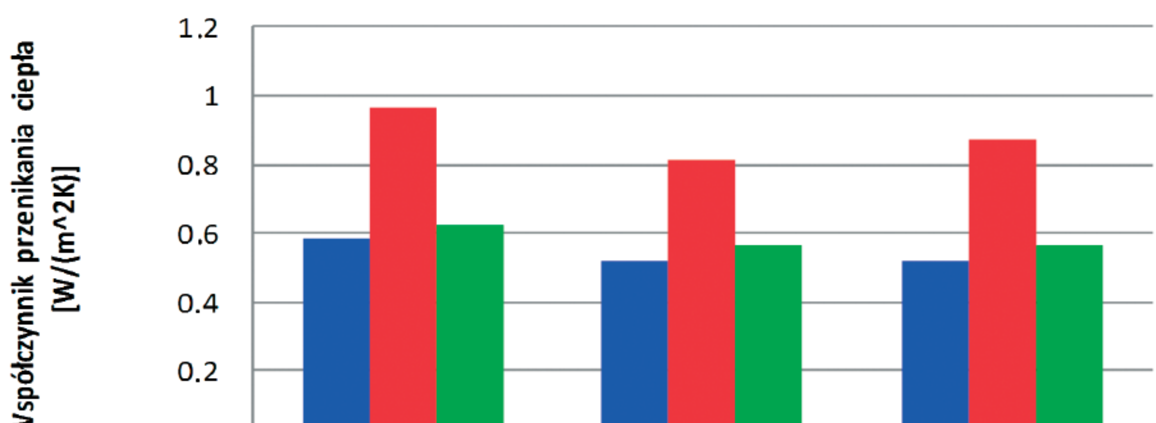


Figure 14.
Measurement results: blue line – heat flux, red line – temperature (in the room, yellow line – outside air temperature, green line – U)



	Building M1	Building M2	Building M3
Variant No 1	0.587	0.521	0.521
Variant No 2	0.963	0.816	0.871
Variant No 3	0.627	0.563	0.565

Figure 15.
Thermal insulation of insulation baffles from the inside

The above-presented values of heat transfer coefficient U for buildings in three variants of thermal insulation indicate a significant improvement in thermal insulation. Thermal insulation after insulation on the internal side using light weight concrete 5 cm thick gives the best results of U heat transfer coefficient at the level of 0.59 W/m^{2}K (25 cm thick brick wall) and 0.52 W/(m^{2}K), (12 cm thick brick wall). Nevertheless, it is worth noting that variant three in the form of thermal insulation using a log 14 cm in diameter gives comparable results as for option one.

After the calculations of thermal insulation of the insulated partitions from the internal side (Tab.10), the temperature was analyzed in the characteristic points and on the surface of the partition along with the determination of the f_{Rsi} temperature factor. The results for individual details of buildings in three variants of insulation are presented in the following Table 11.

Table 11.
Temperature and values of the temperature factor f_{Rsi} in selected points of the partition for state after modifications from the inside – cross section

Results for variants after insulating from the inside			
	Variant No 1	Variant No 2	Variant No 3
Building M1			
t_1	10.9°C	11.7°C	13.1°C
Temperature factor f_{Rsi}	0.59	0.63	0.69
t_2	-	-	-
t_3	4.7°C	6.5°C	4.7°C
Temperature factor f_{Rsi}	0.32	0.40	0.32
Building M2			
t_1	9.4°C	10.4°C	14.5°C
Temperature factor f_{Rsi}	0.53	0.57	0.75
t_2	3.4°C	4.3°C	3.4°C
Temperature factor f_{Rsi}	0.26	0.30	0.26
t_3	6.2°C	7.4°C	6.2°C
Temperature factor f_{Rsi}	0.38	0.44	0.38
Building M3			
t_1	13.0°C	14.1°C	16.8°C
Temperature factor f_{Rsi}	0.69	0.74	0.86
t_2	4.3°C	6.0°C	5.9°C
Temperature factor f_{Rsi}	0.30	0.38	0.37
t_3	6.7°C	9.1°C	8.6°C
Temperature factor f_{Rsi}	0.41	0.51	0.49

The above temperature results together with the calculated temperature factor f_{Rsi} indicate unambiguously that in the case of a partition corner inside the analyzed building No. 1 for all three cases of thermal insulation there is a risk of moisture condensation, as indicated by the value of f_{Rsi} less than f_{Rsi}, max = 0.72 according to the applicable Technical Conditions. In the case of building no. 2, the risk of condensation does not occur only for variant three of insulation, while calculations for details of the building at Mickiewicz 8 Street indicate a risk of condensation in the corner only in variant one insulation. The presented calculations, for the characteristic points selected above, proved to be the places most exposed to the occurrence of surface condensation, which is confirmed by the above results. The temperature at the interface between the insulation layers and the existing partition structure as well as inside the layers of the existing structure in all considered cases remains positive, without revealing a dangerous shift of negative isothermal temperatures into the existing masonry structure. In addition, it is also worth noting that on the surface of the horizontal cross-sections the temperature on the inner surface of the partition is at least 14.9°C for building No. 1 in Variant two insulation and 15.7°C for buildings No. 2 and 3 in the second option of insulation, without showing the risk of surface condensation.

6. SUMMARY

The carried out simulations and analyses confirmed the humidity stability of the existing walls with a wooden frame and brickwork filling. The existing layer system of the envelope does not bring about the accumulation of water content in the envelope.

The investigated objects have low (as compared to the applicable requirements) thermal insulation. The thermal performance of the envelope depends on the applied solutions of architectural details and on the type of material filling the frame.

A significant part of the preserved, half-timbered buildings may be subjected to repairs, renovation or thermo-modernization works in the near future. When designing new solutions, differences in technical and architectural solutions should be taken into account (including the way architectural details are made). Buildings must be subject to individual assessment in terms of the existing state. The planned solutions should take into account the actual value of thermal insulation or humidity of the envelopes (which are the initial, baseline values for analyses). It is also advisable to determine the actual conditions of the indoor climate, consistent with the current or planned functional use of the premises, and to adopt a calculation period longer than 3 years.

REFERENCES

[1] Ustawa z dnia 7 lipca 1994, Prawo Budowlane, z późniejszymi zmianami (The Act of July 7, 1994, Construction Law, as amended).

[2] Rozporządzenie Ministra Infrastruktury z dn. dnia 12 kwietnia 2002 r. w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75. poz. 690). z późniejszymi zmianami (Regulation of the Minister of Infrastructure dated on April 12, 2002, on technical conditions which should be met by buildings and their location (Journal of Laws No. 75, item 690). with later changes).

[3] Rozporządzeniu WSWiA z dnia 16 sierpnia 1999r. w sprawie warunków technicznych użytkowania budynków mieszkalnych (Regulation of WSWiA of August 16, 1999 on technical conditions for the use of residential buildings) (Dz.U. z 1999r., nr 74, poz. 836, z późniejszymi zmianami).

[4] Orlik-Kożdoń B., Steidl T. (2017). Impact of internal insulation on the hygrothermal performance of brick wall. *Journal of Building Physics*, 41, 120–134.

[5] Szymanowska-Gwiżdż A, Orlik-Kożdoń B. (2018). Impact of envelope structure on the solutions of thermal insulation from the inside; *Architecture Civil Engineering. Environment 4*(11), 123–134.

[6] Radoń J., Kuncel H., Olesiak J. (2006). Problemy cieplno-wilgotnościowe przy renowacji ścian budynków z muru pruskiego (Thermal and humid problems in the renovation of walls of half-timbered buildings), *Acta Scientarum Polonorum*, Architektura, Kraków, 45–53.

[7] Szymanowska- Gwiżdż A., Steidl T. (2016). Impact of building walls of historic objects from half-timbered wall in their state of thermal protection, *Civil and Environmental Engineering Reports, 20*(1), 171–178.

[8] Heim D., Krawczynski S. (2009): Procesy wilgotnościowe Fizyka Budowli. Ochrona zabytków – seria monografie (Humidity processes Physics of buildings. Protection of monuments – a series of monographs), pod redakcją P. Klemm. Politechnika Łódzka, Łódź, 140–155.

[9] Fechner H. Häupl P. Stopp H. and Strangfeld P (1999). Measurements and numerical simulation of the heat and moisture transfer in envelope parts of buildings. Proceedings Of the International Conference on Thermophysical Properties of Materials. Singapore.

[10] EN 15026 Hygrothermal performance of building components and building elements. Assessment of moisture transfer by numerical simulation

[11] Pokorska Silva I., Nowoświat A. (2019). Identification of thermal parameters of a building envelope based on the cooling process of a building object; *Journal of Building Physic* in press, 1–25, DOI: 10.1177/1744259119881167

[12] Nowoświat A., Pokorska-Silva I. (2018). The influence of thermal mass on the cooling off process of buildings. *Perioica Polytechnica Civil Engineering*, 62, 173–179.

[13] V. Ezerskiy, M. Kosior-Kazberuk, (2010). Modelowanie procesów przewodzenia ciepła w zasolonych materiałach ściennych (Modeling of heat conduction processes in saline wall materials); *Przegląd Budowlany* 9, 28–33.

[14] Kozakiewicz P., Matejak M. (2013). Klimat a drewno zabytkowe. Dawna i współczesna wiedza o drewnie (Climate and antique wood. Old and contemporary knowledge of Wood). Warszawa, Wydawnictwo SGGW.

[15] Dobrowolska E., Jankowska A., Laskowska A. (2017). Wytrzymałość i wybrane właściwości fizyczne drewna poddanego różnym metodom sztucznego starzenia (Strength and selected physical properties of wood subjected to various methods of artificial aging) Ochrona budynków przed wilgocią, korozją biologiczna i ogniem, seria Monografia nr 13, Wrocław.

[16] PN-EN 335-1:2007 Trwałość drewna i materiałów drewnopochodnych. Definicja klas użytkowania (Durability of wood and wood-based materials. Definition of usage classes) cz.1: Postanowienia ogólne.

[17] EN ISO 9869-1:2014 Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance – Part 1: Heat flow meter method.

[18] ISO 10211: 2017: Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations.

[19] ISO 13788:2012 Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods.