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ANALYSIS OF TEMPERATURE AND HUMIDITY PROCESSES IN EXISTING HALF-TIMBERED PARTITIONS

ANALIZA PROCESÓW CIEPLNO-WILGOTNOŚCIOWYCH W ISTNIEJĄCYCH PRZEGRODACH Z MURU PRUSKIEGO

A b s t r a c t

The paper presents the analysis of the inner surface of half-timbered walls in multi-family residential houses created in the early twentieth century. The analysis was made in order to avoid the possibility of mold. The analysis of partition's moisture growth was performed at the existing state and after designed thermal insulation from the inner side. The measurements and analyzes are a prelude to further research and analysis of such types of objects.

Keywords: *mold fungi*, *partitions' humidity*, *surface temperature*

S t r e s z c z e n i e

W artykule dokonano analizy temperatury powierzchni wewnętrznej ścian z muru pruskiego w wielorodzinnych domach mieszkalnych powstałych na początku XX wieku pod kątem możliwości powstania pleśni. Przeprowadzono analizę przyrostu zawilgocenia przegrody w stanie istniejącym oraz po projektowanym dociepleniu od strony wewnętrznej. Pomiary i analizy są wstępem do dalszych badań i analiz tego typów obiektów.

Słowa kluczowe: *grzyby pleśniowe*, *zawilgocenia przegród*, *temperatura powierzchni*

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1. Introduction

A characteristic feature of residential buildings from the turn of nineteenth and twentieth century in the Upper Silesia region is the presence of multi-family building associated with the nineteenth century industrial revolution and historical changes taking place at that time. With the development of the century, colonies and housing estates were formed, including industrial ones, built also by the owners of developing industrial plants. One of the characteristics of such construction is locating in the highest floors (mostly unused attics), walls of half-timbered structure. At present, attempts are being made to adapt attics for living space, connected with the necessity to improve thermal comfort.

The paper presents the research results conducted into a housing estate of railwaymen in Pyskowice. The aim of this study was to determine temperature and humidity phenomena in partitions for the cases of their insulation from the inside with homogeneous material for thermal insulation. Research will be continued and the final goal will be to broaden the knowledge in the field of possibilities to reduce heat loss in these types of objects.

2. Object of study

The construction of the housing estate in Pyskowice began after the launch of the railway line from Opole to Gliwice via Pyskowice. Already in 1910, along the railway line, there were 12 family railwaymen houses. After World War I, new buildings for railwaymen were built, but also for miners and steelworkers working outside Pyskowice [1].

In the housing estate, there are multi-family buildings with three residential floors, with flats of fairly low standard, and single-family housed in detached and terraced buildings. The buildings are currently inhabited. The housing standards in both types of buildings are similar [4].

Buildings described and analyzed in this paper are three-floor basement residences, covered with wooden roof rafter framings. Construction material of external and foundation walls is of ceramic brick. Wall thickness depends on the floor level, traditionally, in the ground it is most commonly 52 cm, decreasing towards the top. Dormer's peaks, in their entirety

Fig. 1, 2. Pyskowice, examples of the building development of railway housing estate, visible frame construction of the attic's walls (photo by authors) or in parts, were made with the use of tier wooden frames, filled with ceramic brick. In this case, brick wall thickness was 12 cm. This type of wall was used for floor housing without residential function – non-used attics and the highest levels of staircases. Areas between wooden elements were usually plastered.

In recent years, due to the large increase in heating costs, the residents decided to improve the insulation of external walls. Thermomodernization treatments of various kinds were performed. There were also attempts to adapt lofts for residential purposes.

For such adaptations, the essential importance for the thermal comfort of premises and technological possibilities of construction works, has the specific nature of half-timbered walls. Attempts at insulating partitions from the inside were made, which may have entailed the occurrence of adverse phenomena in the partition [3].

3. The scope of research

The scope of research was adapted to the needs of the carried out analyses of thermal humidity processes, and included:

– measurements of brick layers and wooden elements, and humidity measurements in situ, on the inner surface of external partitions, which were used to determine the boundary conditions of existing partitions for further analysis,
– determination of thermal insulation and possibility of condensation on the inner surface of existing external partitions,
– a forecast of condensation possibility on the inner surface of external partitions, in the case of their insulation from the premises side,
– analysis of humidity changes of the partition in the existing state and after the design of thermal insulation from the inside,

The forecast of humidity changes covered a period of 1 statistical year.

4. Research method

Analyses of temperature and humidity processes were performed for two-dimensional theoretical models, with consideration of the actual conditions of external climate, parameters of premises' internal climate, in accordance with their purpose and actual humidity of the partitions. Geometric models of selected parts of the partitions were performed on the basis of in-situ measurements. For temperature and humidity estimates of selected locations in the building, program THERM 7.19 was used, based on the use of FEM, for the calculation of any two-dimensional model of building element. The program allows to obtain temperature values at any point of partition's cross section, total heat flux and heat transfer coefficient U [W/(m^{2}K)]. Values obtained in the program were used to determine temperature coefficient on the inner surface of the external partition, i.e. $f_{Rsi,}$ determining the risk of surface condensation. Preliminary calculations were made in accordance with PN-EN ISO 13788 [2]: Temperature and humidity properties of building components and building elements. The temperature of the inner surface to avoid the critical surface humidity and interlayer condensation. The assignation of temperature coefficient was made for the parameters of the local climate, i.e. the nearest weather station in Katowice

For the calculation, the boundary conditions were adapted:

- Outside air temperature: t = –2.4ºC (annual average temperature for the coldest month),
- Inside air temperature: t = +20 ºC,
- Heat transfer coefficients h_e = 25 W/(m^{2}K); h_i = 7.69 W/(m^{2}K); for the surface condensation condition 4.0 W/(m^{2}K).

For the calculation of the risk of condensation, premises humidity was adopted in accordance with the Technical Conditions, i.e. 50%.

The analysis of changes in partition's humidity at the period of 1 year for the existing state and after the design of insulation from the inner side, was performed with the use of a custom program for the calculations of humidity increase in building partitions. The program operates in EXEL and is based on an algorithm contained in the Standard [2]. The calculations were made on the basis of data from the meteorological station in Katowice, using, for the standard meteorological year monthly average temperatures, monthly minimum and maximum temperatures. As for the inside temperature, standard conditions were adapted, i.e. t_i =20ºC and φ = 50%.

5. Partition models adapted for the calculations

Calculations included the partitions of attics, characterized with the construction typical for half-timbered walls and their modifications consisting of partitions insulation from the premises side.

For the calculation of the critical temperature, flat partition was selected with the cross-section of wooden pillars 14 × 14 cm and thickness of the brick filling 12 cm, with lime plaster and structural knot-angle of the external wall. As insulation material, Remmers SLP lime-silicate plates were adopted. Coefficient of thermal conductivity under normal conditions, of lime-silicate plates is λ = 0.0626 (W/mK), diffusion resistance coefficient μ = 4,4 (based on Technical Instruction No. 0223 Remmers).

The markings of analyzed partition models were adopted (as in Fig. 3):

- detail_P1: flat partition, a combination of ceramic filler with a wooden pillar,
- detail_P2: flat partition, a combination of ceramic filler with a wooden pillar, with insulation of 6 cm from the premises side,
- detail_P3: flat partition, a combination of ceramic filler with a wooden pillar, with insulation of 8 cm from the premises side,
- detail_P4: flat partition, a combination of ceramic filler with a wooden pillar, with insulation of 10 cm from the premises side,
- detail_N1: corner of the external partition with corner wooden pillar,
- detail_N2: corner of the external partition with corner wooden pillar, with insulation of 6 cm from the premises side,
- detail_N3: corner of the external partition with corner wooden pillar, with insulation of 8 cm from the premises side,
- detail_N4: corner of the external partition with corner wooden pillar, with insulation of 10 cm from the premises side.

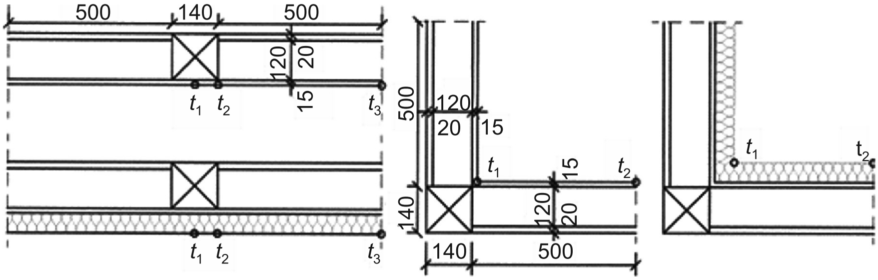

Fig. 3. Models of analyzed partitions and places of calculated temperatures

Adapted values of the thermal conductivity coefficient λ [W/mK]: pine wood (0.16), ceramic brick (0.77), lime plaster (0.88), lime-silicate plates (0.063).

The analysis of changes in humidity of the partition at the period of 1 year, was carried out for the brick element of the partition existing, for variants: w0 (existing state), and with plates insulation of 6, 8, and 10cm (respectively variants w1, w2, w3).

6. Measurements of partitions humidity in situ

In order to check the level of humidity of partition's inner surface in non-used premises in the existing state, humidity measurements were performed. They were made using a measuring instrument Testo 635-2 with a probe to measure materials humidity (manufacturer's calibration protocol No. 02356831, measuring accuracy +/–1%). Moisture values, showed by weight percent in relation to dry material mass. Too high humidity may be a problem when mounting newly designed insulation from the inner side. Its size affects the performance of computational prediction of climate and microclimate effect on the future temperature and humidity state. The measurements were carried out on the inner surface of half-timbered partition (wall plastered from the inside). The measurements will be used for further analysis and should be treated as preliminary. Measuring points at the wood level were highlighted in gray.

The measurements are summarized in Table 1.

Table 1

Measured values of moisture, showed by weight percent in relation to dry material mass

Point No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Humidity value [%]	1.9	1.6	1.9	1.6	1.8	1.8	1.9	2.5	1.5	1.8
Point No.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Humidity value [%]	3.2	3.1	4.0	2.2	0.8	2.4	1.4	1.0	1.3	0.5

Slightly higher humidity occurred in the brick wall, in the part with the window.

7. Analysis results

The surface temperatures of selected knots were marked t_1, t_2 i t_3. They occur in (Fig. 1), the calculated values are summarized in Table 2 and 3.

Table 2

Values of temperatures [ºC] depending on the detail (flat partitions) and places of appearing

Temperature markings in selected knots	Details			
	Detail_P1	Detail_ P2	Detail _P3	Detail _P4
t_1	14.0	16.7	17.1	17.5
t_2	9.8	16.3	17.0	17.4
t_3	8.1	16.1	16.8	17.3

Table 3

Values of temperatures [ºC] depending on the detail (corners) and places of appearing

Temperature markings in selected knots	Details			
	Detail_ N1	Detail _N2	Detail _N3	Detail _N4
t_1	7.2	13.1	14.0	14.3
t_2	8.1	16.1	16.2	17.3

In accordance with WT requirements, the size of $f_{Rsi\min}$ temperature coefficient, determined in accordance with the procedure PN-EN ISO 13788, in heated rooms to a temperature of at least 20ºC, assuming the average relative inside air humidity φ_I = 50%, can be adapted at the level of 0.72. Such value, with properly designed partition, for the minimum inside temperature of partition surface, at which there is no likelihood of mold (called the critical temperature), should be exceeded. From the calculation practice it shows that the minimum temperature factor, calculated for local climatic conditions, may reach much higher values, and thus increase design requirements. By adopting the calculation procedure, contained in [2], the value of minimum temperature factors for all months of the year, were set. The most unfavorable conditions for the assumptions occur in the winter months – in February (Table 4). For critical conditions (month of February), calculated on the basis of the available climate data base, the inner surface temperature cannot be less than 16.2ºC. This will prevent condensation on the inner surface of the corner. State requirements, contained in the Regulation [5] require that the minimum surface temperature was 13.8ºC.

Table 4

Values of the minimum factor $f_{Rsi,\min}$ for the critical month, for a meteorological station in Katowice

Month	p_e [Pa]	$p_{sat}(\theta_{si})$ [Pa]	$\theta_{si.\min}$ [ºC]	ΔP [Pa]	$f_{Rsi,\min}$
February	478	1844	16.2	907	0.832

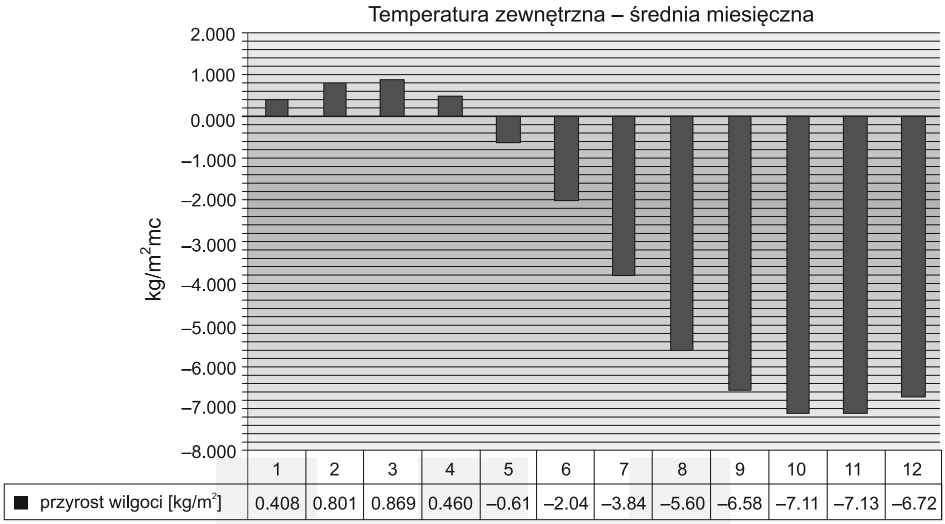

Fig. 4. Humidity increase in the wall for average monthly temperatures (variant w1)

Table 5

Values of humidity increases [kg/m²] in individual months of the year

		Months											
		1	2	3	4	5	6	7	8	9	10	11	12
W0	av	–0.61	–1.15	–2.02	–3.17	–4.77	–6.56	–8.59	–10.5	–12.1	–13.3	–14.2	–14.8
	min	–0.16	–0.32	–0.79	–1.44	–2.33	–3.29	–4.39	–5.59	–6.37	–6.97	–7.48	–7.67
	max	–1.12	–2.24	–3.95	–6.55	–9.44	–13.0	–17.1	–21.1	–24.3	–27.1	–28.9	–30.2
W1	av	**0.41**	**0.80**	**0.87**	**0.46**	–0.61	–2.04	–3.84	–5.60	–6.58	–7.11	–7.13	–6.72
	min	**0.95**	**1.81**	**2.41**	**2.77**	**2. 82**	**2.72**	**2.45**	**2.03**	**2.19**	**2.63**	**3.16**	**4.09**
	max	–0.25	–0.63	–1.78	–4.45	–7.57	–12.0	–17.2	–22.4	–26.0	–29.0	–30.4	–30.9
W2	av	**0.41**	**0.80**	**0.94**	**0.69**	–0.11	–1.19	–2.57	–3.92	–4.64	–4.98	–4.92	–4.50
	min	**0.85**	**1.61**	**2.18**	**2.54**	**2.66**	**2.66**	**2.52**	**2.26**	**2.46**	**2.90**	**3.41**	**4.24**
	max	–0.13	–0.37	–1.24	–3.35	–5.83	–9.42	–13.6	–17.8	–20.7	–23.1	–24.1	–24.5
W3	av	**0.39**	**0.76**	**0.91**	**0.74**	**0.11**	–0.67	–1.88	–2.98	–3.54	–3.79	–3.70	–3.31
	min	**0.76**	**1.43**	**1.95**	**2.30**	**2.44**	**2.48**	**2.40**	**2.23**	**2.44**	**2.85**	**3.31**	**4.05**
	max	–0.07	–0.24	–0.94	–2.70	–4.77	–7.79	–11.3	–14.8	–17.3	–19.3	–20.1	–20.4

av – average temperatures, min – minimum temperatures, max – maximum temperatures,
partition variants: w0 – existing partition, w1 – 6 cm of insulation, w2 – 8 cm of insulation, w3 – 10 cm of insulation.

The value of the critical temperature, determined for the local conditions, will be exceeded in all indicated points with insulation thickness of min. 8cm, in the case of flat partition. In order to obtain a temperature higher than 16.2ºC in the corner, the insulation thickness would have to be larger.

For the average monthly temperatures, a lack of humidity increase in the insulated partition will occur during the calculation period (one year), despite periodic monthly increases. The annual permanent increase of wall's humidity may occur with the appearing of minimum temperatures.

8. Conclusions

The measurements and calculations indicate the necessity for precise analysis in the case of insulating the half-timbered walls from the inside. The type of insulating material, thickness, and attachments method should be selected referring to the local conditions in each case separately.

It is suggested that temperature and humidity calculations, due to the rather problematic humidity calculation model contained in [2], should be carried out not only for the average conditions but mostly for critical conditions, including maximum and minimum outside temperatures, and increased humidity of inside air, i.e. not less than 60%. Such actions will allow the design of internal insulation with the likelihood of avoiding the risk of condensation on the inner surface and minimize possible, even short-term, presence of external conditions conducive to the formation of mold and humidity accumulation in the partition. The number of conducted measurements was considered insufficient to perform statistical analyzes. Further studies of the phenomena occurring in the contact surface of wooden elements with brick, for different variants of internal insulation, will be conducted in the next heating season. The authors of this paper treat presented tests and calculations as preliminary due to the imperfection of the calculation method set in [2]. However the method used provides a good solution to the problem. The moisture content, calculated by [2] will be more extensive than is necessary and more successful. It was recognized that phenomena appearing in the joint plane of wooden elements with brick, for different variants of internal insulation, require analysis related to the two-dimensional coupled heat and moisture flow. Final calculations will be performed using AnTherm program with the use of carried out tests.

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