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Hygrothermal Assessment of Internally Insulated Prefabricated Concrete Wall in Polish Climatic Condition

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Abstract**—**Internal insulation of external walls is often problematic due to increased moisture content in the wall and interstitial or surface condensation risk. In this paper, the hygrothermal performance of prefabricated, concrete, large panel, external wall typical for WK70 system, commonly used in Poland in the 70's, with inside, additional insulation was investigated. Thermal insulation board made out of hygroscopic, natural materials with moisture buffer capacity and extruded polystyrene (EPS) board was used as interior insulation. Experience with this natural insulation is rare in Poland. The analysis was performed using WUFI software. First of all, the impact of various standard boundary conditions on the behavior of the different wall assemblies was tested. The comparison of results showed that the moisture class according to the EN ISO 13788 leads to too high values of total moisture content in the wall since the boundary condition according to the EN 15026 should be usually applied. Then, hygrothermal 1D-simulations were conducted by WUFI Pro for analysis of internally added insulation, and the weak point like the joint of the wall with the concrete ceiling was verified using 2D simulations. Results showed that, in the Warsaw climate and the indoor conditions adopted in accordance with EN 15026, in the tested wall assemblies, regardless of the type of interior insulation, there would not be any problems with moisture - inside the structure and on the interior surface.

Keywords**—**Concrete large panel wall, hygrothermal simulation, internal insulation, moisture related issues.

I. INTRODUCTION

IMPROVING the insulation properties of external walls is a commonly used method for thermoretrofitting of building in Poland.

Usually thermal insulation is mounted on the exterior surface of the partition, but it is not always possible. The problem in Poland is not only the old heritage buildings, which are characterized by high richness of architectural details and are protected by applicable law, but also the multi–dwelling buildings from prefabricated concrete panel elements, commonly built from the sixties to the mid-eighties. Housing communities or cooperatives managing these buildings often do not have sufficient funds to retrofit the facade, or there is a conflict of interest that prevents them to carry out the retrofitting works. The solution in this case is application of the interior insulation.

However, the use of interior insulation is connected with the risk of mould growth and high moisture state in the partition's materials. Relative humidity in the room makes the accumulated water vapour pass through the wall to the outside. In the wrong partition made, the condensation could appear and in turn may lead to wall damage. Therefore, the correctly performed vapour diffusion barrier [3], [13] or the use of capillary-active insulation, which will help to regulate the humidity inside the rooms is so important [20]. The use of a vapour diffusion barrier may lead to high interior relative humidity, large fluctuations of the interior relative humidity and excessive moisture load on the construction [12]. Listiburek [13] noticed that vapour barrier, while designed to prevent assemblies from getting wet, might prevent assemblies from getting dried. That is why, during the last years, another concept to use the capillary active insulation, e.g. calcium silicate (CaSi), autoclaved aerated concrete (AAC), or biodegradable, natural, organic materials like hemp, wood fibers, cork, flax, straw has been developed.

Only a few examples in the literature exist that describe the capillary active insulation as the solution for interior insulation of exterior walls. Häulp et al. presented the hygrothermal investigations for masonry, historical building facades of museums and residential buildings in Germany [15] and Rijksmuseum in Amsterdam [11], insulated with 30 mm CaSi. In both cases, there were no problems with the moisture accumulation inside the wall and on the interior surface. In contrast, Vereecken and Roels showed in an experimental X-ray study [4] and numerical calculation [5] that walls with capillary active insulation can story much more moisture than walls with vapour diffusion barrier. Therefore, it is recommended for each case to analyse the hygrothermal performance of wall with interior insulation.

Wegerer et al. [16] presented research on demonstration objects onto which four various interior insulation system made of woodfibre have been installed. However, they have limited to measure the temperature and relative humidity between the interior insulation and the existing wall to check the risk of mould growth.

Most of this research focuses on the masonry, brick walls of historic buildings. Only limited information is available on the hygrothermal performance of prefabricated panel concrete walls with interior insolation. Lisiburek [13] presented the recommended solutions of interior insulation prefabricated concrete walls with vapour barrier for different climate zone of North America.

In the current paper, the hygrothermal assessment of large panel prefabricated concrete wall with interior insulation, based on numerical simulation, was presented. Analyses were

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performed for solutions with natural, bio-based insulation like hemp fiber, wood fiber board and classical expanded polystyrene board (EPS).

II. Methodology

A. Investigated Structure

Typical large panel prefabricated concrete wall of WK70 system used in Poland in the 70th years with different interior insulation materials was tested with numerical simulations. The original wall consists of three layers:

- external layer with a thickness of 6 cm of concrete
- insulation layer with a thickness of 6 cm of expanded polystyrene (EPS)
- structural layer with a thickness of 8 cm of concrete.
- and thermal transmittance of this wall is 0.71 W/(m^{2}K).

The studied insulation materials represent the different type of insulation: hemp fibre board (4.7.3), wood fibre board (3.3.3) and expanded polystyrene board (EPS), covered with traditional gypsum board (3.6.1) or earth dry board (3.1.2). The configuration of tested wall assemblies is shown in the Table I.

TABLE I
The Investigated Wall Assemblies

Wall assembly	Insulation thickness [mm]	Lining material thickness [mm]	Total thickness [mm]	Heat transfer coefficient U [W/(m^{2}K)]
WK70+3.3.3+3.6.1	40	12.5	0.27	0.40
WK70+3.3.3+3.1.2	40	20	0.28	0.40
WK70+4.7.3+3.6.1	80	12.5	0.31	0.31
WK70+4.7.3+3.1.2	80	20	0.32	0.31
WK70+EPS+3.6.1	80	12.5	0.31	0.27
WK70+EPS+3.1.2	80	20	0.32	0.27
WK70+3.3.3 (15 cm)+3.6.1	150	12.5	0.38	0.20

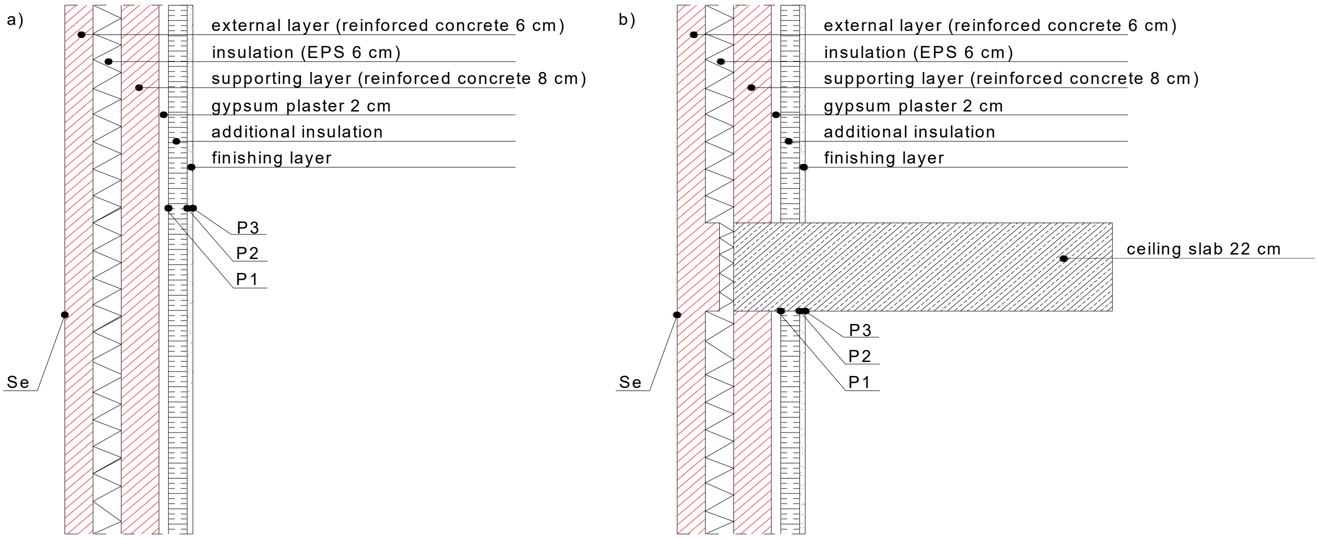

Fig. 1 Scheme of investigated construction (a) one-dimensional standard cross-section, (b) two-dimensional joint of wall and ceiling

According to the Polish Building regulation [17], the required U-value (the heat transfer coefficient) for exterior wall is 0.23 W/(m^{2}K) and from the 1 January 2020 – 0.20 W/(m^{2}K). The cases presented in Table I do not fulfil this requirement, except for WK70+3.3.3(15 cm)+3.6.1,where the insulation thickness was changed from 40 mm to 150 mm.

In the first step, the one-dimensional analysis of a wall without any joints and thermal bridge was performed. However, practical experience shows that even the interior insulation system in standard cross section shows proper function, it may be the joint or thermal bridge of a construction that cause problems. That's way, the joint of the wall with a concrete ceiling was analysed.

The hygrothermal simulations of the wall assemblies were performed with software package WUFI [8] which is a numerical simulation tool developed by Fraunhofer Institute for Building Physic in German. WUFI Pro has been validated by extensive research and testing [2], [9], [14], [18] and complies with the benchmark test defined by European standard EN 15026 [6].

The relative humidity and the temperature on the interior surface (P3), in the cross section between the lining layer and the additional insulation (P2), in the cross section at the rear side of additional insulation (P1) and the total water content of the constructions were investigated. One–dimensional standard cross section 1D with the marked positions that was used for analysis is shown in Fig. 1 (a) and two–dimensional joint of wall and ceiling 2D in Fig 1 (b).

The standard cross section (Fig. 1 (a)) was analysed with WUFI Pro and the joint of the wall and ceiling (Fig. 1 (b)) with WUFI 2d.

B. Boundary Condition and Materials

The investigated wall was assumed to face West direction, since the West direction is the direction that is most exposed to the wind in Poland. The wall was modelled as the wall in tall building (>20 m), since higher buildings are most exposed to the effect of driving rain than lower buildings. The colour of the facade surface was assumed to grey, typical for the large concrete panel building. In the absence of any impregnation layer on the exterior surface of the wall, driving rain water absorption coefficient was adopted to 70 % in accordance with the inclination and type of wall. The exterior boundary conditions were taken from database of WUFI software for the city of Warsaw. The weather data included hourly values of temperature, relative humidity, solar radiation, barometric pressure, long-wave counter radiation, rain load.

WUFI offers three different models for the indoor climate: in accordance with the Standard EN-ISO 13788 [7], EN-15026 [6] or recommendations W.T.A. [19]. In order to check the impact of adopted internal conditions (Table II) on the solutions of simulations for two wall assemblies WK70-3.3.3+3.1.2 and WK70-4.7.3+3.1.2, comparative analysis was performed.

TABLE II
THE INVESTIGATED WALL ASSEMBLIES

Internal boundary conditions in accordance with:	Temperature	Relative humidity
EN-ISO 13788	$\theta_{int} = 20^oC$	humidity class 3
EN-15026	$\theta_{int} = 20^oC$ for $\theta_{ext} \leq 10^oC$ $\theta_{int} = (20 \div 25)^oC$ for $10^oC < \theta_{ext} < 25^oC$ $\theta_{int} = 25^oC$ for $\theta_{ext} \geq 25^oC$	$\varphi_{int} = (30 \div 60)\%$ depending on the outdoor temperature
W.T.A.	Sinusoidal variable from $\theta_{int} = 20^oC$ in winter to $\theta_{int} = 24^oC$ in summer	Sinusoidal variable from $\varphi_{int} = 40\%$ in winter to $\varphi_{int} = 60\%$ in summer

TABLE III
HYGROTHERMAL PROPERTIES OF MATERIALS

Materials	Bulk density ρ [kg/m^3]	Porosity P [m^3/m^3]	Specific heat capacity c_p [J/(kg·K)]	Thermal conductivity λ [W/(m·K)]	Vapour diffusion resistance μ [-]
Gypsum plaster	1721	0.30	850	0.2	13
EPS	16.5	0.98	1570	0.037	58
Wood fibre board (3.3.3)	159	0.91	2000	0.045	4
Hemp fibre board (4.7.3)	96	0.91	2300	0.049	2
Gypsum board (3.6.1)	925	0.65	1000	0.16	10
Earth dry board (3.1.2)	1366	0.50	1100	0.24	18
Concrete	2320	0.14	850	1.5	19

The hygrothermal properties of used materials are presented in Table III. The data for insulations and lining materials were determined on the tests performed at the Building Research Institute in Warsaw within the H-house project [10]. The properties of expanded polystyrene (EPS.), concrete and gypsum plaster were taken from database of WUFI software.

The initial moisture content of all materials was 80% RH, and the initial temperature was 20 ^oC. For a reliable assessment of the construction, not only the initial behaviour during the first years after construction should be analysed but also the hygrothermal conditions during the dynamic equilibrium. So all simulations were executed until any moisture fluctuations were caused only by seasonal changes, which in this study has been limited to 5-year period.

III. RESULTS

A. Effects of Boundary Condition

Figs. 2 and 3 show respectively total water content of two wall assemblies WK70-3.3.3+3.1.2 and WK70-4.7.3+3.1.2 for tree different types of internal boundary condi-tions according to one-dimensional construction. Variant1 (w1) corresponds to the conditions consistent with the Standard EN 15026 [6], variant 2 (w2) with the Standard EN- ISO 13788 [7] and variant 3 (w3) with W.T.A [19].

Regardless of the adopted boundary conditions, in both options of the wall assemblies, there is not any increasing dampness in the time. The highest total water content was reached for variant 2 (w2) of internal boundary condition, for variant 1(w1) and variant 3 (w3) the total water content values were close to each other. The highest total water content for variant 2 (w2) is the result of the high relative humidity assigned to internal boundary condition according to the Standard EN-ISO 13788. Based on the performed analysis, it could be concluded than for the worst case analysis, the indoor boundary condition should be adopted according to the Standard EN-ISO 13788. However, a study conducted by Holm and Künze [1] on the effect of climate on the internal heat and moisture behavior and durability of building envelopes shows that the adoption of the conditions corresponding to the variant 1 (w1), provides results most similar to reality. Therefore, in this study, all analyses were performed for internal boundary condition, according to EN-ISO 15026 [6], for the normal moisture load.

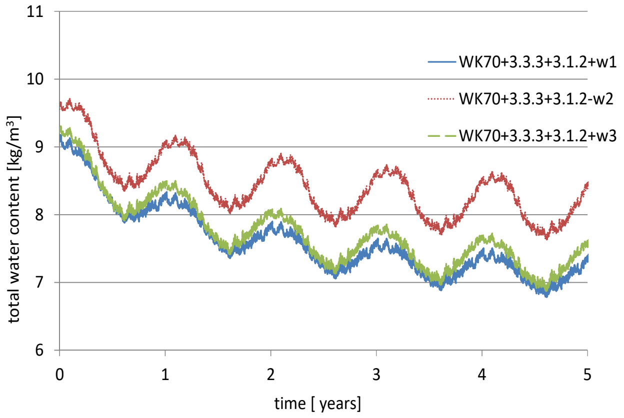

Fig. 2 Total moisture content of WK70-3.3.3+3.1.2 wall for three variants of internal boundary condition

B. One-Dimensional Wall Assembly

Table IV shows the minimum temperature on the interior surface (P3), in the cross section between the lining layer and the additional insulation (P2), in the cross section at the rear side of additional insulation (P1) and on the exterior surface (Se) for one-dimensional wall assembly.

Because, there were not significant differences due to the type of used inner finishing layer: gypsum board (3.1.2) or earth dry board (3.6.1), this article shows only results for the partition with earth dry board (3.6.1) like finishing material.

In the first winter period, the highest total moisture content 10.43 kg/m^3 was reached by WK70+3.3.3(15 cm) +3.6.1 assembly (Fig. 4). In spring, it decreased to 9.967 kg/m^3, as the construction was drying out. During the next years, the total moisture content was decreasing until the dynamic equilibrium with the total moisture content of 8.891 kg/m^3 in winter and 7.663 kg/m^3 in spring was reached. The lowest total moisture content was noted for the WK70+3.3.3+3.6.1 assembly with the smallest insulation thickness of 40 cm. In the first winter period, it was 9.082 kg/m^3, and in the first summer period – 7.509 kg/m^3, whereas in the dynamic equilibrium state, respectively 7.509 kg/m^3 in winter and 6.590 kg/m^3 in summer. Thus, the smaller thickness of the insulation, the lower total moisture content with wall assembly.

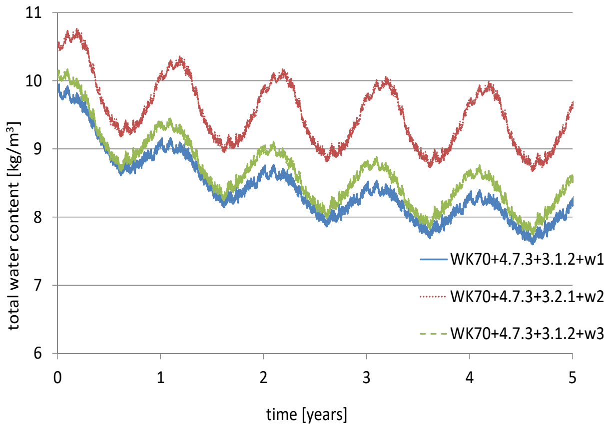

Fig. 3 Total moisture content of WK70-4.7.3+3.1.2 wall for three variants of internal boundary condition

TABLE IV
MINIMUM TEMPERATURES FOR EACH SOLUTION OF ONE-DIMENSIONAL WALL ASSEMBLY IN SELECTED CROSS-SECTIONS

Wall assembly	T (P3) min [°C]	T (P2) min [°C]	T (P1) min [°C]	T (Se) min [°C]
WK70+3.3.3+3.6.1	18.75	17.79	5.71	-14.79
WK70+3.3.3+3.1.2	18.76	17.72	5.73	-14.79
WK70+4.7.3+3.6.1	19.05	18.24	5.71	-14.79
WK70+4.7.3+3.1.2	19.02	18.18	5.72	-14.92
WK70+EPS+3.6.1	19.02	18.46	3.87	-15.00
WK70+EPS+3.1.2	19.16	18.41	3.85	-15.00
WK70+3.3.3 (15 cm)+3.6.1	19.34	18.79	1.62	-15.08

The relative humidity at equilibrium in WK70+3.3.3(15 cm) +3.6.1 assembly, at the rare side of additional insulation (Fig. 5 - P1) was 85% and temperature 3.2 °C in winter and in summer 58% and 1.62 °C. On the other hand, in the case of WK70+3.3.3+3.6.1 assembly at the same position, the relative humidity was 65% and temperature 9.2 °C in winter, and 54% and 27.0 °C in summer. Also, the smaller thickness of insulation, the less difference is between the relative humidity of the winter and summer season.

Comparing the solutions with a different kind of insulation but with the same thickness (WK70+4.7.3+3.6.1 and WK70+EPS+3.6.1), we can see that the solution with the hemp fibre board (4.7.3) as the insulation was characterized by greater amplitude of relative humidity between summer and winter period, and lower values of relative humidity during the summer.

The results show that adding insulation from hygroscopic materials with low vapour diffusion resistance factor gives the shortest drying out period compared with traditional insulation (EPS).

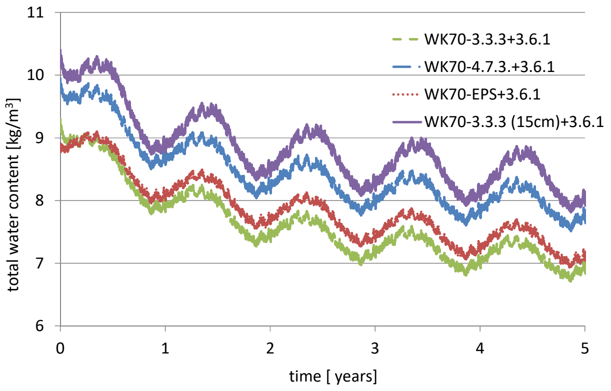

Fig. 4 The total moisture content for different wall assemblies – one-dimensional standard cross-section

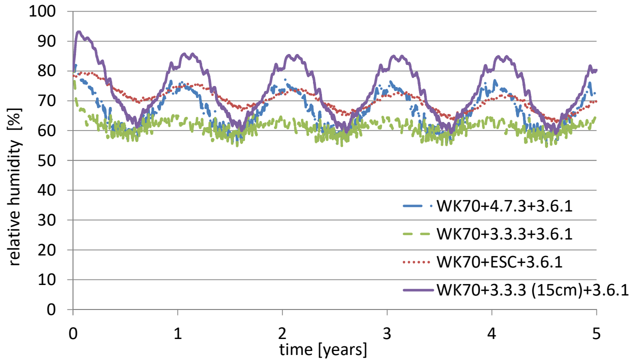

Fig. 5 Relative humidity in the cross-section at the rear side of the additional insulation (pos. P1) for different wall assemblies – one-dimensional standard cross-section

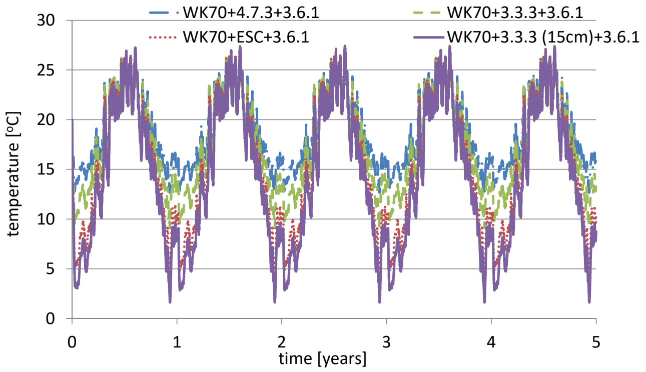

Fig. 6 Temperature in the cross-section at the rear side of the additional insulation (P1) for different wall assemblies – one-dimensional standard cross-section

The relative humidity and temperature in the cross-section between the finishing layer and the additional insulation (P2) were shown, respectively, in Figs. 7 and 8. Due to the insulation effect, range of temperature and relative humidity changes in this cross-section is much smaller than in the cross-section in the rear side of the additional insulation (pos. P1)

Once dynamic equilibrium was attained, the relative humidity was 60% and temperature 25.4 ºC in winter, while the relatively humidity was 33% and temperature 18.0 ºC in summer. As we can see, moisture conditions in this cross section, from the point of view of condensation are not critical.

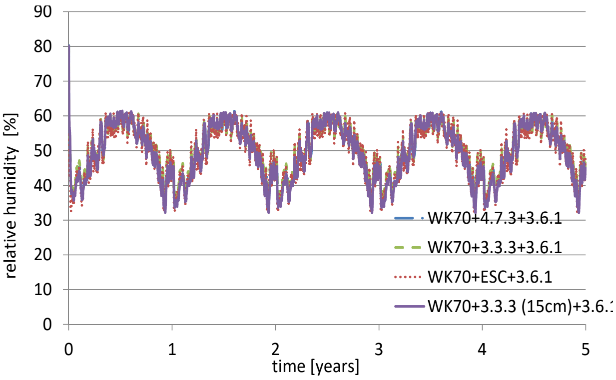

Fig. 7 Relative humidity in the cross-section between the finishing layer and additional insulation (P2) for different wall assemblies – one-dimensional standard cross-section

C. Two-Dimensional Joint of Wall and Ceiling

Fig. 9 shows the curves of relative humidity at the rear side of additional insulation (P1) for two-dimensional joint of wall and concrete ceiling (right below the ceiling), and Fig. 10 shows the curves of temperature.

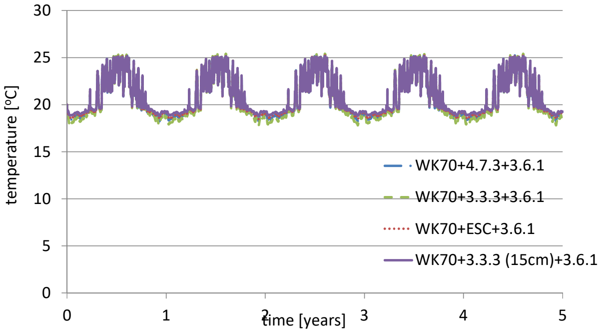

Fig. 8 Temperature in the cross-section between the finishing layer and additional insulation (P2) for different wall assemblies – one-dimensional standard cross-section

Compared the joint of wall and concrete ceiling to the standard cross section, temperature (pos. P1, Figs. 6 and 8) decrease during winter was reduced due to the thermal bridge effect. The concrete ceiling has high thermal conductivity, generating more intensive thermal flow from the interior towards the exterior. Hence, the minimal temperature behind the additional insulation in winter was higher at the joint of wall and concrete ceiling (thermal bridge) than at the standard cross section.

The temperature at the rare side of additional insulation in the same position (P1) for all investigated wall assemblies (standard cross-section) was showed in Fig. 6. Temperature at this position never falls below the freezing point, reaching minima of 1.62 ºC in winter for WK70+3.3.3(15 cm) +3.6.1, and 5.71 ºC for WK70+3.3.3+3.6.1, hence there is no frost risk here.

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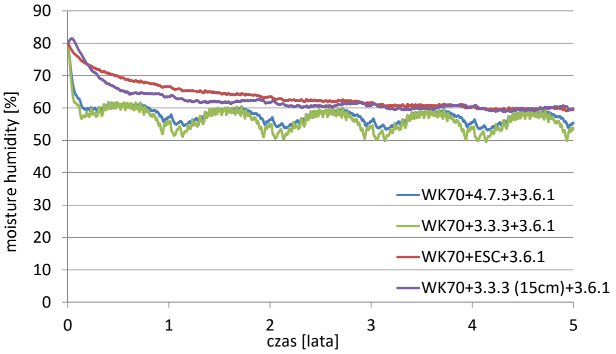

Fig. 9 Relative humidity in the cross-section at the rear side of the additional insulation (P1) for different partition solutions - joint of wall and ceiling

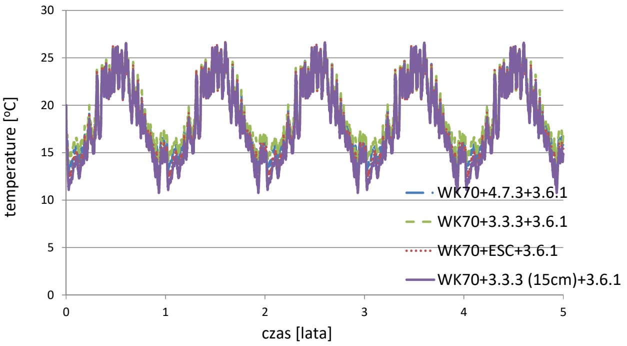

Fig. 10 Temperature in the cross-section at the rear side of the additional insulation (pos. P1) for different partition solutions - joint of wall and ceiling

On the other hand, the values of relative humidity in the same section (pos. P1) due to higher temperatures at the thermal bridge are lower than at the standard cross section (Figs. 5 and 7). For example, for WK70 + 3.3.3 (15 cm) +3.6.1, the equilibrium relative humidity at the cross section on the back wall of additional insulation was 61% at 12.42 °C and 58% at 21.84 °C during the summer.

TABLE V
MINIMUM TEMPERATURES FOR EACH SOLUTION OF WALL ASSEMBLY IN SELECTED CROSS-SECTIONS (JOINT OF WALL AND CEILING, DIRECTLY UNDER THE CEILING)

Wall assembly	T (P3) min [°C]	T (P2) min [°C]	T (P1) min [°C]	T (Se) min [°C]
WK70+3.3.3+3.6.1	16.78	15.93	13.87	-15.93
WK70+4.7.3+3.6.1	16.80	16.13	12.65	-15.93
WK70+EPS+3.6.1	16.71	16.05	11.52	-15.95
WK70+3.3.3 (15 cm)+3.6.1	16.85	16.21	10.76	-15.92

The closer the interior, the impact of the thermal bridge on the temperature inside the wall is getting smaller. Comparing the temperature in the cross-section between the finishing layer and the additional internal insulation (P2) shown in Tables IV and V, we can see that, for the joint of wall and concrete ceiling, they are on average 2.2 ^{o}C lower than at the standard cross-section. A similar situation exists on the inner surface of the wall (P3) with the direct contact with the internal air. Here, also the differences in temperature between the joint of wall and concrete ceiling and the standard cross-section are smaller and similar to the cross-section between the finishing layer and the additional internal insulation. They are on average 2.2 ^{o}C more.

IV. CONCLUSION

Based on the numerical simulations, performed with WUFI software, the hygrothermal performance of the concrete prefabricated wall typical for WK70 system, commonly used in Poland in the 70's, with additional inside insulation was evaluated. The investigations were done for various types of internal insulation, commonly used EPS and for the insulation of natural materials of vegetable origin in the form of hemp and wood fiber panels of varying thicknesses of 40, 80 and 150 mm. The tests allowed us to formulate the following conclusions regarding the analyzed solutions:

1) The thickness of applied interior insulation affects the thermal and humidity conditions in the external wall. The greater the thickness of the insulation, the lower the temperature inside the wall during winter and the greater the overall moisture content in the wall, which in turn reduces drying potential of the wall.
2) The climatic conditions in the room (temperature, humidity) significantly affect the conditions inside the wall. At the same time, the effect is dependent on the hygrothermal properties of the materials from which the wall is made.
3) The temperature decrease inside the wall caused by the use of additional internal insulation did not contribute to its freezing, the temperature never dropped below 0 °C, and the relative humidity did not exceed 85%.
4) In the moderate climate of Warsaw and with normal indoor conditions (for residential buildings) according to the PN EN-ISO 15026 standard, in none of the cases analyzed, interstitial and surface condensation was appeared.
5) External concrete layer with a thickness of 6 cm can be treated as a protection against driving rain and its deep penetration due to the influence of wind.
6) Laying additional insulation on the inside of the partition made of prefabricated concrete slab, which can be considered as a vapour barrier, should be remembered that the partition will breathe into the room. Therefore, in this type of solution, vapour impermeable finishing materials should be avoided as this may result in condensation.
7) If the assembly and climate conditions are similar to those analyzed in this study, the hygrothermal conditions inside the wall will be unproblematic.

REFERENCES

[1] A. Holm, H. M. Künze, "The impact of the indoor Climat on the hydrothermal Behaviour and the durability of External Components – Standard Boundary Conditions vs. hygrothermal Indoor Climat Simulation" *11 BMC International Conference on Durability of Building Materials and Components*, Istanbul, Turkey, 2008.

[2] A. Karagiozis, A. Desjarlais, H. M. Künzel, A. Holm. "The evolution of hygrothermal design: WUFI to WUFI-Plus" *Journal of Building*

Enclosure Design, pp. 24-29, summer 2010.

[3] E. Latif, M. A. Ciupala, S. Tucker, D. Ch. Wijeyesekera, D. J. Newport, “Hygrothermal performance of wood-hemp insulation in timber frame wall panels with and without a vapour barrier”. *Build. Environ,* vol. 92, pp. 122-134, 2015.

[4] E. Vereecken, S. Roels, “A comparison of the hygric performance of interior insulation systems: A hot box-cold box experiment”, *Energy and Build.*, vol. 80, pp. 37-44, 2014.

[5] E. Vereecken, S. Roels, “Capillary active interior insulation: do the advantages really offset potential disadvantages?” *Materials and Structures*, vol. 48, pp. 3009-3021, 2015.

[6] EN 15026:2008 - Hygrothermal Performance Of Building Components And Building Elements - Assessment of Moisture Transfer By Numerical Simulation.

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

[8] H. M. Kunzel, “Simultaneous Heat and Moisture Transport in Building Components. One and two dimensional calculation using simple parameters”, IRB Verlag, Fraunhofer-Institut für Bauphysik, 1995.

[9] H. M. Künzel, T. Schmidt, A. Holm, “Exterior surface temperature of different wall constructions comparison of numerical simulation and experiment”, *in: Proc. 11th Symposium on Building Physics*, Dresden, Germany, 2002, pp.441–449.

[10] http://www.h-house-project.eu (2.03.2017)

[11] J. Grunewald, U. Ruisinger, P. Häulp, “The Rijksmuseum Amsterdam – hygrothermal analysis and dimensioning of thermal insulation” *in Proc. 3rd International Building Physics/Science Conference*, Montreal, 2006, pp. 345-352.

[12] J. Mlakar, J. Strancar, “Temperature and humidity profiles in passive-house building blocks”, *Build. Environ*. vol. 60, pp. 185–193, 2013.

[13] J. W. Lstiburek Joseph, “Understanding vapour barriers”, *ASHRAE journal,* vol.40, pp. 46.8: 40. 2004

[14] O. Hägerstedt, J. Arfvidsson, “Comparison of field measurements and calculations ofrelative humidity and temperature in wood framed walls, in: Zmeskal O. (Ed.), *Thermophysics*, Brno University of Technology, Faculty of Chemistry, Valtice, Czech Republic, 2010, p.9.

[15] P. Häulp, K. Jurk, H. Petzold, “Inside thermal insulation for historical facades in Research in Building Physics” *in Proc. 2nd International Conference on Building Physics,* Leuven, Belgium, 2003, pp. 463-469

[16] P. Wegerer, J. N. Nackler, T. Bednar, “Measuring the Hygrothermal Performance of an Interior Insulation made of Woodfibre Boards”. *Energy Procedia*, vol. 78, pp. 1478–1483, 2015.

[17] Polish law: Dz.U. poz.926,(2013),Rozporzzenie Ministra Transportu, Budownictwa I Gospodarki Morskiej zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (in polish).

[18] S. O. Mundt-Petersen, L. E. Harderup, Validation of a 1D transient heat and moisture calculation tool under real conditions, in: R. Karney, A. Desjarlais (Eds.), *Thermal Performance of Exterior Envelopes of Whole Buildings XII*, Clearwater, Florida, USA, 2013, p.12.

[19] WTA- 6-2-01/E – Guideline: Simulation of Heat and Moisture Transfer specifies hygrothermal simulations as an alternative to the „Glaser-method.

[20] Z. Pavlík, R. Černý, “Hygrothermal performance study of an innovative interior thermal insulation system”, *Applied Thermal Engineering*, vo. 29, pp. 1941-1946, 2010.