

CASE STUDY OF APPLICATION OF CAPILLARY ACTIVE THERMAL INSULATION SYSTEMS USED AS AN INTERIOR INSULATION FOR HISTORICAL BUILDINGS

Šimon Vacek¹, Radovan Kostelník²

¹ Department of Building Construction, STU Bratislava, Faculty of Civil Engineering, Radlinského 11, 813 68 Bratislava, Slovakia, Email: simon.vacek@stuba.sk

² Department of Building Construction, STU Bratislava, Faculty of Civil Engineering, Radlinského 11, 813 68 Bratislava, Slovakia, Email: radovan.kostelnik@stuba.sk

ABSTRACT

The trend of reducing energy consumption and the impact of human activities on nature, has increased significantly in recent years. This trend is also noticeable in civil engineering industry. It has an impact not only on new, but also on restored or adapted buildings. Buildings such as monuments or historical buildings are also included in this category. It's necessary to realize that in case of these types of buildings, there are other values which are more important than technical parameters which should be considered. Mainly it is the social, artistic and craftsmanship value of these buildings. In connection with these types of buildings, the application of interior thermal insulation is usually suggested method to improve thermal parameters of walls and reduce energy consumption. Application of these systems appears to be the most appropriate way to preserve values mentioned above. Modern material research also takes place in this area and brings new developed materials such as capillary active isolation systems. Capillary active insulations solve some of the problems connected with the addition of a thermal insulation on the inner side mentioned in [14]. This paper brings hygro-thermal analysis of four types of mentioned systems applied on massive one-layer masonry made of fireclay bricks, what is most common wall type of historical buildings in Slovakia. These types are thermal insulation plaster, multi-layer system predominantly made of wood-fiber and active layer, calcium silicate system and system made of polyurethane boards with grid of holes filled with capillary active material.

Key words: capillary active insulation systems, historical buildings, interior thermal insulation

INTRODUCTION

This paper serves as base for experimental measurement. It should help to find appropriate systems to be applied in experiment and help to assess their real potential in in-situ application. Paper monitors the behavior of application of interior capillary active thermal insulation systems [1,2,3] applied on the external masonry walls shown in figures (Figures 1 and 2). The first model (OC) is original masonry wall. The second (IP) consider the application of thermal insulating plaster [4,5]. Another option is the application of calcium-silicate-based contact system (CS) [6,7]. And the last two options are applications of innovative variations of capillary active thermal insulations. One of them is multilayer board (WF) based on woodfibre which contains inserted functional layer (Pavadentro®) (EP 1900884 A1, 2008). The last of them is polyurethane based board which contains grid of drilled holes filled with capillary active material (IT)(IQtherm®) [8].

MODELS

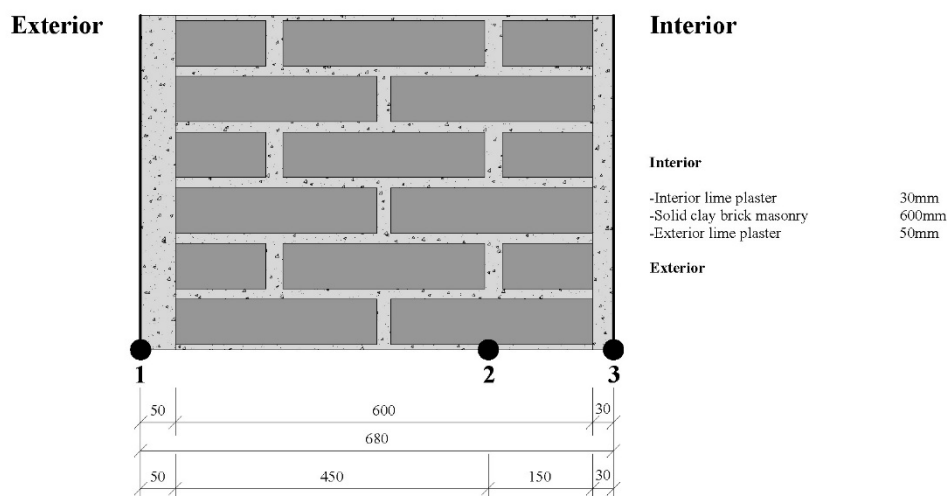


Figure 1. – Original construction and position of monitoring positions (OC)

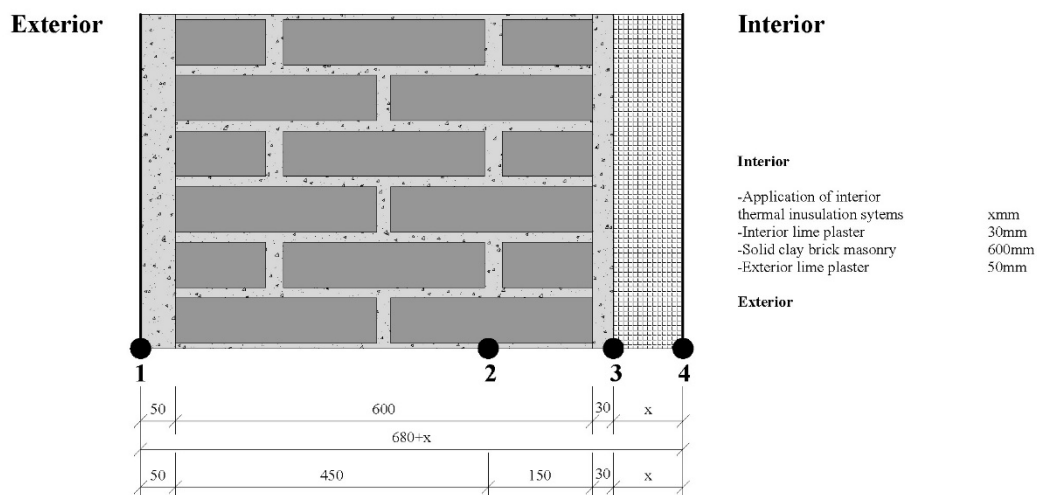


Figure 2. – Application of thermal insulation on the interior side and position of monitoring positions (IP/CS/WF//IT)

Monitoring positions monitors temperature and relative humidity (Figure 1,2). Two of them lay on surfaces of the wall fragment. Monitoring point number 2 is situated in masonry, 15 cm from the inner side of masonry to show values in position where are usually situated ends of wooden beams supporting ceiling. These elements are sensitive to higher humidity because of decay [9,10]. In case of additional insulation there is one more point situated on the surface of original wall but now is cover with new layers. Position is important for comparing with original wall.

COMPUTATION ANALYSIS

The computational model was created in the WUFI®Pro.5.3 software (Wärme- und Feuchtetransport instationär). The translation from German: „Transient heat and moisture transport “. The software was designed for one-dimensional coupled heat and moisture transport in multi-layer components. Mathematical and physical basis was put by Kunzel H.M in his dissertation "Simultaneous Heat and Moisture Transport in Building Components. One- and two-dimensional calculation using simple parameters." [11]. Mathematical

model considers thermal conductivity, enthalpy flow through moisture movement with phase change, shortwave solar radiation, night-time cooling by long-wavelength radiation. Heat transfer by convection based on airflow is neglected due to one dimensional simulation. In case of moisture transport, software calculates the water vapor diffusion and solution diffusion. Conveying water vapor by air convection is neglected. In the case of liquid moisture transport mechanisms, the capillary conductivity and surface conductivity are considered [12]. The physical base of capillary active thermal insulations and capillary transport is described in [13,14,15]

All the input data important for the calculation were used from the available software library, because of this paper is preparation for experimental measurement so there are no real input data obtain by measurement in situ and data obtainable in our nation standards such as STN 730540-3 [16] doesn't include necessary values. The climate data (reference climate year) that entered in the calculation was used from the software database too. Interior climate is defined by our national standards STN 730540-3 [16].

SIMULATION INPUT DATA

The original wall consists of single layer masonry wall made of fire clay bricks and mortar. The masonry is protected against exterior climate by lime plaster on the outside and finished with same plaster on the inside. Application of insulation is achieved by adding new layers on the inner side of the wall. The new surface finish is final coat of paint. All insulating systems except insulating plaster consist of three basic layers. These layers are adhering, insulation panel, finishing. All systems have same thickness of insulation. It is 8 cm because that is technological limit thickness of insulating plaster applied in two steps each 4 cm. All simulation material input data are shown in table below (Table 1). Material parameters that enters simulation are time dependent (dependent on water content, temperature and humidity) and values listed in table below are constant.

Table 1. – Simulation input material data

| Input material data | | | | | | | | | | |
|---------------------------------------|------------------------------------|-----------|-------------------|--------------------------------|----------------------------|-------------------------------|---|------------------------------------|-----------------------|--|
| Model type | Material | Thickness | Bulk density | Porosity | Specific heat capacity dry | Thermal conductivity dry 10°C | Water vapor diffusion resistance factor | Typical built-in moisture (RH 80%) | Free water saturation | Water absorption coefficient |
| | | m | kg/m ³ | m ³ /m ³ | J/(kg.K) | W/(m.K) | - | kg/m ³ | kg/m ³ | kg/(m ² .s ^{0.5}) |
| Original wall (OC) | Lime plaster exterior | 0,05 | 1600 | 0,3 | 850 | 0,7 | 7 | 30 | 250 | 3 |
| | Solid brick masonry | 0,6 | 1900 | 0,24 | 850 | 0,6 | 10 | 18 | 190 | 0,05 |
| | Lime plaster interior | 0,03 | 1600 | 0,3 | 850 | 0,7 | 7 | 30 | 250 | 3 |
| Insulation plaster (IP) | Original wall | | | | | | | | | |
| | Trass-lime heat insulation plaster | 0,08 | 611 | 0,76 | 802 | 0,06 | 6,9 | 63 | 412 | 0,2 |
| Calcium-silicate system (CS) | Original wall | | | | | | | | | |
| | adhesive - y tong multipor | 0,01 | 833 | 0,686 | 850 | 0,155 | 15,1 | 12,6 | 35 | 0,00309 |
| | insulation - y tong multipor | 0,08 | 115 | 0,96 | 850 | 0,04 | 4,1 | 8,1 | 197 | 0,013 |
| | finish - y tong multipor | 0,005 | 833 | 0,686 | 850 | 0,155 | 15,1 | 12,6 | 35 | 0,00309 |
| Woodfibre system (WF) | Original wall | | | | | | | | | |
| | adhesive | 0,01 | 1313 | 0,5 | 863 | 0,497 | 18,7 | 6,73 | 60,45 | 0,0052 |
| | insulation - pavadentro | 0,04 | 166 | 0,91 | 2100 | 0,043 | 10 | 27,4 | 909 | 0,12 |
| | functional - mineral layer | 0,005 | 1500 | 0,4 | 850 | 0,93 | 450 | 15,9 | 42 | 0,006 |
| | insulation - pavadentro | 0,04 | 166 | 0,91 | 2100 | 0,043 | 10 | 27,4 | 909 | 0,12 |
| | finish - lime plaster | 0,02 | 1600 | 0,3 | 850 | 0,7 | 7 | 30 | 250 | 3 |
| PUR+capillary active mat. system (IT) | Original wall | | | | | | | | | |
| | adhesive - remmers IQ fix | 0,01 | 1313 | 0,5 | 863 | 0,497 | 18,7 | 6,73 | 60,45 | 0,0052 |
| | insulation - remmers IQ therm | 0,08 | 44,5 | 0,98 | 1400 | 0,031 | 69 | 4,05 | 5,47 | 0,0027 |
| | finish - remmers IQ top | 0,005 | 465 | 0,81 | 1173 | 0,106 | 8,4 | 50,7 | 105,29 | 0,0135 |

The annual variation of the outdoor temperature and incident heat flux values is estimated by available meteorological data from software database for the city of Vienna (similar climate to Bratislava), using a one-hour time step. The set indoor thermal comfort conditions correspond to a temperature range between 20°C and 26°C (exterior temperature dependent) corresponding to EN 15026. When the internal temperature drops below 20°C, the heating elements are activated, using a temperature setpoint equal to 20°C. (without

cooling systems). Moisture loads are set to normal according to EN 15026. Internal air humidity 40-60% corresponds to standard loads for family house, offices or similar indoor spaces.

Wall is oriented to the north to avoid sun drying potential. Building is situated in wind exposure category type medium (small villages or cities situated in valleys). Façade is up to 10m high and sits below pitched roof which provide partially natural covering against rain loads what corresponds to rain exposure factor 1 and rain deposition factor 0,35 according to ASHRAE stan. 160. Initial conditions for wall elements are set to standard. All general simulation input data are shown in table below (Table 2).

Table 2. – Simulation input general data

| Simulation input data | |
|-----------------------------------|------------------------------------|
| Type | Value |
| Outdoor climate (reference year) | Vienna - Austria |
| Indoor climate | according to EN 15026 |
| avg. int. temperature | 20-26°C |
| moisture load | normal |
| avg. int. relative humidity | 40-60% |
| heat/moisture/air change source | no |
| structure | wall |
| inclination | 90° |
| orientation | North |
| rain load | according to ASHRAE stan. 160 |
| building height | <10m |
| exposure category | medium |
| rain exposure factor | 1 |
| rain deposition factor | 0,5 |
| adhering fraction of rain | 0,7 (inclination dependent - wall) |
| exterior heat resistance | wind dependent |
| short wave radiation absorptivity | 0,4 (normal bright stucco) |
| ground short wave reflectivity | 0,2 (standard value) |
| interior heat resistance | 0,125 m ² .K/W |
| initial moisture in component | 80% initial rel. humidity |
| initial temperature in component | 20°C |
| calculation period | 1.1 2019 - 1.1 2024 |
| time step | 1h |

RESULTS

The building envelope is exposed to moisture on both the external (due to climate conditions) and the internal (e.g. due to human activity) side; as a result, a dynamic moisture equilibrium is developed, which is affected by the intensity of the moisture loads, the temperature of the wall and the thermal and hygric properties of the materials. Application of thermal insulation layers in building envelopes is known to have a significant impact on the hygrothermal behavior of the wall. Thermal insulation affects the concentration and accumulation of condensed water vapor and water inside the porous wall materials and cavities either explicitly, by forming a water vapor barrier, or implicitly, by modifying the temperature profile across the wall and consequently the characteristics of water vapor mass transfer through the wall. As shown in table and charts below (Table 3, Figure 3,4), the numerical outputs confirm expected results compared to similar experimental and numerical studies [3,5,10,11,14,17].

Following part shortly summarize working principle of a capillary active interior insulation system. During the heating season, the temperature and vapor gradient induces an outward vapor transfer. If the temperature between the glue mortar and the insulation (in case of IP just plaster) is lower than the dew point, interstitial condensation may occur. Though, a capillary active material typically has pores in the range of $0.1 - 1 \mu\text{m}$ which result in a large liquid conductivity in the capillary moisture range. The capillary active insulation can absorb the liquid water and redistribute it inwards (towards the room) by a liquid flow which follows the inwards capillary pressure gradient [2]. The capillary active materials are often characterized by a thermal performance which is lower than found for the more traditional insulation materials. Moreover, the thermal conductivity of these materials can be highly moisture dependent. These facts lead to higher water content in whole fragment and layers, decrease thermal resistance of insulation and whole fragment, increase relative humidity of the interior wall surface and air.

The last important fact is that capillary-active insulation systems are very sensitive to additional modifications. It means that the most optimal solution is the complete system of the manufacturer, with no further modifications mainly in three basic layers, which are adhesive, capillary-active insulation material and plaster (in case of thermal IP just one). It is also appropriate to respect other complementary products such as, for example, interior coatings (vapor open), individual elements for electrical installations and other service installations.

Applying interior insulation can induce damage patterns to the existing wall structure. These patterns are interstitial condensation, moisture accumulation, thermal bridges, damage to wooden beam ends, frost damage, mould growth and many others. To prevent damage patterns is important to know exact behavior of wall fragment before and after application of insulation system. Most significant parameters are water content, relative humidity profiles and temperature profiles and their combination in case of frost damage and mould growth. Examples of profiles from simulation are shown in figures below (Figure 3,4) The numerical output data are listed in table below (Table 3.)

Table 3. – Numerical output data

| Model type | Material | Output data | | | | | | | | | | | |
|---------------------------------------|------------------------------------|--------------------------------------|--------------------------------------|---|---|--------------------------------------|------------------------------------|--------------------------------|--------------------------------|--|--|-----------------------------------|-----------------------------------|
| | | heat flux left side (exterior) | heat flux left side (exterior) | moisture flux left side (exterior) | moisture flux left side (exterior) | total water content sim. start | total water content sim. end | total water content min. | total water content max. | water content in layer sim. start | water content in layer sim. end | water content in layer min. | water content in layer max. |
| | | MJ/m ² | MJ/m ² | kg/m ² | kg/m ² | kg/m ² | kg/m ² | kg/m ² | kg/m ² | kg/m ³ | kg/m ³ | kg/m ³ | kg/m ³ |
| Original wall (OC) | Lime plaster exterior | 1288,87 | 1282,68 | -3,24 | -3,24 | 13,2 | 7,59 | 6,05 | 13,2 | 30 | 37,03 | 18,66 | 91,59 |
| | Solid brick masonry | | | | | | | | | 18 | 8,55 | 7,5 | 18 |
| | Lime plaster interior | | | | | | | | | 30 | 20,47 | 16,87 | 30 |
| Insulation plaster (IP) | Lime plaster exterior | 767,2 | 757,41 | -2,56 | 3,08 | 18,25 | 12,61 | 10,49 | 18,25 | 30 | 40,86 | 18,9 | 91,67 |
| | Solid brick masonry | | | | | | | | | 18 | 11,05 | 10,36 | 18 |
| | Lime plaster interior | | | | | | | | | 30 | 27,06 | 23 | 32,12 |
| | Trass-lime heat insulation plaster | | | | | | | | | 63,09 | 39,04 | 29,37 | 63,09 |
| Calcium-silicate system (CS) | Lime plaster exterior | 511,6 | 500,3 | -2,09 | 0,29 | 14,04 | 11,65 | 9,47 | 14,89 | 30 | 43,18 | 19,03 | 92,29 |
| | Solid brick masonry | | | | | | | | | 18 | 13,09 | 12,13 | 18,21 |
| | Lime plaster interior | | | | | | | | | 30 | 34,97 | 23,35 | 43,87 |
| | adhesive - ytong multipor | | | | | | | | | 12,55 | 17,47 | 3,54 | 19,83 |
| | insulation - ytong multipor | | | | | | | | | 8,1 | 5,05 | 1,93 | 8,1 |
| | finish - ytong multipor | | | | | | | | | 12,55 | 2,46 | 1,84 | 12,55 |
| Woodfibre system (WF) | Lime plaster exterior | 540,19 | 528,33 | -2,22 | 1,11 | 16,09 | 12,77 | 11,02 | 16,98 | 30 | 43,04 | 19,02 | 93,17 |
| | Solid brick masonry | | | | | | | | | 18 | 13,06 | 12,32 | 18,04 |
| | Lime plaster interior | | | | | | | | | 30 | 28,31 | 26,64 | 36,15 |
| | adhesive | | | | | | | | | 6,73 | 5,91 | 4,85 | 11,11 |
| | insulation - pavadentro | | | | | | | | | 27,4 | 18,35 | 17,63 | 27,41 |
| | functional - mineral layer | | | | | | | | | 6,73 | 3,75 | 2,46 | 6,73 |
| | insulation - pavadentro | | | | | | | | | 27,4 | 18,22 | 11,91 | 27,4 |
| | finish - lime plaster | | | | | | | | | 30 | 19,35 | 16,65 | 30 |
| PUR+capillary active mat. system (IT) | Lime plaster exterior | 428,81 | 416,32 | -1,94 | 0,48 | 14,1 | 11,67 | 10,09 | 15,51 | 30 | 44,27 | 19,06 | 91,93 |
| | Solid brick masonry | | | | | | | | | 18 | 13,54 | 12,85 | 18 |
| | Lime plaster interior | | | | | | | | | 30 | 28,57 | 27,58 | 31,48 |
| | adhesive - remmers IQ fix | | | | | | | | | 6,73 | 6,19 | 5,42 | 7,63 |
| | insulation - remmers IQ therm | | | | | | | | | 4,05 | 3,11 | 2,64 | 4,05 |
| | finish - remmers IQ top | | | | | | | | | 50,7 | 16,97 | 13,47 | 50,7 |

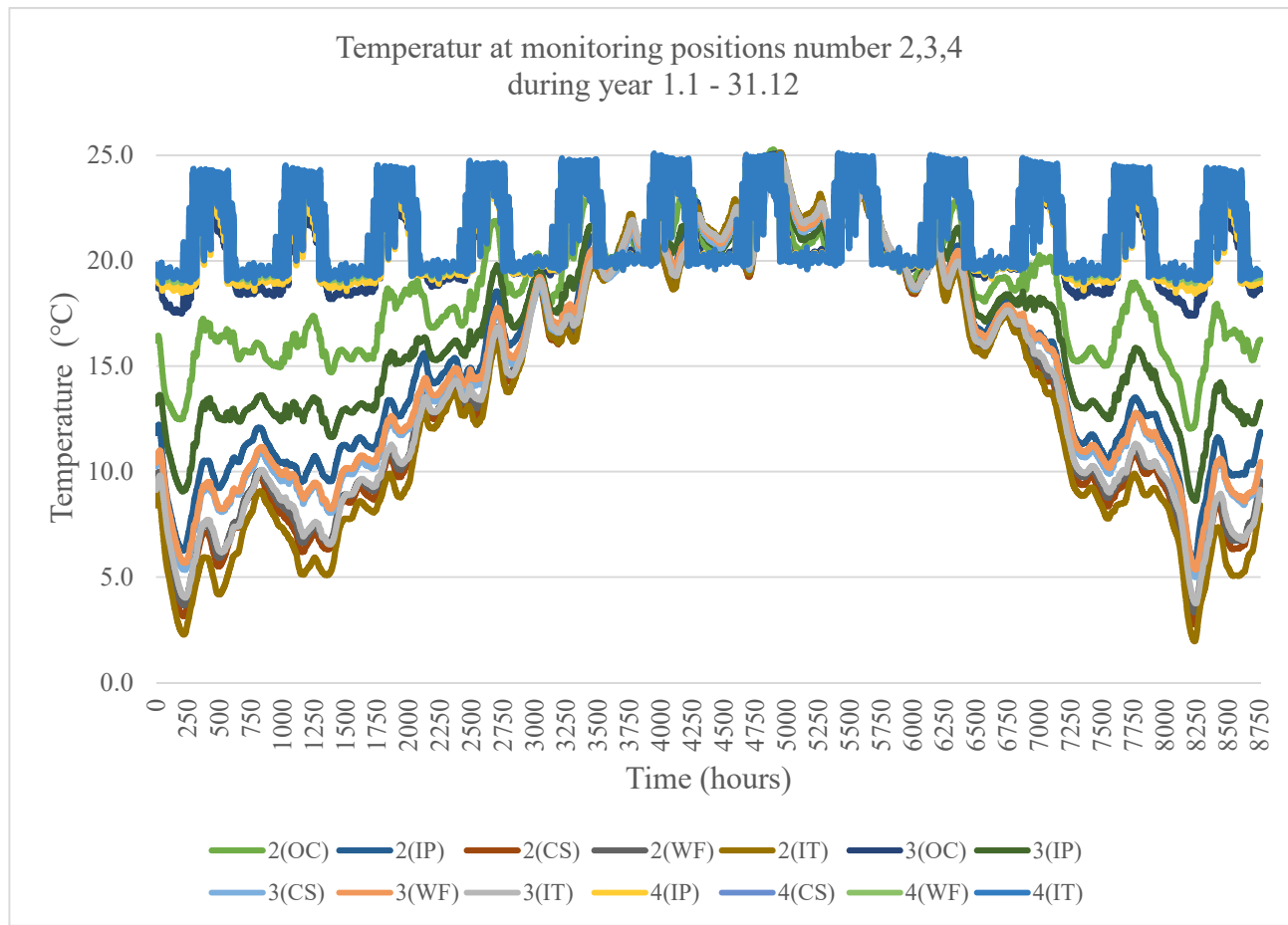


Figure 3. – Temperature at monitoring positions 2,3,4 during last year of simulation

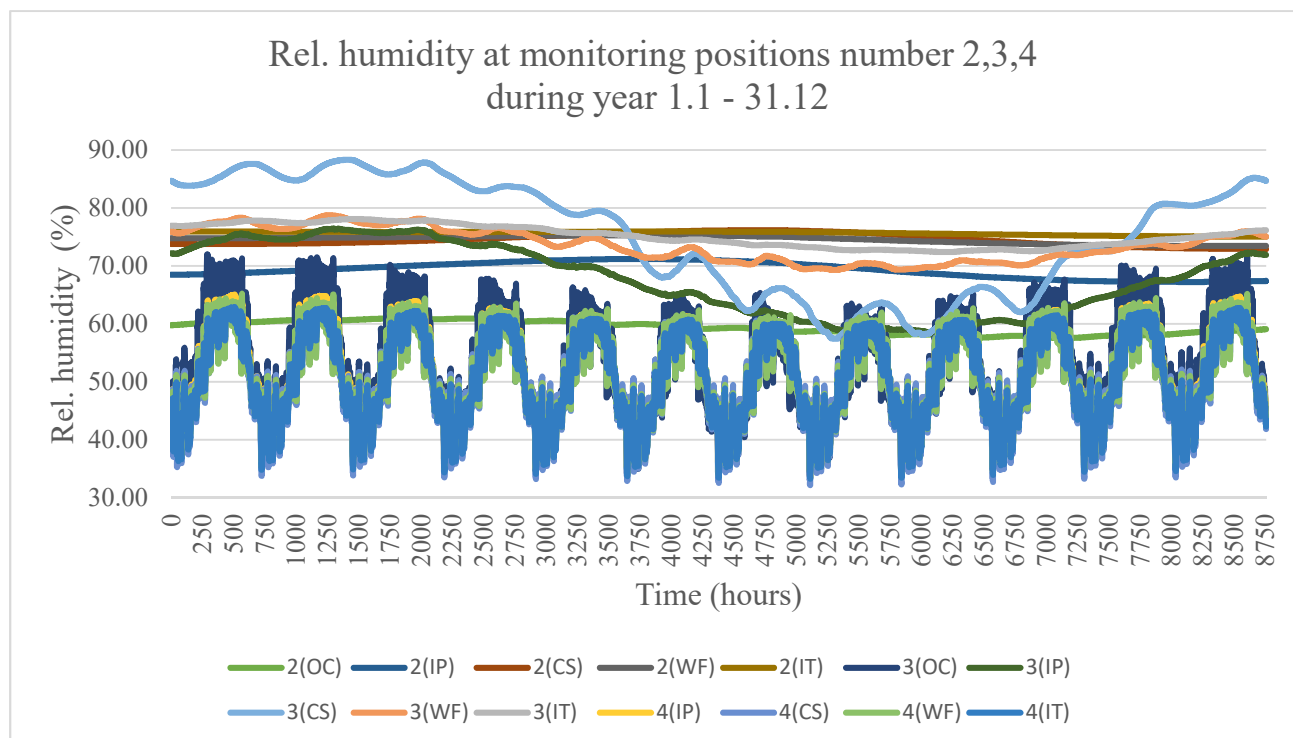


Figure 4. – Relative humidity at monitoring positions during last year of simulation

CONCLUSION

Application of interior thermal insulation systems appears to be the most appropriate and, in some cases, the only way to preserve artistic and craftsmanship values of monuments and historical buildings. The main principle of capillary-active thermal insulation working mechanism is described above. It is also important to consider that there is risk induced by addition of interior thermal insulation. Capillary active thermal insulation systems bring solutions for some of them but on the other hand bring some of their own. Table below lists main advantages and disadvantages compared to standard insulation systems (non-capillary active) (Table 4.).

All of systems works on the same physical principles. That fact leads to similar results with small differences. Optimal solution for maximal improvement of thermal resistance is IT system. This system is based on hard PUR board. PUR has the lowest thermal conductivity from tested variations and system capillary activity is based only on grid of drilled holes filled with capillary active material. On the other hand, this system shows adverse water content values and relative humidity profiles compared to other systems. In comparison to other studies IT system shows even worse values. WF system is the only one that can be considered for ecologic and its results are comparable to other systems. In case of CS systems, there is still huge amount of calcium-silicate material variations on the market. Compared to other studies [17], there are different results between calcium silicate types. Interesting in this case appears, filling of the calcium silicate board with non-capillary active high-performance thermal insulation such as PUR, PIR or vacuum insulation. The insulation plaster is the only solution for curved shapes such as walls and vaults. Insulation plaster has the highest thermal conductivity but shows the most similar relative humidity and temperature profiles with original wall. There is still a possibility to improve its properties by mixing it with better insulating material such as aerogel.

Table 4. Main advantages and disadvantages of capillary active systems

| Advantages | Disadvantages |
|---|--|
| <i>-Allows drying of wall inwards the interior</i> | <i>-Increasing of thermal conductivity coefficient due to liquid water transport</i> |
| <i>-Allows to avoid of surface condensation</i> | <i>-Increasing of relative humidity on the interior surface</i> |
| <i>-Similar moisture profiles as original wall (advantage in case of built timber beams ends)</i> | <i>-Increasing of the relative humidity of the interior air</i> |
| | <i>-Sensitive to system modifications</i> |

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REFERENCES

- [1] Häupl P, Jurk K, Petzold H. 2003. Inside thermal insulation for historical facades. Research in Building Physics. Lisse: Swets & Zeitlinger; 463-469.
- [2] Vereecken E, Roels S. 2016. Capillary active interior insulation: a discussion. Energy Efficiency and Comfort of Historic Building, Belgium, Brussel. 191-197.
- [3] Scheffler G, Grunewald J. 2003. Material development and optimization support by numerical simulation for capillary-active inside insulation material. Research in Building Physics. Lisse: A.A. Balkema Publishers: 463-469.
- [4] Barbero S et. al. 2014. Analysis on existent thermal insulating plasters toward innovative applications: Evaluation methodology for a real cost-performance. Energy and Buildings 77. ISSN 0378-7788. 40-47.
- [5] Bianco I et. al. 2015. Thermal insulating plasters as a solution for refurbishment historic building envelopes: First experimental results. Energy and Buildings 95. ISSN 0378-7788. 96-91.
- [6] Scheffler G. 2011. Hygric performance of internal insulation with light-weight autoclaved aerated concrete. Proceedings 5th International AAC Conference. Bydgoszcz, September 14-17. 323-336.
- [7] Kreft O, Straube B, Schoch T. 2011. Internal thermal insulation with light weight autoclaved aerated concrete. 5th International Autoclaved Aerated Concrete Conference. Bydgoszcz, Poland, September 14-17. 251-256.
- [8] Remmers IQ-Therm – The intelligent interior insulation – The unique capillary thermal insulation, [online],[14.7.2018].http://www.remmers.co.uk/fileadmin/user_upload/brochures/interior_insulation/796_-_iqtherm/796_GB_iQ-Therm.pdf
- [9] Stopp H, Strangfeld P, Toepel T, Anlauff E. 2010. Messergebnisse und bauphysikalische Lösungsansätze zur Problematik der Holzbalkenköpfe in Aussenwänden mit Innendämmung (English verison). Bauphysik 32(2): 61-72.
- [10] Morelli M, Svendsen S. 2013. Investigation of interior post-insulated masonry walls with wooden beam ends. Journal of Building Physics 36. ISSN 1744-2583. 265-293.
- [11] Kunzel H. M. 1995. Simultaneous Heat and Mass Transport in Building Components : dissertation thesis. Stuttgart : Fraunhofer institut für bauphysik. ISBN 3-8167-4103-7. 63 . [online], [14. 7. 2018].
https://www.ibp.fraunhofer.de/content/dam/ibp/de/documents/Publikationen/Dissertationen/hk_dissertation_etcm45-30731.pdf
- [12] WUFI@Pro.5.3 Manual, Department of Hygrothermics at the Fraunhofer IBP (2010) . [online], [8. 9. 2019]. https://wufi.de/download/WUFI_Pro_4_Manual.pdf

- [13] Binder A, Zirkelbach D, Kunzel H. 2010. Test Method to Quantify the Wicking Properties of Insulation Materials Designed to Prevent Interstitial Condensation. USA : ASHRAE. [online], [14. 7. 2018]. https://web.ornl.gov/sci/buildings/conf-archive/2010%20B11%20papers/26_Binder.pdf
- [14] Vereecken E, et. al. 2015. Interior insulation for wall retrofitting – A probabilistic analysis of energy savings and hygrothermal risks. Energy and buildings 89. ISSN 0378-7788. 231-244 .
- [15] Scheffler G, Grunewald J. 2003. Material development and optimization support by numerical simulation for capillary-active inside insulation material. Research in Building Physics. Lisse: A.A. Balkema Publishers: 463-469.
- [16] National standard, STN 730540-3 : 2012, Thermal protection of buildings. Thermal performance of buildings and components. Part 3: Properties of environmental and building products.
- [17] Koronthalyová O, Matiašovský P. 2003. *Thermal conductivity of fiber reinforced porous calcium silicate hydrate-based composites*. Journal of Thermal Envelope and Building Science 27.ISSN 1097-1963. 71-89s.