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The influence of the mass moisture content of the masonry on the choice of insulation system for historic buildings

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Abstract. When discussing the energy efficiency of historic structures, increased humidity of the perimeter wall is a crucial problem. It greatly affects the choice of insulation system, because if the drying of the structure becomes impossible, permanently increased humidity of the structure can lead to serious damage to the perimeter structure. The contribution focuses on the interior insulation design of historical structures with various types of elevated humidity with the use of dynamic simulation techniques to evaluate the appropriateness of several thermal insulation materials. The degree of drying and the thermal-humidity response of the buildings after the historic wall has been insulated from the inside will be assessed based on the findings of HAM simulations.

1 Introduction

Depending on atmospheric conditions, each solid material contains a certain amount of water. The level of wetting depends on the temperature and relative humidity of the surrounding environment, porosity and pore structure of the material. The term material moisture can be characterized as the amount of water found in the pore structure of a dry material. It is expressed by the mass or volume ratio of water to the solid part of dry matter.

The source of increased humidity can be rainwater, subsurface, surface, underground, condensed, operational, built-in and soil moisture. It is soil moisture that poses the greatest risk of increased moisture in perimeter structures in historic buildings. Those buildings were built several decades or even centuries ago, when barriers against the penetration of soil moisture into the structures were not yet available. For this reason, the statement that the perimeter structures of listed buildings show a certain level of increased humidity may be true. At the same time, legal equirements on energy efficiency also force the construction industry to take a responsible approach to the renovation of buildings and to make their energy management as efficient as possible. Thermal protection of historic buildings could save up to 40% of total energy consumption and 36% of CO_2 emissions in Europe [1]. The high architectural and cultural value of these buildings, especially their exposed facade elements, prevent the use of thermal insulation in the most effective way - from the exterior

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side. Therefore, the only solution to reduce the energy consumption of historical buildings is the use of insulating materials from the interior. This form of use of thermal insulation in combination with increased moisture in the structure can cause irreversible degradation processes due to the accumulation of moisture and cause moisture damage, frost damage, wood rot, e.g. in ceiling constructions, formation of mold and thermal bridges in the connections of the partition with the perimeter structure [2-7].

According to [8], masonry moisture can be classified as:

Table 1. Humidity classification according to STN P 73 06 10.

Humidity	**Mass moisture content M%**
Very low	< 3
Low	3.0-5.0
Increased	5.0 – 7.5
High	7.5 - 10
Very high	> 10

The paper investigates the effect of capillary active calcium silicate board and mineral wool with a vapour barrier layer on the inner surface of the structure and examines the heat-moisture response of a historical wall with levels of initial humidity according to STN P 73 06 10 - very low (3 M% - mass moisture content) and low (5 M%)

2 Methodology with input and boundary conditions

The experiment was performed by the WuFi simulation program [9], which enables the analysis of one-dimensional complex heat and water transfer in building materials under dynamic boundary conditions [10,11]. Numerical analysis took place over a period of 5 years in climate conditions of Košice according to [12].

The balance equations of heat and moisture transfer in the simulation tool are described as:

$$\frac{dw}{d\varphi}\frac{\partial\varphi}{\partial t} = \nabla.((D_\varphi\nabla\varphi + \delta_p\nabla(\varphi.p_{sat})) \quad (1)$$

$$\frac{dH}{dT}\frac{\partial T}{\partial t} = \nabla.(\lambda\nabla T) + h_v\nabla.(\delta_p\nabla(\varphi.p_{sat})) \quad (2)$$

Whereas the liquid water transport coefficient is defined as:

$$D_\varphi(w) = D_w(w).\frac{dw}{d\varphi} \quad (3)$$

Where: dH/dT (J/(m^3 K)) is the heat storage capacity of the moist building material, $dw/d\varphi$ (kg/m^3) represents the moisture storage capacity of the building material, $\partial T/\partial t$ (K/s) Is the temporal change of the temperature, $\partial\varphi/\partial t$ (1/s) is the temporal change of the relative humidity, δ (kg/(msPa)) the water vapour permeability, p_{sat} (Pa) the partial pressure of saturated watet vapour in the air, h_v (J/kg) the latent heat of evaporation of water, λ (W/(mK) the thermal conductivity, T (°C) is the thermodynamic temperature, φ (–) the relative humidity, D_φ (kgm/s) liquid transport coefficient of the building material, D_w (m^2/s) liquid diffusivity [9-11].

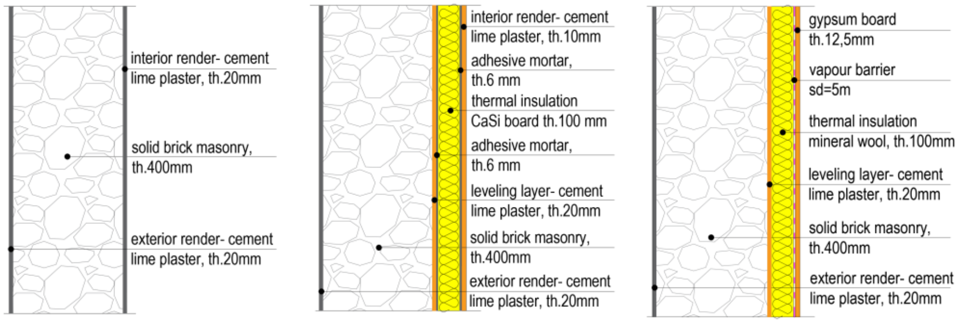

Fig. 1. Assessed compositions of solid brick masonry with internal insulations.

The initial condition in the 1st calculation scenario was considered 3 M% mass moisture content of the perimeter brick wall and in the 2nd calculation scenario 5 M% mass moisture content. Figure 1 shows the composition of evaluated structures - uninsulated brick wall, brick wall insulated with capillary active calcium silicate board and wall insulated with mineral wool in combination with vapor barrier layer with diffusion equivalent air layer thickness sd=5m.

3 Results

As part of the results, the course of mass moisture content of nodal points in the structure was analysed over a period of 10 years. These points were chosen on the basis of the most risky parts, namely on the surface of the masonry (or under the thermal insulation), in the 100 mm depth of the masonry from the interior and in the middle of the masonry.

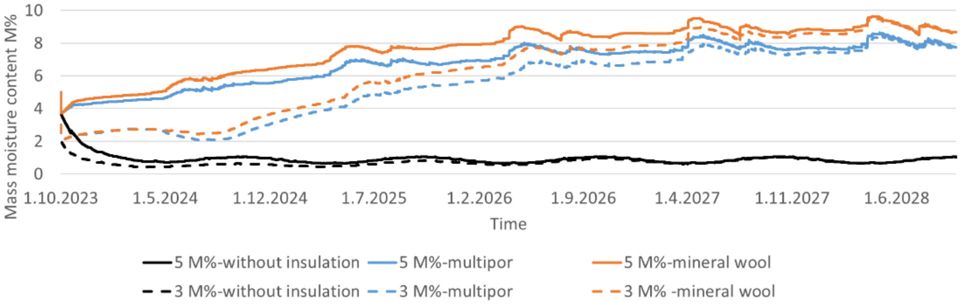

Fig. 2. Course of mass moisture on the surface of masonry at initial moisture of 3 M% and 5 M%.

Figure 2 shows the course of the mass moisture of the masonry under the layer of thermal insulation or plastering in the case of an existing composition. In the case of an uninsulated wall, a drying trend can be seen from an initial mass humidity of 3 M%, or 5 M% to approximately 1 M% after the first year. In the following period, it is possible to observe cyclically recurring wetting in the autumn period and drying in the spring months. Mass humidity reaches its maximum value in the month of October and minimum in April. After a five-year monitoring period, the waveforms merge and show identical mass moisture. After using the calcium silicate board, the mass moisture shows an increasing trend during the simulated period. In the summer months, slight drying can be observed, but it is negligible compared to the rising trend. After 4 years, the mass moisture stabilizes and the value oscillates between 7 and 8% mass moisture. After the application of mineral wool in combination with a vapor barrier layer with an equivalent diffusion thickness of sd=5m, the drying of the structure towards the inside is limited and a steeper trend of wetting of the structure is evident. After 2.5 years of the simulated period, in the case of mineral wool with an initial moisture content of 3 M%, the mass moisture will exceed the value of a calcium-silicate board with an initial moisture content of 5 M%. It is clear from this that the structure, which includes a calcium-silicate board, shows a more favourable course of mass moisture.

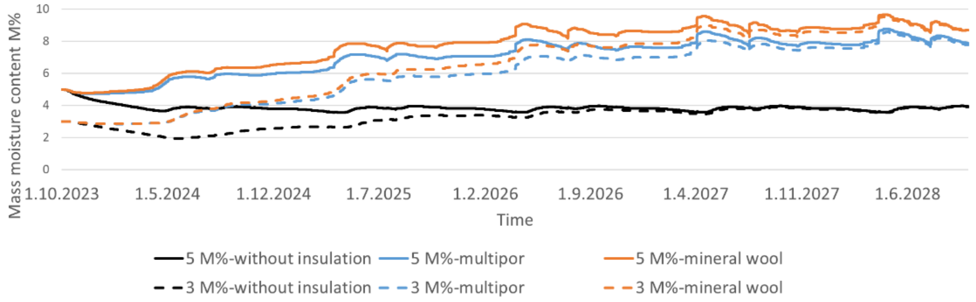

Fig. 3. Course of mass humidity at a depth of 100 mm from the interior at initial humidity of 3 M% and 5 M%.

Figure 3 shows the curves of mass moisture at a depth of 100 mm in the structure. The development of mass moisture is similar to that on the surface of masonry. The mass humidity of the wall at this depth is influenced not only by the parameters of the internal environment, but also by the conditions of the external environment. This tendency is demonstrated by the case of an uninsulated wall, where the average mass humidity is approximately three times higher than on the surface of the masonry. At this depth, the internal warm air has less influence on the mass humidity level and is more dependent on the external air parameters. The development of mass moisture when using thermal insulation is similar to that on the surface of masonry. Calcium-silicate board even in the case of an initial moisture content of 5% after a period of 5 years shows a lower final moisture content than mineral wool with an initial moisture content of 3%.

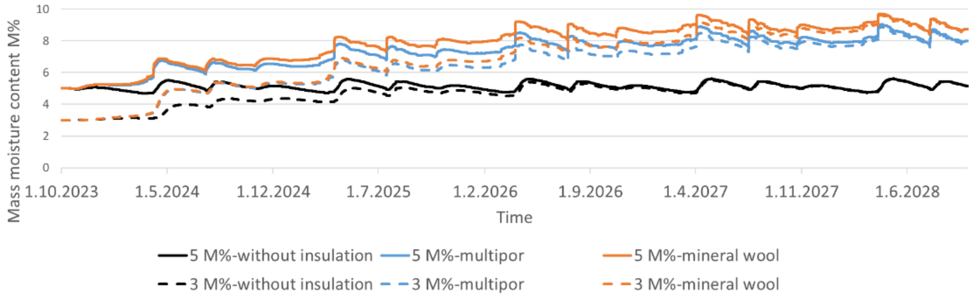

Fig. 4. Course of mass moisture in the middle of the masonry at initial moisture of 3 M% and 5 M%.

Figure 4 shows the curves in the middle of a 400 mm thick wall. In this part of the masonry, the parameters of the internal environment influence the course of mass moisture to a negligible extent. The development of mass humidity depends on the external parameters of the environment - on the amount and intensity of precipitation and solar radiation. The mass humidity for a period of 5 years with an uninsulated wall is around 5 M%, which represents, according to [8], the upper limit of a low level of humidity. In the case of calcium-silicate board, this value is at the level of 8 M% and in the case of mineral wool 9 M%. According to [8], these values are already at a high level.

Conclusion

From the results, it can be concluded that thermal insulation boards with open porosity (capillary activity) are a safer solution for reducing their energy consumption than vapor-tight insulation systems for the perimeter walls of listed buildings, where any level of moisture content is assumed. These boards with their pore structure are able to receive water and gradually release it towards the interior, thus preventing excessive accumulation of water. In the case of a vapor-tight insulation system of mineral wool, drying towards the interior is limited and a larger amount of water in the constructions is evident. The vapor barrier layer should have a sufficiently high diffusion resistance to prevent internal condensation during the heating season. At the same time, during the cooling season (in the summer months) it must have a sufficiently low diffusion resistance factor to prevent summer condensation. It is possible to state that calcium silicate board in terms of water accumulation has a more favourable effect than mineral wool even with a higher initial mass humidity. However, it should be noted that any intervention supporting the increase of the thermal insulation capacity of the structure automatically disrupts its thermal and moisture behaviour. It is necessary to find a compromise between the degree of insulation and the accumulation of water in the structure in order to eliminate the risks of any malfunctions as much as possible. At the same time, if the wall is too wet, it is necessary to use an effective drying method before insulating it.

The overall thermal-moisture behaviour of insulation systems on the internal surface is closely related to the parameters of the internal environment (temperature and relative humidity), therefore, in the next phase of research in this issue, the most favourable conditions of the internal environment will be quantified and defined to maximize the potential of insulation systems for the purposes of internal insulation.

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