Hygric Performance of a Sandstone Wall Retrofitted with Interior Thermal Insulation

J. Maděra, M. Jerman, and R. Černý

Abstract **—**Temperature, relative humidity and overhygroscopic moisture fields in a sandstone wall provided with interior thermal insulation were calculated in order to assess the hygric performance of the retrofitted wall. Computational simulations showed that during the time period of 10 years which was subject of investigation no overhygroscopic moisture appeared in the analyzed building envelope so that it performed in a satisfactory way from the hygric point of view.

Keywords**—**Sandstone wall, interior thermal insulation, moisture, computational modeling.

I. Introduction

APPLICATION of interior thermal insulation systems in buildings is not a natural solution but sometimes no other option is available. A typical example is a historical building where the facade has to be kept in its original appearance. Common exterior insulation systems then cannot be used.

In constructing interior thermal insulation systems, many designers place water vapor barrier just under the internal plaster, directly on the surface of insulation layer so that both insulation layer and load bearing structure are protected against water vapour penetration. However, this is a solution, which can perform well on theoretical level only. In the practice, it is very difficult to avoid mechanical damage of water vapor barrier placed in such an inappropriate way. A sole nail or hook driven into the wall for instance if hanging up a painting can damage the proper function of the barrier. In addition, even in the case that the barrier would perform without mechanical damage, the absence of water vapor removal from interior through the envelope in winter period when air ventilation in the interior is usually limited, can lead to undesirable increase of relative humidity in the interior and to worsening of internal microclimate.

The mechanical damage of water vapor barrier can be avoided by placing the barrier between thermal insulation and load bearing structure.

J. Maděra is with the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, 166 29 Prague, Czech Republic (phone: +420-2-2435-5435; fax: +420-2-2435-4446; e-mail: madera@fsv.cvut.cz).

M. Jerman is with the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, 166 29 Prague, Czech Republic (phone: +420-2-2435-5436; fax: +420-2-2435-4446; e-mail: milos.jerman@fsv.cvut.cz).

R. Černý is with the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, 166 29 Prague, Czech Republic (phone: +420-2-2435-5044; fax: +420-2-2435-4446; e-mail: cernyr@fsv.cvut.cz).

However, the amount of water condensed in the insulation layer would be in certain time periods of year relatively high. One of the possibilities is to use thermal insulation material which cannot be damaged by long-term water exposure. Nevertheless, the presence of water will always have negative effect on thermal insulation properties. In the climatic conditions of North and Middle Europe the danger of liquid water generation is concentrated to winter months mostly. Therefore, the worsening of thermal insulation function would occur just in the winter period of year when it is absolutely undesirable.

An alternative to application of traditional water vapor barriers is using water vapor retarder instead which permits a part of water vapor to diffuse further to load bearing structure [1, 2]. In such case, even if the retarder is placed between thermal insulation layer and load bearing structure, the amount of condensed water in thermal insulation layer is lower. The structure is then not damaged because it is exposed to such water vapor flux only which can be transported through it without condensation.

The requirements to thermal insulation layer in the above arrangement are high. It should have low thermal conductivity in dry state. The thermal conductivity even should not increase too much if moderate presence of liquid water appears. In addition, the material should have high capability of liquid water transport. It is supposed to redistribute the condensed water backward to the indoor room as fast as possible in order to maintain sufficiently low moisture content, thus good thermal insulation properties of the insulation layer. Hydrophilic mineral wool materials meet well these requirements to thermal and hygric properties [3]. Therefore, they were chosen as thermal insulation materials for the interior insulation system analyzed in this paper.

II. Materials and Building Envelope

In the computational analysis in this paper, we have tested the hygric performance of a sandstone wall with the thickness of 500 mm provided with the interior thermal insulation system consisting of internal plaster, insulation material and water vapor retarder (Fig. 1). On the interior side, there was lime-metakaolin plaster with a thickness of 10 mm. As the thermal insulation material, two hydrophilic mineral wool insulation boards with different densities were used, namely MW-soft and MW-hard. The thickness of mineral wool was 100 mm. As water vapor retarder a lime-cement based binder 10 mm thick was applied. No air gap between the water vapor retarder and the load-bearing structure was assumed. On the external side there was the same plaster as inside, with the thickness of 20 mm. The basic parameters of materials of the described building envelope [3-5] are shown in Table I, where ρ is bulk density (kg/m^3), ψ porosity (-), c specific heat capacity (J/kgK), μ water vapor diffusion resistance factor (-), w_{hyg} hygroscopic moisture content by volume (m^3/m^3), λ_{dry} thermal conductivity (W/mK), κ_{app} – apparent moisture diffusivity (m^2/s).

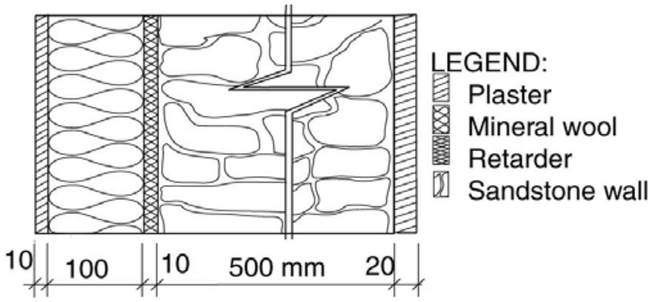

Fig. 1 Composition of building envelope used to computational simulations

TABLE I
BASIC MATERIAL PROPERTIES OF MATERIALS OF BUILDING ENVELOPES

Material	ρ (kg/m^3)	ψ (-)	w_{hyg} (m^3/m^3)	κ_{app} (m^2/s)
Plaster	1490	0.42	0.095	8.0e-9
Water vapor retarder	1493	0.41	0.01	7.29e-6
MW –soft	71	0.97	0.00005	8.40e-6
MW - hard	170	0.93	0.0021	4.07e-5
Sandstone	1890	0.32	0.009	2.5e-6

Material	μ (-)	λ_{dry} (W/mK)	c (J/kgK)
Plaster	18	0.87	1004
Water vapor retarder	6.4	0.60	1000
MW –soft	4.3	0.043	810
MW - hard	7.1	0.047	801
Sandstone	7.5	0.48	550

The main aim of the computational simulations performed was to analyze the hygrothermal performance of the designed insulation system with different mineral wool based materials.

For the computational analysis of the studied problem, the computer code HEMOT [6] was used. The numerical simulation tool HEMOT has been developed at the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague in order to support coupled heat and water transport in porous building materials. It allows simulation of transport phenomena in constructive building details for 1D and 2D problems, whereas the basic variables characterizing the hygrothermal state of building constructions (temperature, moisture content, relative humidity) can be obtained as functions of space and time. The mathematical formulation of coupled heat and moisture transport equations is done according to Künzel [7] and the code works on the basis of finite element method.

The proper initial and boundary conditions of the model are a crucial factor affecting the reliability of the calculations. Therefore, the calculations should be done for exactly the same situation as in the practical reconstruction on building site. First, the boundary conditions for the external side should be as accurate as possible. This can be achieved by using the meteorological data for the locality as close as possible to the real object. From the point of view of long term reliability, the application of so called "reference year" data should be preferred. Second, the initial conditions should be realistic. To this point, the calculations should be done first for the construction without the interior insulation system in order to find the long-term conditions in the wall before the reconstruction.

In this paper, the 1st of July was chosen as the starting point for the calculations. The systems with interior thermal insulation were exposed from inside to constant conditions (temperature equal to 21 °C and relative humidity equal to 55 or 70 %) and from outside to climatic conditions corresponding to the reference year for Prague (Fig. 2). The comparison of calculated data for two subsequent years in a longer time period was chosen as the main evaluation factor.

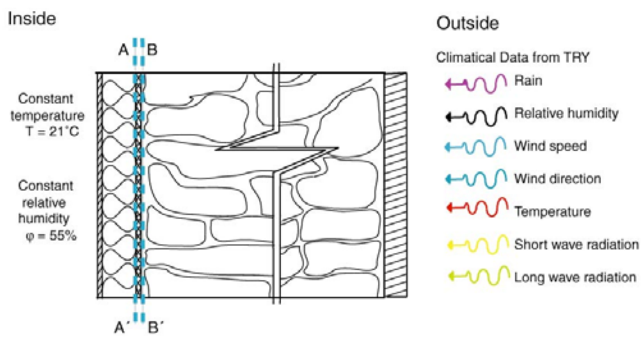

Fig. 2 Boundary conditions for the studied envelopes

III. COMPUTATIONAL RESULTS AND DISCUSSION

The long-term performance of the system should be characterized not only by calculated temperature and relative humidity. Also overhygroscopic moisture fields have to be determined, which decide about the real hygrothermal performance of the system. The critical places, where long-term water accumulation can appear, should be detected. We have chosen two critical profiles in the evaluation of the hygrothermal performance of the envelope, A-A´, B-B´, where the profile A-A´ was between water vapor retarder and insulation material, profile B-B´ was between load-bearing structure and water vapor retarder. In these profiles we calculated the dependence of the relative humidity, moisture content and temperature on time. The results are organized according to the particular alternatives.

A. Mineral wool MW-hard

Fig. 3 shows the relative humidity fields in the system. In Figs. 4-5 we present the calculation of relative humidity as function of time in profiles A-A´ and B-B´. The maximum value of relative humidity in the internal insulation system was equal to 69 %, so it was far from condensation limit. Fig. 6 shows the moisture content fields in the system. In Figs. 7-8 we present the calculation of moisture content as function of time in profiles A-A´ and B-B´. Clearly, no overhygroscopic moisture appeared. Fig. 9 shows the temperature fields in the system.

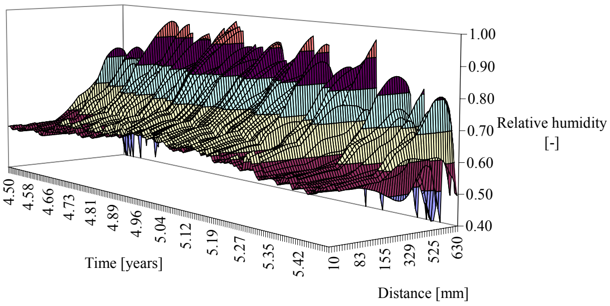

Fig. 3 Relative humidity in the sandstone wall, MW-hard

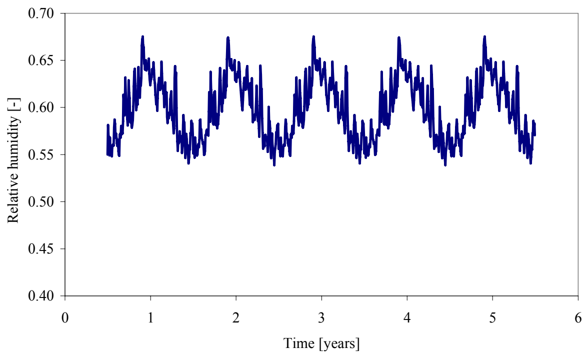

Fig. 4 Relative humidity in the A-A´ profile, sandstone wall, MW-hard

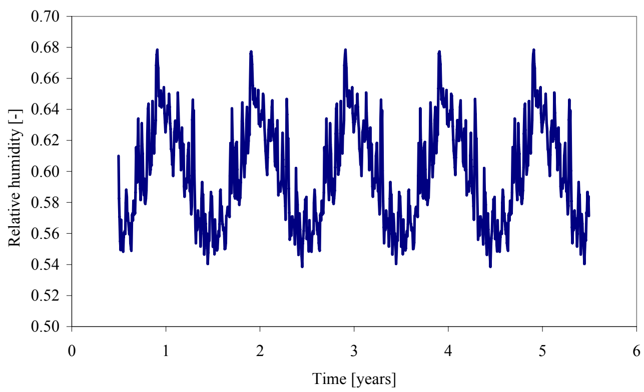

Fig. 5 Relative humidity in the B-B´ profile, sandstone wall, MW-hard

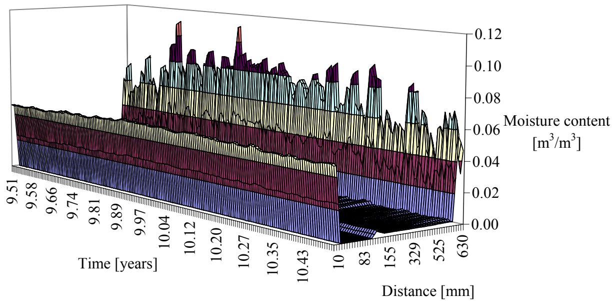

Fig. 6 Moisture content in sandstone wall, MW-hard

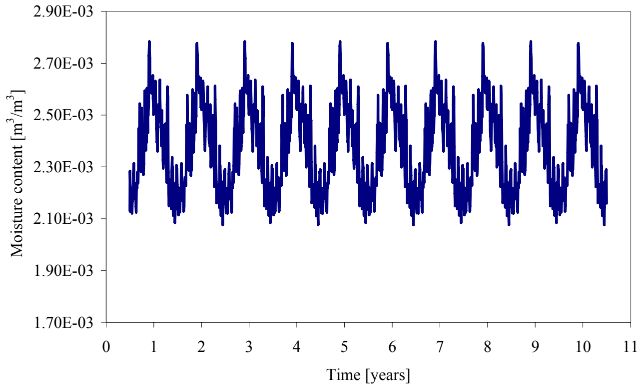

Fig. 7 Moisture content in the A-A´ profile, sandstone wall, MW-hard

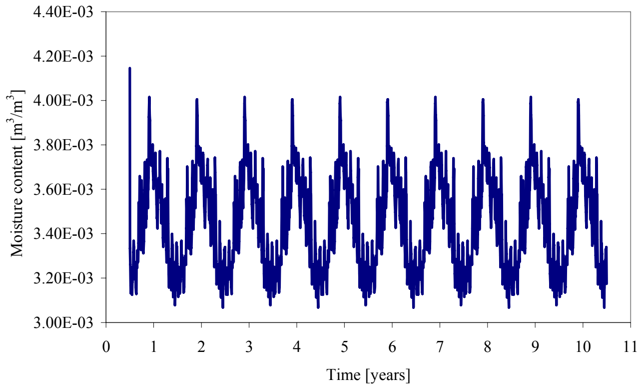

Fig. 8 Moisture content in the B-B´ profile, sandstone wall, MW-hard

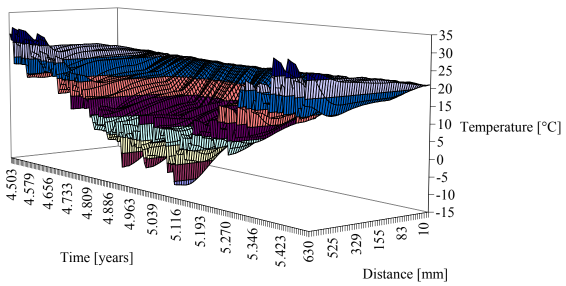

Fig. 9 Temperature in the sandstone wall, MW-hard

B. Mineral wool MW-soft

For the mineral wool MW-soft no overhygroscopic moisture appeared similarly as for the mineral wool MW-hard. The relative humidity and moisture content fields as function of time in the whole system and in profiles A-A´ and B-B´ are presented in Figs. 10 – 15. The maximum value of relative humidity in the internal insulation system was equal to 82 %, so similarly as with the calculations for MW-hard it was far from condensation limit. The temperature fields were not presented in this particular case because the results were very similar to those in Fig. 9.

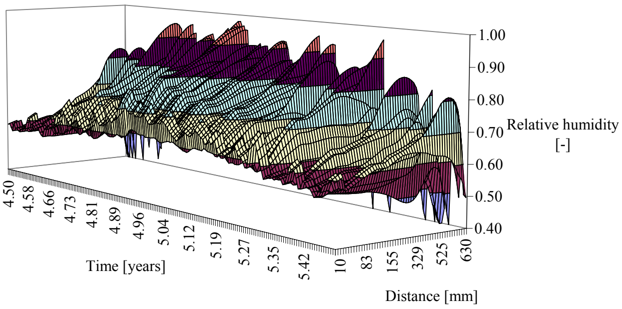

Fig. 10 Relative humidity in the sandstone wall, MW-soft

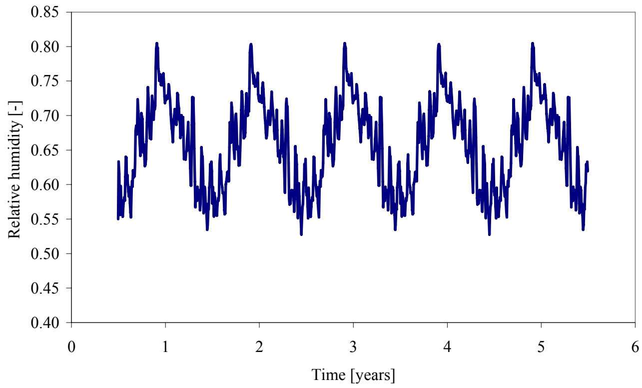

Fig. 11 Relative humidity in the A-A´ profile, sandstone wall, MW-soft

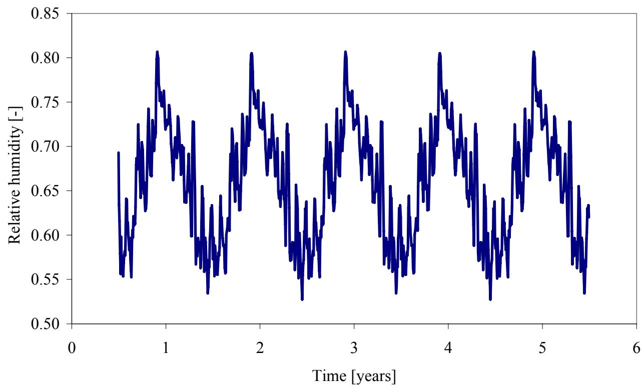

Fig. 12 Relative humidity in the B-B´ profile, sandstone wall, MW-soft

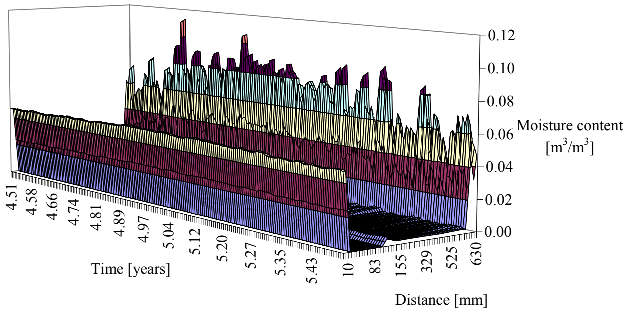

Fig. 13 Moisture content in sandstone wall, MW-soft

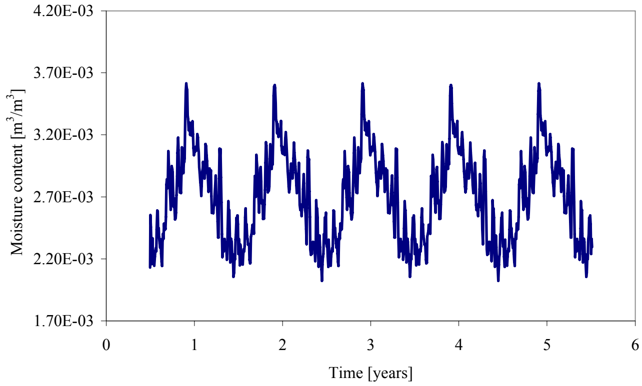

Fig. 14 Moisture content in the A-A´ profile, sandstone wall, MW-soft

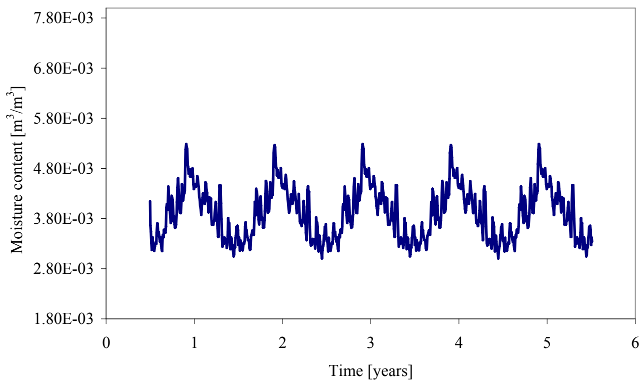

Fig. 15 Moisture content in the B-B´ profile, sandstone wall, MW-soft

IV. Conclusion

The computational results obtained in this paper showed that in the studied interior thermal insulation system the mineral wool MW-hard with higher density exhibited better hygrothermal performance than MW-soft with lower density because the maximum values of relative humidity were lower in the critical profiles of the envelope. Nevertheless, building envelopes with both mineral wool types performed well as no overhygroscopic moisture appeared in the time period of at least 10 years.

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