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COMPUTATIONAL SIMULATION OF HYGROTHERMAL PERFORMANCE OF PLASTERS WITH ENHANCED MOISTURE ACCUMULATION CAPABILITY

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Series of computational simulations are performed within this paper in order to investigate the hygrothermal response of several plasters with enhanced accumulation properties. The newly developed plasters are modified from the reference sample by adding various amounts of super absorbent polymers. Then, the basic physical, thermal and hygric properties are determined in the laboratory conditions and subsequently used as an input parameter in the computational simulations. The simulation output showed that even a thin layer of exterior and interior plaster may significantly affect the hygrothermal performance of the entire building envelope due to increased moisture and thermal buffering of the surface layers. Differences in relative humidity distribution across the studied construction were generally up to 10 % between individual plasters, differences of temperature distribution were mostly negligible, except for the cases when sudden changes of surface temperature were observed. Then, the thermal buffering was evident and the differences of temperature in surface layers were up to 4 °C among studied plasters.

Keywords: Hygrothermal analysis, Advanced plasters, Buffering effect.

1 INTRODUCTION

Moisture level significantly affects the durability of constructions, their thermal performance, and quality of indoor air (Abdul Hamid and Wallentén 2017, Sehizadeh and Ge 2016, Maljaee *et al.* 2016, Lohonayi and Korany 2013). As the building envelopes are subjected to the effect of changing weather conditions from the exterior and numerous sources of water vapor from the interior, the proper design may significantly increase the performance of the construction. Nowadays, there exist many ways of how to control the moisture loads both in the constructions and in the interior of the buildings. As far as material selection is concerned, applying advanced types of renders for both exterior and interior surface of the building envelope might be a prospective solution regarding the building envelope performance. Addition of vermiculite, perlite or super absorbent polymers (SAP) to the mixture increases the absorption capacity of those mortars (Gonzáles *et al.* 2001, Yang *et al.* 2011, Hasegawa *et al.* 2009), which can significantly help to control moisture levels in both construction and interior space.

However, a proper understanding of the behavior of moisture that is retained in the pore space of the building materials is essential for the prediction of hygric or hygrothermal performance. As a result of adding agents to increase moisture accumulation capacity, the moisture buffering of the plasters will be affected, which can imply also changes to thermal buffer properties of the material. Since the plasters on the exterior side are exposed to low temperatures during the year, also phase changes of retained liquid moisture may be observed, which will further affect the hygrothermal performance of whole construction. For that reason, the assessment the effect of applying new types of renders should be done using computational simulation with an advanced computational model that will include the water/ice phase change feature.

In the proposed paper, the newly developed plasters with enhanced moisture accumulation capability are analyzed by the computational simulation. First, the necessary material parameters are determined in the series of laboratory experiments. Those parameters are then used as input data in the computational model. The objective of the computational simulation is to study complex behavior building envelope provided by advanced plasters. Based on the simulation results, recommendations for further application of the interior plasters are given.

2 STUDIED MATERIALS

The investigation of hygrothermal performance was done on the brick wall provided with three types of modified plasters on both exterior and interior surfaces. The scheme of the studied envelope is shown in Figure 1.

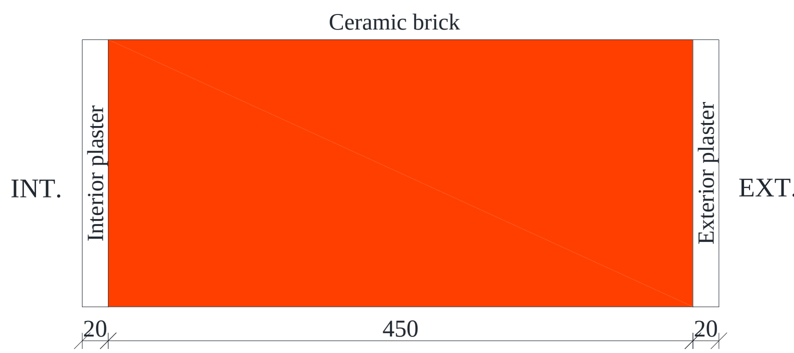

Figure 1. Scheme of the studied building envelope.

The ceramic brick was marked as CB, and the plasters were marked as P-ref, P-2%, and P-3%. The P-ref refers to a reference plaster Knauf MV1 core plaster, while P-2% and P-3% refer to the modified reference plaster by adding 2 wt% or 3 wt% of SAP (Favor PAC 300 by Evonik Ltd.), respectively. The basic physical, thermal and hygric properties are summarized in Table 1, where the following symbols are used: ρ_v is the bulk density, ρ_{mat} is the matrix density, ψ is the total open porosity, λ is the thermal conductivity, c is the specific heat capacity, μ is the water vapor diffusion resistance factor, κ_{app} is the apparent moisture diffusivity, and w/c is the water-cement ratio.

The sorption and desorption isotherms of studied plasters, which are crucial parameters for description of water vapor transport and accumulation capabilities are shown in Figure 2. All the material parameters were obtained in the laboratories of the Department of Materials Engineering and Chemistry, FCE CTU Prague within the frame of this project. The material parameters of ceramic brick were measured in the same laboratories, but the data was adopted from Čáchová *et al.* (2014).

Table 1. Basic material parameters of studied materials.

Parameter/Material	**CB**	**P-ref**	**P-2%**	**P-3%**
ρ_v (kg·m^{-3})	1389	1593	1225	1203
ρ_{mat} (kg·m^{-3})	2581	2548	2574	2563
ψ (-)	0.279	0.375	0.524	0.531
λ (W·m^{-1}·K^{-1})	0.59	0.53	0.38	0.36
c (J·kg^{-1}·K^{-1})	825	920	1087	1099
μ (-)	22.1	16.8	9.8	7.3
κ_{app} (m^2·s^{-1})	$2.15\cdot10^{-9}$	$9.93\cdot10^{-8}$	$6.80\cdot10^{-7}$	$1.02\cdot10^{-6}$

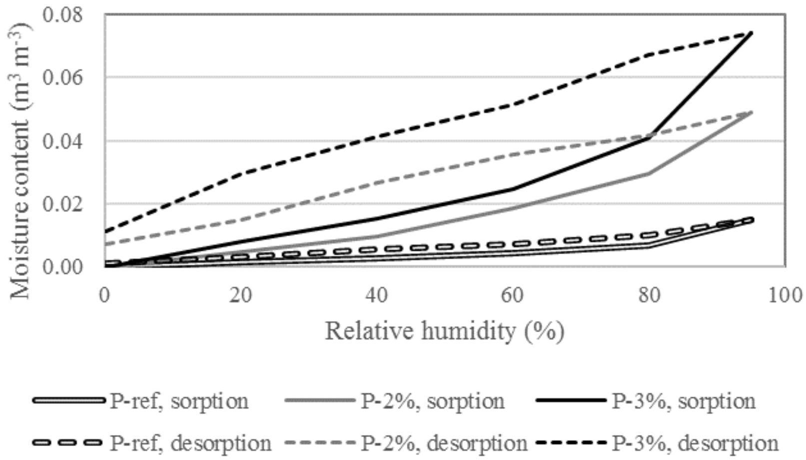

Figure 2. Sorption and desorption isotherms of studied plasters.

3 COMPUTATIONAL MODEL

The simulations were performed under time-dependent boundary conditions using the finite element method. Computer simulations of the hygrothermal performance of studied building envelope were conducted for the time period of three years using the HEMOT simulation tool, which is a pre-processing tool for the general finite element package SIFEL (Kruis *et al.* 2010). In the simulations, a slightly modified version of Künzel's (Künzel 1995) mathematical model of coupled heat and moisture transport was used, which is based on a calculation of temperature and partial pressure of water vapor along the studied domain. The input parameters for the model are bulk density, matrix density, open porosity, thermal conductivity, specific heat capacity, water vapor diffusion resistance factor, sorption isotherm, moisture diffusivity, and water retention function. The input parameters are shown in Table 1. The model includes the feature for a description of water/ice phase change using the effective specific heat capacity c_{eff} defined as in Eq. (1);

$$c_{eff} = \begin{cases} c_s & (T \le T_1) \\ \left[1-\cos\left(\frac{2\pi(T-T_1)}{T_2-T_1}\right)\right]^n \left(\frac{c_{eff,\max}-c_s}{2^n}\right)+c_s & \left(T_1 < T \le \frac{T_1+T_2}{2}\right) \\ \left[1-\cos\left(\frac{2\pi(T_2-T)}{T_2-T_1}\right)\right]^n \left(\frac{c_{eff,\max}-c_l}{2^n}\right)+c_l & \left(\frac{T_1+T_2}{2} < T < T_2\right) \\ c_l & (T \ge T_2) \end{cases}, \quad (1)$$

where T (K) is the temperature, T_1 and T_2 (K) are limiting values of the temperature range defining the phase change, c_{eff} (J·kg^{-1}·K^{-1}) is the effective specific heat capacity, c_s and c_l (J·kg^{-1}·K^{-1}) are the specific heat capacity of the material in frozen and unfrozen state, respectively, $c_{eff,\ max}$ (J·kg^{-1}·K^{-1}) is the maximum effective specific heat capacity calculated from the heat released/consumed during the phase change. More details on the c_{eff} model and calculation procedure are given by Kočí *et al.* (2018).

Boundary conditions for the interior were kept constant at 21 °C and 55 % of relative humidity during the simulation. The exterior conditions were represented by hourly weather data from the Test Reference Year for the location of Šerák, the Czech Republic that can induce very severe conditions to the constructions.

4 RESULTS AND DISCUSSION

As the objective of the paper was to predict the hygrothermal behavior of the construction, selected outputs are provided in the following figures. Figure 3 shows the distribution of relative humidity in the studied element for the winter period (February 1), while Figure 4 shows the same variable for the summer period (July 1). The presented results clearly show that even a thin layer of exterior and interior plaster may significantly affect the moisture distribution in the entire building envelope.

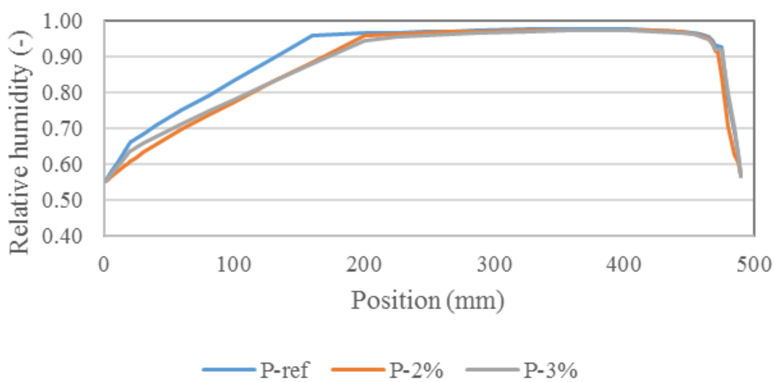

Figure 3. Relative humidity distribution in the studied element on February 1.

Differences of relative humidity in the brick masonry in studied envelopes are generally up to 10 % in the summer period and up to 6 % in the winter period. In extreme cases, the observed differences were more than 20 %. The better performance was observed for plaster P-3%, however, the differences compared to P-2% were practically negligible. Since adding SAP to the plaster decreases the strength of the material, it would be more practical to use P-2% than P-3% in the practice. However, it would be worth of investigation how P-1% would respond when analyzed using the same scenario, i.e. same building envelope loaded with same boundary condition.

As the moisture buffering feature may be in relation to the thermal buffer effect, also the temperature distribution in the studied envelope was investigated. The highest differences were observed on exterior plaster surface and adjacent layers in case of rapid temperature changes of the weather, especially in the winter period. Those changes are mostly induced by solar radiation, which may heat up the surface by several degrees in a short period. In such case, the thermal buffer effect due to the presence of the absorbent was most evident. Example of such sudden heat-up on April 10 is shown in Figure 5. The temperature differences are apparent only in the layers closed to the surface, in the remaining part of the construction differences are almost negligible. However, for the most time of the year, the temperature differences between individual studied envelopes are very low, generally not more than 0.1 °C.

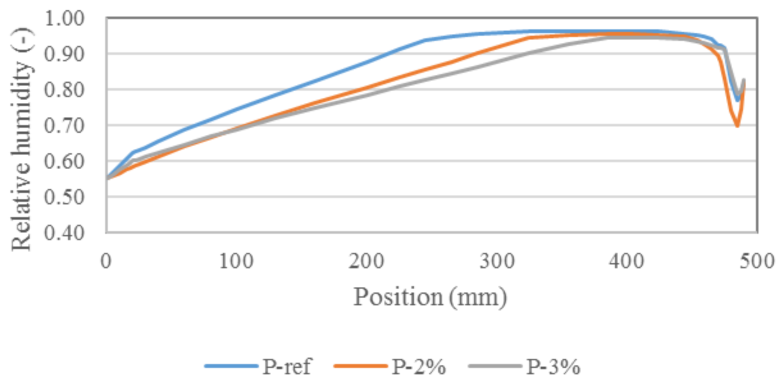

Figure 4. Relative humidity distribution in the studied element on July 1.

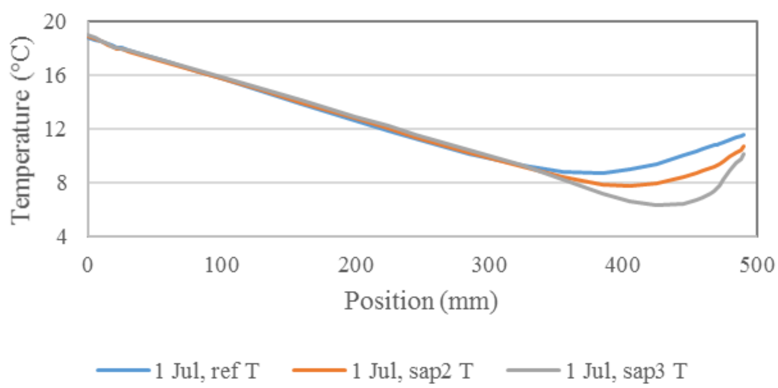

Figure 5. Temperature distribution in the studied element on April 10.

5 CONCLUSIONS

Three different plasters with enhanced moisture accumulation properties were studied in this paper. The plasters were modified by adding super absorbent polymer and their basic physical, hygric and thermal properties were measured. Then the hygrothermal performance was analyzed using computational modeling and several conclusions were drawn:

- Exterior plaster with enhanced accumulation properties may significantly affect the overall hygric performance of the construction,
- Differences in relative humidity distribution were generally up to 10 %, in extreme cases more than 20 %,
- Differences of temperature distribution were mostly negligible, except the cases when sudden changes of surface temperature were observed. Then, the thermal buffering was evident and the differences of temperature in surface layers were up to 4 °C,
- Another mixture with 1-2 wt% of super absorbent polymer should be investigated as well to find a compromise between material's strength and its hygrothermal properties.

Acknowledgments

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