HEAT AND MOISTURE TRANSPORT IN A CAST GYPSUM WALL WITH EXTERIOR THERMAL INSULATION

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Abstract

Heat and moisture transport in cast gypsum wall consisting of flue gas desulphurization (FGD) gypsum blocks and exterior thermal insulation is modeled using the computer code TRANSMAT 4.2 developed at the Department of Structural Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague. Several modifications of FGD gypsum and several different thermal insulation boards are considered. Temperature and relative humidity fields are calculated for the time period of five years.

Key words: computational simulation, FGD gypsum, thermal insulation

1 Introduction

Flue gas desulphurization (FGD) gypsum can be potentially used as a material for load bearing structures. Modifications of this material can enhance its original properties and increase its service life. In this paper, a computational assessment of hygrothermal performance of a building envelope based on several modifications of FGD gypsum is done. The thermal insulation function of the wall is achieved by exterior thermal insulation boards on the mineral wool, polystyrene and calcium silicate basis.

2 Materials and building envelopes

In the computer simulations of temperature and relative humidity fields we have solved three variants of FGD gypsum wall, based on the raw material and on two types of hydrophobized gypsum. Thermal insulation was considered in three variants as well. Insulation I was hydrophilic mineral wool material with low value of hygroscopic moisture content, namely DU soft, developed by ROCKWOOL, Insulation II hydrophobic material with higher value of water vapor resistance factor on polystyrene basis and Insulation III was calcium silicate based material SILCAL 250, developed by Calsitherm, GmbH, Germany, a capillary active material with higher value of hygroscopic moisture content. On the external side of the wall, there was lime-cement plaster. Fig. 1 shows the composition of the building envelope used to calculations.

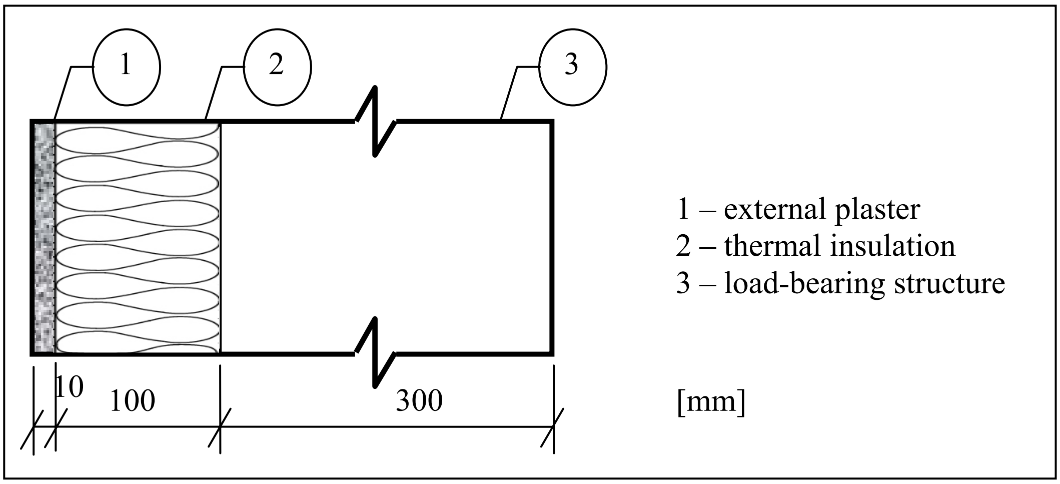

Fig 1 Composition of building envelope used to computer simulation

The basic FGD gypsum material (we will denote it S0 in what follows) was β-form of calcined gypsum with purity higher than 98 % of FGD gypsum, produced at the electric power station Počerady, CZ. The water/gypsum ratio was 0.627. After classification according to the Czech standard ČSN 72 2301, this material was categorized as G-13 B III [1]. The first modification of FGD gypsum (S3) contained the admixture IMESTA IBS 47 produced by Imesta Inc., Dubá u České Lípy, CZ. The other (S4) contained the admixture ZONYL 9027 produced by Du Pont, USA. The water/gypsum ratio was the same as for S0. The composition of gypsum materials is shown in Table 1.

Table 1 Composition of gypsum materials

Material	Water/gypsum ratio	Admixture	Concentration
S0	0.627	none	none
S3	0.627	IMESTA IBS 47	0.5 % by mass
S4	0.627	ZONYL 9027	5.0 % solution

Table 2 Basic materials properties of gypsum

	ρ [kg/m^3]	c [J/kgK]	κ [m^2/s]	μ [-]	θ_{sat} [m^3/m^3]	θ_{hyg} [m^3/m^3]	λ [W/mK]
S0	1019	840	2.63e-7	5.4	0.6	0.23	0.47
S3	942	840	1.47e-7	5.4	0.61	0.181	0.41
S4	941	840	7.32e-9	5.4	0.62	0.166	0.38

The basic thermal and hygric properties of non-modified and modified gypsum materials were measured in our laboratory [2] and are given in Table 2. Here, ρ is the density, c the specific heat capacity, κ the moisture diffusivity, μ the water vapor diffusion resistance factor defined as a ratio between the water vapor permeability in the air and in the studied porous material, θ_{sat} the saturated moisture content, θ_{hyg} the hygroscopic moisture content, and λ the thermal conductivity. The properties of thermal insulations and lime-cement plaster were partially obtained from the material database of TU Dresden and partially measured in our laboratory. The material properties of insulation boards are given in Table 3.

Table 3 Material parameters of insulation materials

	ρ [kg/m^3]	c [J/kgK]	κ [m^2/s]	μ [-]	θ_{sat} [m^3/m^3]	θ_{hyg} [m^3/m^3]	λ_{dry} [W/mK]	λ_{hyg} [W/mK]	λ_{sat} [W/mK]
I	96	840	$1 \cdot 10^{-8} \cdot e^{0.0478 \cdot \theta}$	2.2	0.95	0.01	0.039	0.047	1.13
II	30	1300	$2 \cdot 10^{-11} \cdot e^{0.0475 \cdot \theta}$	50	0.95	0.011	0.04	0.1	0.56
III	235	1000	$2 \cdot 10^{-8} \cdot e^{0.0521 \cdot \theta}$	2.1	0.88	0.21	0.07	0.084	0.38

3 Computational model

For the calculations we employed the computer simulation tool TRANSMAT 4.2 [3] which was developed at the Department of Structural Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague. The construction of the code is based on the application of the general finite element computer simulation tool SIFEL (SImple Finite ELements) developed at the same Department. The moisture (1) and heat (2) balance equations were formulated in the simplified form suggested by Künzel [4]:

$$\frac{d\rho_v}{d\varphi}\frac{\partial\varphi}{\partial t} = div\left[D_\varphi grad\varphi + \delta_p grad(\varphi p_s)\right] , \tag{1}$$

$$\frac{dH}{dT}\frac{\partial T}{\partial t} = div\left(\lambda gradT\right) + L_v div\left[\delta_p grad(\varphi p_s)\right] \tag{2}$$

where ρ_v is partial moisture density, φ the relative humidity, δ_p the water vapor permeability, p_s the partial pressure of saturated water vapor in the air, H the enthalpy density, L_v the latent heat of evaporation of water, λ the thermal conductivity and T is the temperature. The liquid water transport coefficient is defined as (3)

$$D_\varphi = \kappa \frac{d\rho_v}{d\varphi} , \tag{3}$$

The boundary conditions of the model were chosen in such a way that the analyzed building envelopes were exposed from inside to constant conditions (temperature equal to 21°C and relative humidity equal to 55 %) and from outside to the climatic conditions corresponding to the reference year for Prague. The 1st of July was chosen as the starting point in the calculations.

We have chosen two critical profiles for the evaluation of the hygrothermal performance of the envelope, A-A´ and B-B´. The profile A-A´ was between the insulation board and the gypsum structure (the distance of 110 mm from the exterior), the profile B-B′ was the cross section of the wall from the exterior to the interior. In these profiles we have assessed the hygrothermal performance based on the calculated dependence of relative humidity and temperature on time.

The scheme of typical envelope employed in computer simulations including the boundary conditions and the critical profiles is shown in Fig. 2.

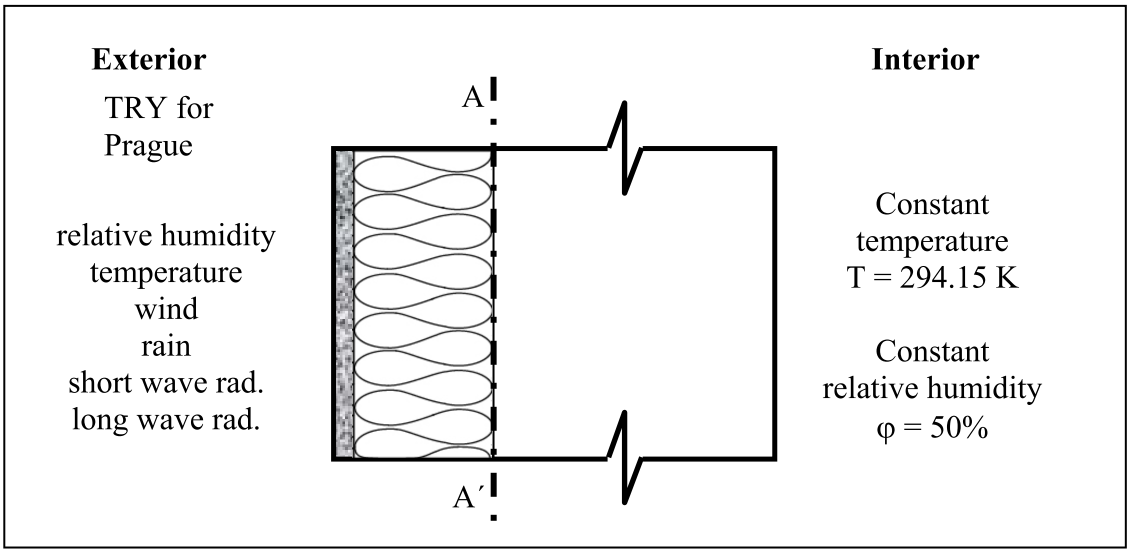

Fig 2 Scheme of typical envelope

4 Computational results

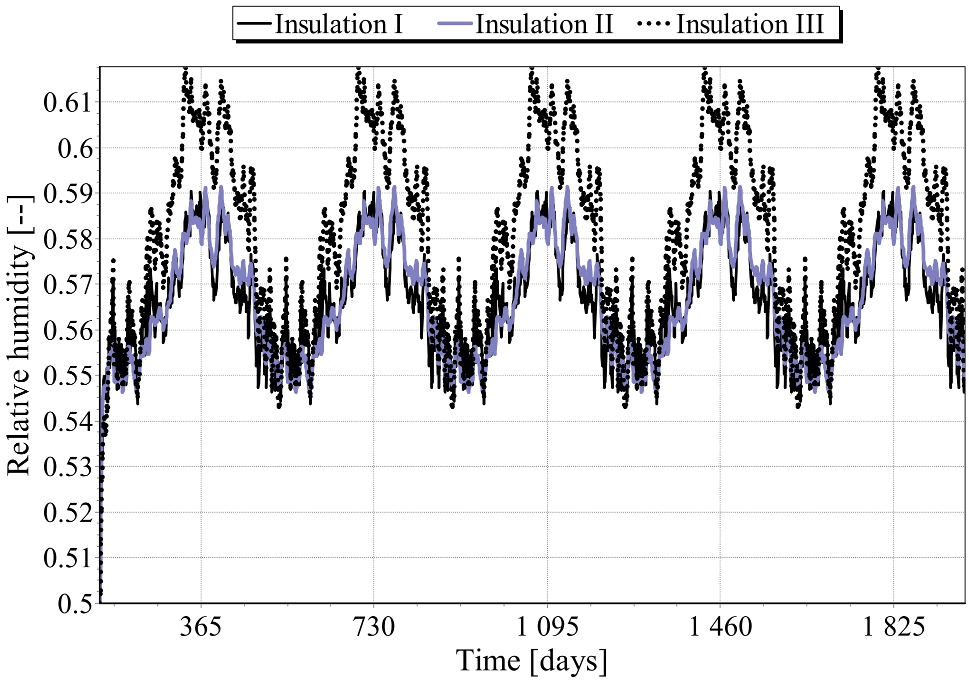

Fig 3 Relative humidity, non-modified (S0) gypsum wall, profile A-A′

Figs. 3, 4, 5 show the dependences of relative humidity on time in profile A-A′ of the walls based on the three gypsum modifications S0, S3 and S4 with different thermal insulation boards. The results are clearly very similar, so that the effect of gypsum hydrofobization is very small. The biggest amplitude of the yearly oscillations of relative humidity is achieved with Insulation III for all variants of the gypsum wall.

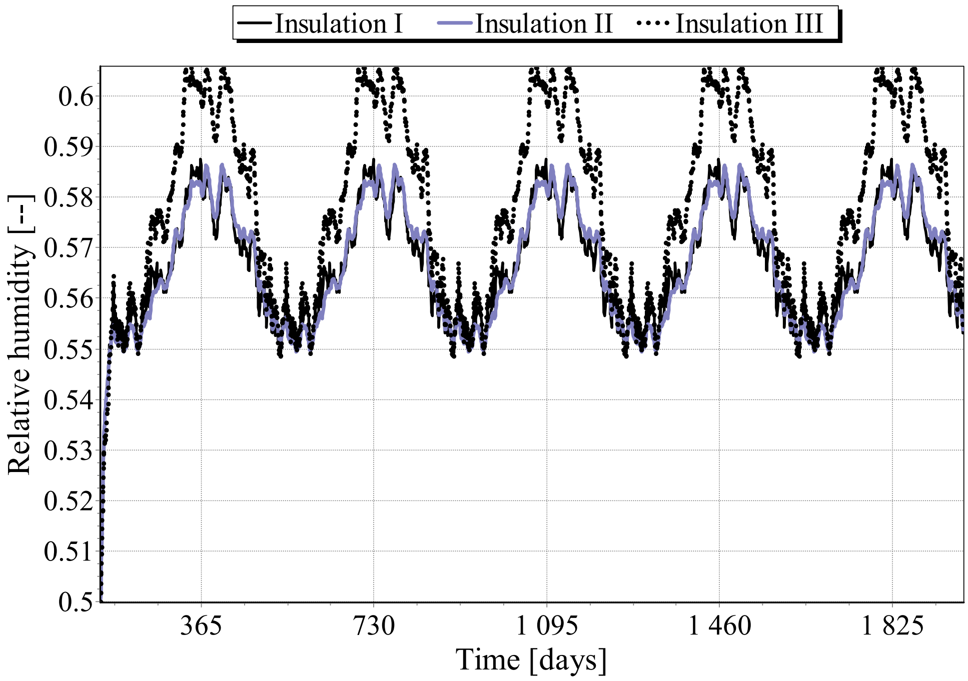

Fig. 4 Relative humidity, modified (S3) gypsum wall, profile A-A′

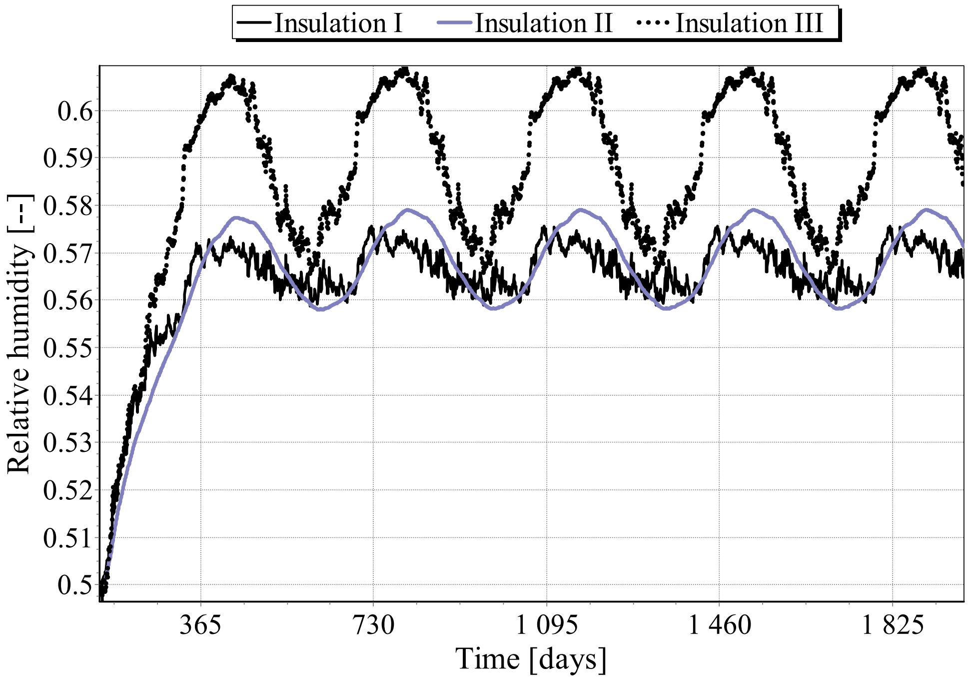

Fig. 5 Relative humidity, modified (S4) gypsum wall, profile A-A′

Fig 6 shows a comparison of the dependences of relative humidity on time in profile A-A´ for the three studied types of load bearing structures with insulation II. The results for the non-modified (S0) and modified (S3) gypsum wall are almost coinciding and the differences between S0 and S3 on one side and S4 on the other are very low, typically about 1% relative humidity.

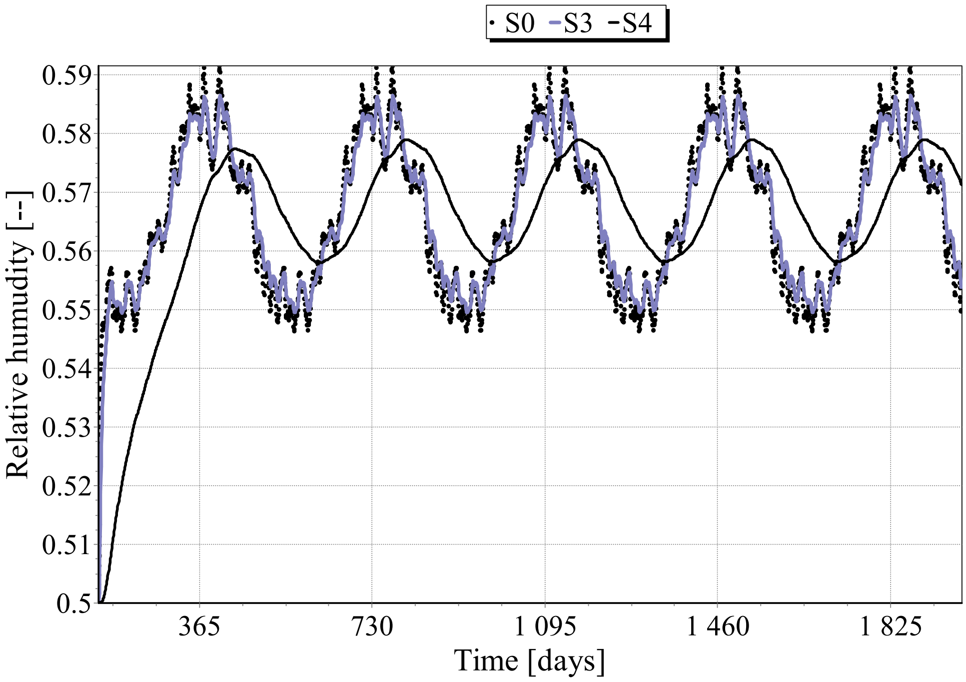

Fig. 6 Relative humidity, non modified (S0), modified (S3) and modified (S4) gypsum wall, Insulation II, profile A-A´

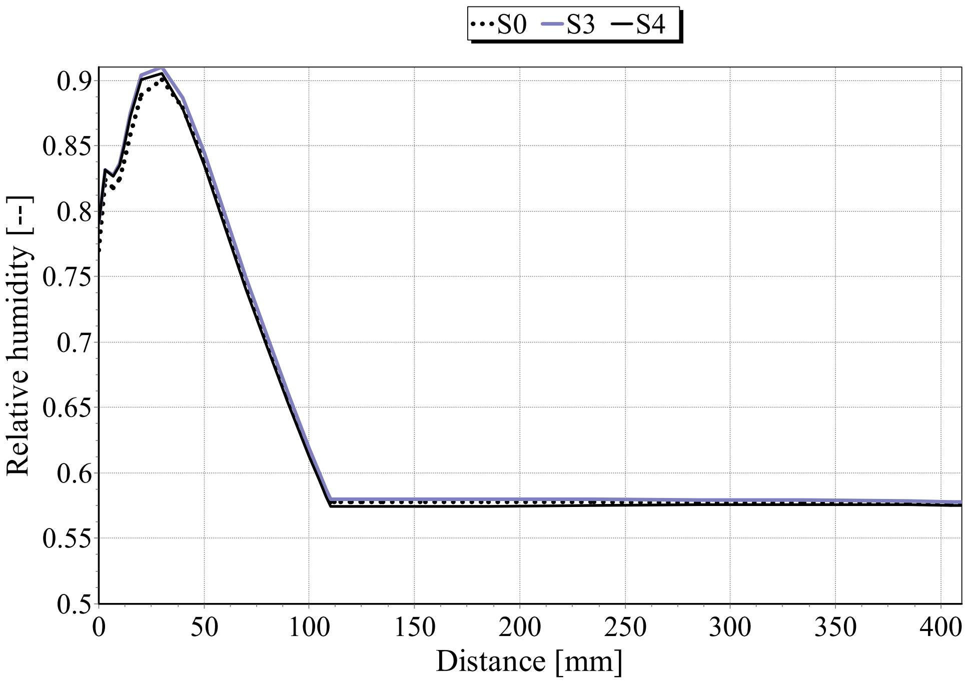

Fig. 7 Relative humidity, non modified (S0), modified (S3) and modified (S4) gypsum wall, Insulation II, profile B-B´, January 15

Fig. 7 shows an example of the relative humidity profile in the wall based on the non-modified (S0), modified (S3) and modified (S4) gypsum with the most common among the thermal insulation boards, Insulation II, for January 15 which can be considered as characteristic for the winter period. Apparently, there is a condensation region in the part of the insulation board which is due to the low moisture diffusivity and high water vapor diffusion resistance factor of the insulation material together with its low hygroscopicity. However, the data analysis shows that the condensate remains in the wall for only about 10-20 days per year. In addition, the overall thermal insulation function of the Insulation II layer is not affected in a significant way as it is demonstrated in Fig.8 showing that the temperature profile is almost linear in the part corresponding to the thermal insulation board. Therefore, Insulation II can be considered as suitable for practical application.

In all gypsum walls with Insulations I and III which were hydrophilic and capillary active, respectively, there appeared no condensation during the whole time period of five years. The reason is clearly the fact that they were able to redistribute the condensed water in a very short time period.

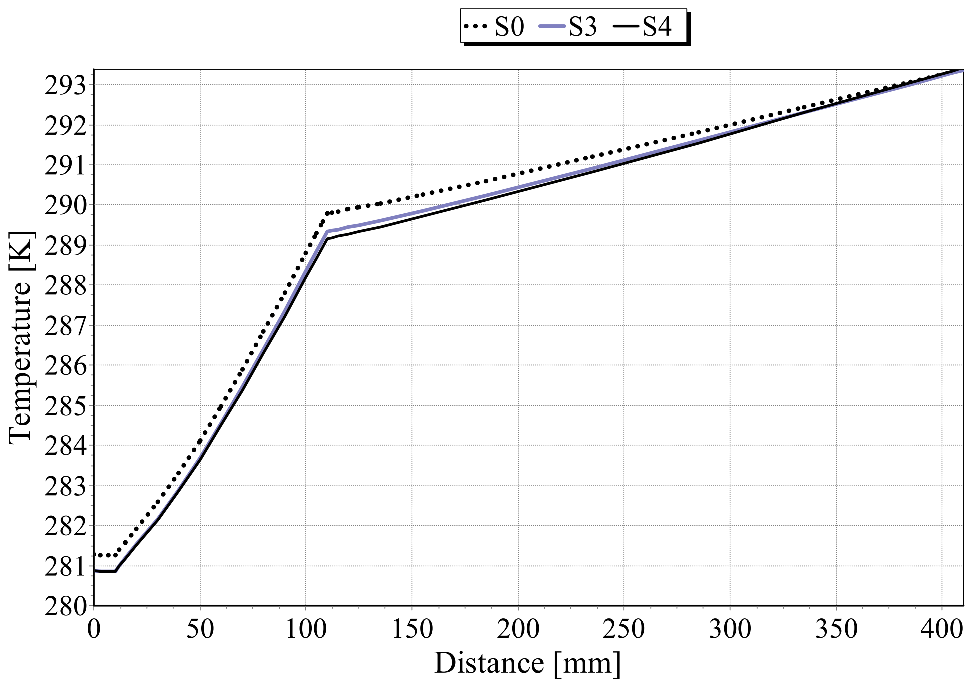

Fig. 8 Temperature, non modified (S0), modified (S3) and modified (S4) gypsum wall, Insulation II, profile B-B´, January 15

5 Conclusions

The computational analysis in this paper revealed that the use of hydrophobization admixtures in a cast-gypsum element of a building envelope did not lead to any improvement of hygrothermal behavior of the envelope provided by an exterior thermal insulation. Therefore, the application of a gypsum element without any hydrophobization seems to be a more favorable solution.

Among the thermal insulation materials, hydrophilic and capillary active thermal insulation boards, denoted as Insulations I and III, respectively, exhibited very good hygrothermal performance but the hydrophobic insulation with high water vapor diffusion resistance factor denoted as Insulation II performed also reasonably well. Considering the typical prices of the particular types of thermal insulations, a logical solution for the practice seems to be the cheaper Insulation II despite its worse hygrothermal performance compared to Insulations I and III.

Acknowledgement

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