C-1-1 Wall hydrophobization and internal insulation: the impact of impregnation strength and depth on moisture levels and moisture damages

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ABSTRACT: Hydrophobization is a recently upcoming approach to reduce latent moisture damages in internally insulated facades. Hydrophobization lessens the water absorption by the facade materials, and is thus presumed to decrease moisture levels and damages in exposed facades. Hydrophobization however also (highly) decreases the drying speed of the facade, hence threatening the desired positive impacts. This paper evaluates whether the strength and depth of impregnation can be tuned such that a final positive outcome is obtained, via numerical simulations that investigate the impact of hydrophobization on the hygrothermal behavior of internally insulated walls. It is shown that the effects of the hydrophobization are strongly linked to the type of internal insulation, as well as to the strength and depth of the impregnation.

KEY-WORDS: Hydrophobization, internal insulation, brick, capillary absorption coefficient

INTRODUCTION AND OBJECTIVES

Brick masonry walls exposed to wind-driven rain exhibit elevated moisture contents [1], which can induce a risk of frost damage, mould growth, and/or wood decay in the facades [2]. Installing interior insulation – to decrease transmission losses and/or increase thermal comfort – may aggravate these dangers [3], because both the inward drying and the wall temperatures may be reduced [4]. Hydrophobizing the facades could potentially lessen these moisture problems, since it minimizes water absorption by facade materials [5]. Hydrophobization does though also strongly slow down the drying speed of the facades [6], which may threaten the desired positive impacts.

This paper therefore evaluates whether the wetting and drying behavior of a hydrophobized masonry wall can be influenced such that a positive final outcome is obtained. An assessment of the impacts of impregnation strength and depth on the hygrothermal performance of masonry walls hence forms the prime objective of this paper. To that aim, the hygrothermal behaviors of three wall configurations (uninsulated, and with two different interior insulation systems) with impregnations of various strength and depth are compared. This is done via numerical hygrothermal simulations with Delphin, a coupled heat and moisture transfer simulation program [7].The first section of the paper introduces our implementation of brick impregnation with different strengths in Delphin. In the second section the effect of brick hydrophobisation on the global moisture levels in the walls as well as their influence on potential moisture damages in the walls are evaluated.

VIRTUAL BRICK HYDROPHOBIZATION

Hydrophobizing brick typically leads to a reduction of both moisture storage and transport [8][9] but their exact impacts have not been adequately quantified yet. For our study thus, we have opted to scale down the moisture retention curve of the initial brick model to four different levels, respectively 75%, 50%, 25% and 10% of the original moisture retention curve, aiming at representing a spectrum of impregnation strengths. Given the link between moisture content and moisture permeability, such moisture storage reduction also results in a moisture transport reduction; the vapor permeability is, on the other hand, left untouched. These modifications strongly impact the wetting and drying behavior of the brick, as illustrated below.

Fig. 1 illustrates the impact on the wetting behavior, with capillary absorption curves of the (un)treated bricks, simulated for 8 cm high samples that are wholly (un)treated. The reduced moisture storage and transport results in a linear decrease of the capillary moisture content, as well as in a quadratic decline of the capillary absorption coefficient: when the moisture retention curve is scaled down to 10% (the strongest impregnation applied in this study), the resulting absorption coefficient is brought down to about 1% of its original value. The obtained range of capillary absorption coefficients – ranging from 2 to 100 times smaller than the original value – characterizes the desired wide spectrum of impregnation strengths.

Fig. 2 exemplifies the impact on the drying behavior, with drying curves for bilayer composites consisting of an untreated saturated bottom layer of 4 cm and an (un)treated dry top layer of 1 or 4 cm. Drying conditions (at 20 °C and 50 % RH) are imposed at the top surface of the top layer, and the moisture present in the 4 cm bottom layer hence needs to dry out via the 1 or 4 cm (un)treated top layer. Fig. 2 clearly shows that both strength and depth of the impregnation affect the impact on the drying behavior. For the 1 cm top layer, hydrophobization has a minor effect only, except for the 10% impregnation. For the 4 cm top layer, the impact of hydrophobization is sizeable for both the 25% and 10% impregnations. Moreover, for the 4 cm top layer, the impact of impregnation is relatively stronger, given that the drop in drying speed, relative to the untreated brick, is far more pronounced, as can be clearly seen for the 25% and 10% strengths.

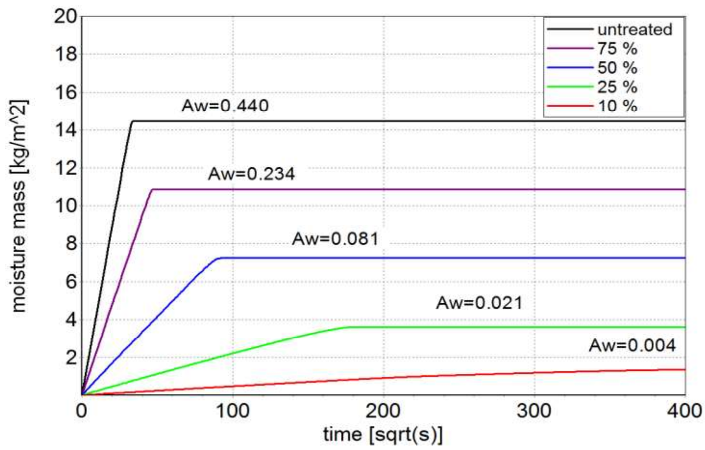

Fig. 1. Water uptake curves for different impregnation strengths (A_w: absorption coefficient [$kg/m^2s^{0.5}$]).

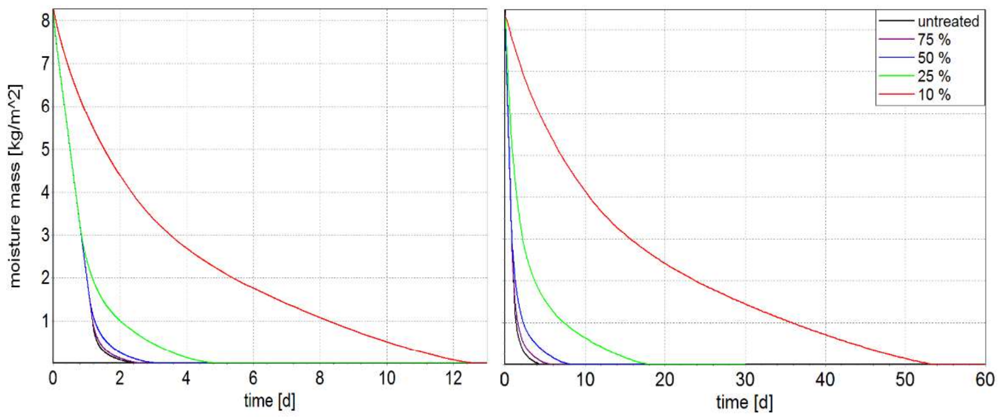

Fig.2. Drying test for different hydrophobization strengths, with a treated layer of 1 cm (left) and 4 cm (right)

While our approach for virtual hydrophobization can certainly be discussed, these uptake and drying simulations indicate that the main impacts of water-repellent treatments are indeed captured [8, 9]. Until the hygric properties of hydrophobized materials are actually measured – a task that we are currently performing – this approximation is an acceptable initial attempt. In earlier analyses, the presence of an impregnation has often been accounted for via complete exclusion of the wind-driven rain loads [10]. It is shown below however that this approach yields overly optimistic results.

HYDROPHOBIZATION AND INTERNAL INSULATION

With the virtual hydrophization of brick established, the paper turns towards the assessment of the hygrothermal performance assessment of internal insulation solutions with (out) water-repellent impregnation. In what follows, first the numerical simulation methodology is presented, and successively the wetting and drying behavior of the walls and the impacts on the potential moisture damages is evaluated.

Simulations performed

Three different wall configurations are studied in this paper, as shown in Fig. 3. The reference case is an un-insulated masonry wall of 30 cm thickness. The two insulated configurations respectively use a vapor and water tight (XPS, extruded polystyrene) and a vapor open capillary active (CaSi, calcium silicate) internal insulation, with a thickness of 14 cm. For all configurations, various impregnation strengths (none, 75%, 50%, 25%, 10%) and depths (1 cm, 4 cm) are superimposed. For CaSi, a glue mortar of 4 mm is applied between insulation and masonry wall. As interior finishing, the reference and CaSi cases use a 1 cm plaster layer, while the XPS case applies a 1 cm gypsum board. Since all simulations are one-dimensional, some aspects of the construction, like the mortar joints and wooden beams, are neglected. The masonry wall is thus presumed to be composed of one (untreated walls) or two (treated walls) isotropic brick materials.

These wall configurations are subjected to a hygrothermal simulation under atmospheric excitation, wherein a South-West orientation and a temperate maritime climate (Essen, Germany) are applied. The exterior boundary conditions consist of convective heat exchange and long- and short-wave radiation on the thermal side, and of convective vapor exchange and wind-driven rain on the hygric side. Given that some researchers represent such hydrophobization by (simply) fully excluding wind-driven rain [10], such variations are equally considered. The interior boundary conditions consist of convective heat exchange and long-wave radiation and convective vapor exchange for heat and moisture respectively, with constant indoor conditions (20 °C & 50 %RH). At the exterior and interior surface, standard values for the convective heat and vapor surface transfer coefficients are used. The simulations cover a simulation interval of 5 years, as it takes some time for the moisture conditions and damages to come to a sufficiently steady response.

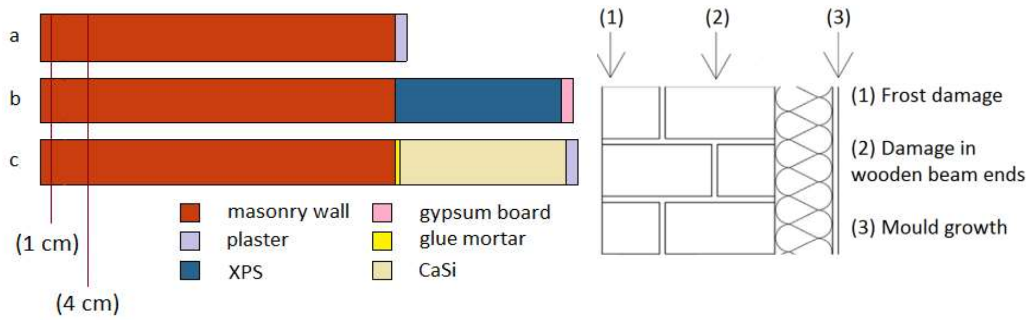

Fig.3. Wall composition (left) and potential damage planes for hygrothermal risks (right). a: non-insulated, b: vapour tight (XPS), c: capillary active (CaSi).

Moisture level impacts

Fig. 4 depicts the temporal evolution of the average moisture content inside the masonry wall, during the last year of the simulation, for the uninsulated wall, the wall with CaSi insulation, and the wall with XPS insulation, each with different impregnation strengths and depths. In these graphs, the outcomes for the 75% impregnation strength are not shown, as they are similar to the results for the untreated wall.

For the uninsulated wall, the moisture levels inside the masonry increase and decrease rapidly, in response to the wetting by wind-driven rain and drying via convective vapor exchange. As can be clearly seen in the blow-up at the right in the Fig., hydrophobization does not affect these moisture levels significantly, except for the strong impregnations (25%, 10%). This is not unexpected with respect to the drying episodes, given the observations in

Fig. 2. For the wetting episodes though, it does imply that weak impregnations, while decreasing the capillary absorption coefficient in Fig. 1 perhaps considerably, have an insufficient effect. It should finally be observed that an impregnation cannot be reliably simulated by excluding wind-driven rain, as indicated by the drastically different results for the 'untreated (no rain)' and '10%, 4 cm' cases respectively.

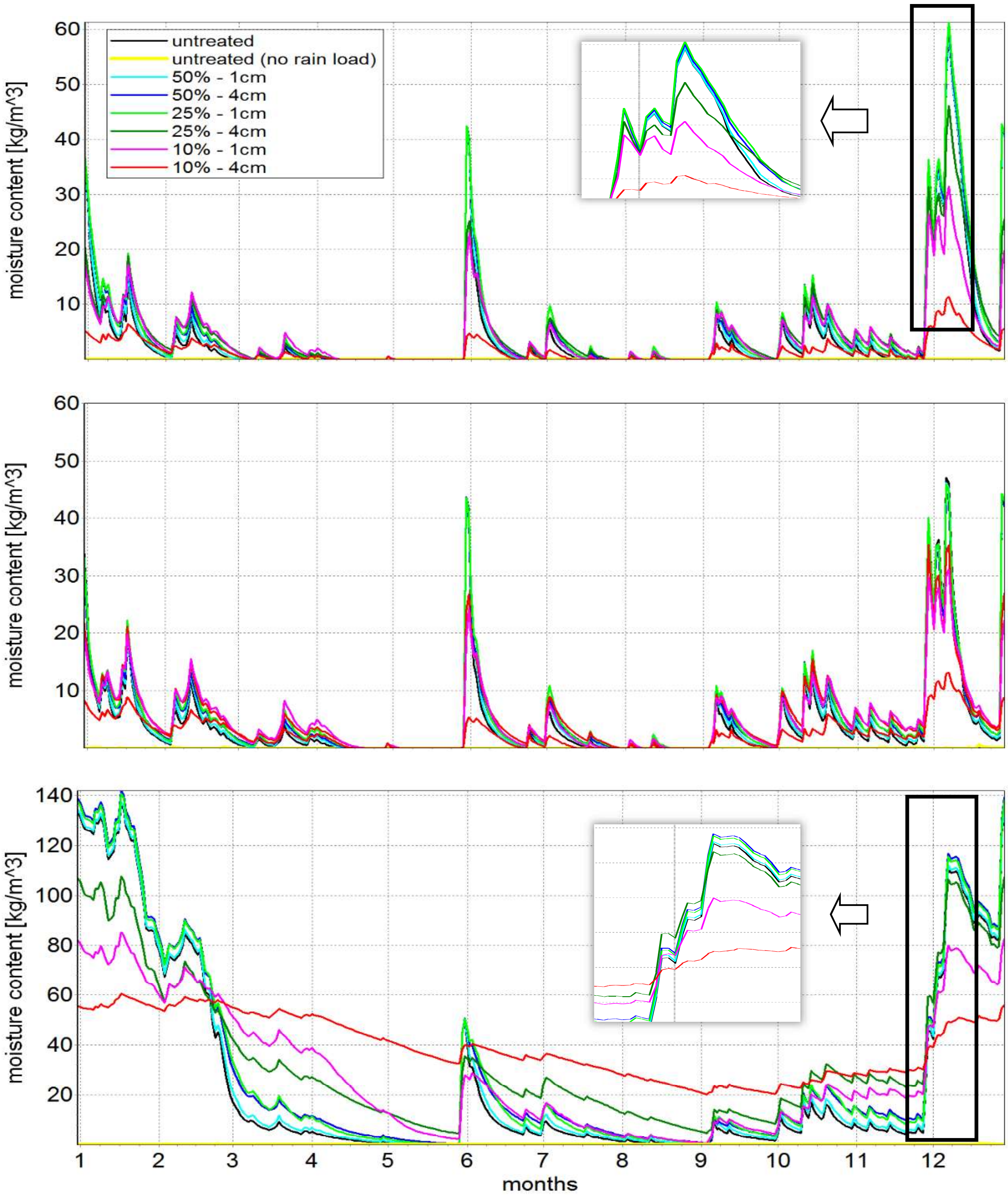

Fig.4. Average moisture contents in the masonry, for uninsulated (top), CaSi (center), XPS (bottom).

For the vapor open capillary active CaSi internal insulation, the observations are very similar: the magnitude and evolution of the moisture levels are similar to those of the uninsulated wall, and the hydrophobization impact is equally comparable. The CaSi insulation thus succeeds in avoiding the typical increase of the moisture contents inside masonry, by its capability for inward drying, and possibly also by its less substantial decrease in the wall temperatures (due to its higher thermal conductivity).

For the vapor and water tight XPS internal insulation, the situation changes dramatically. Firstly, the moisture levels are indeed higher relative to the uninsulated and CaSi configurations, a result of negligible inward drying and low wall temperatures. Secondly, the restricted impact of the weak impregnations is also seen here: only the strong impregnations significantly affect the moisture levels. The blow-up at the right in the Fig. again shows that only these strong impregnations really reduce the moisture uptake during wetting. The entire Fig. exhibits though that their simultaneous reduction of the drying speed has crucial consequences, yielding generally (more) elevated moisture levels in the masonry wall. These are apropos not seen when impregnation is approximated by excluding wind-driven rain, as that approach overly amplifies the finite wetting reduction, while simultaneously completely neglecting the finite drying reduction.

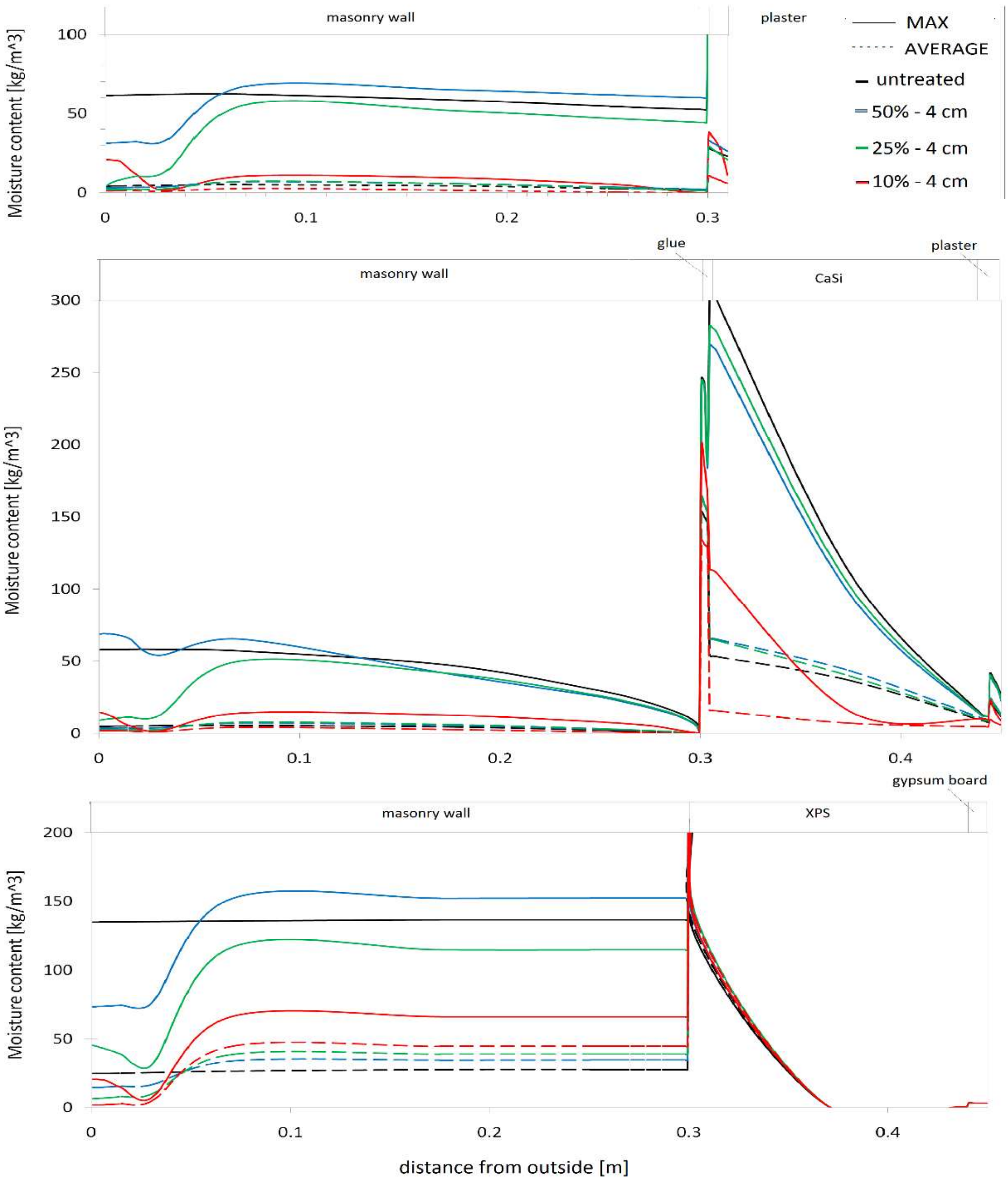

Fig.5. Average (full lines) and maximum (dashed lines) moisture content profiles for uninsulated (top), CaSi (center), XPS (bottom).

Fig. 5 depicts the same results in alternative fashion: the average and the maximum moisture contents that are present inside the wall construction during the last (5th) year of the simulation. In these Fig.s, only a restricted number of impregnations is presented, to not overburden the graphs. The selected impregnations are the stronger (50%, 25% and 10%) and deeper (4 cm) versions, all others give intermediate results.

For the uninsulated wall, it is evident that the weak(er) impregnations do not significantly affect the average and maximum moisture contents in the wall, and that only the strongest impregnation has a certain impact. A similar observation is valid for the CaSi internal insulation, where only the strongest hydrophobization really decreases the moisture levels. These lower moisture contents also manifest themselves inside the CaSi insulation material, which could have a positive effect on its thermal resistance. For the XPS internal insulation, on the other hand, progressively stronger impregnations do indeed increasingly reduce the maximum moisture contents, but at the same time they raise the average moisture contents. Again, the combined impacts of hydrophobization on the wetting and drying behavior are revealed here.

Moisture damage impacts

The prime goal of applying masonry hydrophobization in combination with internal insulation is a reduction of the potential moisture damages. These potential moisture damages are exemplified in Fig. 3 and include:

1. Frost damage to the brick caused by freeze-thaw alternations and overcritical moisture contents inside the masonry wall;
2. Wood decay in embedded beam ends due to overcritical relative humidities (and sufficiently moderate temperatures) in the wood material;
3. Mold growth on an interior surface because of overcritical relative humidities (and sufficiently modest temperatures as well as a mold-sensitive finishing) at the surface;

The frost damage risk is quantified with the number of moist freeze-thaw cycles during the last simulation year, at 5 mm from the exterior surface. A freeze-thaw cycle is considered 'moist' if the ice volume is larger than 25% of the porosity as this corresponds to the lower limit of the critical moisture content for bricks. The risk on wood decay is enumerated via the VTT-wood decay model, which is incorporated in Delphin. The model requires the temperatures and relative humidities that the wood would be subjected to. Given that the beams are not part of our model, these are approximated with the conditions at a distance of 5 cm from the interior interface of the masonry wall. The mold growth risk is computed with the VTT-mold growth model [11], which is an integrated part of Delphin as well, needing the temperatures and relative humidities occurring at the surface.

For the frost damage risk, zero moist freeze-thaw cycles are counted for the uninsulated and CaSi insulated wall, for all (un)treated variants. For the XPS insulated wall, on the contrary, that count adds up to 24 cycles for the untreated wall, again illustrating the impact of the vapor and water tight insulation material on the hygrothermal behavior of the wall. The weakest 75% impregnation strength brings that down to 18 and 15 cycles, for the 1 cm and 4 cm impregnation depths respectively. For the stronger impregnations, these counts go back to zero. These results show that hydrophobization can have a positive impact in relation to frost damage at the exterior surface. Given the relatively rough nature of our frost damage risk criterion though, these findings need to be approached with caution.

Fig. 6 illustrates the outcomes for the wood decay risk, clearly illustrating the relative similarity between the uninsulated and CaSi insulated wall with respect to moisture transfer and moisture damages, as well as showing the negative impacts thereon of the XPS insulation material. It is moreover demonstrated that hydrophobization does have a positive impact on the wood decay risk for the uninsulated and CaSi insulated walls, but in a limited way only. For the XPS insulated wall such impregnation has a negative effect, probably due to the continuously high relative humidities in the wall. It should be pointed out though that the results from the wood decay model cannot be considered reliable, given the very high wood loss values reached in very short time intervals. This is possibly caused by supplying it with conditions in the brick rather than for the wooden beam ends.

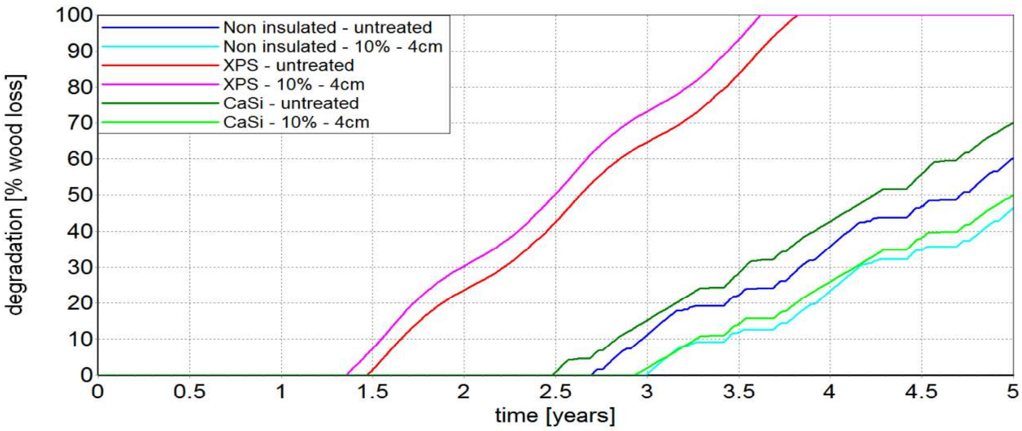

Fig.6. Wooden beam decay for untreated and treated with the highest strength and depth walls.

Fig. 7 finally exemplifies the mold growth risk. The graph only depicts results for the uninsulated wall, since the CaSi and XPS insulated walls have zero risk for mold growth (at the interior surface). The uninsulated wall does however suffer from mold, as shown in the Fig. by the evolution of the mold index during the five year simulation interval. In most cases, the mold index rises rapidly at the end of the 1st year, remaining above 3 for the remainder of the simulation interval. A mold index of 3 (and above) implies that (over) 10 % of the surface is visually affected by mold [11]. Fig. 7 moreover shows the small impact of the weaker hydrophobizations, which only delay but not avoid mold growth. Only the strongest and deepest impregnation (10%, 4 cm) is able to eliminate mold growth at the surface.

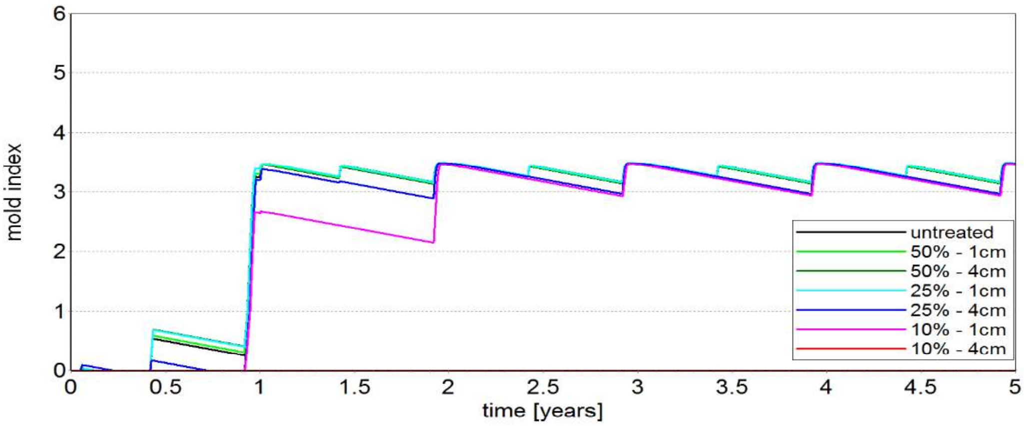

Fig.7. Mold growth (for uninsulated wall – all other cases have a mould index that equals zero)

CONCLUSIONS

In this study, the impact of brick hydrophobization on the hygrothermal performance of masonry walls with(out) internal insulation has been studied, by assessing its effects on the overall moisture levels in the walls and on the potential moisture damages in the walls. By doing so, the initial research question, on whether the impregnation can be tuned such that a final positive outcome is obtained, can be answered.

The evaluation of the moisture levels demonstrated that weak(er) and shallow(er) impregnations typically do not have a sizeable effect, as their impact on neither the wetting and nor the drying of the brick wall is (sufficiently) large. When a strong and/or deep impregnation is applied, the moisture levels typically drop for the uninsulated and CaSi insulated wall. This is not so for the XPS insulated wall though, where strong and deep impregnations do decrease the maximal moisture contents but also do increase the average moisture contents. It is clear that the reduced drying speed has a more dominant effect than the reduced rain absorption. The different behavior of the XPS insulated wall can probably be explained that all drying needs to occur via the external surface, and that the impacts of hydrophobization of that external surface hence have a stronger effect.

The assessment of the moisture damages reveals a similar image. With respect to the frost damage, uninsulated and CaSi insulated walls did not show exposure to freeze-thaw cycles, and that remained so when impregnating. For the XPS wall, the untreated version suffered from freeze-thaw cycles, which were swiftly reduced by use of hydrophobization. In this case, even a weak or shallow hydrophobization already had some effect. In relation to wood decay, the effect of hydrophobization was limited: there was a slight positive influence for the uninsulated and CaSi insulated walls, and a minor negative impact for the XPS insulated wall. All in all however, the wood decay was not modified dramatically. Finally, for the mold growth, no problems were detected for the insulated walls, only the uninsulated wall was affected. It was shown there that solely the strong and deep impregnations could alleviate that problem.

All in all thus, it is suggested that the interaction between impregnations with different strengths and depths and the hygrothermal behavior of (internally insulated) masonry walls is a complex issue, requiring further research. It should finally be kept in mind that our analysis models the hydrophobization in a certain virtual way, and that only a limited number of configurations and exposures have been considered. Any extrapolation of our findings should thus be treated with much caution.

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