Postprint: *Vereecken E, Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures 48(9): 3009-3021.*

CAPILLARY ACTIVE INTERIOR INSULATION: DO THE ADVANTAGES REALLY OFFSET POTENTIAL DISADVANTAGES?

Evy Vereecken[1], Staf Roels[2]

[1] *Building Physics Section, KU Leuven*
Kasteelpark Arenberg 40 – bus 2447, B-3001 Leuven, Belgium
Tel. +32 16 32 13 47
Fax. +32 16 32 19 80
Evy.Vereecken@bwk.kuleuven.be

[2] *Building Physics Section, KU Leuven*
Kasteelpark Arenberg 40 – bus 2447, B-3001 Leuven, Belgium

Abstract

Nowadays, capillary active interior insulation systems are often promoted because of their ability to avoid interstitial condensation, while a drying out remains possible. Additionally, their alleged performance to regulate the indoor climate is often used as a selling point. This paper compares the hygrothermal performance of a capillary active interior insulation system to this of a traditional vapour tight system. Where the previous studies on capillary active insulation systems mainly focused on historical buildings, this study investigates the applicability to standard single leaf masonry walls. Apart from the risk on interstitial condensation, also the impact on the indoor climate and the impact that wind-driven rain has on the hygrothermal behaviour of the retrofitted wall have been analysed.

The capillary active system is found to be more sensitive to small modifications of the wall structure (e.g. interior finishing coat, wall thickness), while hardly any differences could be observed for the wall with a vapour tight system. In addition, wind-driven rain can hamper a good hygrothermal behaviour of a capillary active interior insulation system by inducing a lower thermal resistance or an increased indoor relative humidity. Therefore, it should be checked if the advantages of using capillary systems offset the potential disadvantages. A case-specific study is recommended to ensure the applicability of a capillary active interior insulation system.

Key words:

Interior insulation, capillary active insulation, hygrothermal performance, wind-driven rain, indoor relative humidity, thermal resistance

Introduction

Energy concerns have resulted in the construction of low-energy, zero-energy and even energy positive buildings. Though, since the regeneration of our building patrimony is a slow and cumbersome process, a large part of our existing building stock still exists of buildings built before the first energy crises. In many European countries, the walls of these buildings are often single leaf masonry walls, which are rarely insulated. To increase the thermal performance of these walls, exterior or interior insulation can be applied. The latter method is known as the most risky technique, since it could induce interstitial condensation, frost damage, mould growth near thermal bridges and other damage patterns (Straube and Schumacher 2007). Though, in cases of historical buildings, buildings with a worth-preserving facade (Häupl et al. 2003; Grunewald et al. 2006) or buildings in the urban context which are restricted to a strict road building line, the thermal performance of the non-insulated walls can only be improved by applying interior insulation.

Adding interior insulation to an existing facade will change its hygrothermal performance significantly. During the heating season, the temperature in the masonry wall decreases strongly. If the temperature inside the wall drops below the dew point, interstitial condensation may occur. This phenomenon can arise if a vapour open insulation system is applied. Hence, to avoid interstitial condensation, often a vapour tight insulation system is recommended. The latter systems, however, avoid a drying out of the masonry wall towards the inside and can hence introduce other moisture related damage patterns.

To exclude the latter disadvantage as well as the risk on interstitial condensation, nowadays, often more innovative, especially capillary active interior insulation systems (Grunewald et al. 2006; Pavlik and Cerny 2010; Remmers IQ-Therm) are promoted. A capillary active material typically has pores in the range of 0.1 – 1 µm which results in a larger liquid conductivity in the capillary moisture range. As a consequence, capillary active insulation can absorb the liquid water and redistribute it towards the room by a liquid flow. Hence, interstitial condensation can be avoided, at least when a good contact between the masonry wall and the insulation is provided (Scheffler and Grunewald 2003).

Several papers (Grunewald et al. 2006; Häupl et al. 2003) illustrate the advantage of capillary active insulation systems for historical buildings. But, compared to traditional renovation projects in an urban context, the investigated buildings are constructed out of thicker exterior leafs often comprising an exterior less absorptive clinker layer. In addition, mostly a controlled indoor environment is assumed to simulate for instance the conditions in a museum or to impose suitable boundary conditions for the risk assessment on interstitial condensation. The question arises whether capillary active insulation systems also perform better than the more traditional vapour tight systems for standard single leaf wall constructions and a non-controlled indoor environment.

Results of a hot box – cold box experiment (Vereecken and Roels 2014) showed that, for the investigated steady-state winter condition, the stored moisture increase inside the wall assembly due to vapour diffusion was much lower in the traditional vapour tight system than in the capillary active systems. Hence, from the point of view of interstitial condensation, there was no reason to apply a capillary active interior insulation system. Starting from these experimental findings, this paper compares – based on numerical simulations – the hygrothermal performance of a single leaf masonry wall provided with respectively calcium silicate (vapour open, capillary active system) and XPS (vapour tight system). Where the experimental study was limited to a steady-state winter condition, in this study an extension to realistic climatic conditions, including wind-driven rain (WDR), is made.

In a first section of this paper, the applied methodology is described. Next, an overview of the results is given. Attention is paid to the thermal resistance, the indoor and surface relative humidity, interstitial condensation, etc. To end the main conclusion are summarized.

Methodology

The hygrothermal behaviour of the different interior insulation systems is compared based on a case-study. In what follows the simulation model, the boundary conditions and the investigated wall configurations are described.

Energy and mass balances

To study the hygrothermal performance of the wall structures, the coupled heat and moisture transfer in the building components is simulated with HAMFEM (Janssen et al. 2007), a program verified in (Hagentoft et al. 2004) that solves the conservation equations of energy and mass by means of a finite element method. The conservation of energy and mass in the walls are described by respectively:

$$\left(c_0\rho_0 + c_l w\right)\frac{\partial T}{\partial t} + \left(c_l T\frac{\partial w}{\partial p_c}\right)\frac{\partial p_c}{\partial t} = \nabla\left(\lambda\nabla T - c_l T g_l - \left(c_v T + L_v\right)g_v\right) \tag{1}$$

$$\frac{\partial w_k}{\partial t} = \nabla\left(K_l\nabla p_c\right) + \nabla\left(\frac{\delta_v p_v}{\rho_l R_v T}\nabla p_c + \frac{\delta_v p_v}{\rho_l R_v T^2}\left(\rho_l L_v - p_c\right)\nabla T\right) \tag{2}$$

with c_0, c_l and c_v the specific heat capacity of the material, liquid water (4180 J/kgK) and vapour (1880 J/kgK), respectively, ρ_0 the material density (kg/m^3), w the moisture content (kg/m^3), T the temperature (K), t the time (s), p_c the capillary pressure (Pa), λ the thermal conductivity (W/mK), g_l and g_v the liquid and vapour flow (kg/m^{2}s), respectively, L_v the heat of vaporisation (3.13 10^6 J/kg), K_l the liquid permeability (s), p_v the vapour pressure (Pa), δ_v the water vapour permeability (s), ρ_l the density of water (1000 kg/m^3) and R_v the gas constant of water (461.89 J/kg.K).

The moisture balance of the room is described by the effective capacitance (EC-) model (Janssen and Roels, 2008), wherein the air capacity is enlarged by using the hygric inertia of the room (HIR*):

$$\left(\frac{V}{R_v T_i} + \frac{100 HIR^* V}{p_{v,sat}(T_i)}\right).\frac{\partial p_{vi}}{\partial t} = \left(p_{ve} - p_{vi}\right).\frac{nV}{3600 R_v T_i} + G_{vp} - G_{vw} \tag{3}$$

with V the room volume (m^3), T_i the indoor temperature (K), $p_{vi/e}$ the partial vapour pressure of indoor/outdoor air (Pa), n the ventilation rate (1/h), G_{vp} the indoor vapour production (kg/s). The HIR*-value (kg/(m^3.%RH)) takes into account moisture exchanging elements such as books, furniture, etc. In the current study, the moisture exchange between the exterior wall and the room is not included in the HIR*-value, but described by G_{vw} (kg/s), which can be written as:

$$G_{vw} = \beta A\left(p_{vi} - p_{vs}\right) \tag{4}$$

with β the moisture transfer coefficient (s/m), A the surface area (m²) and p_{vs} the partial vapour pressure at the surface (Pa).

Boundary conditions

Exterior conditions

The analysis is performed for a north-west oriented wall of a 10 x 10 x 10 m³ building located in Essen, Germany. In the analysis the Test Reference Year (Blümel 1986) is used. Wind-driven rain on the wall is calculated by wind direction, wind speed and rain on a vertical surface area (Janssen et al. 2007). The catch ratio on the facade is set equal to the value determined on the wall center of the building (Blocken and Carmeliet 2006). The exterior convective heat transfer coefficient $h_{c,e}$ is assumed to be function of the wind velocity (Sharples 1984):

$$h_{c,e} = 1.7V_{loc} + 5.1 \tag{5}$$

where V_{loc} given by:

$$V_{loc} = 1.8U_{10} + 0.2 \text{ (windward)} \tag{6}$$

$$V_{loc} = 0.2U_{10} + 1.7 \text{ (leeward)} \tag{7}$$

with U_{10} the reference wind speed measured at 10 meter above ground level (m/s). The exterior mass transfer coefficient is related to the convective heat transfer by use of the Lewis analogy: 7.7 x 10^{-9} x $h_{c,e}$. The short-wave absorptivity and the long-wave absorptivity are kept constant at 0.6 and 0.9, respectively. To enable a better view on the influence of the WDR loads, **Fig.** 1 shows for the north-west oriented wall the rain load and the cumulative rain load on the facade as a function of time. In the simulation hourly climate data are used. The simulation is started from July 1st.

Fig. 1 Wind-driven rain at the center of the north-west oriented facade of a 10 x 10 x 10 m³ building (Blocken and Carmeliet 2006).

Interior conditions

The analysis is performed for a bedroom occupied by two persons. From 23 PM till 7 AM a moisture production of 70 g/h occurs. At other moments, the moisture production is equal to 10 g/h. The ground surface of the room is 12 m². The height of the room measures 2.5 m. The interior heat transfer coefficient is kept constant and is set at 8 W/(m²K). The interior moisture transfer coefficient is set at (8/2) x 7.7 x 10^{-9} s/m, which is obtained based on the Lewis relation and by taking only half the total heat transfer coefficient to exclude the radiation part.

The indoor relative humidity is not controlled by an HVAC system. Instead, the indoor relative humidity is calculated based on the moisture balance (Eq.(3)). An interaction between the room and the exterior wall (7.5 m²) is included by the last term at the right hand side of this moisture balance. The impact of the room enclosure (finishing of interior walls, books, furniture, etc.) on the interior relative humidity, is taken into account by a HIR_{8h} (equal to HIR* for the implemented 8h/16h moisture production scheme) of 0.7 g/(m³.%RH), as measured for the moisture buffer impact in a student room (Vereecken et al. 2011). The indoor temperature is kept constant at 18 °C, except when the outdoor temperature exceeds 18 °C. In the latter case, windows are assumed to be opened and the indoor temperature is assumed to be equal to the outdoor temperature, but not higher than 25 °C.

The air change rate (ACH) is determined based on the Sherman and Grimsrud model (Sherman and Grimsrud 1980; ASHRAE 2009). The ACH is minimum 0.5 h^{-1}. If the exterior temperature exceeds 18 °C, than the ACH is set to 5 h^{-1}. In the analysis, inter-zonal air circulations are neglected.

Wall structures

In a first step, two reference wall assemblies are investigated. Those two reference walls consist of a 29 cm thick masonry wall, which is simplified in a single isotropic brick layer, neglecting the mortar joints. Hence, a one-dimensional simulation suffices. This approach is legitimized for the current study, as was shown in (Vereecken and Roels 2013). The insulation systems applied to the reference walls consist of:

Capillary active system: 0.4 cm glue mortar – 7.5 cm calcium silicate (CaSi) – 1 cm plaster
Vapour tight system: 3.88 cm extruded polystyrene (XPS) – 1.25 cm uncoated gypsum board

The insulation thickness applied in both systems might seem strange as it are no commercially available values, but is chosen in such a way that the dry thermal performance at 50% relative humidity is equal for both reference walls (R_{dry} = 1.56 (m²K/W), which corresponds to a U-value of 0.64 W/(m²K)). To investigate the profit of adding an insulation system, the reference walls are compared with a 29 cm masonry wall with a 1 cm plaster as interior finishing layer, but without insulation. After analyzing the reference system, the impact of (1) a thinner masonry wall (19 cm) and (2) a latex interior finishing coat is studied. The material properties are given in Appendix A.
Between the masonry wall and the capillary active system, in reality, a hydraulic interface resistance will be present, as concluded based on the imbibition experiments performed in (Vereecken 2013). For realistic climatic conditions, this interface resistance was, however, found to have a negligible influence and can hence be neglected (Vereecken 2013; Vereecken and Roels 2014). The initial temperature and relative humidity in the wall are set at 20 °C and 50%, respectively.

Results

The performance of the two interior insulation systems is compared based on the surface relative humidity, the surface temperature, the accumulated moisture content, the thermal resistance, etc. As a reference, the results for a non-insulated wall are plotted. To exclude effects due to the starting conditions, the results starting from January 1st in the second year are given. Exception to this form the results for the capillary active system with the latex coat. For the latter wall composition the results for the third year are shown, since in the second year an annual periodic behaviour was not yet reached.

Comparison of the reference system

The hygrothermal behaviour for a wall not exposed to wind-driven rain (WDR) as well as for a wall exposed to wind-driven rain is studied. Note that the absence of wind-driven rain can occur e.g. by a sufficiently large roof overhang or when applying a vapour open hydrophobation on the exterior surface.

Relative humidity between masonry and insulation

Fig. 2 shows the relative humidity between the masonry wall and the insulation system. As a reference, the relative humidity between the non-insulated masonry and the plaster layer is given. During the heating season, applying interior insulation results in an increased relative humidity. When wind-driven rain is excluded, the relative humidity stays below 85%. Due to the ability of a capillary active system to redistribute the moisture inwards, the relative humidity in cases of a capillary active system is lower than found for the vapour tight system. No interstitial condensation is induced. When the wall is exposed to wind-driven rain, in the case of the capillary active interior insulation system the relative humidity between the masonry wall and the insulation system shows large peaks. After a peak in WDR load, compared to the non-insulated wall, a much lower decrease in relative humidity is found. The reason for this is multiple. Firstly, moisture induced by the WDR loads is stored in the glue mortar and the calcium silicate layer. An inwards drying out of this moisture occurs slower than found for the moisture in the non-insulated wall. In addition, during the heating season, due to the low temperature of the masonry wall with interior insulation, drying out towards the exterior occurs more slowly. For the vapour tight system, the relative humidity between the masonry wall and the insulation system reaches during the entire year a value of almost 100%. In the current study, however, the WDR peak during summer is quite extreme. Nevertheless, the difference in behaviour of a capillary active and a vapour tight system is clearly shown.

It can be concluded that the capillary active interior insulation system performs best when comparing the relative humidity between the masonry wall and the insulation system. The liquid permeability of the capillary active system is crucial in achieving this behaviour, as mentioned in (Vereecken 2013).

Fig. 2 Relative humidity at the warm side of the masonry wall: a) without and b) with wind-driven rain.

Accumulated moisture content

To investigate the accumulated moisture content in the wall assemblies, a subdivision is made between the accumulated moisture in the masonry wall (with exclusion of the insulation system and the finishing layer) and the accumulated moisture in the insulation system. If no wind-driven rain is included (not shown), the accumulated moisture content in the brick layer is negligible. Though, in the case of the capillary active system some moisture is accumulated in the calcium silicate layer and in the glue mortar layer. In the XPS no moisture is accumulated.
When the wall is exposed to WDR loads, during the heating season, for the wall with a vapour tight interior insulation system, in the brick layer an increased accumulated moisture content is found (**Fig.** 3a). Since an inwards drying out is not possible, the drying occurs slower than found for the capillary active system. The accumulated moisture content in the brick layer if a capillary active system is applied, is only slightly higher compared to the accumulated moisture content in the non-insulated wall. The reason for this is the redistribution of the moisture towards the insulation system and the room. The accumulated moisture content in the calcium silicate layer and in the glue mortar is shown in **Fig.** 3b. The peaks in accumulated moisture content induced by the WDR loads are clearly visible.

Fig. 3 Accumulated moisture content in a) the brick layer and b) the capillary active insulation system.

To have a better view on the moisture distribution in the wall, **Fig.** 4 shows for the different wall assemblies the maximum moisture content in function of the position in the wall. The annual maxima at all positions for a wall not exposed to WDR loads as well as for a wall exposed to WDR loads are shown. Additionally, for the walls exposed to wind-driven rain, the yearly averaged moisture content and the moisture profile at a certain moment (January 5th 8:00 AM) are shown. When the wall is exposed to wind-driven rain, adding a vapour tight interior insulation system results in a higher moisture content in the masonry wall. Mainly at the warm side of the masonry wall an increased moisture content is found. If a capillary active system is applied, the moisture is captured in the glue mortar layer and the calcium silicate insulation. As a consequence, at the warm side of the masonry wall a lower moisture content is found. Remark, that at the warm side of the masonry wall embedded beam ends can be located. Hence, in cases of wooden beam ends a vapour tight interior insulation system is discommended when the wall is exposed to high WDR loads. The applicability of a capillary active interior insulation system in cases of embedded wooden beam ends seems promising, but demands a more in depth study.

Fig. 4 Moisture profiles: a) no insulation, b) vapour tight XPS-system, c) capillary active system. 1 = masonry wall, 2 = plaster, 3 = XPS, 4 = gypsum board, 5 = glue mortar, 6 = calcium silicate.

Thermal resistance

The accumulated moisture content in the wall assemblies can result in a decrease in thermal resistance. To determine the thermal resistance taking into account the moisture content in the wall assembly (R_{wet}), the wall assembly is divided in small elements. For each element the moisture dependent λ-value (Eq.(11)) is calculated based on the moisture profiles determined with HAMFEM and the incremental R_{wet}-values are calculated. By summation of the latter values, the total moisture dependent R_{wet} values is obtained. The influence of the accumulated moisture content on the thermal resistance is shown in **Fig.** 5, where the absolute decrease in thermal resistance (W/(m²K)) is defined by R_{dry}-R_{wet} and the relative decrease in thermal resistance (%) as ((R_{dry}-R_{wet})/R_{dry})x100). The WDR loads are found to influence the thermal resistance. The largest decrease in total thermal resistance (compared to the dry thermal performance) is found for the capillary active system. In the beginning of June, due to the large WDR peak a decrease of more than 30% is found. Though, this decrease is of minor importance given its appearance during the summer. During the heating season, a decrease up to approximately 0.2 m²K/W is found. This corresponds to a total U-value of 0.74 W/(m²K). For the vapour tight system, a smaller decrease in thermal resistance is found.

Fig. 5 Decrease in thermal resistance for the total wall assembly ($R_{dry,total}$ = 1.56 W/(m²K))

Frost damage

Frost damage can occur due to a high moisture content in the masonry wall in combination with a temperature below the freezing temperature. For the temperatures below zero, **Fig.** 6 shows the hourly temperature together with the moisture content at the same time in case the walls are exposed to WDR loads. The larger moisture content and the lower temperature due to the addition of an interior insulation system are clearly visible. Also the slightly higher moisture content found for the vapour tight system (compared to the capillary active system) can be observed. Though, this small difference between both systems is expected to have only a minor influence on the risk on frost damage.

Fig. 6 Combination of subfreezing temperatures and moisture content at the exterior surface (hourly values, obtained during the entire year).

Interior surface and room relative humidity

Fig. 7 shows the relative humidity at the interior surface during the period from January till April. When WDR loads are excluded, in general, for the capillary active system and the vapour tight XPS-system a similar course is obtained. The non-insulated wall shows – due to the lower surface temperature – a slightly higher surface relative humidity.

For the walls exposed to WDR loads, WDR induced peaks are clearly visible in the case of the non-insulated wall and the wall with the capillary active system. The moisture in the wall is redistributed inwards. The wind-driven rain has no influence on the relative humidity at the interior surface in the case of the vapour tight XPS-system.

A less pronounced, though still significant influence is found for the interior room relative humidity. For instance, the indoor relative humidity in December reaches a value of 66% when a capillary active system is used while with a vapour tight system a value of 44% is obtained.

Fig. 7 Relative humidity at the interior surface: a) without and b) with wind-driven rain.

The moisture buffering capacity of the wall assemblies can be indicated by the moisture buffer value (MBV). This value expresses the amount of moisture uptake or release when the studied building component is exposed to repeated daily variations in relative humidity between two given levels and this normalized per m² open surface area and per % RH change (Janssen and Roels 2009). **Fig.** 8 compares the MBV for the different wall assemblies, if the interior surface is assumed as the open surface area. A comparison with the classification suggested by Rode et al. (2007), indicates the non-insulated wall with a 1 cm plaster layer and the wall with the capillary active system as an excellent moisture buffering element. The wall assembly with the XPS-system can be classified as moderate moisture buffering elements. Note, however, that, although the moisture buffer values are calculated for the entire wall assembly, mainly the finishing layer will be determinative for the moisture buffering capacity. To prove this, as a reference also the MBV for a 1 cm plaster layer and a 1.25 cm gypsum board are given. The MBV's of the finishing layers show a good agreement with the wall assemblies with the corresponding finishing layer.

Fig. 8 Simulated moisture buffer value for the reference wall assemblies, 1 cm plaster and 1.25 cm gypsum board.

Preliminary parameter study

As a preliminary study, the influence of two small modifications made to the wall structure is investigated: (1) a smaller masonry thickness: 19 cm (R_{dry} of the total wall assembly = 1.45 m^2K/W), (2) original composition (29 cm) but with a 0.1 mm latex interior finishing coat. The study is limited to walls exposed to wind-driven rain.

Relative humidity between masonry and insulation

The relative humidity between the masonry wall and the capillary active insulation system is shown in **Fig.** 9. For the 19 cm thick masonry wall, the relative humidity between the masonry wall and the insulation system shows only a negligible difference with the reference case. When a latex finishing coat is applied, the drying potential is reduced. Hence, after WDR loads, between masonry wall and capillary active system a higher relative humidity is found. For the vapour tight insulation system, both modifications have no or a negligible impact (not shown).

Fig. 9 Relative humidity between the masonry wall and the capillary active insulation system: influence of an interior finishing coat.

Accumulated moisture content

Fig. 10 shows the accumulated moisture content in the capillary active insulation. The influence of the masonry thickness is only worth mentioning during large WDR peaks. In cases of a thinner masonry wall, the insulation system is reached sooner. When applying a vapour tight finishing coat, due to the reduced drying potential, more moisture is accumulated in the insulation system. In the vapour tight system, no moisture is stored.

The influence of the modifications on the moisture profiles for the capillary active system and the vapour tight system can be observed by comparing **Fig.** 11 with **Fig.** 4. For both systems, the higher moisture content in the thinner masonry wall is visible. Applying a vapour tight interior finishing coat only has an influence if a capillary active system is applied. Both a thinner masonry wall and a vapour tight finishing coat result in an increased moisture content in the capillary active system.

Fig. 10 Accumulated moisture content in the capillary active insulation.

Fig. 11 Moisture profiles: influence of the masonry thickness a,c) and a vapour tight finishing coat b,d). 1 = masonry wall, 2 = plaster, 3 = XPS, 4 = gypsum board, 5 = glue mortar, 6 = calcium silicate, 7 = latex coat. The reference case is given in **Fig.** 4.

Interior surface and room relative humidity

Fig. 12a shows for a wall with a capillary active interior insulation system the influence of both modifications on the interior relative humidity. A thinner masonry wall results during a heavy rain load in a higher interior relative humidity. The vapour tight interior finishing coat prohibits an inwards moisture flux. As a consequence, during rainy periods, a lower interior relative humidity is found. However, also an outwards moisture flux is hampered. Hence, during the heating season, the interior relative humidity is slightly higher. A similar and even more pronounced trend is found for the interior surface relative humidity, as shown in **Fig.** 12b. When applying a vapour tight system, nor a thinner masonry wall nor the addition of an interior finishing coat has an influence on the indoor relative humidity and interior surface relative humidity (not shown).

Fig. 12 Influence of the modifications in the case of a capillary active system: a) indoor relative humidity, b) interior surface relative humidity.

Note also that, as mentioned above, mainly the finishing layer influences the moisture buffer capacity. The decrease in MBV after applying an interior finishing coat on the capillary active system is clearly visible in **Fig.** 13. Where the capillary active system with 1 cm plaster layer (annotated by CaSi) can be classified as an excellent moisture buffering element (Rode et al. 2007), after the addition of a latex finishing coat the moisture buffering capacity of this wall assembly becomes negligible. The moisture buffering capacity of the capillary active system with a plaster layer and a finishing coat is similar to the results found for the vapour tight XPS-system with a gypsum board and a finishing coat. The strong influence of the finishing coat is in agreement with the behaviour found by Roels and Carmeliet (2006).

It can be concluded that, although a capillary active system is often promoted because of its ability to dampen peaks in interior relative humidity, in reality the buffering capacity of the system will be determined by the finishing layer. A single finishing paint applied by the inhabitant will simply rule out the buffering capacity of the capillary active system.

Fig. 13 Moisture buffer value: influence of an interior finishing coat.

Thermal resistance

Since the accumulated moisture content in the wall assembly with the capillary active system is influenced by the masonry thickness, also the thermal performance will be influenced. As shown in **Fig.** 14a, in cases of the capillary active system, a smaller masonry thickness results – compared to the reference wall assembly – in a larger decrease in thermal resistance. The reason for this is the larger accumulated moisture content in the insulation system. For the vapour tight system, the result is similar as found for the reference wall assembly.

The decrease in thermal resistance due to the additional accumulated moisture content induced by the addition of the vapour tight interior finishing coat is shown in **Fig.** 14b. For the capillary active system, the finishing coat tends to have a large influence on the thermal performance of the wall. Due to a slower drying potential, a smaller thermal resistance is observed over a longer period of time. For the vapour tight system, the decrease in thermal resistance is similar as found for the reference wall assembly.

Fig. 14 Decrease in thermal resistance for the total wall assembly: influence of a) thinner masonry wall, b) applying a latex interior finishing coat.

Conclusions

In this paper, the hygrothermal performance of a capillary active interior insulation system was investigated and compared to the behaviour of a wall with a vapour tight interior insulation system. In respect to the moisture content in the masonry wall, the capillary active system performs best. Especially at the warm side of the masonry wall, the negligible increase in moisture content shows a large difference with the increase found in the case of a vapour tight interior insulation system. This limited moisture content seems promising for a reliable application of wooden beam ends, though, a more in depth study is required.

For sufficiently thick walls or walls protected against wind-driven rain, a capillary active system performs better than a vapour tight system. But, in the case of thinner walls exposed to wind-driven rain, the ability to redistribute moisture inwards can entail a number of drawbacks. The moisture will be partially stored in the capillary active insulation system and will partially enter the room. This induces a decrease in thermal performance of the insulation system and an enlarged indoor relative humidity.

Additionally, it was shown that the hygrothermal performance of a capillary active system tends to be more sensitive to small modifications of the wall structure, while hardly any differences could be observed for the wall with a vapour tight interior insulation system. For instance, the interior finishing coat can have a significant influence on the hygrothermal performance of a capillary active system. Hence, not every interior finishing coat ensures the intended performance of the capillary active system. Because of the sensitivity to small modifications, often a case-specific study is preferable to ensure the applicability of a capillary active interior insulation system. To end, it should be noted that the ability to buffer moisture and hence to regulate the indoor climate – which is often used as a selling point for these systems – mainly depends of the interior finishing layer.

Acknowledgements

The results in this paper have been partially obtained within IWT 3E90050 ‘Global performance approach and economic analysis of interior insulation with regard to renovation projects’ funded by the Flemish Government and KUL OT/09/23 ‘Towards a reliable application of interior insulation for the retrofit of existing buildings’ funded by the KU Leuven. These financial supports are gratefully acknowledged.

Appendix A

The material properties used to simulate the hygrothermal performance of the wall assemblies are given in Table 1 and **Fig.** 15. The vapour permeability is expressed as a function of the moisture content *w*:

$$\delta_v = \frac{2.61 \cdot 10^{-5}}{R_v \cdot T \cdot \mu_{dry}} \cdot \frac{1-\left(w / w_{cap}\right)}{\left(1-p\right)\cdot\left(1-\left(w / w_{cap}\right)\right)^2 + p} \tag{8}$$

where μ_{dry} (-) the dry vapour resistance factor, $w_{(cap)}$ (kg/m³) the (capillary) moisture content and *p* is equal to 0.497.

The vapour permeability of the gypsum board and the latex paint is given by respectively:

$$\delta_v = 1.77 \cdot 10^{-11} + 3.41 \cdot 10^{-11} \cdot \exp\left(\frac{-5.04}{w}\right) \tag{9}$$

and

$$\delta_v = 1.938 \cdot 10^{-10} \cdot \left(2.5 \cdot 10^{-5} + 4.22 \cdot 10^{-7} \cdot exp\left(8.17 \cdot \varphi\right)\right) \tag{10}$$

with φ the relative humidity (-). The thermal conductivity *λ* (W/(mK)) of the materials is given by:

$$\lambda = \lambda_{dry} + a_{wet} \cdot w \tag{11}$$

where λ_{dry} the dry thermal conductivity and a_{wet} a parameter including the moisture dependence (see Table 1).

Fig. 15 a) Moisture retention curve, b) hygroscopic curve finishing coat, c) liquid permeability, d) vapour diffusion finishing coat.

References

1. ASHRAE Handbook – Fundamentals (2009). (p.16-23)
2. Blocken B, Carmeliet J (2006) The influence of the wind-blocking effect by a building on its wind-driven rain exposure, J Wind Eng Ind Aerod 94(2):101-127
3. Blümel K (1986) Entwicklung von Testreferenzjahren (TRY) für Klimaregionen der Bundesrepublik Deutschland. Technical report. BMFT-Bericht FB-T 86-051
4. Derluyn H, Janssen H, Moonen P, Carmeliet J (2008) Moisture transfer across the interface between brick and mortar joint. Proceedings of the 8th Nordic Symposium on Building Physics, pp 865-872
5. Grunewald J, Ruisinger U, Häupl H (2006) The Rijksmuseum Amsterdam – hygrothermal analysis and dimensioning of thermal insulation, Research in Building Physics and Building Engineering, eds. Fazio, Ge, Rao, Desmarais, Taylor & Francis group, Londen, pp 345-352
6. Hagentoft C, kalagasidis A, Adl-Zarrabi B, Roels S, Carmeliet J, Hens H, et al (2004) Assessment method for numerical prediction models for combined heat, air and moisture transfer in building components: benchmarks for one-dimensional cases. J Therm Envel Build Sci 27:327-352
7. Häupl P, Jurk K, Petzold H (2003) Inside thermal insulation for historical facades, Research in Building Physics, eds. Carmeliet, Hens, Vermeir, Lisse: A.A. Balkema Publishers, pp 463-469
8. Janssen H, Blocken B, Carmeliet C (2007) Conservative modelling of the moisture and heat transfer in building components under atmospheric excitation, Int J Heat Mass Tran 50:1128-1140
9. Janssen H, Roels S (2009) Qualitative and quantitative assessment of interior moisture buffering by enclosures. Energ Buildings 50:1128-1140
10. Nicolai, A., Grunewald, j. (2006). Delphin 5: Coupled Heat, Air, Moisture and Salt Transport (User Manual and Program Reference). Dresden University of Technology.

11. Pavlik Z, Cerny R (2010) Hygrothermal performance study of an innovative interior thermal insulation system, Appl Therm Eng 29:1941-1946

12. Remmers IQ-Therm – The intelligent interior insulation – The unique capillary thermal insulation, http://www.remmers.co.uk/fileadmin/user_upload/brochures/interior_insulation/796_-_iq-therm/796_GB_iQ-Therm.pdf . Accessed 7 January 2014

13. Rode C, Peuhkuri R, Time B, Svenbberg K, Ojanen T (2007) Moisture buffer value of building materials. J ASTM Int 4(5)

14. Roels S, Hens H, Adan O, Brocken H, Pavlik Z, Ellis A, Hall C, Kumaran K, Pel L, Plagge R (2004) A comparison of different techniques to quantify moisture content profiles in porous building materials. J Therm Envel Build Sci 27(4):261-276

15. Roels S, Carmeliet J (2005) Water vapour permeability and sorption isotherm of coated gypsum board. Proceedings of the 7th Sumposium on Building Physics in the Nordic Countries. Reykjavik Iceland, pp 609-616

16. Roels S, Carmeliet J (2006) Hygric buffering capacities of uncoated and coated gypsum board. Research in Building Physics and Building Engineering. Fazio, Re, Rao & Desmarais (eds.). Taylor & Francis Group, Londen, pp 27-32

17. Sharples S (1984) Full scale measurements for convective energy losses from exterior building surfaces. Build Environ 19(1):31-39

18. Sherman MH, Grimsrud DT (1980) Infiltration-pressurization correlation: simplified physical modelling. Conference of the American Society of Heating, Refrigeration and Air Conditioning Engineers, Denver, CO, June 22-26

19. Straube J, Schumacher C (2007) Interior insulation retrofits of load-bearing masonry walls in cold climates, Building Science Digest 114

20. Scheffler G, Grunewald J (2003). Material development and optimisation supported by numerical simulation for a capillary-active inside insulation material, Research in Building Physics, eds. Carmeliet, Hens, Vermeir, Lisse: A.A. Balkema Publishers, pp 463-469

21. Vereecken E, Roels S, Janssen H (2011) In situ determination of the moisture buffer potential of room enclosures. J of Build Phys 34(3):233-246

22. Vereecken E, Roels S (2013) Hygric performance of a massive masonry wall: how do the mortar joints influence the moisture flux? Const Build Mater 41:697-707

23. Vereecken E (2013) Hygrothermal analysis of interior insulation for renovation projects. Dissertation, KU Leuven

24. Vereecken E, Roels S (2014) A comparison of the hygric performance of interior insulation systems: a hot box-cold box experiment. Energ Buildings, http://dx.doi.org/10.1016/j.enbuild.2014.04.033

25. Vereecken E, Roels S (2014) A numerical study of the influence of the hydraulic interface contact on the hygric performance of a multi-layered system. Submitted to 13th International Conference on Durability of Building Materials and Components. Sao Paulo, Brasil.

Figure legends

Fig. 1 Wind-driven rain at the center of the north-west oriented facade of a 10 x 10 x 10 m³ building (Blocken and Carmeliet 2006)

Fig. 2 Relative humidity at the warm side of the masonry wall: (a) without and (b) with wind-driven rain

Fig. 3 Accumulated moisture content in a) the brick layer and b) the capillary active insulation system

Fig. 4 Moisture profiles: a) no insulation, b) vapour tight XPS-system, c) capillary active system. 1 = masonry wall, 2 = plaster, 3 = XPS, 4 = gypsum board, 5 = glue mortar, 6 = calcium silicate.

Fig. 5 Decrease in thermal resistance for the total wall assembly ($R_{dry,total}$ = 1.56 W/(m²K))

Fig. 6 Combination of subfreezing temperatures and moisture content at the exterior surface (hourly values, obtained during the entire year)

Fig. 7 Relative humidity at the interior surface: (a) without and (b) with wind-driven rain

Fig. 8 Simulated moisture buffer value for the reference wall assemblies, 1 cm plaster and 1.25 cm gypsum board

Fig. 9 Relative humidity between the masonry wall and the capillary active insulation system: influence of an interior finishing coat

Fig. 10 Accumulated moisture content in the capillary active insulation

Fig. 11 Moisture profiles: influence of the masonry thickness a,c) and a vapour tight finishing coat b,d). 1 = masonry wall, 2 = plaster, 3 = XPS, 4 = gypsum board, 5 = glue mortar, 6 = calcium silicate, 7 = latex coat. The reference case is given in **Fig.** 4.

Fig. 12 Influence of the modifications in the case of a capillary active system: a) indoor relative humidity, b) interior surface relative humidity.

Fig. 13 Moisture buffer value: influence of an interior finishing coat

Fig. 14 Decrease in thermal resistance for the total wall assembly: influence of (a) thinner masonry wall, (b) applying a latex interior finishing coat

Fig. 15 a) Moisture retention curve, b) hygroscopic curve finishing coat, c) liquid permeability, d) vapour diffusion finishing coat

Postprint: *Vereecken E, Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures 48(9): 3009-3021.*

Figures

Figure 1

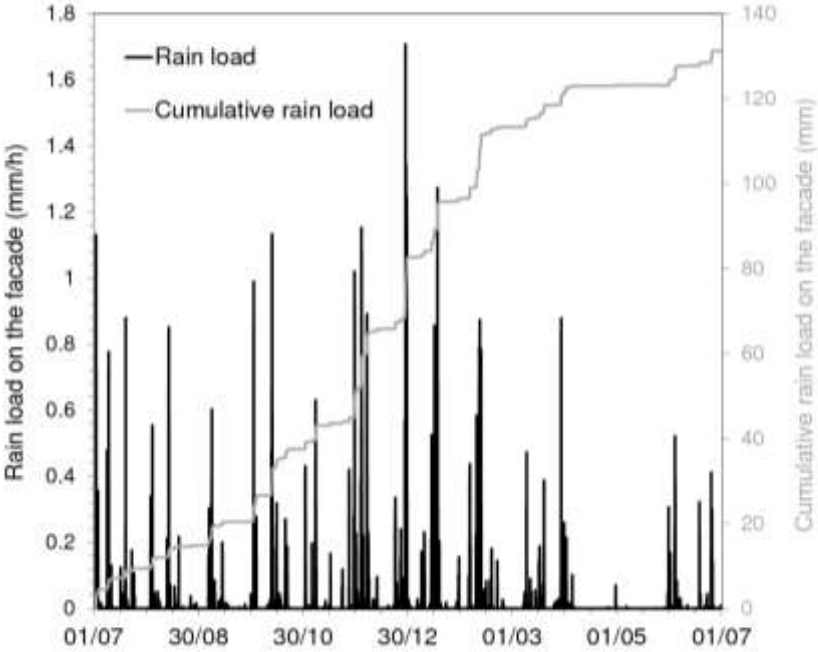
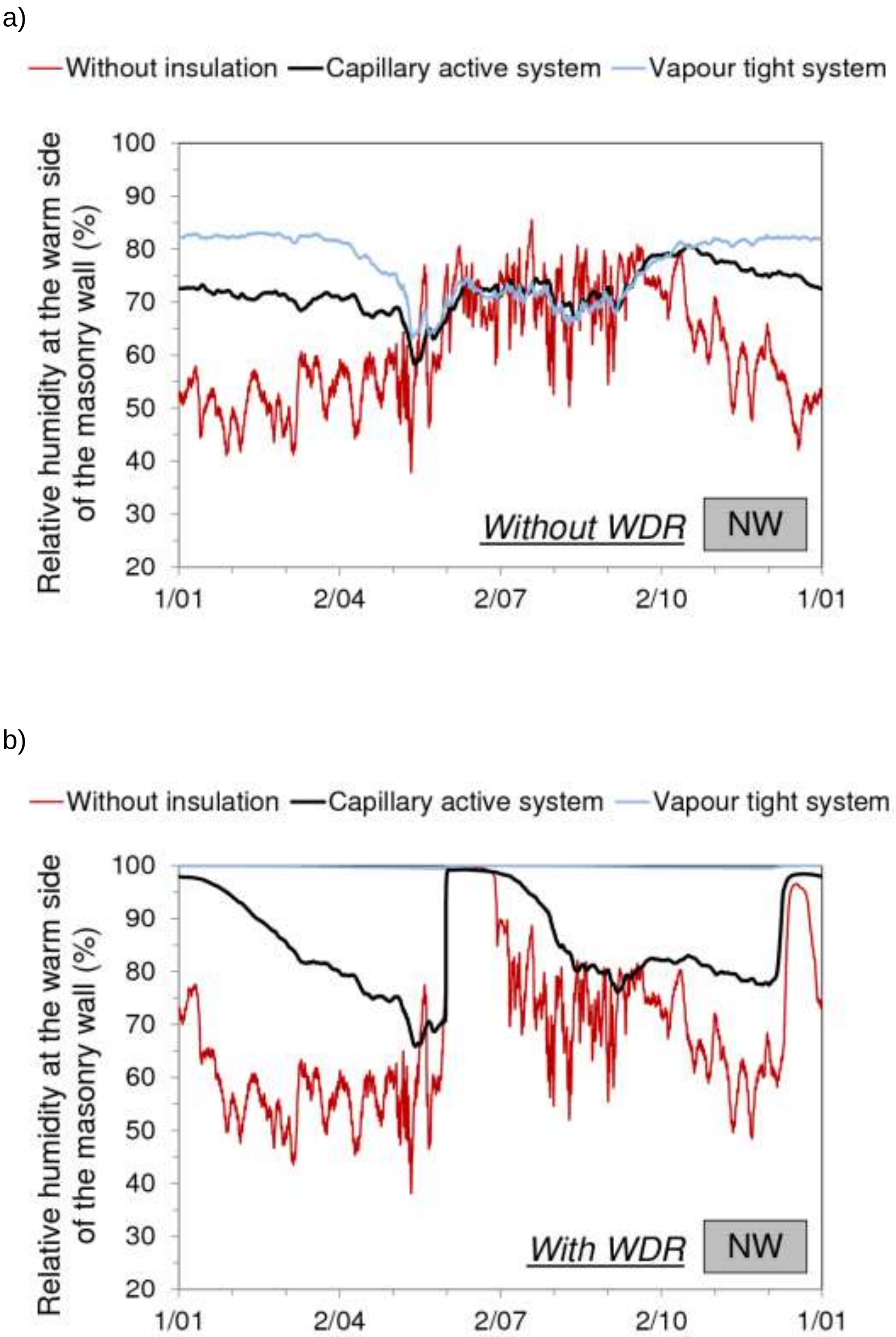


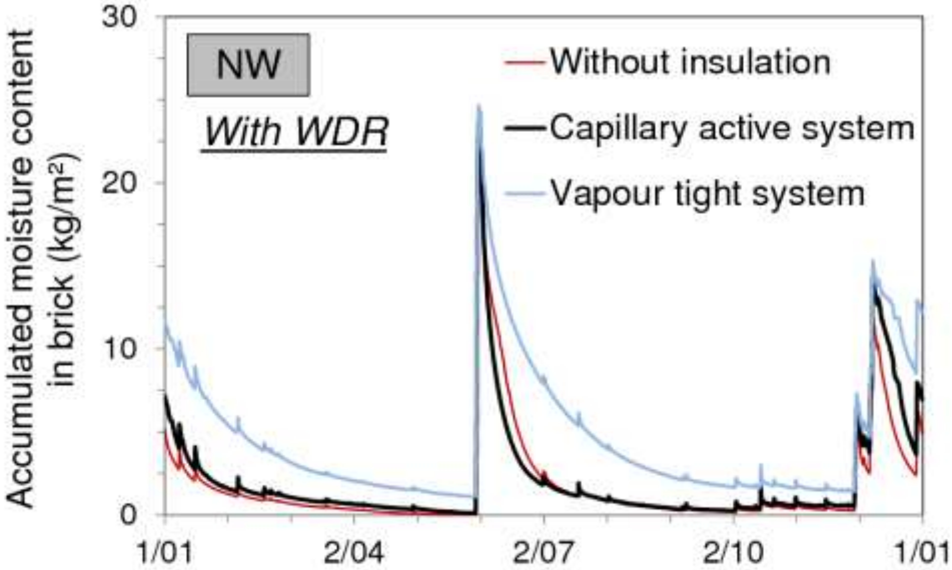
Figure 2


a)
Without insulation
Capillary active system
Vapour tight system
Relative humidity at the warm side of the masonry wall (%)
100
90
80
70
60
50
40
30
20
1/01
2/04
2/07
2/10
1/01
Without WDR
NW
b)
Without insulation
Capillary active system
Vapour tight system
Relative humidity at the warm side of the masonry wall (%)
100
90
80
70
60
50
40
30
20
1/01
2/04
2/07
2/10
1/01
With WDR
NW

Postprint: *Vereecken E, Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures 48(9): 3009-3021.*

Figure 3

a)



b)

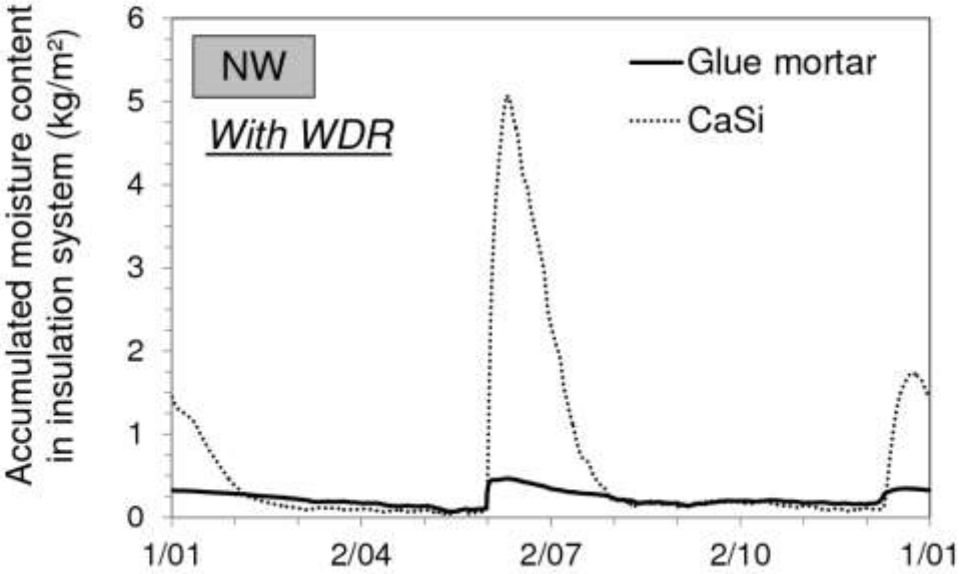
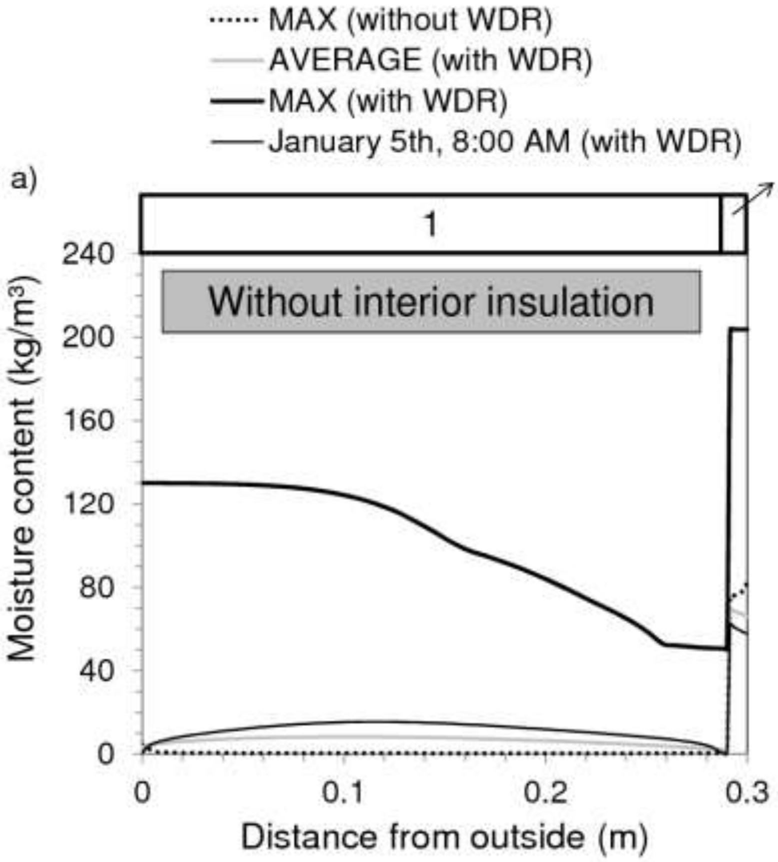
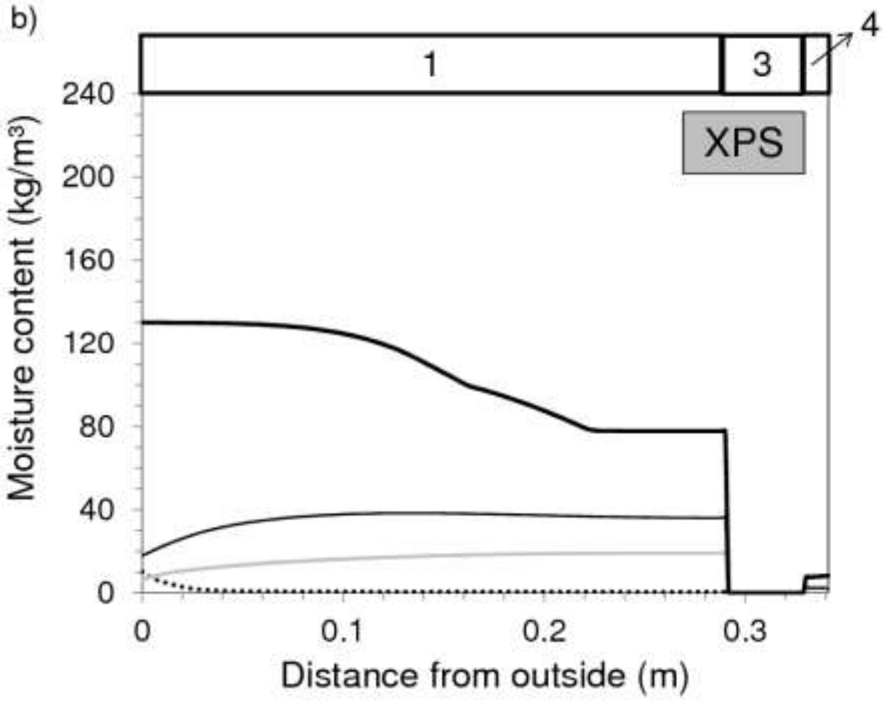


Figure 4

a)


MAX (without WDR)
AVERAGE (with WDR)
MAX (with WDR)
January 5th, 8:00 AM (with WDR)
a)
1
2
Without interior insulation
Moisture content (kg/m³)
0
40
80
120
160
200
240
0
0.1
0.2
0.3
Distance from outside (m)

b)


b)
1
3
4
XPS
Moisture content (kg/m³)
0
40
80
120
160
200
240
0
0.1
0.2
0.3
Distance from outside (m)

c)

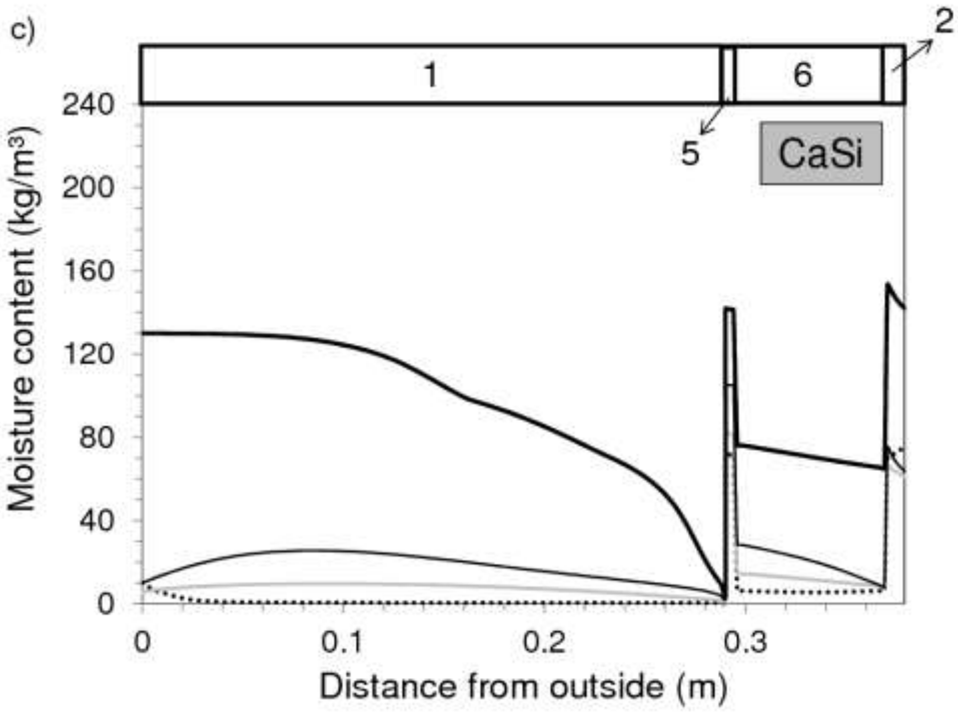
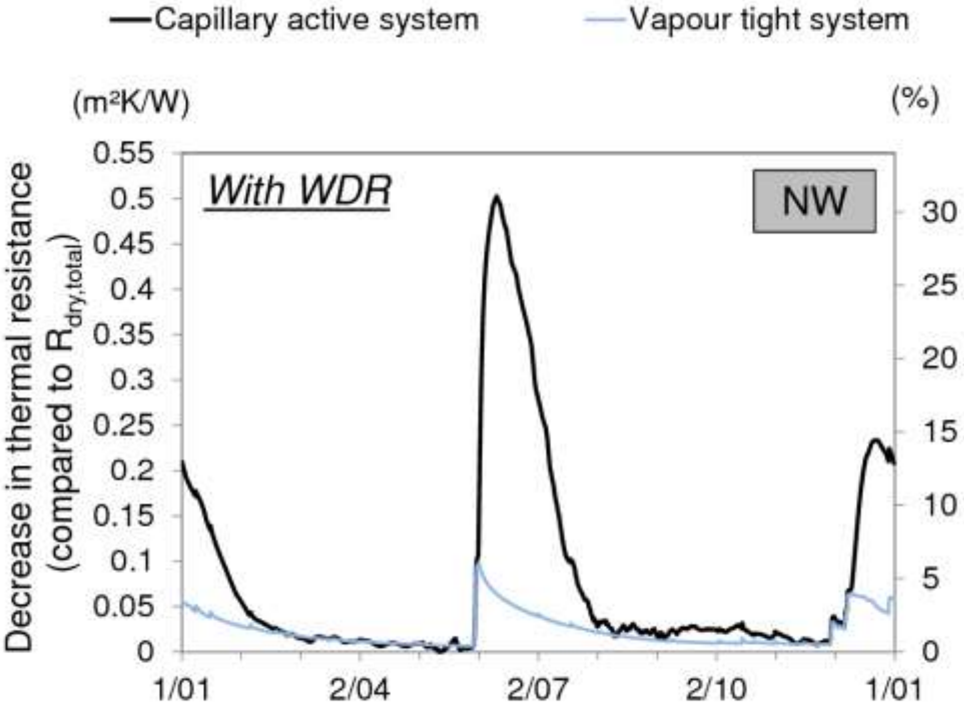

c)
1
6
2
5
CaSi
Moisture content (kg/m³)
240
200
160
120
80
40
0
0
0.1
0.2
0.3
Distance from outside (m)

Figure 5


Capillary active system
Vapour tight system
(m²K/W)
(%)
Decrease in thermal resistance (compared to R_dry,total)
With WDR
NW
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
30
25
20
15
10
5
0
1/01
2/04
2/07
2/10
1/01

Postprint: *Vereecken E, Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures 48(9): 3009-3021.*

Figure 6

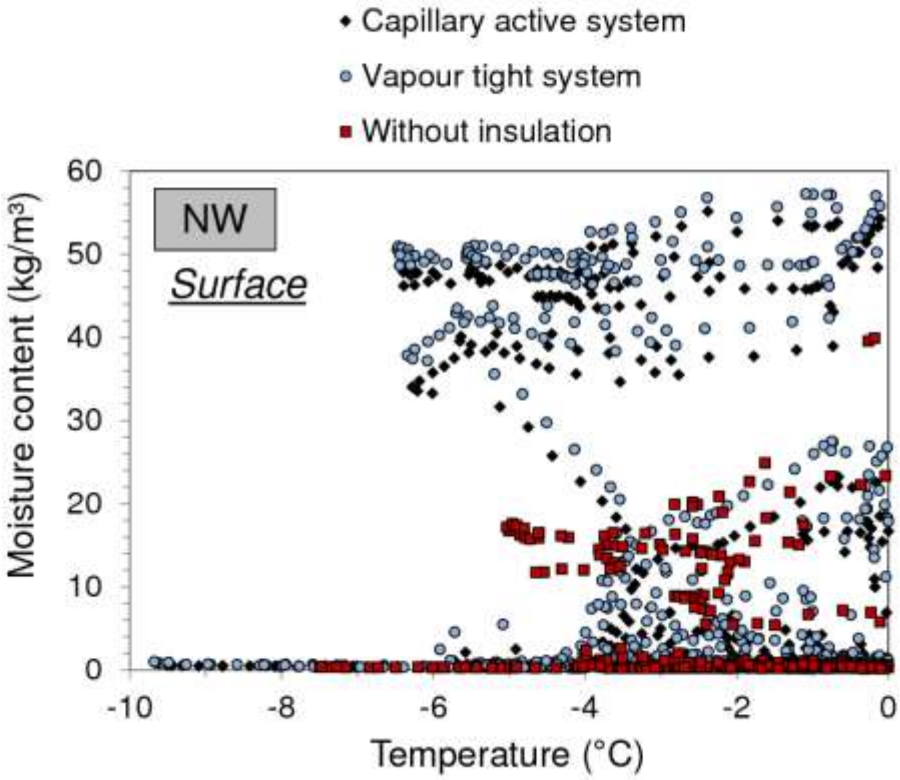
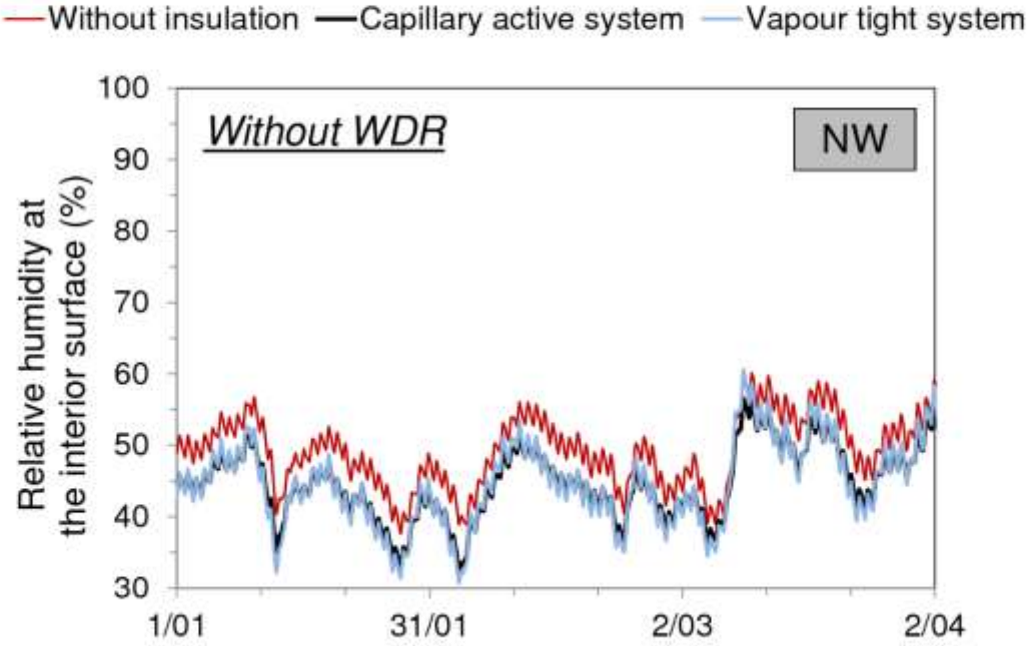
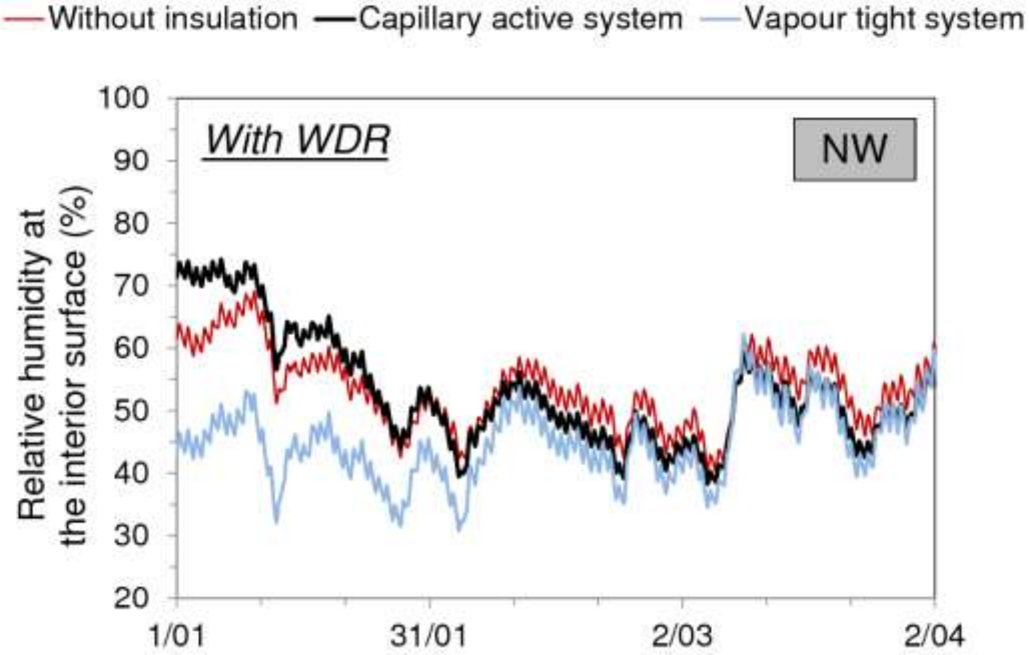


Figure 7

a)


Without insulation
Capillary active system
Vapour tight system
Without WDR
NW
Relative humidity at the interior surface (%)
100
90
80
70
60
50
40
30
1/01
31/01
2/03
2/04

b)


Without insulation
Capillary active system
Vapour tight system
With WDR
NW
Relative humidity at the interior surface (%)
100
90
80
70
60
50
40
30
20
1/01
31/01
2/03
2/04

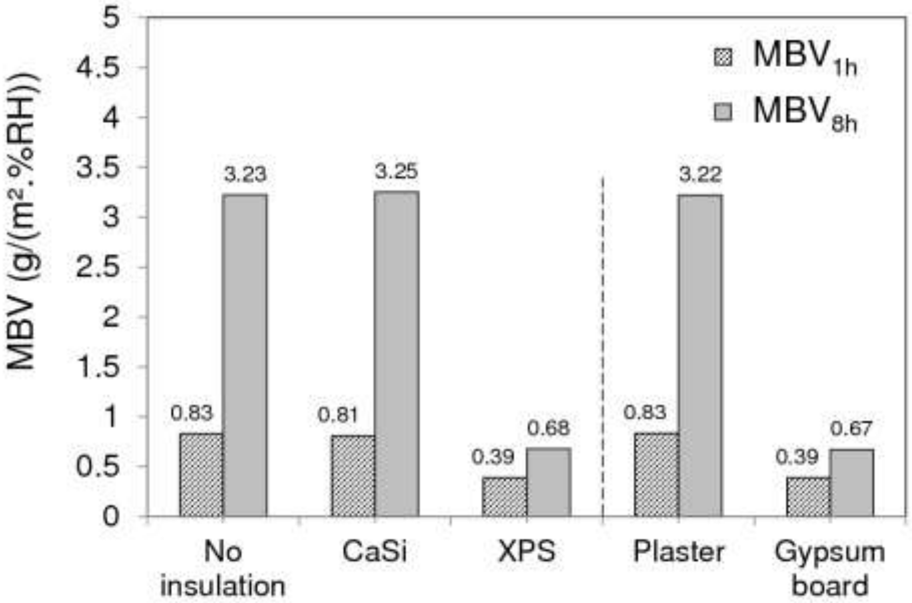


Figure 8

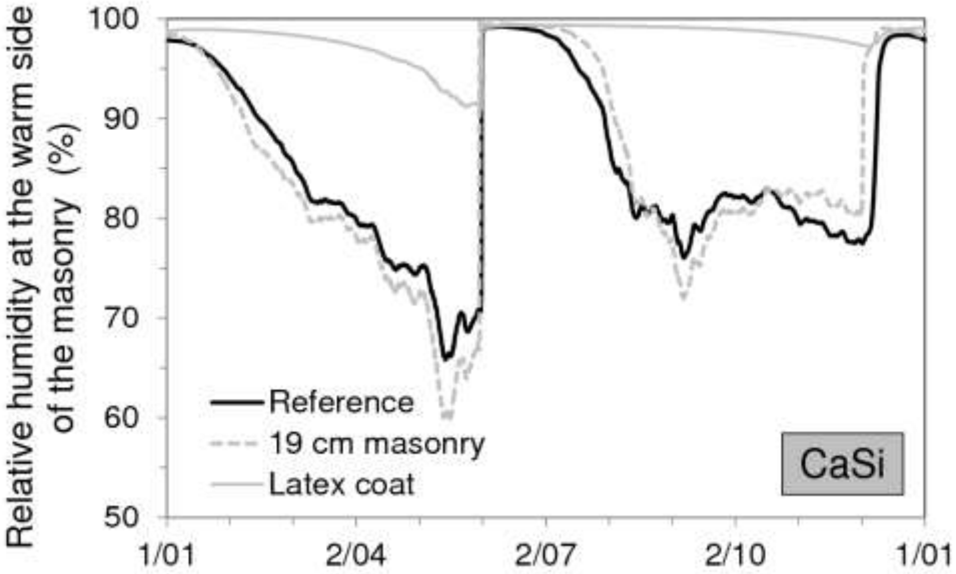


Figure 9

Postprint: *Vereecken E, Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures 48(9): 3009-3021.*

Figure 10

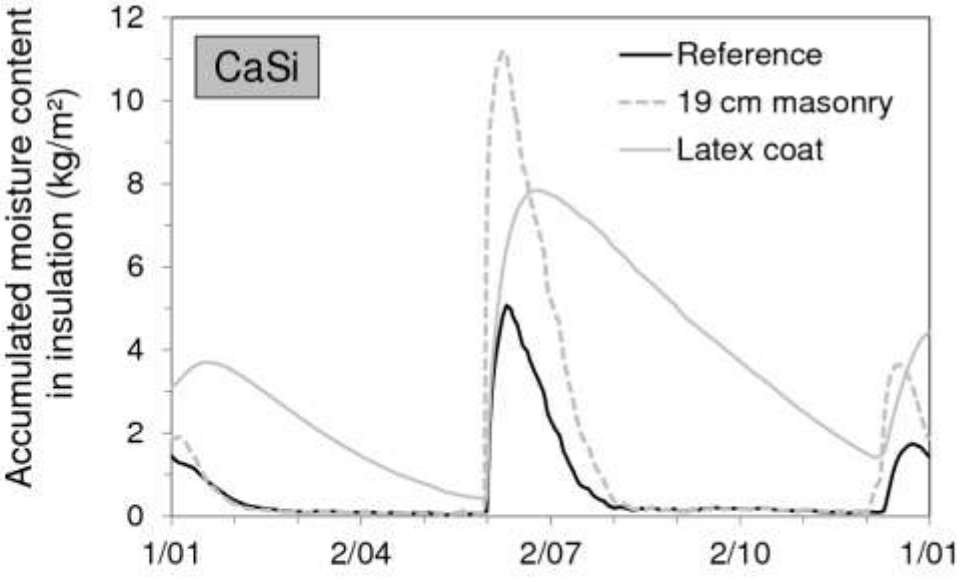
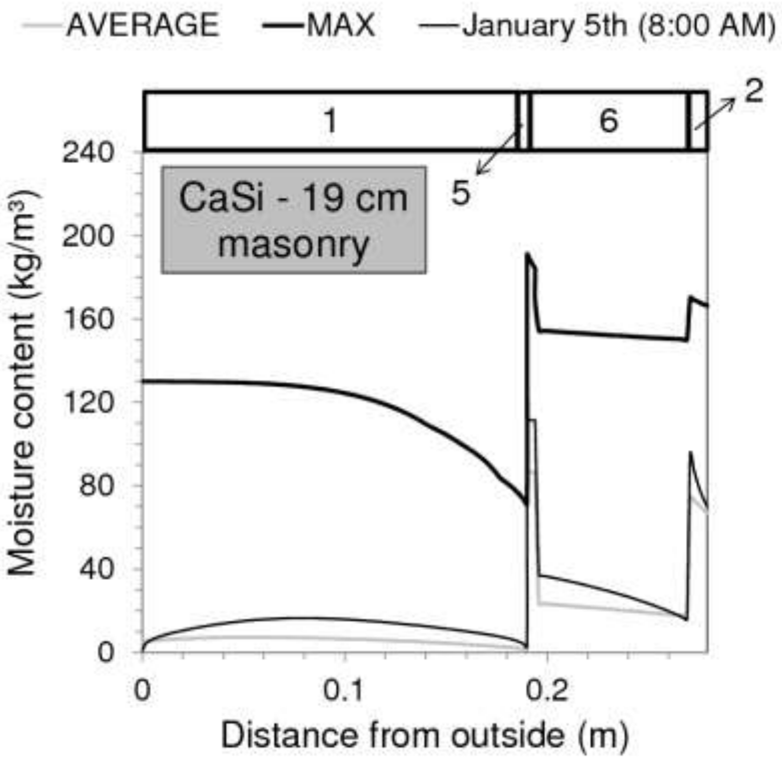
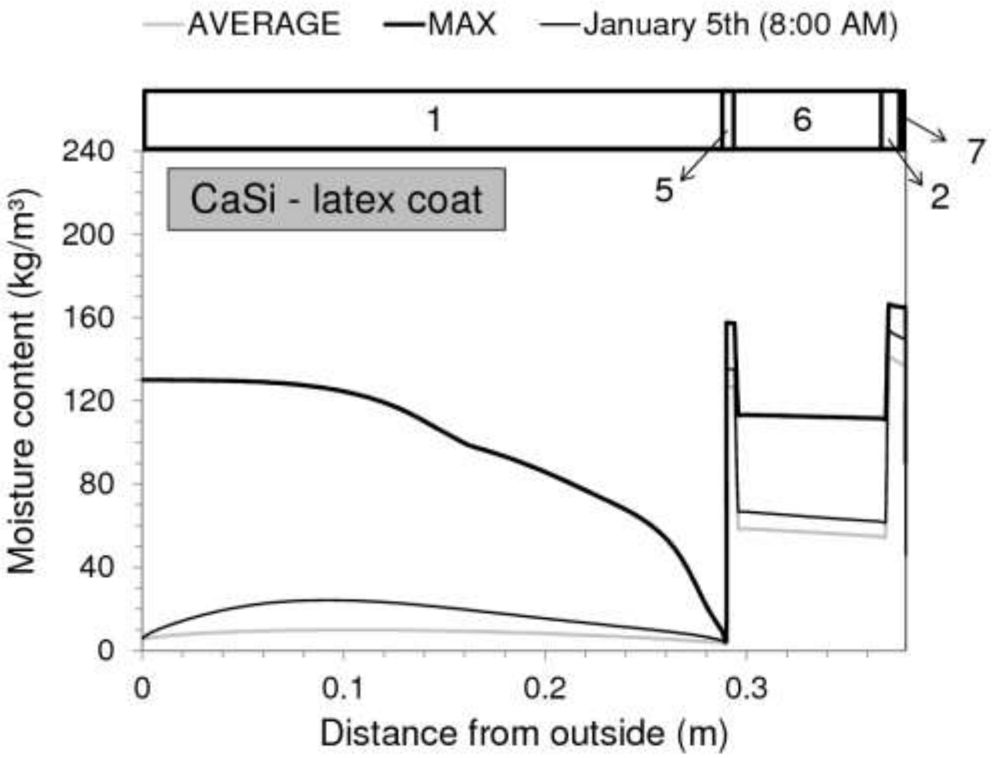


Figure 11

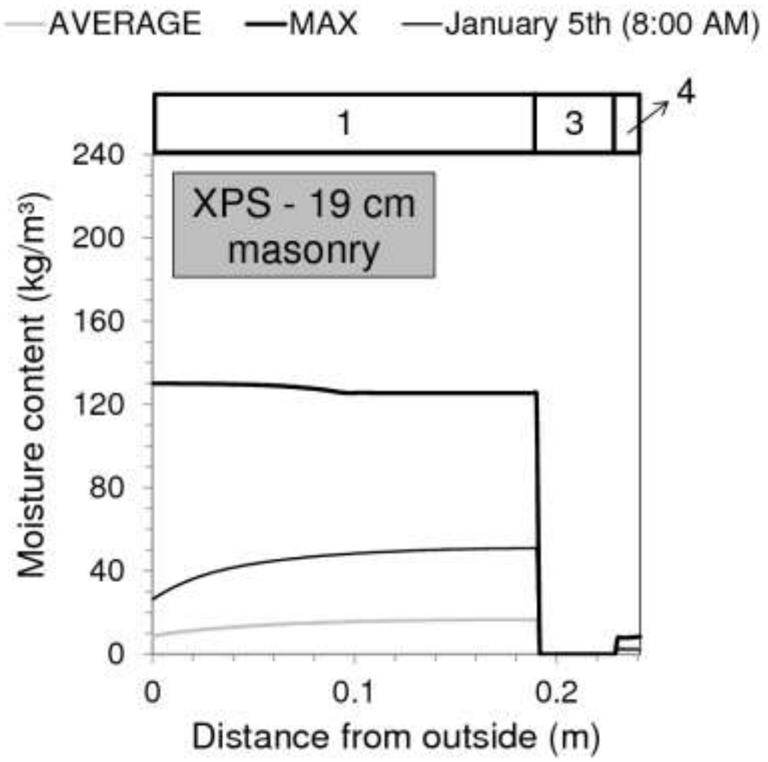
a)


AVERAGE
MAX
January 5th (8:00 AM)
1
6
2
5
CaSi - 19 cm masonry
Moisture content (kg/m³)
0
40
80
120
160
200
240
0
0.1
0.2
Distance from outside (m)

b)


AVERAGE
MAX
January 5th (8:00 AM)
1
6
7
5
2
CaSi - latex coat
Moisture content (kg/m³)
0
40
80
120
160
200
240
0
0.1
0.2
0.3
Distance from outside (m)

c)


AVERAGE
MAX
January 5th (8:00 AM)
1
3
4
XPS - 19 cm masonry
Moisture content (kg/m³)
240
200
160
120
80
40
0
0
0.1
0.2
Distance from outside (m)

d)

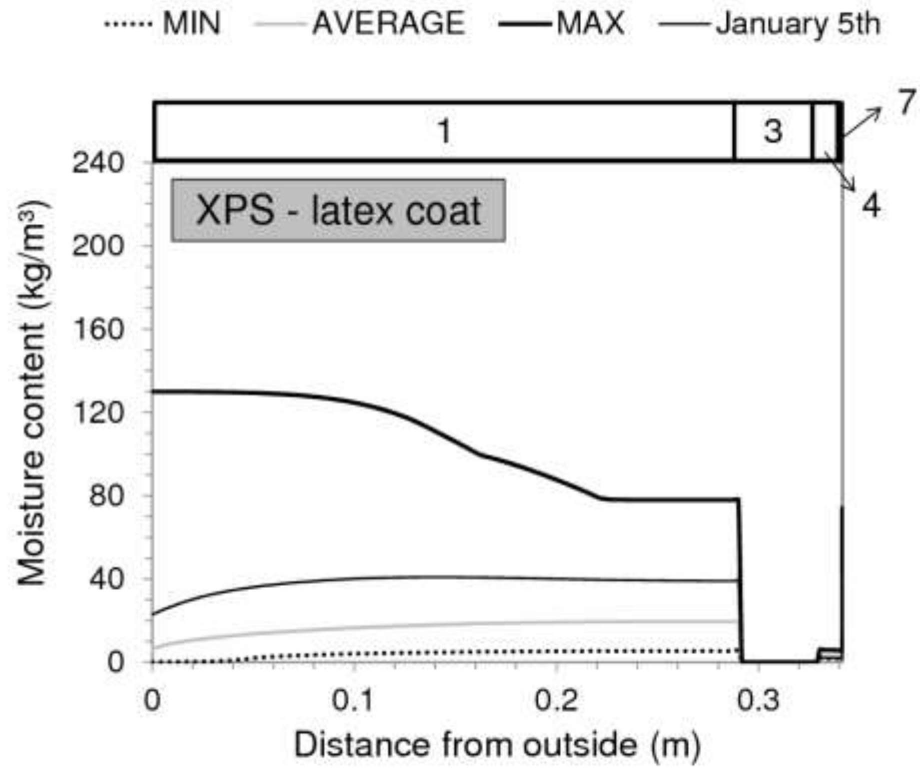
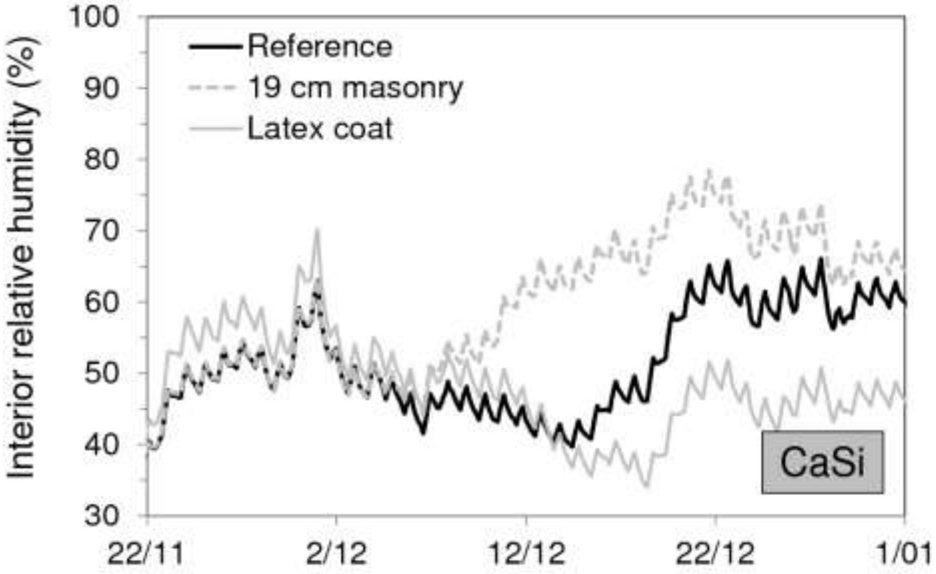

MIN
AVERAGE
MAX
January 5th
1
3
7
4
XPS - latex coat
Moisture content (kg/m³)
240
200
160
120
80
40
0
0
0.1
0.2
0.3
Distance from outside (m)

Figure 12

a)


Interior relative humidity (%)
100
90
80
70
60
50
40
30
Reference
19 cm masonry
Latex coat
CaSi
22/11
2/12
12/12
22/12
1/01

b)

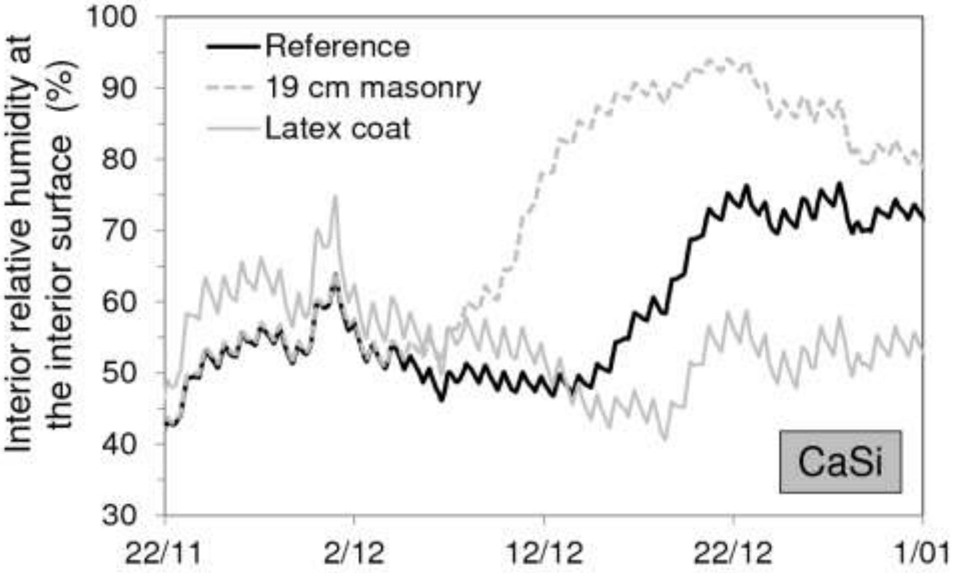

Interior relative humidity at the interior surface (%)
100
90
80
70
60
50
40
30
Reference
19 cm masonry
Latex coat
CaSi
22/11
2/12
12/12
22/12
1/01

Figure 13

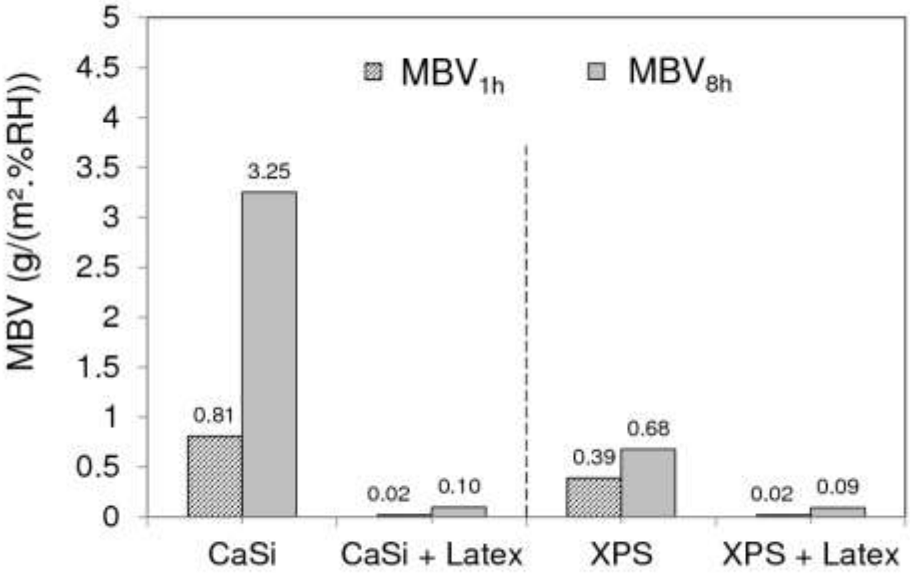
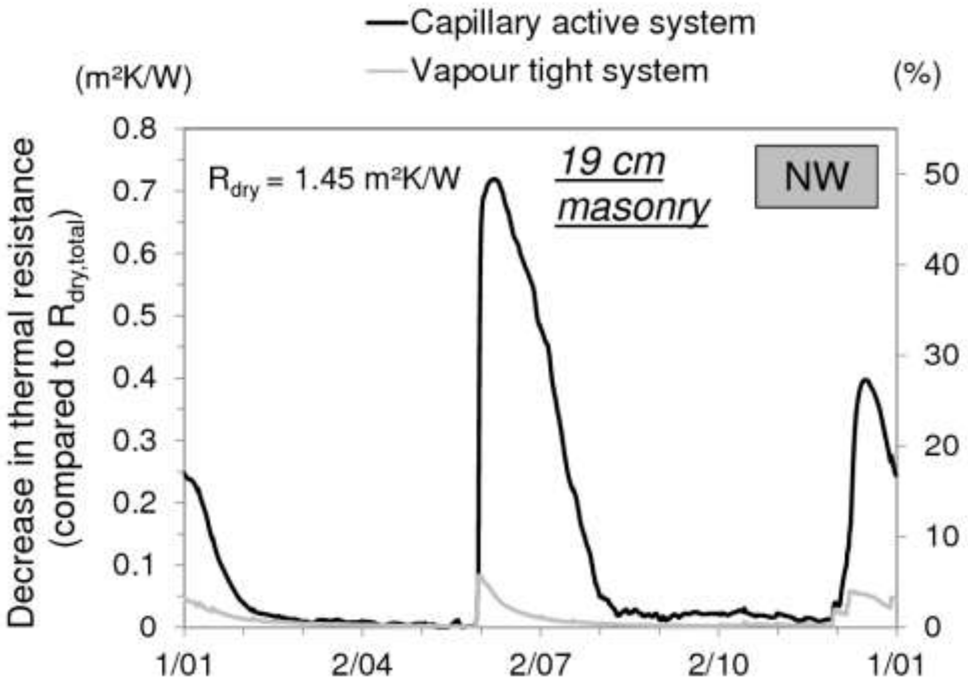
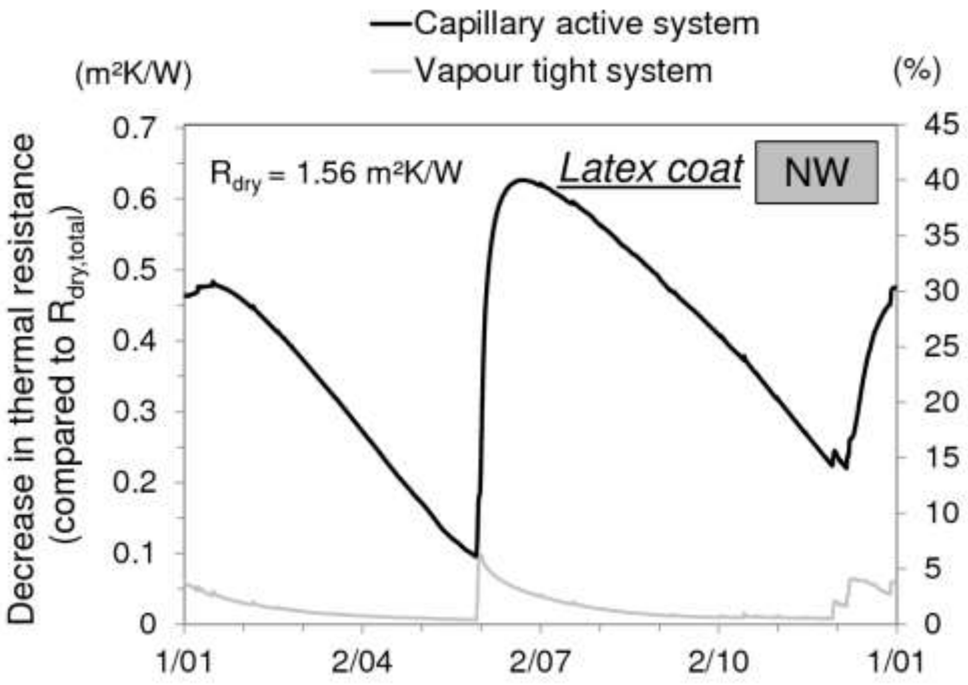

MBV (g/(m².%RH))
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
▨ MBV1h
▨ MBV8h
0.81
3.25
0.02
0.10
0.39
0.68
0.02
0.09
CaSi
CaSi + Latex
XPS
XPS + Latex

Figure 14

a)


Capillary active system
Vapour tight system
(m²K/W)
(%)
Decrease in thermal resistance (compared to R_dry,total)
R_dry = 1.45 m²K/W
19 cm masonry
NW
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
40
30
20
10
0
1/01
2/04
2/07
2/10
1/01

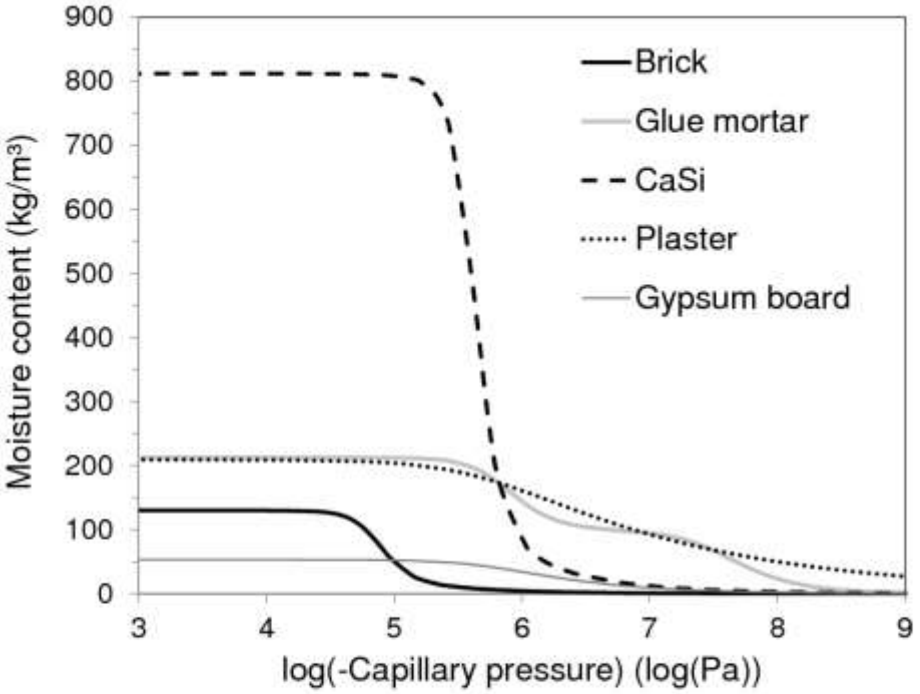
b)


Capillary active system
Vapour tight system
(m²K/W)
(%)
Decrease in thermal resistance (compared to R_dry,total)
R_dry = 1.56 m²K/W
Latex coat
NW
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
45
40
35
30
25
20
15
10
5
0
1/01
2/04
2/07
2/10
1/01

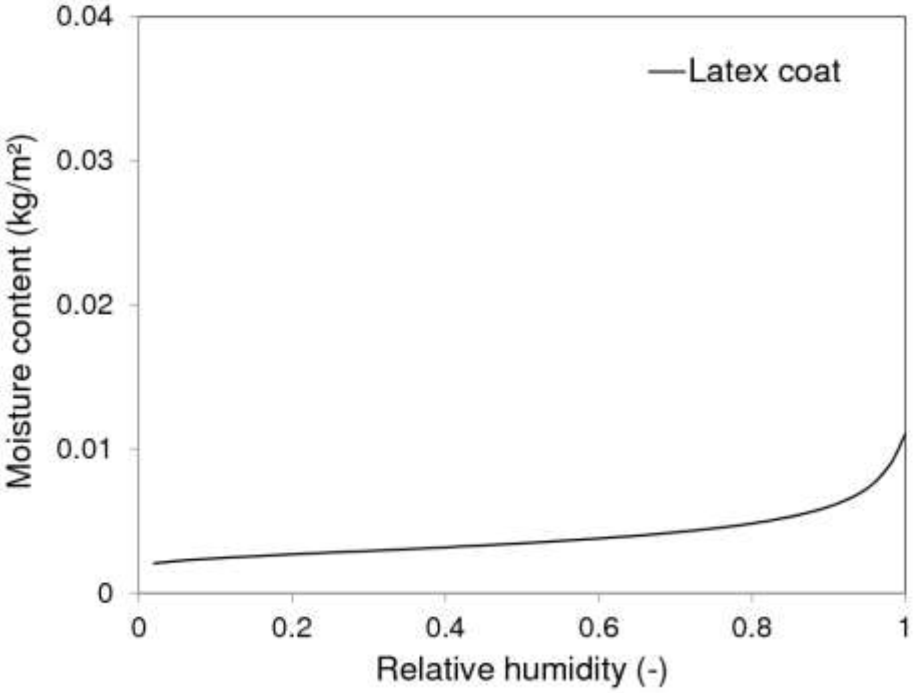
Postprint: *Vereecken E, Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures 48(9): 3009-3021.*

Figure 15

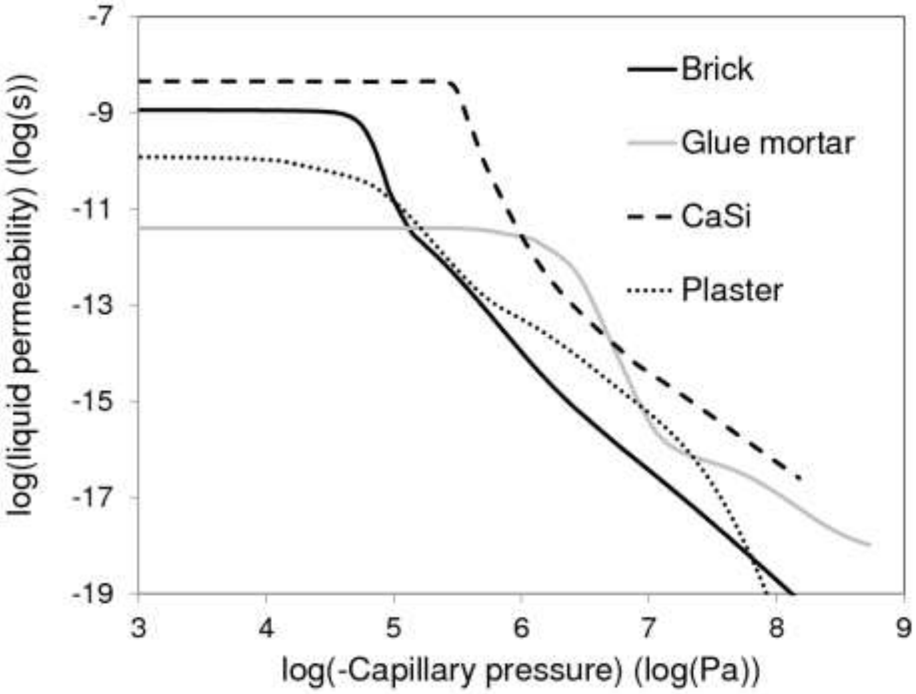
a)



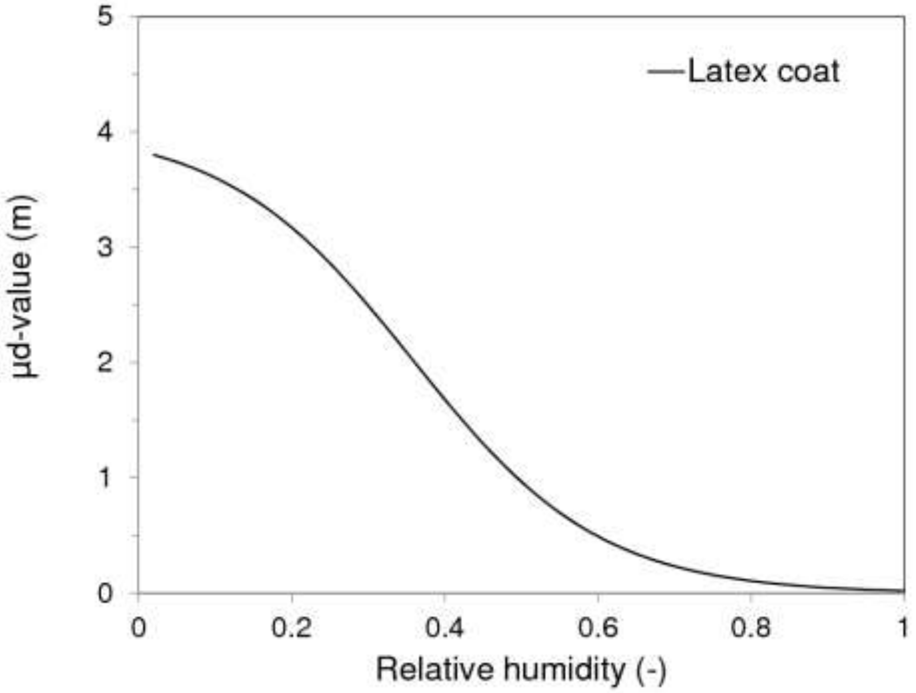
b)



c)


-7
-9
-11
-13
-15
-17
-19
3
4
5
6
7
8
9
log(liquid permeability) (log(s))
log(-Capillary pressure) (log(Pa))
Brick
Glue mortar
CaSi
Plaster

d)


5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
µd-value (m)
Relative humidity (-)
Latex coat