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Hygrothermal behaviour of timber frame walls finished with a brick veneer cladding

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Abstract

In this study, two typical timber frame walls with brick veneer cladding have been constructed at KU Leuven to investigate the hygrothermal response of these constructions in a moderate sea climate. Main topic of research is the contradictory criterion for the wind barrier when it comes to the risk on interstitial condensation for winter and summer conditions: in winter a vapour open wind barrier is appropriate, in summer a more vapour tight. Therefore, similar walls but with different types of wind barrier have been investigated. In one set-up a vapour open bituminous impregnated wood fibre board is used as wind barrier, whereas in the second set-up a more vapour tight wood fibre cement board is used. The study shows that a high relative humidity can be expected at the interface between insulation and wind barrier during winter conditions, leading to a high mould growth index. In contrast, the relative humidity at the interface between insulation and inner vapour retarder during summer is lower than expected. This can be caused by the buffering capacity of the hygroscopic materials in the wall.

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Keywords: timber frame wall, brick veneer cladding, interstitial condensation, wind barrier, mould risk

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1. Introduction

An important role of building enclosures is to protect the indoor climate from environmental loads. The control of in- and outward energy and mass flows by the exterior building components is therefore an essential aspect. To reduce the risk of damage, it is appropriate to keep the moisture levels in the walls low enough, especially in case of timber frame constructions. According to Straube and Finch [1], the most important moisture sources leading to the deterioration of the building envelope are 1) precipitation, 2) vapour transfer through the wall by diffusion and/or advection, 3) built-in and stored moisture and 4) capillary or gravity-driven ground water. Regarding the second point, the building component should be designed in a way that a high relative humidity and interstitial condensation are avoided. Today, it is common practice in Europe to provide a vapour barrier/retarder at the inside of the wall, while the layers to the outside have an increasing level of vapour permeability [2]. In this way, the condensation risk of outward vapour flow in the outer layers is limited. However, according to Sandin [3], the optimum moisture design cannot be generally stated. It depends, among others, on the climate and indoor conditions. In winter conditions for moderate European climates, mainly an outward vapour flow will take place through the building component, whereas in summer conditions solar driven inward diffusion may occur. According to Wilkinson [4], the factors that influence solar driven inward diffusion are: 1) exposure to wind-driven rain and solar radiation, 2) moisture absorptive and buffer capacity of the cladding, 3) presence of cavity ventilation, 4) vapour permeability of the sheathing layers behind the cladding and the interior finish/vapour control layers and 5) interior temperature. In case of brick veneer cladding, a cladding with a high moisture buffer capacity yet with low cavity ventilation rates, the relative humidity in the wall will greatly depend on the moisture transfer from the masonry to the inner leaf. In order to reduce the relative humidity in the wall during summer, Sandin [3] proposes three solutions. A first solution is to keep the masonry dry, resulting in no inward vapour transport. This can be achieved by hydrophobation of the wall. Another solution to lower the humidity levels in the wall is to limit the inward moisture transport, for example by a well-ventilated cavity or a wind barrier with a certain vapour resistance. A last solution is to make sure that moisture can freely flow through the building component. This means that no vapour barriers are provided. Furthermore, a study conducted by Geving et al. [5] showed that insulation with a high moisture capacity (e.g. wood fibre insulation) can also help to reduce the relative humidity peaks in the wall. In contrast, during winter conditions, the relative humidity levels are high only in the outer parts of the wall [3]. Wilkinson [4] stated that, compared to summer condensation, the risk on mould growth is lower since temperatures are lower. Nevertheless, providing thermal insulation at the outside of the inner wall will lead to higher temperatures, and consequently a lower relative humidity in the inner wall [3].

In this paper, the hygrothermal conditions in a timber frame wall with brick veneer cladding are studied. Therefore, in-situ measurements on two timber frame walls were conducted at KU Leuven. The only difference between the two walls is the vapour permeability of the wind barrier. A more vapour open wind barrier is advantageous to avoid interstitial condensation in winter conditions, however solar driven condensation in summer may occur. On the other hand, a more vapour tight wind barrier will better resist solar driven moisture ingress yet in this case interstitial condensation in winter conditions may occur. The aim of this study is to investigate which role the exterior sheathing can play in the reduction of moisture related problems in timber frame walls located in a moderate sea climate.

2. Experimental set-up and material properties

Two typical timber frame walls with brick veneer cladding exposed to real outdoor conditions have been constructed at KU Leuven (Figure 1). The height of the walls is 2.7 m, whereas the width is 0.8-0.9 m. The walls are oriented to the South-West, which in Belgium is the direction of prevailing winds and solar radiation. The two walls are identical except for the wind barrier. In one set-up a bituminous impregnated wood fibre board, here a Celit board [6], is used as wind barrier. The second set-up is provided with a wood fibre cement board, in casu a Duripanel board [7]. Both wind barriers have a thickness of 18 mm. The wall's insulation consists of mineral wool with a thickness of 20 cm yet compressed to 18 cm. The wall is finished with a 22 mm thick OSB board at the inside. Furthermore, the thickness of the brick veneer cladding is 9 cm and the cavity depth is 4 cm. The cavity is ventilated by 1 open head joint (3.5 x 1.5 x 9 cm^3) both at the top and bottom. A measuring grid of sensors is installed throughout the wall to monitor temperature and relative humidity (see Figure 1). In addition, the exterior climatic conditions are also registered by the building's weather station.

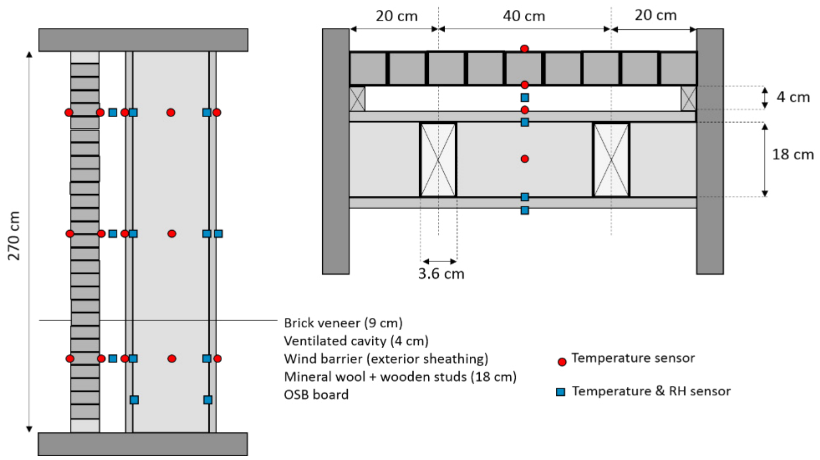

Figure 1: Vertical and horizontal section of the test wall with the sensor positioning

Figure 2 shows the measured vapour diffusion thickness s_d (m) and the sorption curves (in kg/m³) of the different materials in the inner wall. Regarding the two wind barriers, the vapour permeability of the Celit board is much higher. Furthermore, the Celit board clearly has a lower moisture capacity than the Duripanel board.

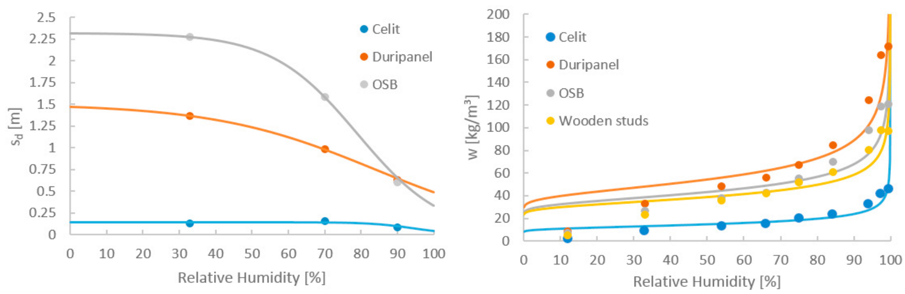

Figure 2: Vapour diffusion thickness and sorption curve of the different materials in the inner wall

3. Elementary stationary example

In order to get an idea of the possible moisture related risks in both walls, a simple stationary calculation is executed without considering the hygroscopic properties of the different materials. The relative humidity at the intersection of the mineral wool layer and the exterior sheathing is evaluated for winter conditions. In addition, the relative humidity at the intersection of the mineral wool layer and the OSB board is evaluated for summer conditions. Relative humidity is calculated as a function of the cavity conditions, which serve as exterior boundary conditions. In winter, the interior boundary conditions are set to 20°C and a relative humidity of 40%, whereas in summer slightly higher values are used, 22°C and 60%. The results are illustrated in Figure 3. From this stationary example it is clear that the more vapour tight wind barrier (Duripanel) is disadvantageous in winter conditions. If the temperatures become very low inside the cavity, interstitial condensation will occur in the wall with the more vapour tight wind barrier. In the other wall (with the Celit board), only a high relative humidity is expected. In contrast, in summer conditions, when the relative humidity inside the cavity becomes high, the more vapour tight exterior sheathing performs better. In both walls, however, this simplified analysis shows a significant risk on interstitial condensation on the OSB board.

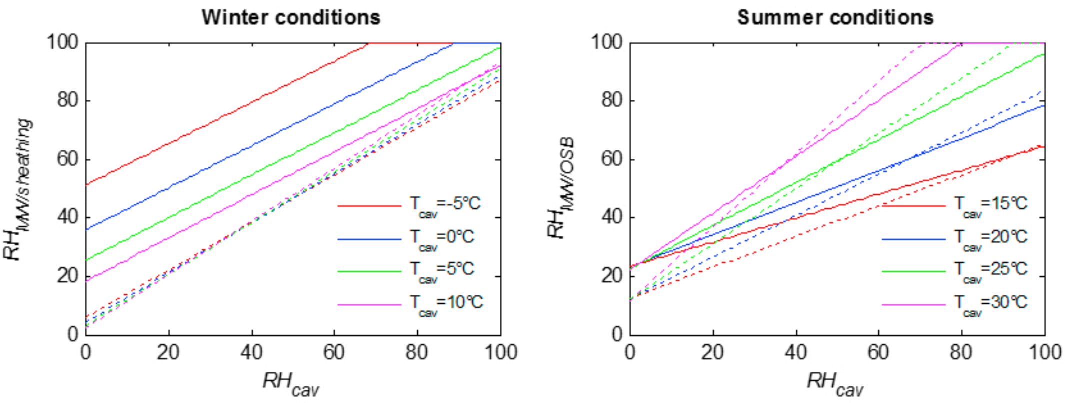

Figure 3: Elementary stationary calculation of the relative humidity at the mineral wool-wind barrier interface in winter conditions and at the mineral wool-OSB interface in summer conditions for the wall with the vapour open wood fibre board (Celit, dotted line) and the wall with the more vapour tight wood fibre cement board (Duripanel, solid line) as exterior sheathing

4. In-situ results

This paragraph presents the results from the in-situ measurements. In Figure 4, the interior vapour pressure (green) is plotted together with the cavity vapour pressures of the two walls (red and blue) for a period between November 2015 and November 2016. In this way, the direction and magnitude of the vapour flux inside the wall can be understood. Due to technical issues, there is no data available for the end of July. In winter conditions, the interior vapour pressure is on average slightly higher than the cavity vapour pressures, leading to an outward vapour flow. However, even in winter conditions, the cavity vapour pressure can peak to higher values, making an inward vapour flow possible. In summer, the cavity vapour pressure can peak to values up to 5000 Pa. The interior vapour pressure is now generally lower, leading to an inward vapour transport. But, during the night, the vapour pressure inside the cavity drops below the interior vapour pressure, changing the vapour flow direction. It must be emphasized that the interior vapour pressures in summer often are quite high. This is due to the malfunctioning of the air conditioning unit in the test building. In this way, vapour pressures are elevated inside the wall. However, during the same period, also temperatures were high inside the building, which is detrimental for summer condensation. The measurements at these moments are thus best interpreted as values in buildings where the interior climate is not regulated.

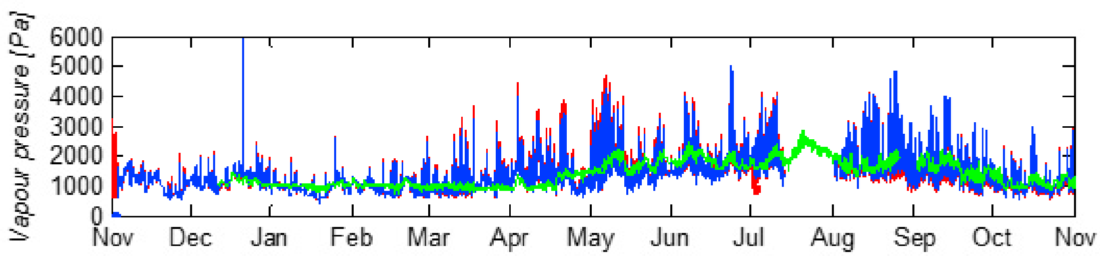

Figure 4: Inside vapour pressure (green) versus vapour pressure inside the cavity of the wall with the wood fibre board (red) and the wall with the wood fibre cement board (blue)

In Figure 5, the temperature and relative humidity at the interface of the mineral wool and the wind barrier respectively OSB board are shown for the same period as the previous figure: November 2015 until November 2016. At the interface between the mineral wool and the wind barrier, a high relative humidity is expected in winter, which is confirmed by the measurements. Moreover, the relative humidity remains very high for multiple months, even when temperature rises during March and April. It can be noticed that the relative humidity in the wall with the more vapour tight exterior sheathing is slightly lower compared to the other wall. This is opposed to the conclusion of the stationary calculation in section 3. Since temperatures are practically equal in both cases, the reason for this is possibly the moisture capacity of the wood fibre cement board, which is much larger than the moisture capacity of the bituminous impregnated wood fibre board. In summer, the relative humidity at this interface decreases due to the higher temperatures. Regarding the interface between the mineral wool and the OSB board, there is a logical trend: low relative humidity in winter conditions and higher humidity conditions in summer conditions are registered. In springtime, when cavity vapour pressures already reach high values, the relative humidity in case of a more vapour open wind barrier is indeed higher at this interface, as was also expected by the simple calculation example. However, the differences are rather small, and the relative humidity rarely reaches high values during the entire measuring period. A possible explanation is the buffering effect of the hygroscopic materials in the wall, especially the Duripanel board and the wooden studs, which are not included in the stationary calculations. Similar to the findings of Geving et al. [5], these materials may help to reduce the relative humidity levels in the walls.

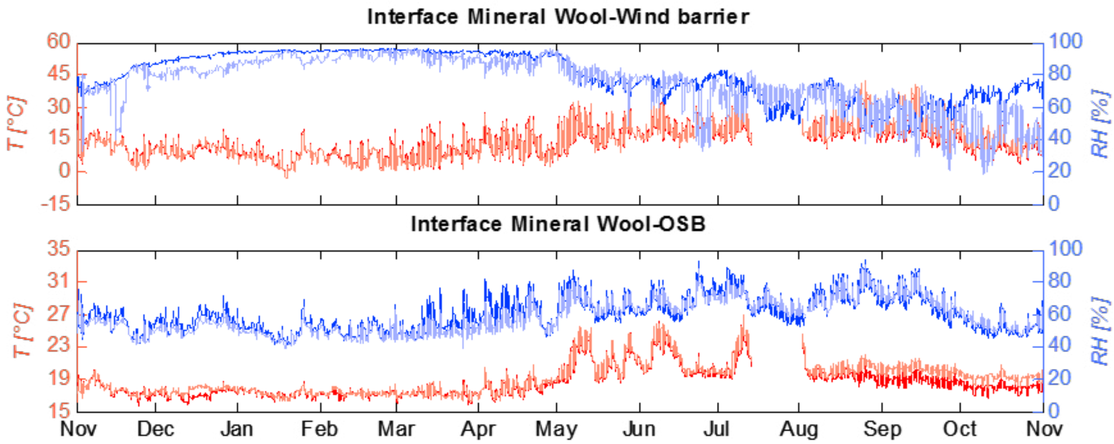

Figure 5: Temperature and relative humidity at the interface of the mineral wool and the wind barrier (top) and the mineral wool and the OSB board (bottom) for the wall with the vapour open (dark curves) and the wall with the more vapour tight (light curves) exterior sheathing

5. Mould risk

To evaluate the moisture related risks in the timber frame walls with brick veneer cladding, a mould prediction model is applied on the in-situ measured data. The VTT mould model developed by Hukka and Viitanen [8] indicates the mould growth development by an index ranging from 0 (no growth) to 6 (heavy and tight growth). In order to calculate a mould growth index over the full length of the measuring period, interpolation is applied in the period where no temperature data was available (end of July). However, the relative humidity in this period was below 80%, the threshold for mould growth, thus this has no influence on the results. Since the wooden studs in the test walls are made of pine, the mould index is calculated for pine and original kiln-dried timber. The results are illustrated in Figure 6. As can be seen, no mould is expected at the interface between the mineral wool and the OSB board. This is due to the fact that relative humidity at this interface in summer is not high for a longer period. The values are fluctuating around the threshold for mould germination. At the interface between the mineral wool and the wind barrier, meanwhile, mould growth visually detectable can be expected. Surface areas less than 10% (for the vapour tight wind barrier) and up to more than 50% (for the vapour open board) are predicted by the VTT model. This mould growth is developed in the winter and spring months, caused by the high values of RH, although temperatures remain relatively low in this period. The lower mould index for the more vapour tight wind barrier is thus opposite to the presumption that a wind barrier with a higher permeability would be more advantageous in winter conditions. As mentioned earlier, a possible explanation is the higher hygroscopic capacity of the board applied. During summer, the mould index decreases for this interface.

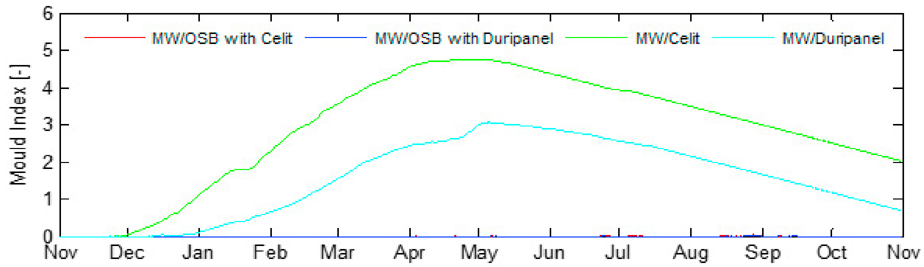

Figure 6: Mould Index for the interface between the mineral wool and the OSB board and the mineral wool and the wind barrier. (Celit = vapour open wind barrier; Duripanel = more vapour tight wind barrier)

6. Discussion and conclusion

In this study, the hygrothermal behaviour of timber frame walls with brick veneer cladding in a moderate sea climate is investigated. Therefore, two typical timber frame walls with brick veneer cladding exposed to real outdoor conditions have been constructed at KU Leuven. The two walls are identical except for the type of wind barrier. In one set-up a vapour open bituminous impregnated wood fibre board is used as wind barrier. This kind of barrier is advantageous to avoid interstitial condensation in winter conditions, however solar driven condensation in summer may occur. The second set-up is provided with a more vapour tight wood fibre cement board which has potentially a higher resistance against solar driven moisture ingress. Yet, in this case interstitial condensation in winter conditions might occur. The results show high relative humidity levels at the interface between the mineral wool and the wind barrier during winter conditions for both walls. In contrast to a simplified stationary calculation, the humidity level of the wall with the more vapour open wind barrier is slightly higher at this interface, possibly caused by the lower moisture capacity of this wind barrier. This is also in contrast with the presumption that the more vapour open wind barrier would be more advantageous in winter conditions due to its higher vapour permeability. Furthermore, differences in relative humidity between the two walls for the mineral wool-OSB interface are rather small. The relative humidity in case of a more vapour open wind barrier is slightly higher, as could be expected. However, the relative humidity at this interface in both walls rarely reaches high values during the entire measuring period. A possible explanation is again the buffer capacity of the hygroscopic materials. Finally, mould risks are the highest at the interface between the mineral wool and the wind barrier. Mould growth will develop in the winter and spring months. At the interface between the mineral wool and the OSB board, there is no mould risk according to the VTT mould model.

To conclude, risk on interstitial condensation and mould growth in timber frame walls with brick veneer claddings is a complicated problem defined by both the moisture transport and the moisture capacity properties of the different layers.

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