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On the hygrothermal behaviour of brick veneer clad timber frame walls: the role of the vapour diffusion resistance of the wind barrier

Michiel Vanpachtenbeke^{1,2,*}, Jelle Langmans³, Jan Van den Bulcke², Joris Van Acker² and Staf Roels¹

¹KU Leuven, Department of Civil Engineering, Building Physics Section, Kasteelpark Arenberg 40 – box 2447, BE-3001 Heverlee, Belgium

²UGent, Department of Environment, Laboratory of Wood Technology (Woodlab), Coupure Links 653, BE-9000 Ghent, Belgium

³Bauphi bvba, Stropkaai 55, BE-9000 Ghent, Belgium

**Corresponding email: Michiel.Vanpachtenbeke@kuleuven.be*

ABSTRACT

The present study looks into the hygrothermal behaviour of timber frame walls with brick veneer cladding in a moderate sea climate. It specifically focuses on the contradictory criterion for the wind barrier when it comes to the risk of interstitial condensation for summer and winter conditions: a vapour open wind barrier is advantageous during an outward vapour flow (i.e. in typical winter conditions for European climates), while during an inward vapour flow (i.e. in summer conditions) a more vapour tight wind barrier is appropriate. Therefore, a field study is conducted on two typical timber frame walls with brick veneer cladding and wind barriers with different vapour diffusion resistance: the s_d -value of the vapour open wind barrier and the more vapour tight wind barrier is 0.15 m and 1 m respectively at 70% relative humidity. The experimental results show little influence of the vapour tightness of the wind barrier: in general, relative humidity levels are similar in both walls. Outcomes of numerical HAM simulations indicate that this may be caused by the moisture buffer capacity of the different materials, which seems to play an important role to regulate the moisture levels inside the timber frame walls. Further research is needed, however, to draw general conclusions about the appropriate design of timber frame walls with brick veneer cladding.

KEYWORDS

Timber frame walls, brick veneer cladding, vapour diffusion resistance, moisture storage capacity, summer condensation

INTRODUCTION

The increasing environmental awareness has a substantial impact on the building sector. Past research made clear that timber as building material can help to reduce the carbon emission and the total energy requirement of buildings (Australian Government FWPRDC, 2004; Milne and Reardon, 2013). Therefore, the market share of timber frame constructions is increasing, even in countries with a tradition of masonry buildings. However, since wood is a moisture sensitive material, susceptible to mould growth and wood decay, it is essential to keep the moisture levels in the walls to an acceptable level, necessitating specific care when designing such walls. 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. In this way, the risk of interstitial condensation in the outer layers of the wall due to an outward vapour flow is limited. A rule of thumb suggests the layers at the warm side of the insulation to be at least 6 and preferable 15 times more vapour tight than the layers at the cold side of the insulation (WTCB, 2013). However, as already stated by different

researchers (Derome and Saneinejad, 2010; TenWolde and Mei, 1965), this design principle is based on cold climates where the ‘warm side of the insulation’ corresponds to the indoor environment. It does not consider possible inward vapour flow. In a country like Belgium with a masonry tradition, timber frame walls are often finished with a brick veneer cladding, which has a high buffer capacity for wind driven rain but low cavity ventilation rates (Langmans et al. 2016). Consequently, high moisture levels in the cavity behind the brick veneer cladding, resulting in an inward vapour flow, might occur. Different solutions influencing inward vapour flow do exist: hydrophobation of the brick veneer cladding, increasing the cavity ventilation rate or using a wind barrier with a higher vapour diffusion resistance (Sandin, 1993). The last solution is maybe the most simple solution, however increasing the risk of interstitial condensation in case of an outward vapour flow. Using the Glaser method (EN ISO 13788), one can get an idea of the potential problem. The relative humidity at the interface between the insulation (in casu mineral wool) and both the interior and exterior sheathing for a common timber frame inner wall has been calculated in function of the ratio of the vapour diffusion resistance of the interior and exterior sheathing (in terms of equivalent air layer thickness s_d : s_{din}/s_{dout}). The indoor conditions are 20°C and 50%. The cavity conditions are 3°C and 90% RH to simulate normal winter conditions and 35°C and 60% RH to simulate normal summer conditions. This simple calculation shows that only in a small range of s_{din}/s_{dout} the relative humidity at the interface between insulation and both sheathings will not reach 100% RH for the assumed winter as well as summer boundary conditions (Figure 1). In case the interior sheathing is 6 to 15 times more vapour tight than the exterior sheathing, the design will certainly lead to interstitial condensation in the assumed summer conditions according to this simple calculation.

Figure 1: According to an elementary calculation, relative humidity conditions will be high at least at one side of the insulation layer, no matter the ratio s_{din}/s_{dout} .

The previous example suggests that summer condensation cannot be avoided with the common type of timber frame walls. Note, though, that the Glaser method does not take into account hygric buffering, nor liquid moisture transport. Therefore, the present paper studies, in detail, the overall hygrothermal performance of brick veneer cladded timber frame walls in a moderate sea climate and its risk of interstitial condensation, with focus on the role of the vapour permeability of the exterior sheathing. Field measurements have been conducted at KU Leuven, Belgium, on timber frame walls with different types of wind barrier. The experimental results are compared with the outcomes of numerical simulations, which allow for extrapolation of the different parameters.

EXPERIMENTAL SET-UP AND SIMULATION MODEL

Experimental set-up

In the VLIET test building of KU Leuven (Belgium), a long-term in-situ measuring campaign is conducted on two typical timber frame walls with brick veneer cladding. The measurements started in October 2015. The walls are 2.7m by 0.8-0.9m and consist of a brick veneer

cladding (9cm), a ventilated cavity (4cm), a wind barrier (1.8cm), mineral wool insulation between wooden studs (18cm) and an OSB board as interior finishing layer (2.2cm), as shown in Figure 2. The brick has an absorption coefficient of $0.2584 \text{ kg/m}^2\text{s}^{0.5}$ and its capillary moisture content is 256.13 kg/m^3 . The wooden studs are made of Scots pine sapwood. Furthermore, the cavity is ventilated by one open head joint ($3.5 \times 1.5 \text{ cm}^2$) at the bottom and top of the wall. The walls are South-West oriented, which is in Belgium the direction of prevailing winds and solar radiation. The temperature, relative humidity and moisture content of the materials is measured at different positions inside the wall. A weather station at the top of the building registers the outdoor climatic conditions.

Figure 2: During field tests, the hygrothermal conditions inside real-scale timber frame walls with a brick veneer cladding are measured.

In one set-up (referred to as ‘open’) a vapour open bituminous impregnated wood fibre board (Celit¹) is used as wind barrier, whereas in the other set-up (referred to as ‘tight’) a more vapour tight wood fibre cement board (Duripanel²) is used. The vapour tightness of the interior finishing layer in both walls, in-casu OSB board, is in general still the highest however. Apart from a higher vapour diffusion resistance, the wood fibre cement board also has a higher moisture buffer capacity in the hygroscopic region compared to the wood fibre board (Figure 3).

Figure 3: Vapour diffusion resistance (left) and moisture buffer capacity (right) of the building materials

Numerical simulation model

The same timber frame wall configuration is modelled in the numerical HAM-simulation program DELPHIN 5.9 (Grunewald, 1997; Nicolai, 2007). Only a simplified 1D model without wooden studs is considered. Since air change rates behind brick veneer cladding ranges from 1-10 air changes per hour (ACH) (Langmans, 2016), a constant cavity ventilation

¹ Isoproc Solutions. Celit 3D. <https://www.isoproc.be/nl/solutions/producten/detail/celit-3d/355>

² Siniat. Duripanel S3(B1). <https://www.siniat.be/nl-be/producten-en-systemen/producten/platen/vezelcementplaat-duripanel>

rate of 5 ACH is assumed. The real indoor and outdoor conditions as in-situ measured are imposed as boundary conditions.

RESULTS

In-situ measurements

By comparing the indoor vapour pressure (red line) with the cavity vapour pressure for the open and tight set-up (dark and light blue line respectively) on daily averaged basis, it is clear that in 2016 inward as well as outward vapour flow occurs (Figure 4). Outward vapour flow mainly occurs in winter periods, whereas inward vapour flow mainly occurs in spring and summer periods. In 2016, based on 10-minute in-situ measured data, 40% of the time the vapour pressure inside the cavity was higher than the indoor vapour pressure (Table 1). The vapour pressure difference in case of inward vapour flow is on average twice as high compared to outward vapour flow, the standard deviation approximately three times higher. These figures show that inward vapour flow in case of brick veneer clad timber frame walls cannot be neglected.

Figure 4: Daily averaged indoor (red line) and cavity (dark and light blue for open resp. tight set-up) vapour pressures indicate in- as well as outward vapour flow throughout the year.

Table 1: The occurrence of inward vapour flow and the vapour pressure difference between indoor climate and cavity (average and standard deviation) clearly show that inward vapour flows must be taken into account in case of brick veneer clad timber frame walls.

	open		tight	
	In	Out	In	Out
Occurrence (%)	40	60	40	60
$\Delta P_{v,average}$ (Pa)	430	240	410	250
$\Delta P_{v,std}$ (Pa)	460	150	450	175

Next, the hygrothermal conditions at the potential condensation layers, the interface between mineral wool and interior and exterior sheathing, are analysed (Figure 5). At the interface between mineral wool and OSB board, a higher relative humidity is observed in summer conditions compared to winter conditions. However, the relative humidity rarely reaches values higher than 80% RH during the entire measurement period. Furthermore, little difference is observed between both set-ups. Only during springtime, when the cavity vapour pressure reaches high values while the indoor vapour pressure is still relatively low, the benefit of a more vapour tight wind barrier can be observed. At the interface between mineral wool and wind barrier, on the other hand, the relative humidity is higher in winter conditions than in summer conditions. Again, little difference is observed between both set-ups: the set-up with the more vapour tight wind barrier does not result in a higher condensation risk than the other set-up. A possible explanation for the fact that only small differences are noted between both set-ups is the moisture buffer capacity of the different materials inside the timber frame wall. To get more insight in the role of the moisture buffer capacity and vapour diffusion resistance, numerical simulations have been performed.

Numerical HAM-simulations

The trends in relative humidity at the interface between mineral wool and interior and exterior sheathing are quite well predicted by the numerical model (Figure 5). Only the relative humidity at the wind barrier in the tight set-up is underestimated in winter conditions. Although the wooden studs are not included in the numerical model, the simulations do not predict a higher condensation risk. This might indicate that the buffer capacity of the other materials inside the walls is already sufficient to lower the relative humidity peaks.

Figure 5: The in-situ measured relative humidity at both sides of the insulation layer shows only little differences between both set-ups. The numerical simulations are in line with the in-situ measured data.

To study the impact of the buffer capacity of the exterior sheathing on the potential condensation risk in winter conditions, the hygrothermal behaviour of the wall is simulated with a wind barrier as vapour tight as the wood fibre cement board, but with the same low moisture storage capacity of the wood fibre board. The results are compared with the original numerical outcomes (Figure 6). A lower moisture buffer capacity indeed leads to a higher relative humidity. In contrast, increasing the vapour diffusion resistance does not generally result in higher relative humidity. It must be stated, however, that the difference in vapour tightness of both wind barriers is less in the range of 80-90% RH compared to lower RH regions.

Figure 6: According to the simulations, the moisture buffer capacity of the wind barrier is more important than the vapour diffusion resistance.

A second simulation focuses on the buffer capacity of the OSB board. Figure 7 shows the change in relative humidity at the mineral wool – OSB interface with a theoretical OSB board without moisture buffer capacity. It is clear that in this case solar driven moisture transport leads to a condensation risk. Even the use of a more vapour tight wood fibre cement board as wind barrier does not eliminate this risk: the tight set-up is below 97% RH for only 6% of the time during which the open set-up is above this level. The different simulation assumptions, amongst them the exclusion of the wooden studs, may affect the hygrothermal conditions inside the wall. Nevertheless, the simulation outcomes emphasize the importance of the moisture buffer capacity of the different materials in the wall.

CONCLUSIONS

The present study investigated the contradictory criterion for the wind barrier in timber frame walls with brick veneer cladding when it comes to interstitial condensation for summer and winter conditions. Therefore, a field study on two typical timber frame walls with brick veneer cladding was conducted. One set-up had a vapour open wood fibre board as wind barrier, advantageous for outward vapour flows, the other set-up had a more vapour tight wood fibre cement board, which has potentially a higher resistance against solar driven

Figure 7: According to the simulations, the moisture buffer capacity of the OSB board is more important in avoiding summer condensation than the vapour diffusion resistance of the wind barrier.

moisture ingress. In contrast to an elementary calculation using the Glaser method, the experimental results showed only little differences in the hygrothermal behaviour of both walls. Numerical simulations indicate that this is probably caused by the moisture buffer capacity of the different materials in the wall, which is at least as important as the vapour diffusion resistance to lower the moisture levels inside the wall. However, to draw general conclusions about the design of timber frame walls, more numerical simulations should be performed. A 2D numerical model can point out the influence of the wooden studs on the hygrothermal behaviour. Also the climatic conditions should be treated as a varying parameter apart from the vapour diffusion resistance and moisture buffer capacity.

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