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Hygrothermal performance of a light weight timber wall assembly with an exterior air barrier

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Abstract

This paper investigates the effect of convection on moisture accumulation, and mould growth potential, in a light-weight timber frame wall system where the air barrier is situated at the exterior and the damaged or unsealed vapour retarder is situated at the interior. A two dimensional numerical HAM (Heat, Air and Moisture) model is constructed and verified to evaluate the hygrothermal behaviour of a light-weight timber frame wall system with varying airtightness attributes. The mould growth potential of the wall system in a Swedish climate is assessed and compared utilizing the data output from the numerical model simulations and a material specific mould growth index.

The results suggest that the joints of the interior vapour retarder need not be sealed in the studied case. While the degree of moisture accumulation is larger behind the exterior air-tight layer of the simulated wall assembly possessing an unsealed interior OSB layer (compared to sealed interior), the influence on mould growth potential is limited.

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Keywords: exterior air barrier; air movements; hygrothermal performance, convection

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1. Introduction

Moisture safety is generally ensured in Swedish light-weight timber framed building envelopes through use of a vapour resistant polyethylene sheeting which lines the interior [1]. The interior polyethylene layer functions as the vapour barrier and also as the air barrier in the envelope system, i.e. stops both moisture convection and diffusion. The fact that the polyethylene layer possesses two functions as opposed to one means the wall is more vulnerable to moisture accumulation in the case of damage to the layer. Any damage to the layer or inadequate sealing of the joints can induce air leakages through the envelope which increases the risk of moisture accumulation and thereby mould growth in the building envelope. This is especially pertinent for the polyethylene material as it is prone to perforation [2], the material is difficult to handle/seal, and improper installation due to poor workmanship is common.

A new method for ensuring moisture safety in light weight timber framed buildings, originating from Norway, supplements the air/vapour barrier at the interior with a carefully sealed (as opposed to unsealed in Sweden) wind and rain resistant layer on the exterior [3]. While inhibiting the wind washing of cavity insulation and rain infiltration, the sealed wind resistant layer also contributes to the airtightness of the envelope, effectively creating an additional exterior air barrier. In fact, this exterior air barrier alone is often sufficient in meeting airtightness requirements [4]. This introduces a certain level of redundancy with regard to the airtightness of the light-weight timber framed building envelope. The interior air/vapour barrier now holds less significance regarding the overall airtightness of the building which affords the layer a greater degree of flexibility. Considering the time and labour invested in the process of sealing, the need to seal the interior vapour barrier to ensure its credentials as an air barrier can be questioned as convective moisture transfer through infiltration/exfiltration is now restricted by the presence of the exterior air barrier.

1.1. Aim

The aim of this study is to investigate moisture accumulation, and following potential risk of degradation through mould propagation, within a light-weight timber wall system where the air barrier is located on the exterior and the vapour retarder is located on the interior, but considered discontinuous (joints are unsealed).

1.2. Method and Material

Finite element analysis is a method which can and has been used to evaluate the hygrothermal performance of such building envelope systems. The works of [5], [6] and [7] are examples of this approach. The investigation of the proposed wall assembly is based on a two dimensional numerical model constructed in the COMSOL Multiphysics software package which accurately replicates transient heat, moisture and air movements within porous building materials. Mould growth potential is included according to [8].

The investigated wall assessed comprises of bituminous impregnated soft fibreboard with a treated exterior surface as the exterior air barrier, mineral wool as the cavity insulation and oriented strand board type 3 (OSB/3) as the discontinuous interior vapour retarder (joints are unsealed).

2. Theoretical and numerical model

In porous building materials, moisture can exist both in the form of vapour and liquid. The model described in this study takes into account only vapour transport (through diffusion and convection). Liquid transport (through capillary suction and due to gravity) is omitted as both bitumen impregnated fibreboard and mineral wool are considered hygroscopic yet non-capillary [11], and interior climatic conditions throughout the investigation are not within the range where liquid transport occurs [12]. The heat transfer model includes conduction, convection and latent heat, and has a thermal capacity that varies with moisture content (similar to [7]). Air flow is assumed to be laminar and is modelled with Darcy's law [13].

The implemented boundaries are based on [14] and [12]. For air transport the air pressure is prescribed directly on the boundaries, except for where gaps are introduced in the otherwise relatively airtight interior OSB layer. Here, the air flow across the boundary is expressed by an analytical model for air flow through a gap in an air tight building envelope component [15]. All fluxes are assumed to be zero at the top and the bottom horizontal boundaries of the investigated wall element. For a more thorough description of the numerical model and boundary equations refer to [16].

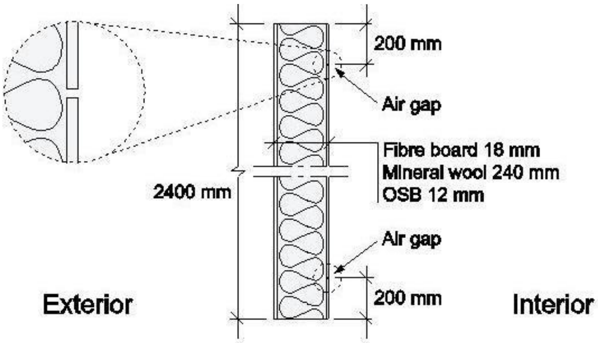

Figure 1. Simulated wall geometry with air gaps between interior OSB boards.

The potential risk of degradation to the light-weight timber wall assembly through mould propagation is found utilizing a material specific, temperature dependent, critical condition over which mould growth is stimulated and sustained. This critical condition was established following an approximation in [8] showing the critical relative humidity for selected building materials. It was predicted that the area of the wall assembly that would be most significant regarding potential mould growth was the interior face of the exterior air barrier material. Critical relative humidity for asphalt impregnated cellulose paper was chosen to represent the bitumen impregnated fibre board, since the latter was not included in [8].

3. Wall element simulation

The geometry of the wall element is shown in Figure 1 and all relevant material properties are given in Table 1. The wall element has a height of 2.4 meters. To simulate the slits present between butted oriented strand boards when unsealed, gaps are introduced in the OSB at a height of 200 mm from the top and bottom of the wall.

The simulated wall is assumed to be positioned at the top floor of a three storey residential building representative of the type of building where this type of wall assembly might be suitable. The top floor is where the overpressure at the interior (compared to the exterior) is at its highest, due to the stack effect, and hence possesses the largest driving potential for air exfiltration out through the wall assembly. This is the most critical location with regards to moisture safety since air exfiltration means transport of humid air from the interior out through the wall cavity.

Table 1. Wall material properties, see [16].

Description	Unit	Mineral wool	OSB	Fibre board
Material layer thickess	m^2	0.24	0.012	0.018
Density	kg/m^3	20	615	274
Porosity	-	0.95	0.9	0.8
Specific heat capacity	J/(kg·K)	840	1500	2068
Thermal capacity	W/(m·K)	0.0347	0.13	0.0469
Air permeability perpendicular	m^2	1.3E-9	8.2E-15	4.6E-14
Air permeability parallel	m^2	3.8E-9	8.2E-15	4.6E-14
Vapour diffusion resistance factor	-	1.5	467	7.8

Simulations are carried out for six different wall assembly types with varying properties on gap size and fibre board air permeability. These wall assembly types are summarized in Table 2. For the sake of comparison, a simulation is first performed for a reference wall assembly type where the interior OSB layer is considered continuous (reference type). Then gaps with a width of 1 mm are introduced in the OSB at the top and the bottom (Type 1). The gaps in the interior layer represent theoretical joint widths between OSB boards. Finally, the influence of the gap width and the air permeability of the exterior fibre board on moisture accumulation within the wall cavity is studied by varying these two parameters one at a time. Two additional wall type assemblies with an increased gap size of 5 and 10 mm are investigated (type 2 and 3 respectively). The increase in gap size reflects the joint widths between OSB boards which could feasibly arise during installation. Two additional wall assembly types with increased values on the air permeability on the fibre board are also simulated. In type 4, the air permeability is altered to give an average air leakage through the wall assembly corresponding to the demand in the passive house standard (0.3 l/sm^2) and in type 5 it is altered to match the demand previously outlined in the Swedish building code (0.8 l/sm^2). The fibre board air permeability in wall assembly type 4 and 5 are both within the range of air permeability values exhibited by different types of untreated, uncoated low density fibre boards.

Table 2. Summary of simulated wall assembly types.

Wall assembly type	Plot colour	Gap width [mm]	Air permeability of fibre board, κ [$m^2 \cdot 10^{-14}$]
Reference type		No gap	4.65
Type 1		1	4.65
Type 2		5	4.65
Type 3		10	4.65
Type 4		1	228.4
Type 5		1	906.9

A steady state case is introduced to visualise, evaluate and compare the behaviour of the HAM model for the wall types in two dimensions. A snapshot of a typical winter condition representative of the south west of Sweden is applied as the boundary condition at the exterior. In this case a relative humidity of 89% and a temperature of 0°C. The interior temperature is set to 20°C and a relative humidity which is described by a 4 $g/m^3 \cdot s$ vapour gain at the interior in relation to the exterior conditions (approximately 48% relative humidity). This is according to an internal moisture class representative of a residential building, referred to in the source as a building with low occupancy [17]. The temperature difference induces an overpressure across the wall of 1 Pa at the lower gap and 2.7 Pa at the upper gap.

A cross section is then taken from the upper (200 mm from the top), middle and lower (200 mm from the bottom) of the wall assembly for all wall types. It was found that, with the exception of the reference wall type, moisture redistribution due to convection is most pronounced at the upper cut line of the wall assembly for all wall types. Therefore, for sake of comparison all steady state data shown is sourced from the upper wall assembly cut line (see Figure 1).

A transient case is introduced to evaluate mould growth potential of wall type 1 when considering commonly occurring exterior and interior climatic conditions in the west of Sweden. The reference wall type is also simulated under these conditions for means of comparison. The data point assessed in the transient case is located on the interior face of the exterior air barrier, 200 mm from the top of the wall (Figure 1). Hourly exterior relative humidity and temperature conditions are represented by climate data sourced from Landvetter, south west Sweden, over a typical reference year. The hour zero represents the 1st of January. The interior temperature condition is set constant all year round at 20 °C, while the interior relative humidity condition is calculated from an internal vapour gain equation and profile tied to the exterior conditions. The pressure difference across the wall varies depending on the exterior/interior temperature difference. Pressure difference is zero when temperature difference is zero.

3.1. Simulation results

Regarding the steady state case, Figure 2 shows that relative humidity values and moisture accumulation is most pronounced at the interior face of the exterior air barrier. It also shows that the air tightness on both the exterior and the on interior have a significant effect on moisture accumulation in the wall cavity.

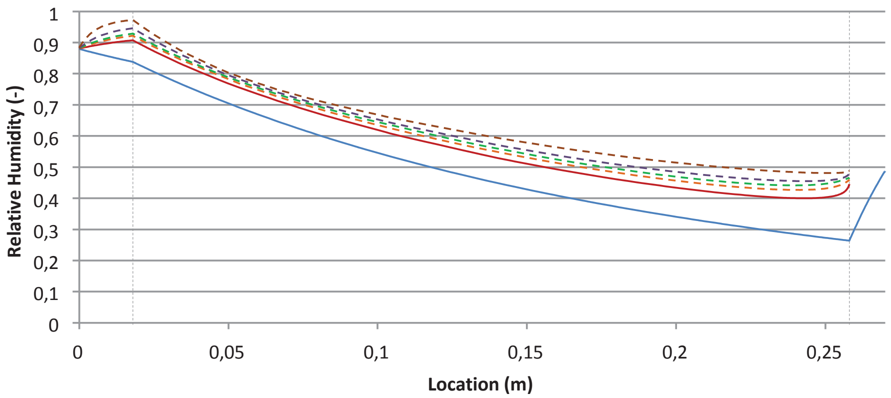

Figure 2. Steady state simulations showing relative humidity (-) over the wall cross section at 200 mm from the top of the wall assembly.

For the transient case, shown in Figure 3, all assembly type 1 (1 mm gap) is compared to the reference case (no gap). Wall 1 exhibits greater values of relative humidity in the winter months than the reference wall (up to 10% in some instances) while towards the summer months these values are almost indistinguishable for both wall types.

The difference in relative humidity values between wall type 1 and 2, at temperatures below 10°C, is because during the winter months the driving potential for convection, and so moisture transfer from the interior into the wall cavity, is at its strongest. Additionally the vapour gain at the interior is also higher during the winter months compared to the summer months, partly due to the fact that less windows are opened to the exterior, amongst other reasons. In the summer where exterior and interior temperatures converge at around 20 °C, both of these factors are diminished leading to similar relative humidity values for both wall types. This convergence of relative humidity values for both wall types in the summer months also coincides with the lowest, and in this case, most pertinent critical relative humidity values. While during the winter when wall type 1 shows noticeably higher values of relative humidity, the mould growth potential of the material is not significant as the temperature is too low to stimulate any kind of growth.

On average it can be seen, in Figure 3, that wall type 1 exhibits a greater tendency to exceed the critical relative humidity value, and often for a greater period of time. It can then be said that wall type 1 presents conditions with the highest potential for mould growth in comparison with the reference wall type. For more thorough investigations, the duration of time exceeding critical relative humidity has to be included.

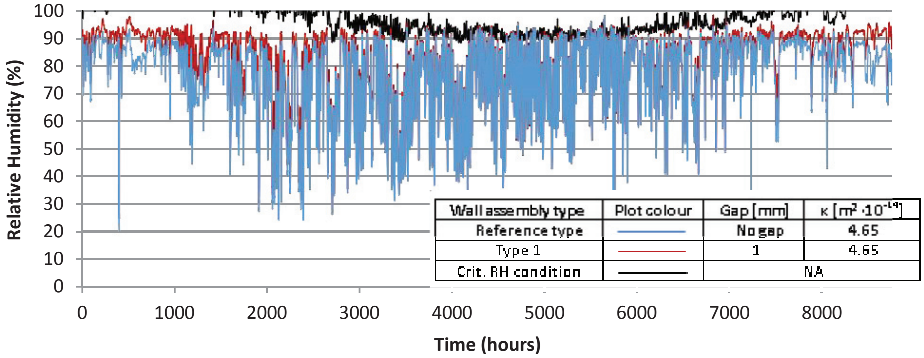

Figure 3. Relative humidity on the inside of the exterior air barrier, 200 mm from the top of the wall (during one year, start 1st of January) compared to critical relative humidity (depending on temperature) for asphalt impregnated paper.

4. Conclusion

The study shows that natural convection plays a role in moisture redistribution within light-weight timber framed wall assemblies. With regard to the previously outlined investigation limitations and simulation types, moisture accumulation due to natural convection over the full year is most pronounced in the upper section of the wall cavity immediately behind the exterior air barrier when the interior vapour retarder is unsealed (gaps present) in comparison to where it is sealed (no gaps). The discrepancy in moisture accumulation between wall types with and without gaps at this point is only evident during the winter months when the interior moisture load is highest and driving potential for a natural convection is strongest. In the summer months both of these factors are diminished and so relative humidity values exhibited in both cases are almost identical. Therefore, the difference in mould growth potential between walls possessing an unsealed interior vapour retarder (gaps present) and a sealed interior vapour retarder (no gaps) is not considered significant in this case. This is because the critical relatively humidity value is only exceeded in the summer months when relative humidity values exhibited in both simulated wall geometries are almost identical. Where there is a discrepancy in relative humidity values, during the winter, the critical relative humidity value is inapplicable as exterior temperatures are sufficiently low to prevent any mould growth regardless of the relative humidity value. Hence, in this case, there is no significant reduction in the risk of mould growth and associated degradation if the internal vapour retarder is sealed (no gaps) than if it is left unsealed (gaps present).

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