7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient
Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Hygrothermal Performance of a Hygroscopic and Permeable Wall Assembly: Impact of a Vented Wall Cavity

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ABSTRACT

Building envelopes that are hygroscopic and permeable to water vapour can contribute to improve the Indoor Environmental Quality (IEQ) in buildings by reducing indoor humidity fluctuations and the concentration of some contaminants like CO_2. However, risks of interstitial condensation and mold growth need to be assessed to ensure the durability of such building envelopes. The objective of this paper is to perform hygrothermal simulations of a case study house designed with a Hygroscopic and Permeable Building Envelope (HPBE) and to assess the impact of having a vented cavity compared to a face-sealed wall.

This contribution presents hygrothermal simulations of a wall assembly performed with WUFI Plus and WUFI Pro. The mold index is calculated from the simulation results and the hygrothermal performance of the vented and unvented wall is compared. The resilience of the construction is assessed by introducing leaks within the envelope. Simulation results indicate a satisfactory performance of this wall assembly regardless of the presence of a vented wall cavity. The wall design with a vented cavity seems more resilient when subjected to large leakages, although the wood fibreboard surface seems more vulnerable to mold growth when unprotected by a plaster. Additional simulations and field data are needed for assessing the benefits of having a vented cavity for HPBE.

KEYWORDS

Moisture management, hygrothermal performance, durability, permeable building envelopes

INTRODUCTION

Scientific background

Sustainable building design goes beyond the achievement of a low energy consumption but also encompasses the creation of a healthy indoor environment while reducing the overall environmental impacts over the entire building life cycle. With around 75% of building failures that are caused by water (May 2005), establishing good water management practices is a key element for ensuring the durability of a building.

Overhangs and gutters, perimeter drains and a vapour retarder on the warm side of an assembly are common recommendations in many jurisdictions for controlling water and water vapour. Vapour retarders slow down the diffusion of water vapour, which mostly occurs from inside to outside in cold weather, hereby reducing risks of condensation on the cold side of an assembly. However, they also hinder their drying potential, which may cause significant moisture damage during accidental leakages (Kunzel 2005). As such, two-way drying is now recommended as a necessary climate change adaption measure, where it is now suggested to avoid interior vapour barriers in all but the most extreme climatic zones (Kesik 2017).

Hygroscopic and Permeable Building Envelopes (HPBE) can contribute to improve the IEQ in buildings by reducing indoor humidity fluctuations (Yang et al. 2014). Besides, the vapour permeability of building materials was found to correlate closely to their carbon dioxide permeability and simulations showed that bedrooms made of building materials with higher water vapour permeabilities experience reduced concentrations of CO_2 (Niemelä et al. 2017).

Surface condensation, visible mould and perceived mould odour are indicators of dampness and microbial growth. Since the relationship between microbial exposure and health effects cannot be quantified precisely, there are no recommended quantitative threshold; only preventing dampness and mould-related problems is recommended (WHO 2009). Recent evidence is showing that visible mould and mould odour are associated with new-onset wheezing in children in a dose-dependent manner, although the underlying mechanisms remain unidentified (Shorter et al. 2018).

A study of 1140 samples of visibly damaged building materials revealed highest median concentrations of fungi in wood and paper materials and lowest in mineral insulation, ceramic products, paints and glues. The percentage of building materials in which no growth was detected ranged from 9-14% for wood to 12-17% for mineral insulation materials. Microbial damage occurred in all material categories included in this study, confirming that microbial growth can occur in a wide variety of building products (Hyvärinen et al. 2002).

Vented and ventilated wall assemblies

Many studies have investigated the impact of ventilated or vented wall cavities on the moisture content and drying rates of building materials. A review about this topic is presented by Straube (2009), from which the main conclusions are presented below.

A vented wall assembly has an air cavity behind the exterior cladding with openings only at the bottom, usually provided for drainage, which also allow for some ventilation to take place. A ventilated wall has openings at both the top and bottom of an air cavity, which promotes higher ventilation airflow rates and drying.

Besides numerical airflow rate calculations, the three main modelling techniques used by researchers to approximate vented/ventilated wall assemblies using hygrothermal models are

1. Ignoring ventilation effects (insertion of a still air cavity)
2. Effective cladding permeance (user selects an increased exterior cladding permeance)
3. Removal of cladding (user removes external cladding, rain and solar radiation loads)

Experimental measurements from Straube showed that techniques # 2 and #3 are in relatively good agreement with experimental results, although the choice of the effective cladding permeance has a significant impact on the results. Thus, the modelling technique #3 was chosen to model the vented wall assembly in this contribution.

While some research reported conflicting results about the benefits of ventilation cladding, this review paper concluded that there was a general consensus in the last years that ventilation cladding can increase the drying potential of a wall, reduce wetting from absorptive cladding and sun-driven moisture.

Most of these studies have been carried with building constructions that included a low permeance layer on the interior. There are insufficient studies to confirm whether having a ventilated wall cavity can significantly improve the hygrothermal performance of wall assemblies that are made of hygroscopic and permeable materials.

This paper aims to investigate the effect of cladding ventilation for a HPBE in a cold a wet climate such as northern Europe. As a first step, hygrothermal simulations of a house are carried out with WUFI Plus, a validated whole building simulation software (Künzel 1995). The mold index (ASHRAE 2016) is calculated over 2 and 5 years for different wall orientations for a vented and unvented wall assembly. Secondly, the resilience of a vented and unvented wall assembly is investigated by simulating water leakages with WUFI Pro.

METHODS

A model of a house was created in WUFI Plus V3.0.3.0 in order to investigate the effect of ventilation cladding in a HPBE. This house is located in Holbæk, Denmark, from which field data is currently being monitored. The weather file selected in WUFI is Lund, which is situated 120 km east of Holbæk at the same latitude.

The envelope of the house is made of a wood structure filled with blown-in woodfiber insulation, interior and exterior wood fibreboards, interior clay plaster and exterior mineral plaster. The house has a ventilated roof and crawl space. A floor plan and a south view of the house are presented in Figure 1. The walls do not have a vented cavity except for the south-east living room wall.

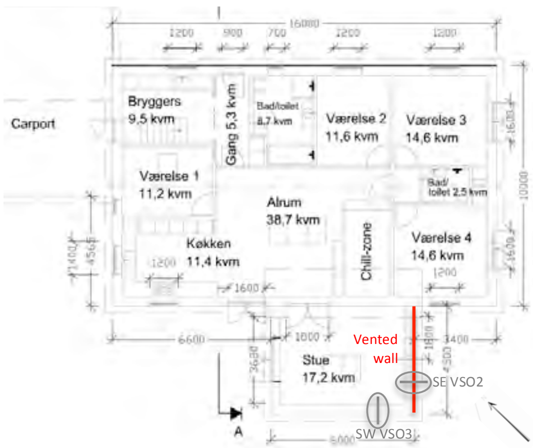
The characteristics of the wall assembly are presented in Figure 2. It can be seen that the mineral plaster is the material with the highest water vapour resistance factor with a μ of 21. It this given configuration, all layers are considered permeable with a s_d value smaller than 2 m where the woodfiber insulation provides the greatest water vapour resistance with s_d =0,68 m.

The building model is divided in 6 zones: the living room (named *stue* on the floor plan) and the rest of the house are modelled as two conditioned zones, accompanied by their respective attic and crawl space, which are simulated as unconditioned zones each with continuous ventilation at 3 ACH. The carport and skylights are excluded from the simulation model.

The wind-driven rain coefficient is set to 0.07 for the walls. This value has been obtained by carrying a linear regression analysis of experimental driving rain data obtained for a 4 m high test wall at the center of the façade (Künzel 1995), which is deemed representative of the current situation. The wall with a vented cavity was modeled by removing the exterior cladding (mineral plaster) and rain and solar radiation loads.

The windows have a glass g-value of 0.55 and an overall U-value of 0.77 W/(m^{2}K). There is mechanical ventilation at 0.5 ACH with 60% heat recovery and an infiltration rate of 0.1 ACH. Natural ventilation at 0.5 ACH takes place from May 15th until September 15th and a fictitious cooling set point of 28°C act as additional natural ventilation to control overheating. The building is occupied by a family of four following a typical occupancy schedule. In the main zone, the moisture generation is equal to 4610 g/day during the week and 8384 g/day during the weekend. In the living room, the moisture load is set at 432 g/ day.

The ASHRAE standard 160 (2016) provides a complete description on how to calculate the mold index at a location of interest in a building assembly. The value of the mold index was computed after two and five years of simulation. The exterior mineral plaster was treated as a medium sensitivity class and the wood fiberboard as a sensitive class.



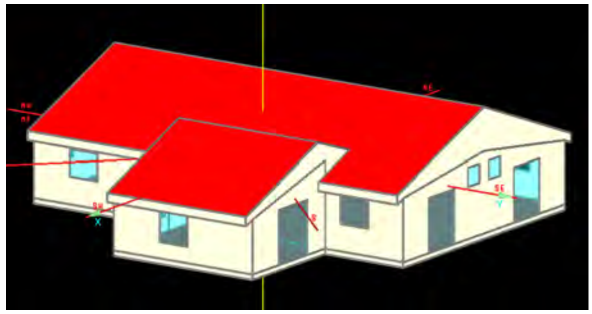


Figure 1. Floor plan and south view of the building model

Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thick. [m]	μ [-]	s_d [m]
Mineral cement Plaster	1434	850	0,9	0,006	21	0,126
Ext wood fibreboard	140	2100	0,04	0,06	3	0,18
Wood fiber insulation	50	2100	0,037	0,34	2,5	0,68
Clay board	615	2000	0,128	0,016	7,4	0,12
Basecoat clay plaster	1844	850	0,1	0,003	14,7	0,04
Topcoat clay plaster	1844	850	0,1	0,002	14,7	0,03

Figure 2. Wall assembly materials characteristics for the unvented wall. The mineral cement plaster is omitted in the vented wall section.

The hygrothermal performance of the vented and unvented wall assemblies subjected to internal moisture sources was also investigated. The assemblies were modeled in WUFI Pro, which can allow the introduction of heat, moisture and air change sources within the wall assembly. The vented and unvented wall assemblies were modeled, subjected to the climate of Lund on the exterior side and to EN 15026 conditions on the interior side with medium moisture loads. For modeling the vented wall, the mineral plaster and rain loads were removed, but the solar load remained, since it cannot be switched off in WUFI Pro. In these conditions, the moisture content is likely to be underestimated but the comparison of a vented and unvented wall can still reveal valuable information on the behavior of these assemblies.

Two different kinds of moisture intrusion were investigated: one based on a fraction of driving rain and one based on the IBP air infiltration model (WUFI 2017). The introduction of 0.01% and 1% of driving rain at the inner face of the wood fiberboard was simulated, as well as Class A and Class C air infiltrations (corresponding to $q_{@50\ Pa}$ of 1 and 5 m^3/m^2h for the whole building and q of 0.07 and 0.33 m^3/m^2h through the component, respectively).

RESULTS AND DISCUSSION

Whole building simulations with WUFI Plus

Table 1 presents the maximum mold index (ASHRAE 2016) computed after two and five simulation years of the SE and SW walls of the building model, which have the highest moisture content. M was calculated at the outer surface, 0.15 cm behind the exterior wood fibreboard and from the average temperature and relative humidity of the fibreboard.

Results show that the unvented wall exhibits a satisfactory hygrothermal performance, with a maximum mold index of 0.01 and 0.02 at the exterior plaster layer for a SE and SW wall respectively. The maximum mold index at 0.15 cm behind the external face of the wood fibreboard is 0.12 or less, well below the critical value of 3.

The unvented wall cavity has a mineral plaster as external rendering, which has a medium sensitivity class, while the external surface of the vented wall has a wood fibreboard as outermost layer, which is classified as a sensitive material. As such, the maximal mold index at the external surface of the vented assembly is higher, and reaches a maximum value of 1.37 over a two year period and of 2.13 over a five year period. A mold index of 3 is likely to be reached by performing simulations over a longer period of time. Therefore, the unvented wall assembly seems less likely to develop mold growth at the external surface. However, the maximum mean mold index is lower for a vented cavity for both wall orientations. Ongoing research will take place to evaluate long-term field performance.

Table 1. Maximum mold index for unvented and vented wall after 2 year (5 years)

Assembly type	Orientation	M, surface	M, 0.15 cm wood f.	M, mean
Vented	SE VSO2 (135°)	1.37 (2.13)	-	0.02 (0.02)
Unvented	SE VSO2 (135°)	0.01 (0.01)	0.09 (0.09)	0.05 (0.05)
Vented	SW VSO3 (225°)	1.37 (2.13)	-	0.02 (0.02)
Unvented	SW VSO3 (225°)	0.02 (0.02)	0.12 (0.12)	0.08 (0.08)

Hygrothermal simulation under water leakages with WUFI Pro

Performing hygrothermal simulations while introducing internal moisture sources within a wall assembly is a method that allows evaluating its resilience and drying potential under challenging situations. Simulations were performed with the presence of a fraction of driving rain or an air infiltration moisture source. The moisture source was introduced in the last element of the wood fibreboard, on the internal face. The maximum mold index for a SW vented and unvented walls under different moisture sources is presented in the Table 2 below.

Table 2. Mold index for unvented/vented walls after two years with various moisture sources

Assembly type	Moisture source	M, surface	M, 0.15 cm wood f.
Vented	None	1.24	0.89
Vented	0.01% driving rain	1.24	0.89
Vented	1% driving rain	1.24	0.89
Vented	IBP Air inf. Class A	1.24	0.89
Vented	IBP Air inf. Class C	1.24	0.89
Unvented	None	0.02	0.40
Unvented	0.01% driving rain	0.02	0.40
Unvented	1% driving rain	0.03	1.10
Unvented	IBP Air inf. Class A	0.02	0.40
Unvented	IBP Air inf. Class C	0.02	0.41

It can be seen that the maximum mold index at the external surface is not significantly affected by the introduction of the tested moisture sources. Observation of water content profiles and moisture fluxes reveal no significant difference (results not shown). The only significant change of the mold index at 0.15 cm behind the fibreboard is under the introduction of 1% of driving rain, when the index is increased from 0.40 to 1.10 for an unvented wall. In light of these results, having a vented cavity for this type of assembly seems to increase its resiliency when subjected to significant, recurrent moisture sources.

In reality, leaks are usually localised and not uniformly distributed as assumed in these simulations. The location of the leak is also important in determining how it will be absorbed and redistributed within the building envelope; leaks at only one location have been investigated here. These simulations may be representative of well distributed leaks, but are not representative of substantial and localized leaks.

CONCLUSIONS

This paper investigated the hygrothermal performance of a vented and unvented permeable and hygroscopic wall assembly. Whole building hygrothermal simulations carried out with WUFI Plus and WUFI Pro indicate that the venting this assembly might increases its resilience and drying potential when subjected to significant moisture sources. However, the external face of the wood fibreboard seems more vulnerable to mold growth when unprotected by the mineral plaster.

From these limited results, it is unclear if providing a ventilated cavity yields significant improvement in terms of hygrothermal performance and resilience of the building envelope. Field data is currently being monitored and will shed additional light on this topic. The results presented in this contribution are applicable only for the specific wall assembly investigated here; additional simulations and field data for different types of hygroscopic and permeable wall assemblies are needed for making general conclusions for such assemblies.

ACKNOWLEDGEMENT

The first author is grateful to the Natural Science and Engineering Research Council of Canada for a Postdoctoral Fellowship.

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