Assessing the benefits of cavity ventilation by hygrothermal simulation

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Summary

There is a controversy between Central Europe and North America concerning the necessity of back ventilating the exterior finishing layers of external wall structures. In the past, several European studies have proven that cavity walls are working as well or even better without back ventilation and it has now become common practice to omit the ventilation plane altogether. On the other hand, recent North American studies have confirmed the benefits of back ventilating the exterior stucco or brick veneer of wood frame walls. In order to solve this discrepancy a simple ventilation model has been implemented into a one-dimensional hygrothermal simulation tool and validated by comparison with experimental data. The simulation results help explain the different perceptions of the benefits of ventilation. Without ventilation an external wall may experience inward vapour drive after a rainy spell. This is generally no problem for a typical Central European wall structure made of masonry that can easily absorb a considerable amount of vapour without any risk of damage. However, it is important when the wall is composed of structural layers that are sensitive to moisture such as OSB or plywood sheathing which are often used in North American wall assemblies. Because the inward vapour drive is greater when the cladding is not ventilated the critical moisture content of the exterior sheathing may be exceeded without cavity ventilation.

1. INTRODUCTION

Non-ventilated wall and roof constructions are state-of-the-art in Europe. In the 80s comparative investigations of fibre-cement clad walls with vented (closed at the top) and ventilated air gaps have shown that the construction moisture in the different masonry walls dried out at similar rates [1, 2]. This lead to the conclusion, that drainage is more important than air convection. Further field tests on cavity walls made of fired clay brick [3] confirmed that a ventilated cavity does nothing to improve the moisture behaviour of the wall while it reduces the thermal performance because there is less space for cavity insulation. Similar experiences have been reported by Hugo Hens [4] who conducted many experiments on cavity walls over the past decades. He has found that unventilated walls outperformed ventilated ones also because air convection loops around the insulation layer are less likely when the cavity is completely filled with insulation material.

However, extensive investigations on wooden wall structures with stucco or brick veneer in North America [5] have proven that a ventilated cavity may be decisive for moisture control, because otherwise solar vapour drive may result in an elevated water content of the stud walls' exterior sheathing. Recent studies on similar walls in Germany [6] seem to confirm the North American findings. An explanation for the controversial research results could be found in the composition of the load bearing structure. Hygrothermal simulation to investigate solar vapour drive in non-ventilated cavity walls [7] have shown that the exterior surface of the inner wythe becomes more humid (RH > 90%) during summer time due to inverted vapour flow. While this phenomenon is of no concern in the case of masonry, more moisture sensitive materials, such as OSB or gypsum board may be adversely affected. There is strong evidence from North America that cavity ventilation can help to reduce this problem. However, the question remains whether this is true for all climates and what other solutions might be possible. In order to facilitate the moisture performance prediction of cavity walls with and

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without ventilation, a simple air convection model is introduced into a standard one-dimensional hygrothermal simulation tool and the results are validated by comparison with field tests.

2. VENTILATION MODEL

Air convection in ventilated cavities of external walls is governed by buoyancy forces and wind pressure differences. Due to the changing nature of wind no steady flow patterns will develop in wall cavities when the wind is blowing. Investigations of the air flow velocity behind ventilated claddings of a high rise building [8] have shown little influence of the overall wind speed. The highest cavity air flows (approx. 0.6 m/s) were measured during calms when solar induced stack effects were present. An evaluation of six additional air flow studies on ventilated wall structures [9] confirmed that air velocities in the cavity are generally smaller than 0.3 m/s. Assuming continuous openings at the top and bottom as well as a fully developed flow behind the cladding, the maximum amount of air changes per hour over the height of one storey would be approx. 300. In the case of a wall with brick veneer which has only some weep holes at the bottom and similar openings at the top, this air change rate is reduced to 20 – 50 h^{-1} [10]. According to past research upward (sun induced buoyancy) and downward cavity flow (wind pressure stratifications) appear to dominate lateral flow. This means that the problem can be reduced to two dimensions or even one dimension when upward and downward flows are of equal likelihood.

The one-dimensional simulation of the hygrothemal performance of building envelope systems deals with the heat and moisture transport processes through the envelope. Since cavity ventilation acts perpendicular to this, it can only be incorporated by defining sources and sinks in the 1D transport equations specified in [11]. The source terms for heat S_h and moisture S_w can be described as follows:

$$S_h = \rho_a \cdot c_{p,a} \cdot ACH_{vent} \cdot d_{vent} \; (T_e - T_{vent}) \; / \; \Delta x \qquad (1)$$

$$S_w = ACH_{vent} \cdot d_{vent} \left(\frac{p_{D,\,e}}{R_D \cdot T_e} - \frac{p_{D,\,vent}}{R_D \cdot T_{vent}} \right) \; / \; \Delta x$$

(2)

with:

$c_{p,a}$	[J/(kg·K)]	thermal capacity of air
d_{vent}	[m]	cavity width (thickness of air layer)
ACH_{vent}	[s^{-1}]	rate of cavity air exchange with outdoor air
p_D	[Pa]	vapour pressure
R_D	[J/(kg·K)]	spec. gas constant for water vapour
T	[K]	absolute temperature
Δx	[m]	width of control volume in the ventilation zone
ρ_a	[kg/m³]	outdoor air density
index e, vent		outdoor air conditions (*e*) res. conditions in the cavity (*vent*)

These source terms are the basis for the simplified ventilation model that has been implemented into the simulation tool WUFI®. It assumes a homogeneous impact of the outdoor on the cavity over the full height of the building assembly. Its practical performance will be checked by comparison with experimental results below.

3. EXPERIMENTAL VALIDATION

Compared to a non-ventilated cavity, the supply of outdoor air will alter the microclimate in a ventilated cavity. This will lead to better drying conditions if the humidity in the cavity is effectively reduced. The moisture transfer process from the materials layers next to the cavity to the cavity air is governed by the vapour pressure differences. An important performance criterion for the ventilation model is therefore its ability to provide the correct vapour pressure in the cavity. The experiments carried out in the frame of a DOE project by the Oak Ridge National Laboratory (ORNL) in collaboration with the Washington State University (WSU) [12] represent a good opportunity to validate the new ventilation model in WUFI®. Fig. 1 shows the test building in Puyallup (approx. 60 km south of Seattle) with 12 different wall sections oriented to the South. The wall considered for our purpose has the following composition:

- conventional three coat cement stucco (22 mm)
- ventilated cavity (19 mm)
- weather resistive barrier (2 x 60 min. building paper)
- OSB sheathing (11 mm)
- glass fibre insulation between wooden studs (150 mm)
- vapour retarder (PE film) and gypsum board (13 mm)

All wall sections were equipped with several temperature and humidity sensors as well as with wood moisture content pins. The measurements started in Oct. 2003 and continued until the next summer. The temperature in the test building was kept between 20° and 22° C and the humidity between 50% and 60% RH. The exterior climate conditions were recorded at the test site by meteorological set-up on the roof of the test building. The material data for the hygrothermal simulations were determined in the laboratory of ORNL [13].

Fig. 1. Test building of the Washington State University with different stud wall sections

The recorded vapour pressure readings in the cavity of the considered test wall section serve as basis for the validation of the simulation results. The WUFI® calculations were carried out with and without cavity ventilation in order to assess the influence of the ventilation model. The air change rate in the ventilated cavity was assumed to be 50 h^{-1} at all times. The results are compared to the measured data for a period of ten months in Fig. 2. While there is a rather good agreement between experiment and calculation in the ventilated case, the results obtained without ventilation model deviate considerable especially during the winter months. Since precipitation at the test location runs through a maximum in winter when drying is slow, the exterior stucco stays wet most of the time during this period. This leads to a high vapour pressure in the cavity and subsequently to an elevated moisture content of the OSB sheathing unless the cavity is ventilated.

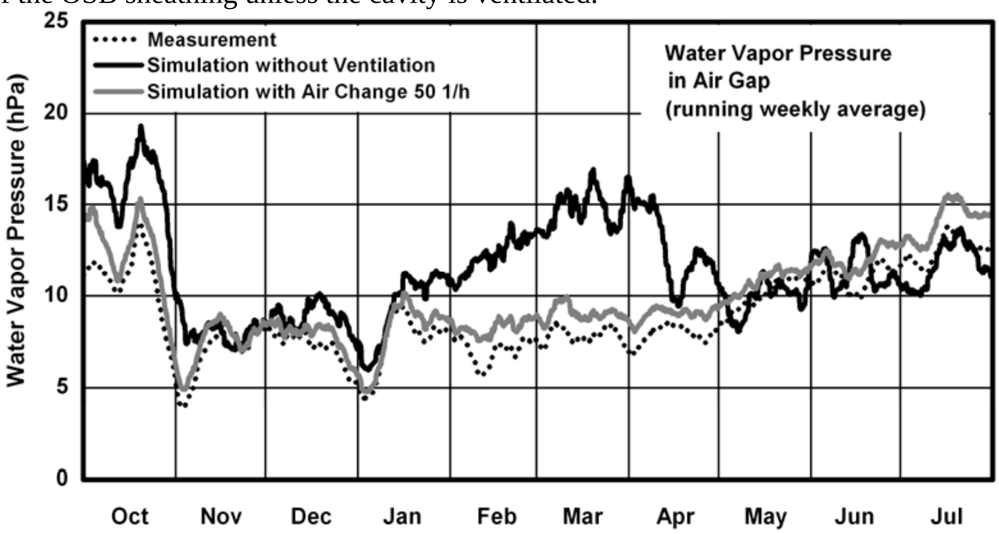

Fig. 1. Vapour pressure variations in the 19 mm thick air gap beneath the stucco calculated with and without ventilation in comparison to measured data from the ventilated cavity wall of the WSU test building [12].

4. CONCLUSIONS

The experimental validation of the ventilation model shows good results and confirms the usefulness of the simplified approach. In order to gain even more accuracy the cavity ventilation rate which has been kept constant here should be modelled depending on wind velocities and solar induced stag effects. The simulation results also confirm the North American experience that back ventilation of exterior claddings helps to keep the sheathing material of stud walls dry. The repetition of the simulations with German climate conditions (not be shown here because of space restrictions) gave similar results. This means that wooden wall structures also benefit from a ventilated cavity for Central European climate conditions.

However, cavity ventilation also has its drawbacks. It may diminish the thermal performance because wind washing and convective looping of the insulation layer may increase. At the same time, there is also a risk of condensation in the cavity during clear nights especially when the walls are well insulated. Therefore a ventilated cavity should only be designed if required for moisture protection. When dealing with traditional masonry cavity walls in Europe, cavity ventilation is generally unnecessary. That doesn't mean that these structures are usually designed without ventilated cavities. Despite decades of research and numerous track records of well-performing non-ventilated cavity walls, the building trades stick to old traditions which made sense as long as energy saving was not an issue. Therefore it is important to differentiate between constructions that need cavity ventilation and those that do not need it. Hygrothermal performance analysis with a ventilation model can help to make this decision.

This is important because not every practitioner has access to the life long experience of Prof. Hens who came to same conclusions long before the authors and should therefore be congratulated for his contributions to state-of-the-art in building physics.

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