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Moisture robustness assessment of a window with integrated solar screen using numerical and experimental methods

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Abstract

In this study, a wood-frame window with an integrated exterior solar shading unit has been investigated.

Numerical simulations have been carried out to quantify the moisture distribution and drying-out rate of the construction detail. The simulations have been compared to measured data from an ongoing experimental study.

The results indicate that built-in moisture in the wall can lead to high levels of relative humidity (RH) in the detail and that design of this detail should be done considering this. Simulations showed that unfavourable RH-levels can be avoided if it is optimally designed. Preliminary measurements indicate the same trends.

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Keywords: window; solar shading; screen; moisture; drying-out rate; experimental; numerical simulations

1. Introduction

Modern buildings have very low heating demands in general. A direct consequences of such low heating demands, is that cooling demands are becoming a dominating factor in buildings, even in what is commonly considered a heating-dominated Nordic climate. Thus, it becomes obvious that shading devices are necessary in order to reduce cooling demands as well as to maintain a satisfactory thermal comfort.

As a response to this, new solutions are emerging on the market. One such solution is to integrate solar shading units in the windows, where the aim is to make an easy-to-handle integrated system for both craftsmen and end-users of the system. Such a system has been developed by a Norwegian window manufacturer.

However, the introduction of a vapour-tight unit like the shading device casing (as shown in Figure 1) in the outer (cold) part of a wood frame wall can lead to moisture related problems. The need for development of well-functioning

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technical solutions of the building envelope and other parts with respect to both strategies and solutions was demonstrated in [1, 2], who, by examining the SINTEF Building and Infrastructure building defects archive, found that 75 % of damages and defects in the Norwegian building stock could be related to moisture damages and furthermore that 66 % was related to the building envelope. To underline the importance, it must be noted that the total annual costs related to repairs of buildings in Norway amount to roughly 1.65 billion Euros [3].

Criteria for mould growth potentials and moisture robustness have been the subject of several previous studies, where a thorough review of the current knowledge is given by Gradeci et.al. [4]. Viitanen [5] established the most used criteria in 1997. Viitanen concluded that the relative humidity (RH) must be higher than 80 % (corresponding to a wood moisture of 20 weight-% at 20°C) for a period of five months for mould growth to be initiated. If the RH increases to 90 %, the initiation period is reduced to four weeks. This is the basis for the criteria used in the SINTEF Building and Research Design Guidelines where the following criteria must be simultaneously fulfilled for mould growth to be initiated: 1) moisture content in wood must exceed 20 %, the period of wetting, 2) The wetting-period must be longer than 4 weeks 3), the temperature must exceed 5°C. These criteria are assessed to be conservative [6].

In this study, a wood-frame window with an integrated exterior screen solar shading unit has been investigated. The screen is mounted in a casing made of aluminum mounted on top of the wood-frame. The introduction of the aluminum casing reduces the drying-out capability of the construction in this area. Numerical simulations, using a 2D finite-element software, have been carried out in order to quantify the moisture distribution and drying-out rate of the construction detail. The results from the numerical simulations have been compared to the initial measured data for the solution from an ongoing experimental study of the same detail. This paper presents initial measurements from the first period of the measurement campaign. The experiment was carried out measuring moisture levels and temperatures in a full-scale build-up of the sample placed in an exterior wall facing real climatic conditions.

2. Methodology and shading device description

2.1. Numerical simulations

Calculations have been carried out using the WUFI 2D tool [7], which is a two-dimensional hygrothermal simulation software. A study of moisture contents and levels considering the design of the detail have been carried out. Fig. 1 (right) shows the WUFI modeling domain. The accuracy of the software have previously been studied by [8] and [9] who concluded that the software was a good tool for determination of the moisture performance of a facade

In order to reduce the complexity and simulation time of the numerical model, some simplifications of the model were made. Simulations have been carried out for a two-year period in order to investigate seasonal drying-out and wetting of the detail. Weather data for a standardized climate-year from Værnes Trondheim, with an average mean temperature of 7.6°C has been used. An interior climate corresponding to Humidity class 2, Offices, dwellings with normal occupancy and ventilation" from NS-EN 13788 [10] has been used. This corresponds to a moisture supply of 4 g/(m³h). This is assessed to be a conservative assumption for well-ventilated buildings.

The head of the window frame is simplified and modeled as a rectangular profile. An adiabatic boundary is set on the lower edge (shown in green on Figure 1 (right)) of the rectangle representing the window head. This gives that no heat or moisture are transferred through the surface, making it a conservative situation in terms of the total drying-out capacity of the detail. The gaskets between the head and aluminum casing are ignored and the frame is modeled in direct contact to the aluminum casing. The cavity inside the aluminium casing is modelled as stagnant air.

2.2. Experimental methodology and set-up

The window with the exterior screen solar shading unit is installed in the ZEB Test Cell Laboratory. The facility is designed to carry out calorimetric, comparative and tests with occupants, on full-scale building envelope systems. The ZEB Test Cell consists of two test cell rooms – internal dimensions (W x L x H): 2.4 m x 4.2 m x 3.3 m – each surrounded by a guarded volume to eliminate heat exchange. The south wall of each test cell room is exposed to real outdoor conditions, having an area (W x H): 2.4 m x 3.3 m. The indoor air condition of the test rooms allows desired conditions.

The window cross-section and sensor placements are shown in Fig. 1. Before installation the transom was conditioned to a moisture content of $20\%_{\text{wt,dry}} \pm 0.5\%_{\text{wt,dry}}$ at $20\text{ }^{\circ}\text{C}$. To minimize the moisture transport towards the already dried part of the construction, an additional moisture barrier was installed, as shown in Fig. 1. Consequently, the drying-out of the transom takes place with the ambient air. Thus representing a worst case scenario.

The combined air temperature and relative humidity sensors installed in three horizontal positions have a measurement uncertainty of $\Delta T_{\text{absolute}} = 0.3\text{ K}$ and $\Delta \text{RH} = 1\%$. The wood moisture content is measured in two positions in accordance with NS-EN 13183-2:2002 [11] including a temperature compensation. Thus the temperature sensors are installed close to the electrodes allowing wood moisture measurement with an uncertainty of $\Delta \text{TIH} = 0.2\%_{\text{wt,dry}}$ under varying temperatures ($-20\text{ }^{\circ}\text{C}$ to $+50\text{ }^{\circ}\text{C}$). All measurement signals are recorded with 1 min intervals. The values are averaged during the data post processing on weekly basis. Recording errors due to failures in the power supply were excluded in the data post processing. The measurements were carried out in the period 01.07.2016 to 31.12.2016

2.3. Solar shading device description

The solar shading device consists of an external screen encased in an aluminium casing, mounted to the head of the wooden window frame. The casing is made of 2 mm thick extruded aluminium with external dimensions (H x W) 100 x 100 mm. An air- and moisture-tight joint between the frame and aluminium casing is ensured using butyl rubber gaskets.

The wall is a traditional wooden-frame wall with 192 x 46 mm studs. As described in Table 1 and shown in Fig. 1, the wall is built up (listed from exterior to interior side): 12 mm gypsum board, wind barrier, mineral wool, vapour-barrier and 12 mm gypsum board as interior cladding. Exterior to that, a 12 mm pine well-ventilated pine used as cladding preventing driving rain from hitting the gypsum board and wind barrier covering the gap to the solar shading casing. Special attention was paid to the 24 mm high cavity between the aluminium casing and the overlying wooden sill. To cover the gap, the wind barrier was continued past the gypsum board and taped (using a vapour open tape) to the aluminium casing. This was done to ensure an as vapour-open solution as possible for the gap.

An initial parametric simulation study showed that condensation could occur in the area behind the casing. This led to the need for the introduction of the asphalt impregnated wood-fibre board (AIWB) as a moisture buffer. The AIWB will retain the moisture during disfavourable conditions and release it during favourable conditions when there is a drying-out potential in the detail.

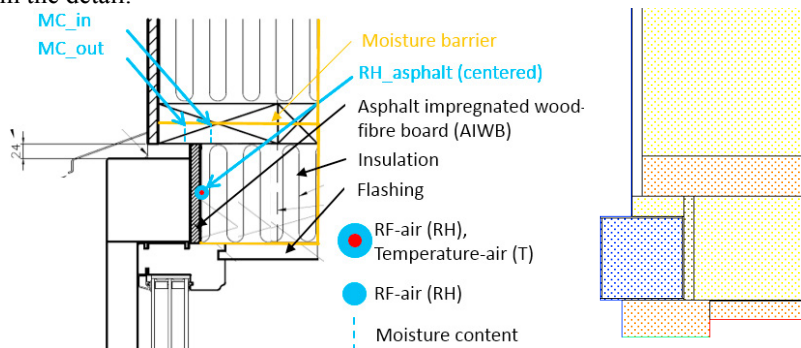


Fig. 1. (left) Vertical center cross-section of the top frame with the solar shading showing the placement of moisture, relative humidity and temperature measurement points. (right) The numerical model from the WUF12D simulation domain.

Table 1. Material data used in the simulations.

Material	Thermal conductivity (W/mK)	Thickness (mm)	Water-vapour resistance μ (-)	Initial moisture content
<i>Wall construction (from exterior to interior side):</i>				
Still air	0.025	Varying	1	1)
Gypsum board (exterior)	0.2 (when dry)	12	8.33	1)
Wind barrier				1)
Mineral wool	0.04	192	1,3	1)
Vapour-barrier	2.2	1	70000	1)
Wood (pine)	0.13	Varying	50 (when dry)	20 %
Wind barrier	2.3	1	100	1)
<i>Miscellaneous materials:</i>				
Aluminum	160	2	200000	1)
High density fibre board (window flashings)	0.18	12	48	1)
Window frame	0.13	n.a.		12 weight-%
Asphalt-impregnated wood- fibre board	0.06	12	17	1)

1) In equilibrium to 80 % relative humidity in air)

3. Results

3.1. Numerical simulations

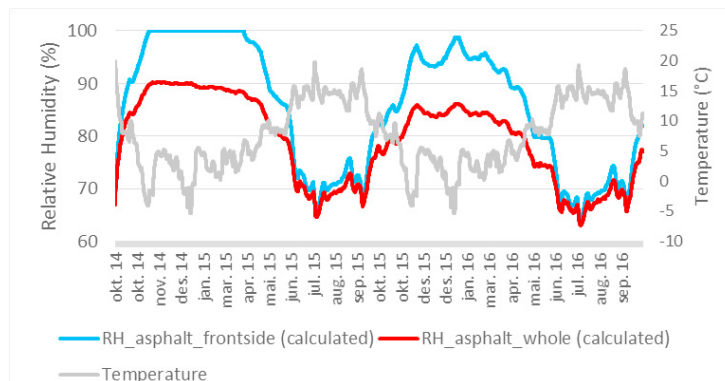


Fig 3. Calculated relative humidity in the outermost part (blue line) of and the average in the entire AIWB (red line) behind the screen cassette using two standardized climatic years for the Trondheim climate. The figure is also showing the calculated temperature in the asphalt-fibre board (grey line).

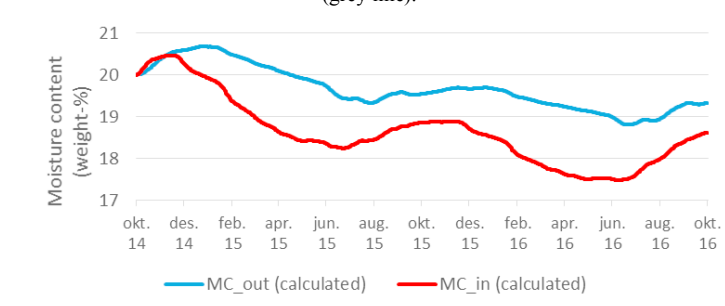


Fig 4. Calculated moisture content for two points in the transom corresponding to the placement of the moisture sensors (MC_out and MC_in) for two standardized climatic years for the Trondheim climate.

The results from the WUFI simulations are shown in Figure 3 and 4. Figure 3 shows that condensation will occur in the part of the asphalt-impregnated wood-fibre board area directly behind the solar shading screen cassette. However, one can also observe that the average relative humidity in the entire board is below 100 % and that condensation not will occur if it is treated as an entire element. Furthermore, looking at the total water content, showed in Figure 4, one can see that most of the built-in moisture dried out during the first warm period (from March to July).

3.2. Preliminary measurement results

The measured moisture content in the two positions in the wood transom above the window are shown alongside external air temperature in Figure 5. It shows that the moisture level decrease from 20 to 17 weight-% in the outermost measurement point (MC_out). The interior measurement point (MC_in) shows a decrease from 20 to 13 weight-% in the two first months with a consecutive moistening up to 20 weight-% in the period from September to December.

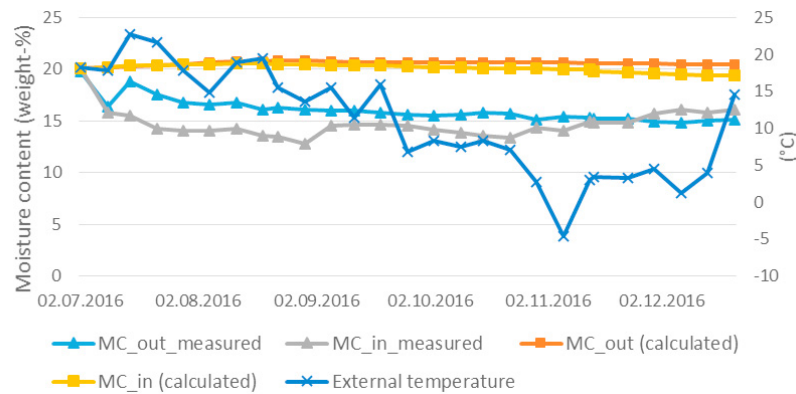


Figure 5. Measured and calculated moisture content (numbers given in weight-%) in the transom and measured external air temperature.

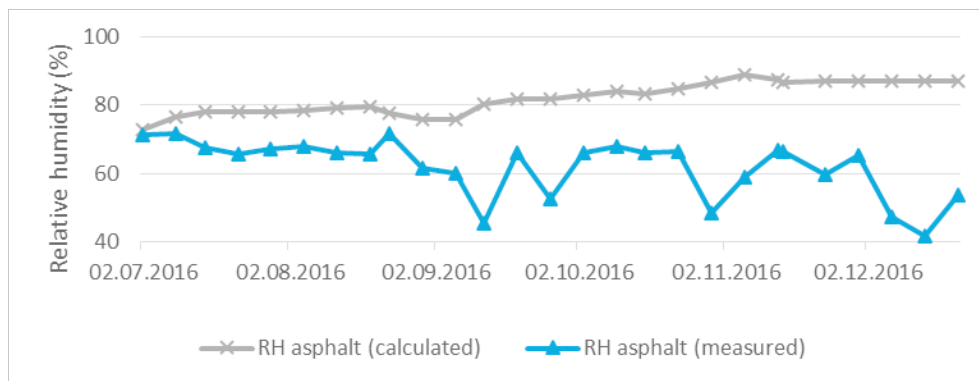


Figure 6. Measured and calculated relative humidity on the interior surface of the asphalt impregnated fibre-board.

4. Discussion

The simulations carried out in WUFI2D using generic climate data for a two year long period, showed that the drying-out capacity of the wall construction surrounding the solar shading casing and window head will be reduced.

However, the simulations showed that moisture levels are kept at an acceptable level. The periods of the first year when the relative humidity levels are above 80 % (e.g. when mould growth could occur) have sufficiently low temperatures to prevent mould growth.

Furthermore, it was found that drying-out of the built-in moisture will occur at a sufficient rate during the first year. All of this requires the following prerequisites to be fulfilled:

- Ventilation of indoor air in accordance with regulations (e.g. the moisture supply should be at a moderate level ($\leq 4 \text{ kg}/(\text{m}^3 \text{ h})$)
- The vapour-barrier must be continuous all along the wall-section, alongside the window flashing and it must be tightened against the window frame (as shown in Fig.1)
- The built-in moisture content of the wooden part of the wall should be kept below 20 weight-% when the construction is closed (e.g. when the vapour-barrier is mounted)
- A sufficient height of the gap between the window head and shading casing must be ensured for the detail to have the necessary drying out capacity. Simulations showed that a 24 mm high gap was sufficient for the particular climatic conditions
- The wind barrier covering the gap must have a low water-vapour resistance (s_d -value $\leq 0.1 \text{ m}$)
- The measurements showed that the drying-out rate of the detail was indeed more favourable than the predictions from the WUFI simulations for the same period of time. Actual solar radiation levels were not corrected for in the simulations

5. Further work

The measurements are carried out for a limited period of time, and the measurement campaign is currently running with an aim to look at the long-term drying-out rate of the detail. Furthermore, actual solar levels should be used in the simulations to account for any effects from this on the drying-out rate.

Acknowledgements

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