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Moisture in Multi-Layer Windows

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Abstract

There is an increasing interest in development of coupled multi-layer window structures. This is to optimize thermal properties and to develop systems with a better climate protected solar shading system. The risk of condensation on the inside of the exterior glass layer in a multi-layer window structure might be a challenge and is often questioned. The risk of condensation will depend on both window properties and indoor and outdoor climate conditions. The air gap between the inner and outer part have to be ventilated with outdoor air to give the window a "drying out" capacity. The U-value of the window and the moisture condition in the air gap both depend on the ventilation of the air gap. Reducing the ventilation improves the U-value, but increases the time of desiccation.Net long-wave radiation from the glass surface to the atmosphere during cloudless night-time will cause exterior glass temperatures lower than the outdoor air temperature, and hence increase the risk of condensation on both sides of the exterior glass. The aim of this work has been to assess for which climate conditions there will be a risk of condensation on the exterior glass layer and what might be the optimal ventilation of the outermost air gap. Simulations of the temperature on the exterior surface of the glazing including the long-wave radiation during night-time have been done and compared to measurements. An assessment has been made studying the risk of condensation and the drying out rate for climate conditions for two locations in Germany. A spreadsheet-based model calculating the U-value of a multilayer glazing unit according to ISO 15099 [1] has been further developed including airflow from exterior openings through the air gap.

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Keywords: Multy-Layer Windows, Moisture, Condensation, Long-wave radiation

1. Introduction

There is an increasing interest in development of coupled multi-layer window structures. This is to optimize thermal properties and to develop systems with a better climate protected solar shading system. The window may, in

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some cases, also be part of the ventilation strategy for the building. The risk of condensation on the exterior glass layer in such multi-layer windows might be a challenge and is often questioned.

The aim of this work has been to assess for which climate conditions there will be a risk of condensation on the exterior glass layer in a multi-layer window and what might be the optimal ventilation of the outermost air gap to reduce this risk and still maintain good thermal properties.

2. The window construction

The window in this study consists of a triple glass window pane (purple, 42 mm), a ventilated air gap (40 mm) with integrated solar shading and an exterior glass (green, 4 mm). Figure 1 show the window construction, upper part (left) and lower part (right).

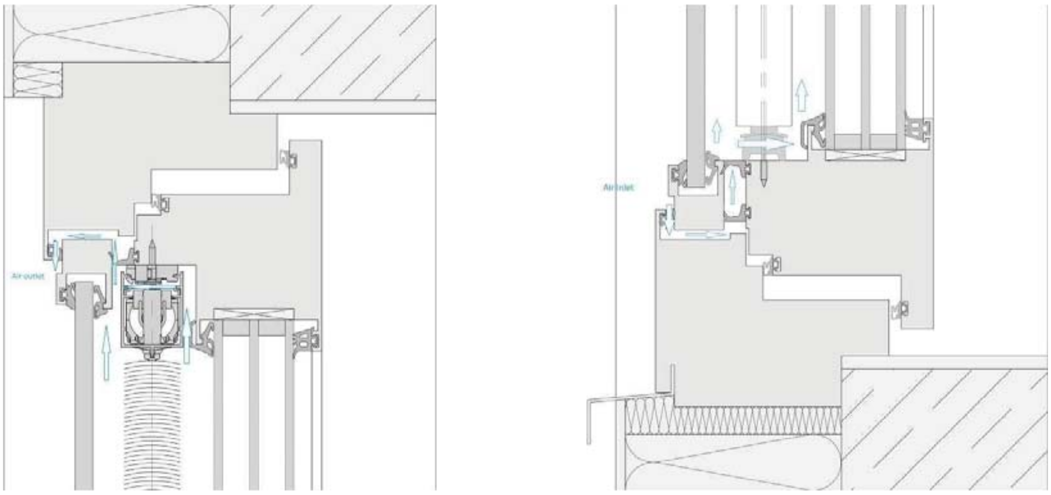

Fig. 1. Window construction, upper part (left), lower part (right).

3. Condensation and drying out mechanisms

The risk of condensation on the exterior glass layer in a multi-layer window structure depends on both window properties and indoor and outdoor climate conditions. Net long-wave radiation from the glass surface to the atmosphere during cloudless night-time will cause exterior glass temperatures lower than the outdoor air temperature, and hence increase the risk of condensation on both sides of the exterior glass. Good airtightness of the inner part of the window is very important to reduce the risk of moisture supply from indoor air. The air gap between the inner and outer part have to be ventilated with outdoor air to give the window a "drying out" capacity. The U-value of the window and thus the moisture conditions in the air gap both depend on the ventilation of the air gap. Decreasing the ventilation improves the U-value, but increases the time of desiccation. Small openings at the top and bottom of the outer part are sufficient and the negative influence on U-value is small.

In principle there are several mechanisms for moisture transport both into and out of an air gap, both from indoor and outdoor sides of the window. In this paper only two drying out mechanisms for the outer cavity of a window, as shown in fig. 1, is discussed. The two mechanisms are "moisture flow by air flow" and "moisture flow by vapour diffusion". The driving force for moisture flow by air flow, from outdoor air through the air gap and back to outdoor air, is the difference between air pressures at the upper and lower gap openings. The pressure difference is the sum of buoyancy and wind pressure. The flow resistance is primarily determined by the cross-section area and the shape of the openings. The driving force for moisture flow by diffusion, through the air gap openings (to/from outdoor air), is the difference between the vapour pressures (or vapour concentration) in the air gap and in the outdoor air. The flow resistance is primarily determined by the cross-section area and the "depth" of the gap openings.

4. Method

4.1. Heat and moisture transfer calculations

A spreadsheet-based model, that calculates the U-value of a multilayer glazing unit according to ISO 15099 [1], has been further developed to additionally calculate the airflow through the exterior gap, openings and the outer cavity. The impact of the airflow on heat loss and temperature distribution throughout the glazing structure as well as the moisture flow from the outer cavity is taken into account. A simplified model for calculating the moisture flow by diffusion through the gap openings is also included. The following simplifications were done to be able to perform the calculations;

- The resistance inside the outer cavity and the effect of the blind is neglected in the calculation of air flow and diffusion. The effect of the blind is also neglected in the heat flow calculation.
- Estimated equivalent Sd-values for the gap openings are used in the calculations of diffusion.

Finally the model has been used to study how different ventilation rates affect the moisture conditions at given temperature conditions calculated in WUFI [4].

4.2. Calculations of the temperature conditions

Two sets of climate conditions have been applied in the calculations:

- Constant outdoor and indoor temperature and standardized surface resistances
- Real climate data for Bellenburg, Germany

WUFI [4] has been applied to calculate the exterior surface temperature and the thermal conditions in the multi-layer window. The so called *Explicit Radiation Balance application* in WUFI has been used to include the long-wave radiation from the exterior glass to the atmosphere during night time. The Explicit Radiation Balance application requires climate data which contains values for the atmospheric counter radiation. Bellenburg has such data.

Calculations are performed based on climate data from two different dataset. The first is the Moisture Reference Year of Holzkirchen. The other data set is from measurements from Bellenburg performed by SAPA. The indoor temperature is set to 20 °C.

The window is modelled as shown in figure 2. The exterior glass is modelled as glass with thermal conductivity of 1 W/(mK). The air gap is modelled as an air layer with additional moisture capacity. The triple glass window pane is modelled as one material with thermal conductivity of 0.0285 W/(mK), calculated for the specific window pane. Monitors are placed on the outside and inside of the exterior glass, in the middle of the air gap and on the outside and inside of the triple glass window pane.

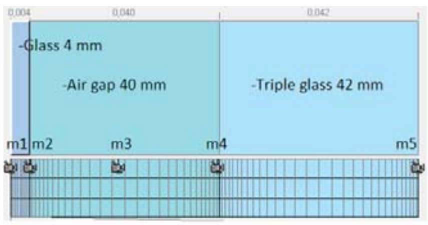

Fig. 2. Model of the multi-layer window in WUFI

The window is 90 ° (vertical position) and facing north. The heat transfer coefficient of the interior surface is set to 0.13 m^2K/W and the exterior surface is set to be wind dependent. Other selected properties for the exterior surface; short wave radiation absorptivity = 0,925, long-wave radiation emissivity = 0,837, ground short-wave reflectivity= 0,2.

5. Results

5.1. Temperature conditions on the exterior glazing

Figure 3 shows the temperatures in the multi-layer window over a period of 4 days for Bellenburg. The 4 days are chosen to show the most unfavourable situation with cloudless sky at night. The figure illustrates how the surface temperature on the exterior glass decreases to a lower temperature than the outdoor air temperature at night due to the long-wave radiation to a cloudless cold sky.

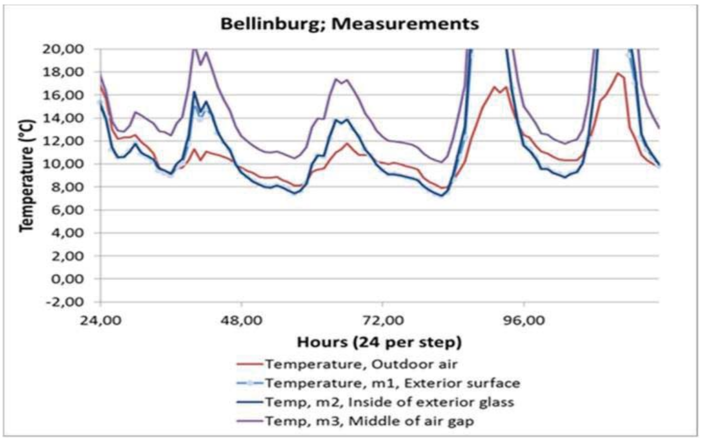

Fig. 3. Temperatures in the multi-layer window calculated in WUFI for climate data from Bellenburg

5.2. Moisture transport – Constant outdoor climate data

By use of the spread sheet model, for stationary calculations, the drying out capacities of two transport mechanisms, airflow and diffusion, has been studied for a window as shown in figure 1. Calculated results, together with the input values for the main parameters, are shown in table 1. The results show that moisture transport by airflow is a factor 15 to 245 larger than the moisture transport by diffusion.

5.3. Moisture transport - weather data for Bellenburg

The calculation program was revised and some calculations with weather data for Bellenburg have been performed. For these calculations the vent openings at top and bottom of the outer window sash is randomly selected (see table 2). Fig. 4 and 5 show measured and estimated (calculated) temperatures and relative humidity for the window and outdoor.

Table 1. Input values and results from the calculations for the window shown in figure 1

Input values							
Glazing		4-40-4E-15Ar-4-15Ar-E4					
Area, upper gap opening	mm²	1000	1000	1000	5000	5000	5000
Area, lower gap opening	mm²	1000	1000	1000	5000	5000	5000
Singular loss coefficient, gap openings		1,4	1,4	1,4	1,4	1,4	1,4
Estimated equivalent S_d-values, gap openings	mm²	10	10	10	10	10	10
Wind speed	m/s	0	1	5	0	1	5
Windpressure coeffisient at upper gap opening		0,8	0,8	0,8	0,8	0,8	0,8
Windpressure coeffisient at lower gap opening		0,6	0,6	0,6	0,6	0,6	0,6
Inndoor temperature	°C	20	20	20	20	20	20
Moisture supply air gap, relative to out door air	g/m³	1	1	1	1	1	1
Relative humidity, RH, outdoor	%	70	70	70	70	70	70
Outdoor temperature	°C	0	0	0	0	0	0
Calculated values							
U-value of the glazing, Ug, with no gap openings	W/m²K	0,53	0,53	0,53	0,53	0,53	0,53
"ΔUg" caused by air flow through the air gap	%	0,5	0,2	2,3	2,1	1,1	6,8
Glass temperatur, surface 2	°C	0,43	0,45	0,29	0,31	0,38	0,03
RH at surface 2	%	88	88	89	89	88	90
Moisture transport out of the air gap by air flow	g/day	19	6	97	87	39	488
Moisture transport out of the air gap by diffusion	g/day	0,4	0,4	0,4	2,0	2,0	2,0

Table 2: Input values for the main parameters for calculations with climate data for Bellenburg

Input values		
Glazing		4-40-4E-15Ar-4-15Ar-E4
Coatings, emissivity		0,03
Upper gap openings, width	mm	5
Upper gap openings, lengths	mm	200
Upper gap openings, area	mm²	1000
Lower gap openings, width	mm	5
Lower gap openings, lengths	mm	200
Lower gap openings, area	mm²	1000
Estimated equivalent S_d-values, gap openings	mm	10
Vertical distance between gap openings	m	1,5
Singular loss coefficient, gap openings	m	1,4

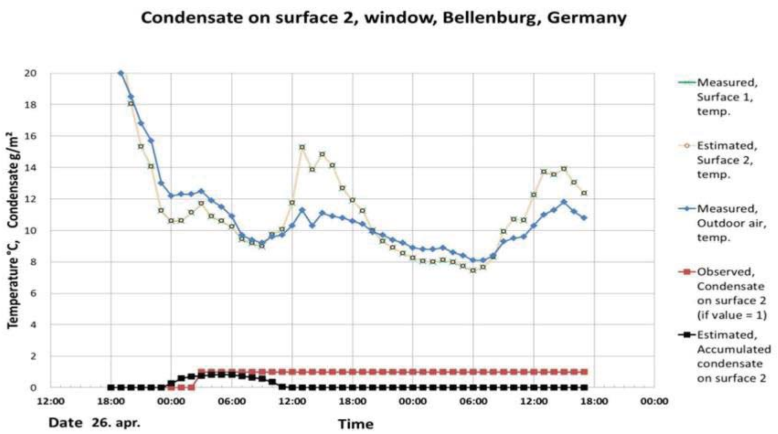

Fig. 4 Estimated accumulated condensate and temperature on the interior of the outer glazing (surface 2) for a window with small openings (1000 mm2) at top and bottom. The measured and observed data is from a window with no ventilation openings at SAPA in Bellenburg.

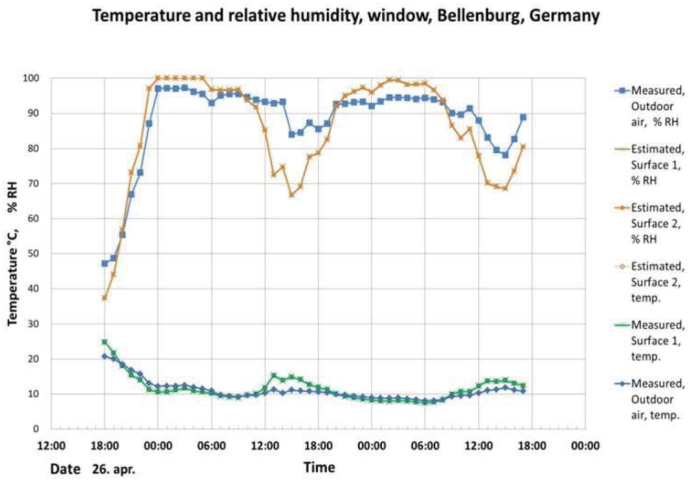

Fig. 5. Measured and estimated temperatures and relative humidities (RH) at the interior side (surface 2) and the exterior side (surface 1) of the outer glazing for a window, with no openings, at SAPA in Bellenburg and corresponding calculated (estimated) values

6. Discussion and conclusions

The calculation model gives results which are in good agreement with measurements regarding the influence of venting of the outer cavity of a multilayer window glazing unit through openings to outdoor air at the top and bottom. This applies to the change in U-value as well as the drying capacity by venting. These findings are also supported by [2] where the heat transfer through a double-casement wooden window was studied both by calculations and measurements by use of a guarded hot-box. Measurements were carried out both with and without gap openings in the outer sash. A drying out experiment, with a moisture source between the glazings showed a drying out rate of approximately 5 g/day for the window sections in question [2].

The calculated and measured temperature profiles clearly show that the surface temperature is lower than the outdoor temperature during some nights and the risk of condensation on the outer glazing can occur. It also shows that the relative humidity in the cavity is 100 % during some nights. The calculated results for Bellenburg show that the moisture and the condensate in the cavity will dry out as temperature rise in the morning. This is the case as long as there are small openings at the top and bottom of the window. Measured data for a testwindow, with no openings, in Bellenburg is also presented for comparison. From these results no drying out is observed. From the performed work the following conclusions can be drawn 1) The calculated and measured temperature profiles clearly show that the surface temperature is lower that the outdoor temperature during some nights and the risk of condensation on the outer glazing can occur 2) Calculations with constant outdoor climate show that small openings to outdoor air at the top and bottom of the outer cavity of a multilayer window glazing unit gives an effective venting and a high drying out capacity with minimal extra heat loss. Calculations with real climate data also support these findings that the moisture and condensate in the cavity will dry out during the early hours of the day 3) The moisture flow by diffusion is negligible compared to the moisture flow by airflow.

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