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Condensation on the outdoor surface of window glazing — Calculation methods, key parameters and prevention with low-emissivity coatings

Hans Joachim Gläser [a,*], Stephan Ulrich [b,1]

[a] Paul-Ehrlich-Str 10, 51643 Gummersbach, Germany

[b] Fraunhofer Institute for Surface Engineering and Thin Films IST, Bienroder Weg 54 E, 38108 Braunschweig, Germany

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ABSTRACT

The market share of thermally insulating, triple glazing installed as window glazing increased to nearly 50% in Germany in 2011 and is continuing to rise in 2012. Dew and frost on the outdoor surface of insulating glazing units with thermal transmittance values U_g below 1.0 W/(m^{2}K) present a severe problem, because unimpeded visual contact, one of the essential features of glazing, is disturbed. The report describes calculation methods to determine the occurrence and prevention of outdoor condensation and the key parameters influencing it. From this parameter study, it follows that condensation on the outdoor surface of window glazing in the form of frost and dew is prevented for all the glazing by low-emissivity (low-e) coatings with a certain thermal emissivity value ε_o between 0 and 1 on the outdoor surface if the outdoor air temperature t_o is lower than the room temperature t_i, normally given for buildings in the Central European climate when outdoor condensation occurs. However, today weather resistant low-e coatings with sufficient transmittance applied on outdoor surfaces of window glazing can only be manufactured on the basis of indium tin oxide with $\varepsilon_o \approx 0.2$. The study shows that with such low-e coatings frost can be prevented as well as the frequency of dew occurrence can be reduced on all vertically installed glazing with thermal transmittance values $U_g \geq 0.47$ W/(m^{2}K) and on the outside of skylight glazing with $U_g \geq 0.70$ W/(m^{2}K). This is sufficient for all window glazing marketed nowadays. Weather-resistant, cost-effective coatings on glass with $\varepsilon_o < 0.2$, which are required for energy-neutral glazing with U_g values < 0.5 W/(m^{2}K), are the subject of ongoing development.

1. Introduction

Dew and frost on the outdoor surface of thermal insulating glazing units for buildings with thermal transmittance values of U_g according to DIN EN 673 [1] below 1.0 W/(m^{2}K) present a severe problem, since unimpeded visual contact, one of the essential features of glazing, is disturbed. This is true especially for skylight glazing (Fig. 1) which is oriented to the west or the north, where outdoor dew and frost can last until well into the morning. A typical sign for outdoor frost on window glazing is the frost-free stripe along the edges of the glazing, also shown in Fig. 1, caused by thermal bridging due to the metal edge spacer of insulating glass units and partly also the window frame construction.

It has been known for a long time that low-emissivity coatings on the outdoor surface of glazing counteract dew and frost [2–4] (Fig. 2). The report aims to identify the key parameters influencing the occurrence of outdoor condensation on glazing installed in buildings, the possiblities for preventing this condensation by low-e coatings on the outdoor surface of such glazing, today's possibilities in this field and future developments.

2. Theoretical background to the occurrence of condensation on outdoor surfaces

Condensation on outdoor surfaces occurs if the outdoor surface temperature t_{os} equals or falls below the dew point temperature t_{DP}. t_{DP} depends on the outdoor air temperature t_o and relative humidity rH_o of the outdoor air. For the special case of $rH_o = 100\%$, interesting especially in the following calculations, it follows for condensation on outdoor surfaces that $t_{DP} = t_o = t_{os}$. For constant rH_o, t_{DP} is a linear function of t_o, expressed by the formula $t_{DP} = f_{rHo}(t_o)$. Plots of t_{DP} as a function of t_o are straight lines, called DP lines. t_{os} also depends on t_o, as expressed by the formula $t_{os} = f_{glass}(t_o)$, where the function f_{glass} depends additionally on a series of conditions, such as the design of the glazing unit, the outdoor weather as well as indoor climatic conditions and the installation angle of the glazing. Condensation on the outdoor surface of glazing occurs for all t_{os} values of a t_{os} curve which fall on or below the DP line for a given relative humidity rH_o of the outdoor air.

In the following, the condensation behaviour of window glazing was investigated with two different algorithms. One, already demonstrated in [5,6], is based on the heat transfer coefficient h_t of the

* Corresponding author. Tel.: +49 2261 23198.
E-mail addresses: glaesergm@arcor.de (H.J. Gläser), stephan.ulrich@ist.fraunhofer.de (S. Ulrich).
[1] Tel.: +49 531 2155 618.

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Fig. 1. Skylight glazing with frost on the outside surface.

glazing unit according to DIN EN 673, whereby the external and internal heat transfer coefficients h_e and h_i, respectively, defined in this DIN EN norm for the calculation of the thermal transmittance value U_g were substituted. h_e was substituted additively by the following three heat transfer terms: 1. the heat exchange calculated according to the Stefan–Boltzmann law between the outdoor surface of glazing (with a thermal emissivity of ε_o) and the sky (at its corresponding equivalent temperature), 2. the heat exchange calculated in the same way between the outdoor surface of glazing and the ground (considering its thermal emissivity $\varepsilon_g = 1$ and its corresponding temperature t_g), and 3. the external convective heat transfer between the outdoor surface of glazing and the exterior calculated by the formula $\alpha_{co} * (t_{os} - t_o)$. h_i was substituted in the same way by two heat transfer terms: 1. The heat exchange calculated by the Stefan–Boltzmann law between the indoor glazing surface (with the thermal emissivity $\varepsilon_i = 0.84$) and the room walls (with $\varepsilon_w = 1$ and the wall temperature t_w, which in the following is set equal to t_i) and 2. the internal convective heat transfer which is given by $\alpha_{ci} * (t_i - t_{is})$ (t_{is} = indoor surface temperature of glazing). (Note: The reduction of ε_g and ε_w to 0.95 and t_w to t_i - 2 °C as reported in the literature does not influence essentially the results discussed in the following.) h_t represents a constant, i.e. a static thermal conductance value based on a set of temperatures defined in DIN EN 673.

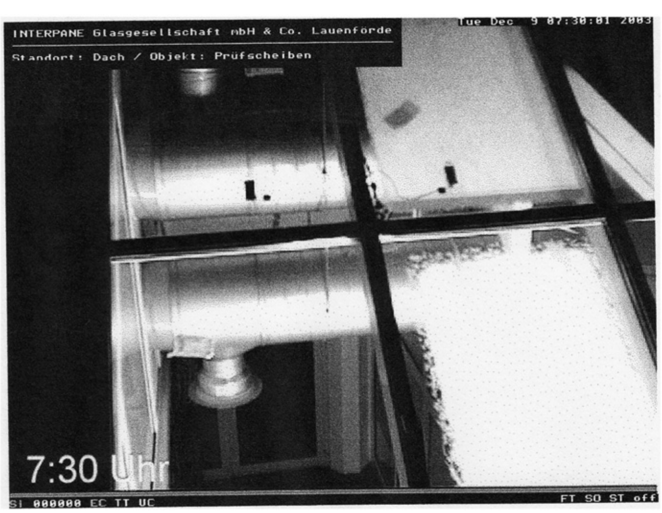

Fig. 2. Frost occurrence and prevention on skylight glazing. Above: glazing with U_g = 1.0 W/(m^{2}K), below: glazing with U_g = 0.7 W/(m^{2}K). Left side: ε_o = 0.17, right side: ε_o = 0.84 (uncoated).
Source: Interpane, 2002/2003.

The second algorithm is derived from a so-termed "thermal balance model" (Fig. 3) based on the physical justification of the fact that the thermal capacity of the individual panes of a glazing and the gases in the interspaces between its panes is negligible. This results in thermal equilibrium of the glazing at each point of time in dependence on the outdoor weather as well as indoor climatic conditions [7]. In this case, the heat fluxes in the interspaces were calculated with the longtime proven formalism for the convective (h_g) and radiative (h_r) heat transfer coefficients as depicted in DIN EN 673 with thermally and spectrally relevant data of the individual panes and gases of the interspaces according to the glazing design. Again, the external and internal heat transfer from and to the glazing were calculated with the same formalism as applied for the calculations of the h_t algorithm.

Therefore, with the algorithm of the thermal balance model, the temperatures of the individual panes can be calculated exactly for all glazing at a given outdoor weather as well as indoor climatic and user-related conditions. The calculations with this algorithm have shown that for glazing designs resulting in $U_g < 1$ W/(m^{2}K), according to DIN EN 673, the thermal resistance of the individual panes have only less influence on the results. Therefore, in this case, to simplify the calculations, the thermal resistance of the individual panes was neglected. Because in the thermal balance model the temperatures of the individual panes were adjusted to the outdoor weather and indoor climatic conditions, the thermal conductance of glazing is dynamic, contrary to the calculations on the basis of the constant h_t value.

3. Parameters influencing the occurrence of condensation on the outdoor surface of glazing

Investigations with both algorithms have shown that for the theoretical treatment of condensation on outdoor surfaces of glazing the following two temperature ranges should be distinguished: $t_o < t_i$ and $t_o \geq t_i$. Normally, $t_o < t_i$ is relevant for buildings in the Central European climate at night, except sometimes in summer. In this case, the thermal capacity of the room behind the glazing can be assumed as unlimited. $t_o \geq t_i$ occurs e. g. for cars and solar collectors also in the Central European climate at night. In this case, the thermal capacity of the room behind the glazing is low, i. e. limited. In this paper, however, only the case $t_o < t_i$ is treated for the occurrence of condensation on the outdoor surface of window glazing in the Central European climate. The case $t_o \geq t_i$ will be the subject of another report.

The aim of this report is: How outdoor condensation can be prevented on window glazing with low-e coatings on the outdoor surface of the glazing? To solve this task, it has to be investigated for which thermal emissivity of the outdoor surface ε_o of glazing the

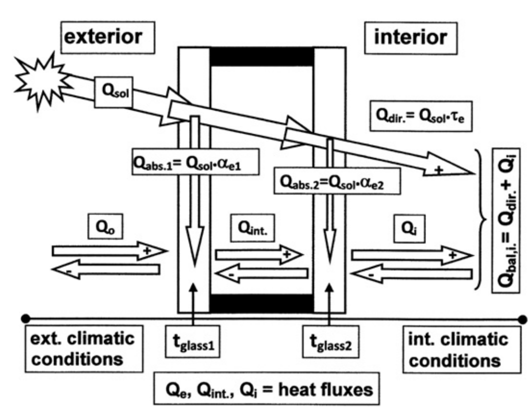

Fig. 3. Diagram of the thermal balance model depicted in the form of an energy flow diagram, here for a double-glazed unit as an example.