Condensation on the outside surface of window glazing – what are the key parameters and how to avoid with Low-E coatings?

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Keywords

1 = Coatings on position one 2 = Low-E 3 = Outside Condensation

Abstract

The market share of triple heat insulating glazing has been increasing to ~40 % in 2010 in Germany. Dew and frost on the outside surface of such insulating glass units with U_g values from 0.4 to 1.0 W/m²K installed as window glazing are a severe problem, because the free look-through being one of the essential functions of glazing is disturbed. This report describes the key parameters influencing the occurrence of outside condensation. From this parameter study it follows that frost can be avoided by adequate Low-E coatings, but this does not hold for dew. Regarding dew, only the frequency of its occurrence can be diminished. The essential result of the study is that dew on the outside surface of glazing cannot be avoided with any Low-E coating if the outdoor temperature exceeds the room temperature. With Low-E coatings having a maximum emissivity of $\epsilon_0 = 0.2$ marketed today frost can be avoided on the outside surface of all vertically installed glazing with $U_g \geq 0.6$ W/m²K and on the outside of skylight glazing with $U_g \geq 0.75$ W/m²K. Since the risk of outside condensation decreases rapidly by decreasing the relative humidity, this result may be conservative. As deduced by a long term weathering test at the company Interpane, dew can be nearly completely suppressed by Low-E coatings with $\epsilon_0 = 0.14$ on the outside of vertically installed glazing with $U_g \geq 0.7$ W/m²K and with $\epsilon_0 = 0.1$ on the outside of skylight glazing. Cost effective coatings on glass with this ϵ_0 being ageing resistant to weathering are subject of ongoing development.

Introduction

Dew and frost on the outside surface of more and more marketed triple heat insulating glass units with U_g values from 0.4 to 1.0 W/m²K installed as window glazing are a severe problem, since the free look-through being one of the essential functions of glazing is disturbed. This is true especially for sky-light glazing (see Fig. 1) installed to west and north where outside dew and frost can last until deep in the morning. A characteristic for outside frost on glazing is the frost-free stripe at the edges of the glazing, as shown in Fig. 1, caused by thermal bridging of the metallic edge spacer of insulating glass units. It is known that low emissivity coatings on the outside surface of glazing counteract dew and frost [1, 2, 3]. The report aims to depict the key parameters influencing the occurrence of outside condensation on glazing, the limit of avoidance of this condensation by Low-E coatings, today's marketing activities in the field as well as possibilities of developing Low-E coatings for the avoidance of outside condensation.

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

Theoretical background of the occurrence of condensation on outside surfaces

In general, condensation on outside surfaces takes place if the dew point t_{DP} of outdoor air exceeds or equals to the outside surface temperature t_{os}. t_{DP} depends on the outdoor air temperature t_o and its relative air humidity rH_o. For constant rH_o it follows that t_{DP} is a linear function of t_o, expressed as the formula $t_{DP} = f_{rHo}(t_o)$. Diagrams are straight lines, in the following called DP lines. Especially for $rH_o = 100$ % it follows: $t_{DP} = t_{os} = t_o$. On the other hand t_{os} depends on t_o too, expressed as the formula: $t_{os} = f_{glass}(t_o)$, whereas the function $f_{glass}(t_o)$ depends on a series of climatic indoor and outdoor conditions, such as on the angle of the glazing's installation. In the following, the graphs of the function $f_{glass}(t_o)$ are called t_{os} curves. Therefore, it follows in general that condensation on the outside surface of glazing occurs for all t_{os} of a t_{os} curve falling on or below the t_{DP} line of a given relative outdoor air humidity. The solution of $f_{glass}(t_o)$ for a given series of climatic, glazing and user-related parameters is possible with an Excel worksheet [4], whereas the occurrence of condensation will be determined by the intersection point of the t_{os} graph with the DP line $t_{DP} = f_{rHo}(t_o)$. For the calculation of the occurrence of condensation on the outside surface of glazing, the following most critical outdoor conditions have to be entered as parameters in the Excel worksheet:

- Absence of or only poor sun irradiation (e. g. at night time or at sunset/sunrise),
- calm air conditions ($\alpha_{co} = 3.6$ W/m²K, i.e. only natural convection),
- cloudless sky,
- no shadow in front of the glazing,
- inclination β of the installed glazing; e.g. $\beta = 30°$(as for skylights) and
- relative air humidity $rH_o = 100$ %.

Fig. 2 shows exemplarily the graph of the function $f_{glass}(t_o)$) of an insulating glass unit with $U_g = 0.7$ W/m²K and an outside surface thermal emissivity $\epsilon_0 = 0.17$ considering the most critical conditions for outdoor condensation and the standard room conditions as well as the DP line for $rH_o = 100\%$, i.e. for $t_{DP} = t_o = t_{os}$ following from the most critical outdoor conditions. In the outdoor temperature range depicted in Fig. 2 the t_{os} curve is nearly a straight line intersecting the DP line for $rH_o = 100\%$ at $t_{DP} = t_{os} = t_o = 5.0$ °C. This is the minimum outdoor temperature considering the most critical outdoor conditions for the occurrence of condensation on the outside surface of the given glazing, in the following called minimum outdoor temperature, t_{omin}. The figure implies: Outside condensation cannot occur for $t_o < t_{omin}$, but for $t_o \geq t_{omin}$.

Influencing parameters for the occurrence of condensation on the outside surface of glazing

There are, in essence, five parameters influencing mostly t_{omin} and thus the condensation on the outside surface of glazing:

1. Influence of air humidity rH_o:

Fig. 3 depicts exemplarily the graph of $f_{glass}(t_o)$ for the same insulating glass unit as in Fig. 2, but now intersecting the DP lines for the relative outdoor humidifies rH_o = 100 % and 90 %, respectively. The standard room conditions and the other most critical conditions for outside condensation were not changed. Fig. 3 implies: t_{omin} increases essentially with decreasing rH_o. The consequences of this result are:

1. The frequency of occurrence of condensation on the outside surface of the glazing depends essentially on the rH_o level of the climate of the region where the glazing is installed.
2. The following calculation shown here have been performed for the most critical situations, especially for rH_o = 100 % which occurs rarely for most climate conditions. Therefore the result of the following calculations may be interpreted as risk of the occurrence of outside condensation.

Especially for the variation of rH_o it follows from Fig. 3: The lower the air humidity rH_o, the lower the risk of outside condensation.

2. Influence of heat transmission coefficient U_g

Fig. 4 depicts exemplarily the graphs of $f_{glass}(t_o)$ for two insulating glass units with U_g = 0.7 and 1.2 W/m²K, respectively, and in both cases for ϵ_o = 0.17 intersected by the DP line for rH_o = 100 % considering again the most critical outdoor conditions of condensation as well as the standard room conditions. Fig. 4 shows: t_{omin} decreases with decreasing U_g. This means: The lower the U_g of a glazing is the higher the risk of outside condensation. This confirms the market's experiences on triple heat insulating glass units in the last years.

3. Influence of the inclination ß of glazing in the facade

Fig. 5 depicts exemplarily the graphs of $f_{glass}(t_o)$ for the insulating glass units with U_g = 1.0 W/m²K and ϵ_o = 0.84 installed in the façade alternatively with the inclination β = 90° and 0°, whereby the most critical parameters for condensation as well as the standard room conditions are assumed again. Fig. 5 shows: t_{omin} decreases with decreasing ß. This means: The lower the installation angle of glazing in façades is the higher the risk of outside condensation. That's especially the problem relating to modern skylight glazing.

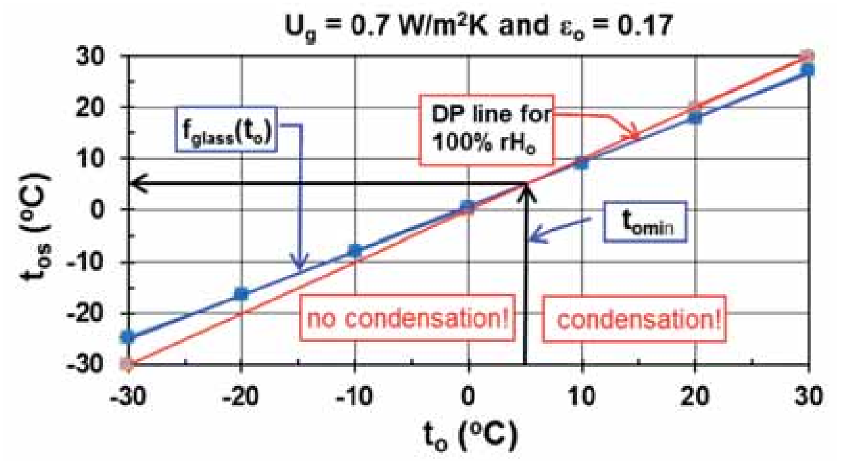

Fig. 2: Outside surface temperature t_{os} of an insulating glass unit with U_g = 0.7 W/m²K and ϵ_o = 0.17 as a function of the outdoor air temperature t_o for the most critical conditions of outdoor condensation and standard room conditions (room temperature t_i = 20 °C, indoor convection coefficient α_{ci} = 3.6 W/m²K, thermal emissivity of the inside surface of glazing ϵ_i = 0.84) linked with the dew point line (DP line) for rH_o = 100 %.

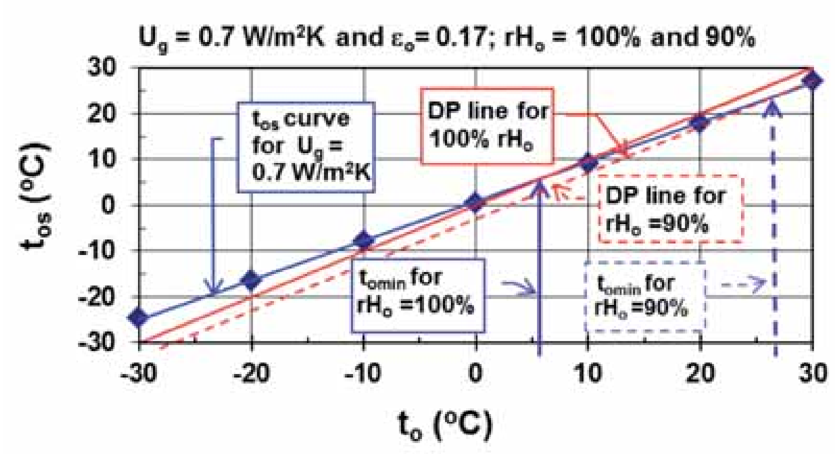

Fig. 3: t_{os} curve for an insulating glass unit with U_g = 0.7 W/m²K and ϵ_o = 0.17 as a function of t_o considering the most critical conditions for outside condensation and standard room conditions linked with the DP lines for rH_o = 100 % and 90 %.

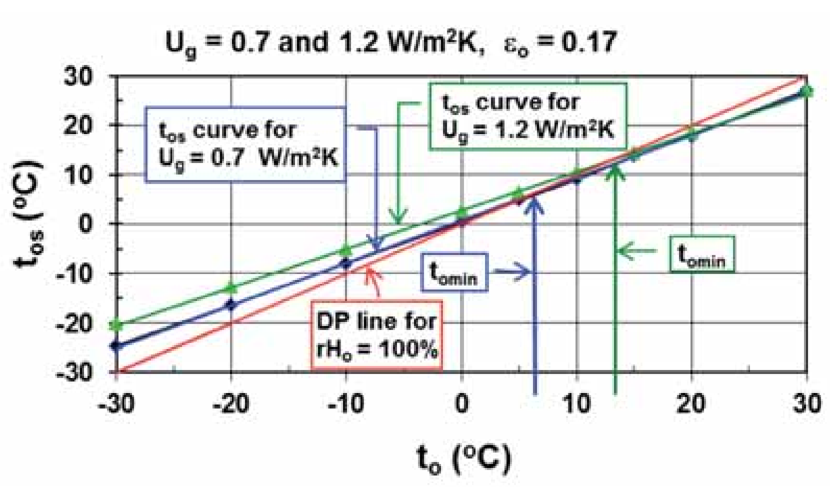

Fig. 4: t_{os} curves of insulating glass units with U_g = 0.7 and 1.2 W/m²K and ϵ_o = 0.17 in dependence on t_o considering the most critical outdoor conditions and the standard room conditions linked with the DP line for rH_o = 100 %.

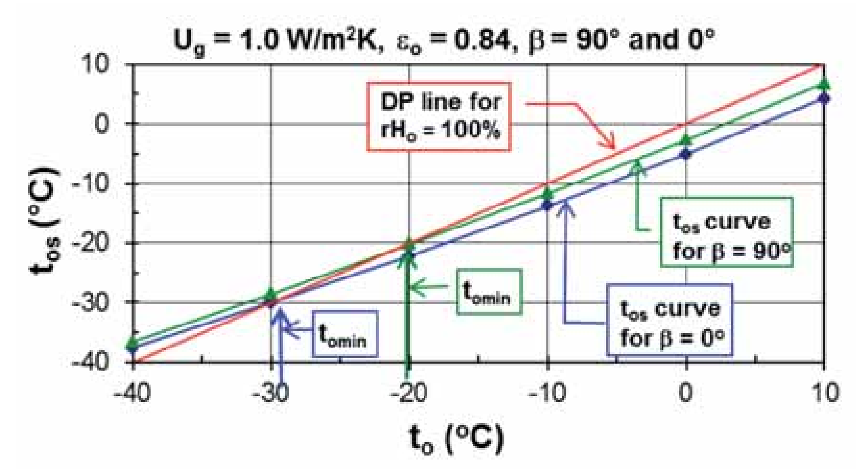

Fig. 5: t_{os} curves of an insulating glass unit with U_g = 1.0 W/m^{2}K and ϵ_o = 0.84 (uncoated outside surface) for β = 90° and 0°in dependence of t_o considering the most critical outdoor conditions and standard room conditions linked with the DP line for rH_o = 100 %.

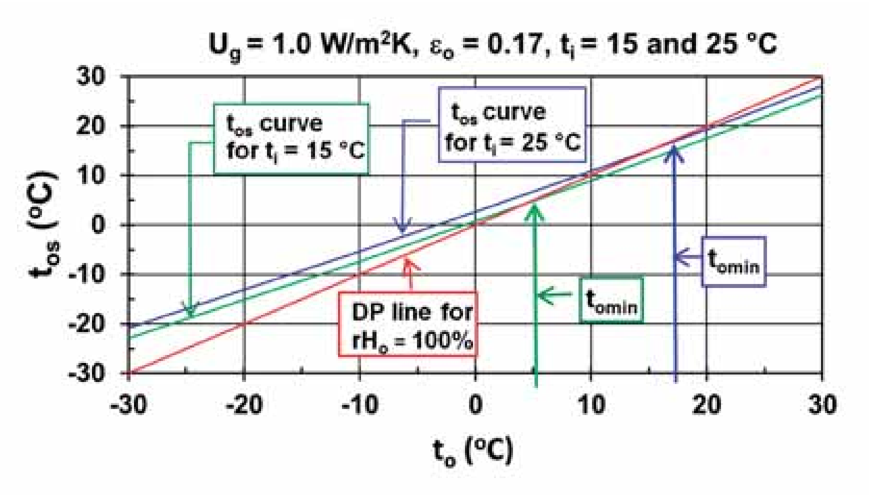

Fig. 6: t_{os} curves of an insulating glass unit with U_g = 1.0 W/m^{2}K and ϵ_o = 0.17 for t_i = 15 and 25 °C in dependence on t_o considering the most critical outdoor conditions and standard room conditions except for t_i linked with the DP line for rH_o = 100 %.

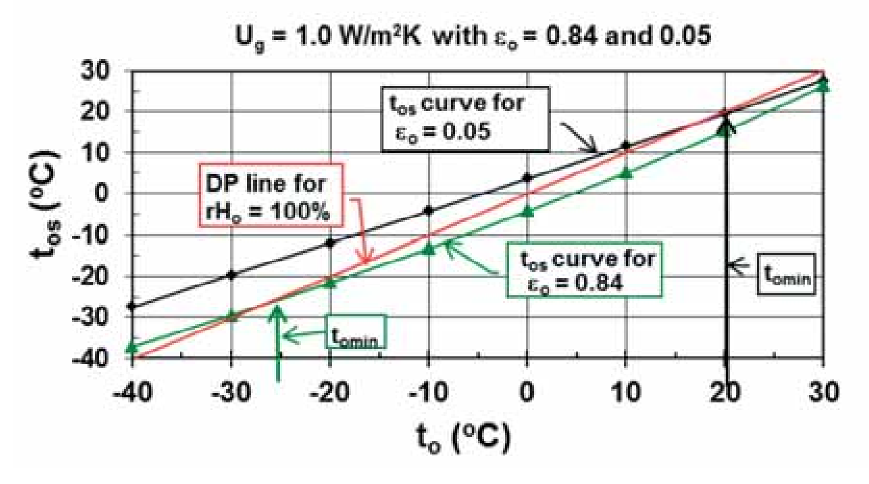

Fig. 7: t_{os} curves for an insulating glass unit with U_g = 1.0 W/m^{2}K and ϵ_o = 0.84 and 0.05 in dependence on t_o considering the most critical outdoor conditions and standard room conditions linked with the DP line for rH_o = 100 %.

4. Influence of room temperature t_i

Fig. 6 depicts exemplarily the graphs of $f_{glass}(t_o)$ for the glass units with U_g = 1.0 W/m^{2}K with ϵ_o = 0.17 at t_i = 15 and 25 °C, respectively, considering again the most critical parameters for condensation as well as standard room conditions. Fig. 6 shows: t_{omin} increases with increasing t_i. This means: The risk of outside condensation decreases with increasing room temperature. But note: The higher t_i is the higher the heat loss from room to outdoor!

5. Influence of the thermal emissivity ϵ_o of the outside surface of glazing

Fig. 7 depicts exemplary the graphs of $f_{glass}(t_o)$) for the glass units with U_g = 1.0 W/m^{2}K and the outside thermal emissivity ϵ_o = 0.15 and 0.05, respectively, whereby again the most critical parameters for outdoor condensation as well as standard room conditions are assumed. Fig. 7 shows: t_{omin} increases considerably with decreasing ϵ_o. This means: Outside condensation on glazing can be very effectively counteracted with a low ϵ_o. As result of this section it follows: The values of rH_o, U_g, β, t_i and ϵ_o are the most influencing parameters for the occurrence of condensation on the outside surface of glazing, whereby a lowering of U_g, β, and t_i increases the risk of outside condensation and a lowering of rH_o and ϵ_o considerably decreases the risk.

Limit of avoidance of condensation on the outside surface of glazing by Low-E coatings

The question arise: Does a limit for the avoidance of condensation on the outside surface of glazing exist when its emissivity approaches to zero? Or in other words, is there a maximum t_{omin} when ϵ_o approaches to 0? ϵ_o = 0 means in our case that radiation exchange between the outside surface of the glazing and the sky does exit no longer. Assuming a glazing with U_g and constant climatic indoor conditions, then it follows for t_{os} [see 5, page 324, equation for Q_{KS} = 0]:

$$t_{os} = \frac{k' t_i + \alpha_{co} t_o}{k' + \alpha_{co}}$$

where α_{co} is the external convective heat transfer coefficient depending on wind speed and $1/k' = 1/U_g - 1/h_e$. (h_e is the external heat transfer coefficient according to DIN EN 673, h_e = 23 W/m^{2}K). Because t_{os} equals t_o for rH_o = 100 %, it follows from the above equation:

$$t_{omin}(rH_o = 100\,\%) = t_i$$

This implies: For ϵ_o= 0 and rH_o = 100 % there exists a maximum t_{omin} being equal to the room temperature t_i. That means: For rH_o = 100 % condensation on the outside surface of glazing cannot be avoided by any Low-E coating if

$$t_o \geq t_i$$

The same results from the calculation with the Excel worksheet [see 4] as shown in Fig. 8. Fig. 9 depicts for the same conditions as given in Fig. 8 the outside condensation behaviour of glazing for the theoretical case $\epsilon_o = 0$ but $rH_o < 100$ %. Fig. 9 shows: In the same way as shown in Fig. 3, provided constant room temperature, t_i (e.g. t_i = 20 °C), t_{omin} shifts for $rH_o < 100$ % to higher outdoor temperatures t_o whereby shifting is the larger the lower rH_o and U_g, respectively. I.e. for $rH_o < 100$ % condensation on the outside surface of glazing occurs at higher outdoor temperatures t_o than the given room temperature t_i.

Consequences for the application of Low-E coatings on the outside surface of glazing

The result of the both last section is that condensation on the outside of glazing can be considerably counteracted by a low emissivity surface ϵ_o e.g. by a low emissivity coating, but not completely avoided. The risk of condensation increases with increasing outdoor temperature and relative air humidity rH_o. Therefore, only a partial solution against outside condensation on glazing is possible with Low-E coatings. The question is: What is the worst case of condensation and can it be avoided by today's economically produced Low-E coatings? Beyond doubt, the worst case of outside condensation on glazing is frost, especially occurring on more and more marketed triple heat insulating glass units and on high performance heat insulating skylight glazing, because it can last in western and northern façades until deep in the morning disturbing completely the free look-through being one of the essential functions of glazing.

Fig. 10 depicts the maximum ϵ_o for Low-E coatings dependent on the U_g value of glazing for avoiding outside surface condensation in the form of frost calculated with the Excel worksheet [see 4] for rH_o = 100 % and $t_{os} = t_{DP}$ = 0.1 °C, whereby the installation angle of β= 30° (skylight window) and the room temperature t_i = 18 °C are the most critical conditions for condensation. From Fig. 10 it can be concluded: With Low-E coatings having an $\epsilon_o \leq 0.14$ frost can be avoided on the outside surface of all vertically and inclined installed glazing with today's upcoming $U_g \geq 0.4$ W/m²K.

The comparison of Fig.11 with Fig. 10 shows that the marginally lowering of the relative air humidity from rH_o = 100 % to 95 % causes a considerable shift of max ϵ_o to higher values. That means: The calculation depicted in Fig. 10 is conservative. From Fig. 10 and 11 it can be deduced that for today's marketed

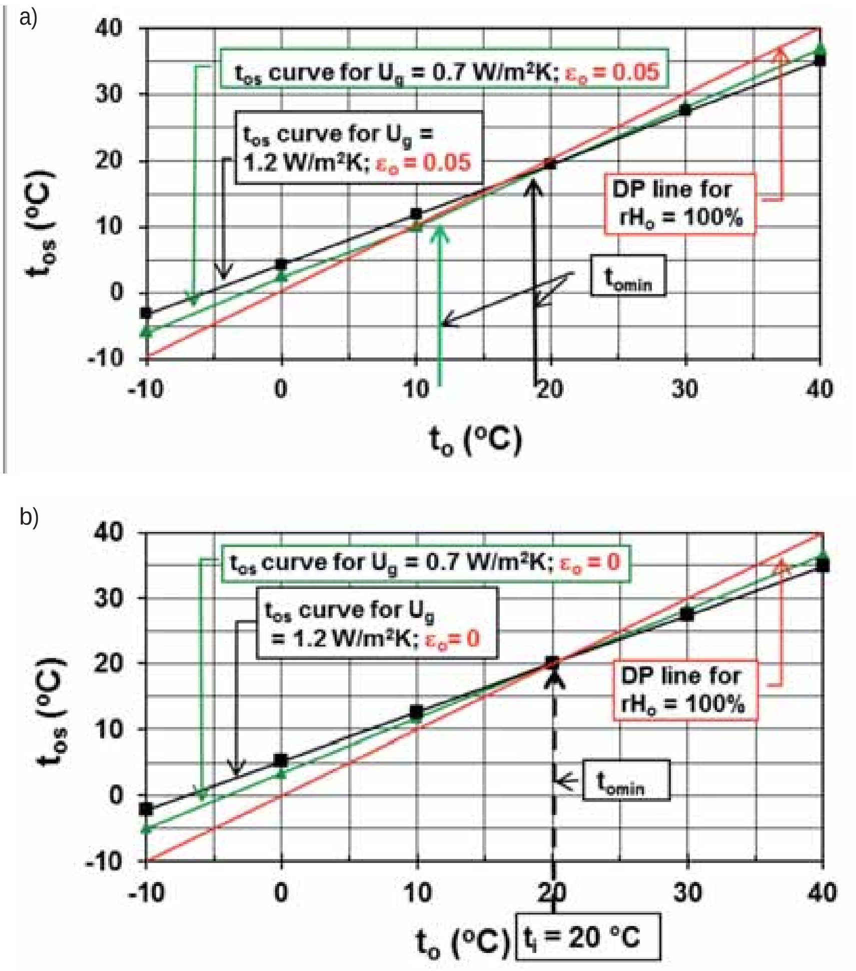

Fig. 8: t_{os} curves for insulating glass units with U_g = 0.7 and 1.2 W/m²K and ϵ_o = 0.05 (s. Fig. 8a) and ϵ_o = 0 (s. Fig. 8b) in dependence on t_o considering the most critical outdoor conditions and standard room conditions (exposed t_i = 20 °C) linked with the DP line for rH_o = 100 %.

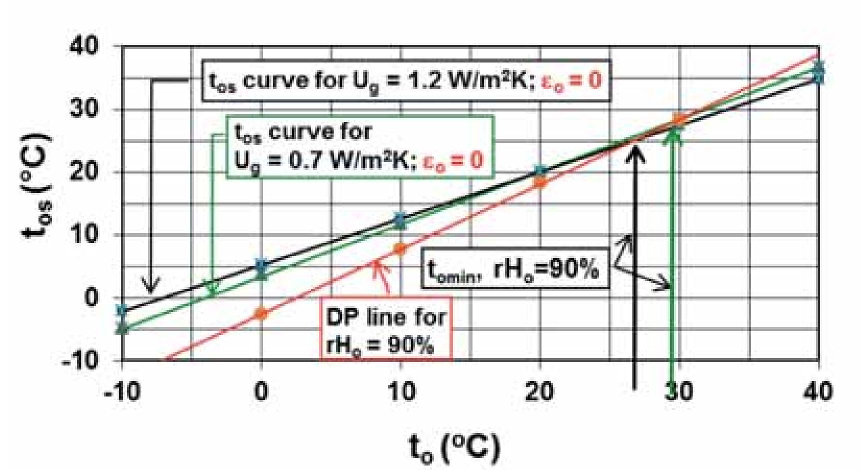

Fig. 9: t_{os} curves of the insulating glass units as in Fig. 8b as a function of t_o linked with the DP line for rH_o = 90 %.

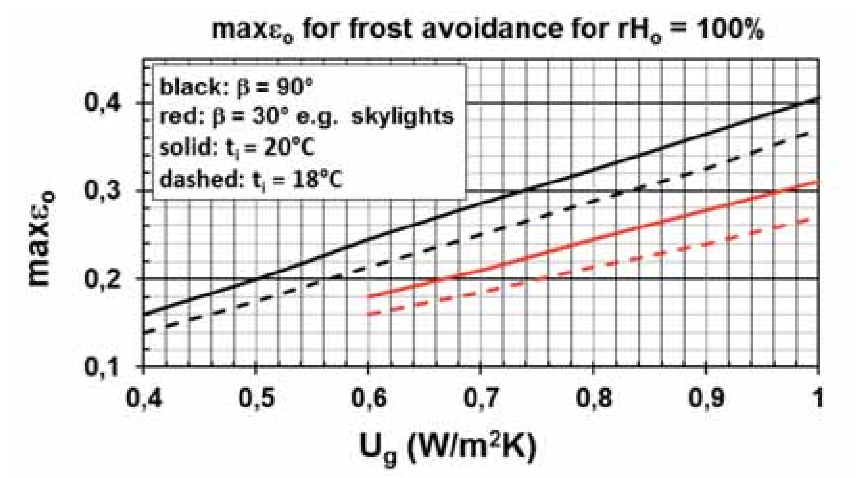

Fig. 10: max ϵ_o in dependence on the U_g value of glazing from 0.4 till 1.0 W/m²K for frost avoidance on its outside surface regarding the two normal, β = 90° and t_i = 20 °C, and the two most critical situations, β = 30° and t_i = 18 °C.

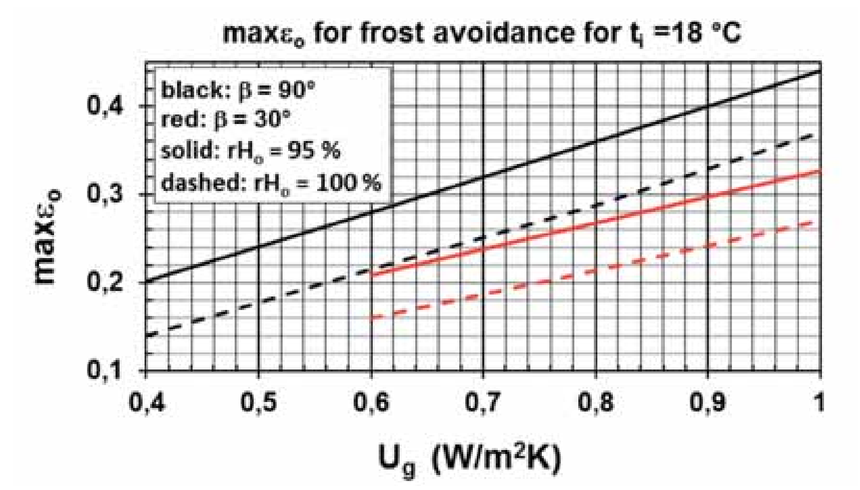

Fig. 11: max ϵ_o in dependence on the U_g value of for the same range as shown in Fig. 10 considering the most critical room temperature t_i = 18 °C, but now for rH_o = 90 % compared with that of rH_o = 100 % (see Fig. 10).

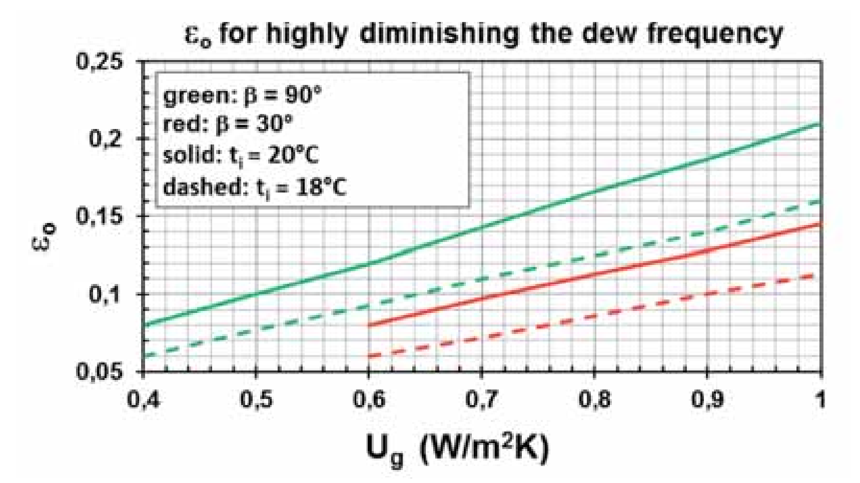

Fig. 12: ϵ_o in dependence on the U_g value of for the same range as shown in Fig. 10 assumed t_{omin} = 11 °C for maximum diminishing the occurrence of dew.

heat insulating glass units with U_g ≥ 0.6 W/m²K an ϵ_{omax} of 0.2 is sufficient for frost avoidance for all vertically installed glazing and for U_g ≥ 0.75 W/m²K for all inclined installed, i. e. skylight glazing. Low-E coatings with ϵ = 0.2 can be industrially produced by CVD and PVD processes and are marketed today.
As shown in section 4, dew occurrence cannot completely avoided by Low-E coatings. Only a diminishing of the frequency of dew occurrence on the outside surface of glazing is possible (and may be also desirable) with ϵ_o values lower than shown in Fig 10. The weathering test at the firm Interpane (Lauenförde, Germany) has shown that a glazing installed in a skylight with β= 45° having U_g = 1.0 W/m²K and a Low-E coating with the thermal emissivity ϵ = 0.17 on the outside surface does not show any outside condensation when observed for a full year [see 2]. That means that in this case outside condensation can take place only very seldom on the given installed glazing depending, beyond doubt, on the considerable diminishing of the risk of outside condensation for relative air humidity rH_o in the range of rH_o = 90 to 100 % as shown in Fig. 3 and 11.

The dew frequency observation on the glazing with U_g = 1.0 W/m²K can be simulated with the Excel worksheet by setting t_{omin} = 11 °C. The extrapolation of this t_{omin} value for dew avoidance to glazing in the U_g range from 0.4 to 1.0 W/m²K with vertically and inclined installation is depicted in Fig. 12. The main findings are: For glazing with U_g = 0.7 W/m²K being common more and more on the today's market, a Low-E coating having a thermal emissivity ϵ_o = 0.14 is necessary for nearly complete avoidance of dew on the outside of vertically installed glazing and ϵ_o = 0.1 on glazing installed with β = 30° (skylights). Low-E coatings with such thermal emissivity being ageing resistant for the positioning on the outside surface of glazing and, at the same time, economically and industrially producible are not yet developed.

Conclusion

The main parameters influencing the outside condensation on glazing are the heat transmission coefficient U_g, the thermal emissivity of the outside of glazing ϵ_o, the installation angle of the glazing β, the room temperature t_i, and the relative outdoor air humidity rH_o. With an Excel worksheet [4] the behaviour of outside condensation can be calculated. The essential result of our investigation is: With an adequate Low-E coating frost can be completely avoided on the outside surface of glazing, but this does not hold for dew. I.e. dew cannot be avoided by any Low-E coating when the outdoor temperature t_o exceeds the room temperature t_i. The frequency of the occurrence of dew on the outside surface of glazing can only be diminished by Low-E coatings since the Low-E effect is not sufficient when the outdoor temperature t_o exceeds the indoor temperature t_i.

With a Low-E coating having a thermal emissivity of $\epsilon = 0.2$ frost can be avoided on vertically installed glazing with $U_g \geq 0.6$ W/m²K and on skylight glazing ($\beta \geq 30°$) with $U_g \geq 0.75$ W/m²K. Low-E coated glasses with $\epsilon = 0.2$ being ageing resistant on the outside of glazing are marketed today. The frequency of the occurrence of dew would be nearly completely suppressed with Low-E coatings having a thermal emissivity of $\epsilon = 0.14$ on the outside of vertical installed glazing and $\epsilon = 0.1$ on skylight glazing. It's an important objective to develop adequate Low-E coatings for this application.

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