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Dedicated to Univ.-Prof. Dr.-Ing. habil. Dr. E.h. mult. Dr. h.c. mult. Karl Gertis on the occasion of reaching emeritus status

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Hygrothermal Effects of Infrared-Reflecting Layers

The long-wave, infrared (IR) exchange of radiation of building surfaces with their environment or within a building component is a thermal transfer which must not be neglected. The reduction of this thermal transfer by means of infrared-reflecting layers can contribute to energy savings. Unfortunately, this contribution is frequently overestimated in practice. The aim of this IBP Report is to clarify the potential of IR-reflecting layers from a hygrothermal point of view.

Background

Most mineral or organic building materials absorb or emit more than 90% of incident long-wave radiation, i.e. the reflection is less than 10%. To speak of infrared-reflecting films or coatings, the reflected ratio of infrared radiation must be clearly higher than 10% (e.g. shiny metal surfaces approx. 90%). In the case of opaque layers of building components, the ratios of emitting and reflecting radiation of a certain wave length always complement one another to 100%, i.e. the higher the long-wave reflection, the lower the emission. This is why those layers are often called "low-e", meaning low IR emittance.

Infrared-Reflecting Façades

In contrast to thermal conduction or heat transfer by convection, the radiation-related heat flow is effective over long distances. This fact explains the phenomenon of the cooling of external surfaces during clear nights. The long-wave radiation exchange with the cold zones of the lower atmosphere causes an energy sink on the surface which is counteracting the heat exchange by convection with the direct environment. Since this cooling of external building envelope surfaces frequently has hygrothermal consequences (condensation or high surface humidity [1]), besides minor additional heat losses, the application of IR-reflecting façade coatings bears an interesting perspective to prevent microbial growth [2].

Heat Transfer in Air Layers in the Interior of a Building Component

While the consequences of long-wave radiation exchange for external or internal surfaces of a building are subject to present research and model development, the impact of IR-reflecting layers on the thermal transfer within a building component has already been investigated several times, e.g. [3]. Because there is still high uncertainty concerning the thermal assessment of this effect in practice, various heat transfer processes (conduction, convection, radiation) as well as their magnitude will be explained by an example. Given a temperature gradient of 10 K over an air layer of 5 cm in an unventilated cavity, the shares of the heat flux density by convection and radiation, which are independent of each other, are described in detail in Fig. 1. As convection concurs with thermal conduction, both processes are considered as sum total in this case.

Radiation-related thermal flux is clearly higher than the convective heat flux in all cases. While, however, convective heat transfer is intensely dependent on the orientation of the air layer and the heat flow, the radiation exchange is independent of direction. Yet, there is an increase of the radiation-related heat flux in contrast to the convective heat flux at higher temperatures (T^4 law). The small decrease of the convective heat flux is due to the slight increase in viscosity of the air at higher temperatures. In case of the heat flow coming from above, there is almost no buoyancy convection. The share drawn in blue in Fig. 1 therefore represents the heat flux by thermal conduction, which slightly increases at rising temperatures (temperature dependence of the thermal conductivity of the air) in contrast to the convective heat flux.

Radiation-related thermal transfer can be reduced by means of IR-reflecting layers. Metallization of the layers of building components adjacent to the air layer allows the reduction of long-wave heat transfer of up to 90% in theory [3]. The air layer of a thickness of 5 cm, which we selected for our exam-

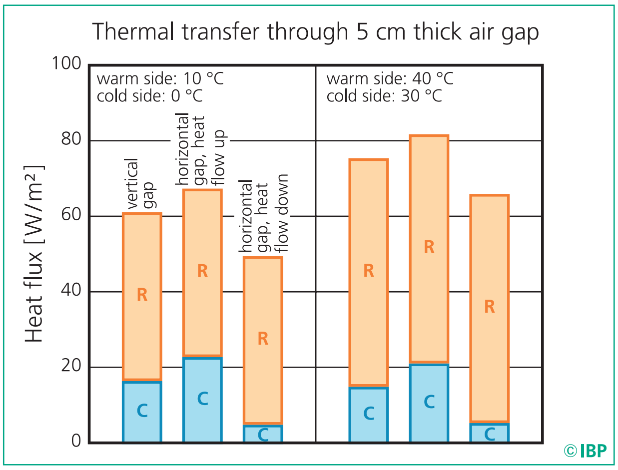

Fig. 1: Theoretically occurring heat flow density in an air layer of 5 cm thickness between two non-metal layers of a building component (ε = 0.95) in dependence of the orientation of the air layer and of the heat flow direction. The temperature difference over the air layer of 0°C on one side and 10°C on the other represents the situation in the external part of a poorly insulated building in winter. The temperature gradient from 30°C to 40°C is typical for the hot season. The convective share is highlighted in blue and the radiation-related share in orange.

ple, would thus produce the following results for the thermal resistance (R values) or the equivalent thickness of an insulation layer for thermal conductivity class 040:

A) vertical air layer: 0,48 m²K/W (≈ 20 mm)
B) horizontal air layer, heat flow from below:
   0,36 m²K/W (≈ 15 mm)
C) horizontal air layer, heat flow from above:
   0,9 – 1,1 m²K/W (≈ 40 mm)

The research findings stated in A and B are to a large extent independent of temperature in the range from 0° to 40 °C, whereas there is a tendency which indicates that smaller temperature gradients result in slightly more favourable values. Case C shows that thermal resistance is higher in winter (1.1 m²K/W) than in summer (0.9 m²K/W). In contrast to C, the R values in A and B change only marginally with thicker or thinner air layers, as long as the thickness is greater than 15 mm. All information, however, is valid only for idealised conditions, i.e. permanently shiny and pollution-free IR-reflecting surfaces, no external air infiltration etc.

The measured R values of air layers in lightweight building structures (data concerning air layer thickness in brackets) with IR-reflecting films on only one side indicate the following results (Desjarlais and Tye quoted in [4]):

A) 0,42 m²K/W (air layer thickness 10 cm)
B) 0,32 m²K/W (air layer thickness 15 cm)
C) 1,3 m²K/W (air layer thickness 15 cm)

The more favourable experimental result in case C is due to the higher air layer thickness in the test set-up, important only in this case (thermal conduction). If in case A an IR-reflecting film is applied on both sides of the air layer, the measured R value will be improved in an only insignificant way to 0.46 m²K/W. The target value mentioned under [3] for the long-wave emission of ε = 0.2 was even slightly undercut by the test (ε ≈ 0.15).

Conclusions

In comparison to normal air layers in vertical building components with an average R value of approx. 0.15 m²K/W an IR-reflecting film applied on one side results in an improvement of less than 0.3 m²K/W. This is equivalent to approx. 10 mm of conventional insulation (k = 0.04 W/(mK)). Similar values are probably valid for pitched roofs with an inclined air layer. The situation is a little more favourable for floors under winter conditions or for flat roofs in summer, when the heat flow comes from above (but only in this case!). Then the application of an IR-reflecting layer on one side with an air layer thickness of 5 cm will improve the R value in one direction by approx. 0.7 m²K/W in winter and 0.5 m²K/W in summer. This improvement is equivalent to a conventional insulation of 20 mm to 30 mm thickness.

The fact that IR-reflecting layers are frequently very vapour-tight due to their metal content can be a problem concerning moisture protection, which must be taken into consideration in any individual case. Yet there are recent developments in the field of breather membranes combining IR reflection and high water-vapour permeability. It must be assumed in any case that the IR reflection is not reduced by ageing or pollution. For the sake of completeness it should be mentioned once again that the energetic effect of infrared reflection in building components is to improve the thermal insulation effect of an adjacent air layer, i.e. without such an air layer there is no effect.

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