EVALUATION OF THE EMISSIVITY OF OUTER SURFACES OF BUILDING CONSTRUCTIONS

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Abstract:
The composition of coating materials, applied in the exterior layers of building constructions, affects the value of emissivity, important for the radiation of thermal energy from outer surfaces of such constructions into the free space. In case of most coating materials the rather rugged surfaces do not admit any direct measurement, based on the monitoring of the intensity of rays, reflected from the surface. The appropriate approach is the integral measurement of the reflected diffusive radiation from the surface, using the “ball method”: its interior sphere for the wavelengths from 5 to 20 μm must be gold-coated. However, such expensive equipment is not available in the Czech Republic, thus the indirect method of the measurement of the thermal resistance of the air gap has been applied where both the thermal flow and the heat radiation are active. The results of such measurements give a chance to evaluate the proportions of both these processes of heat propagation. The paper demonstrates practical results for various coating materials, supported by the automatic measurement device Lambda (Holometrix, U.S.A.).

Keywords:
heat transfer in air layers, thermal radiation, building insulations, experimental measurements

MOTIVATION AND THEORETICAL BACKGROUND

The phenomenon of the progressive damage of building claddings, caused by the condensation of water on the outer surfaces, even in the case of reconstructed buildings, has been analyzed in [4]. The analysis of thermal and moisture distributions both in the outer environment and on the outer surface of walls yields that the processes of heat and moisture transfer are conditioned by the radiation of the outer surfaces to the free atmosphere. This effect is more important in the new building constructions than in the past because the contemporary thermal technical standards have more strict requirements to the insulation ability of outer walls, consequently the thermal conduction through walls is law and the radiation is more significant in the total balance of heat. For comparison, in most insulation systems constructed by former requirements the total neglecting of radiation caused the systematic error about 1 %, which is in modern and reconstructed structures exceeded dramatically.

The thermal fluxes caused by radiation influence the redistribution of heat and moisture substantially during the time period when the direct radiation to the cloudless sky is enabled on the outer surface of the building structure. The temperature in the outer wall near the interface between the wall and its external environment is then (often rapidly) decreasing. The quantitative study of the radiation fluxes, sketched in [4], is based on the identification of concrete parameters of the Stefan-Boltzmann law; for more details to the emissivity, varying with wavelength, and also to the (monochromatic) absorptivity and reflectivity, see [2], p. 117. No real building materials (with a typically porous structure) have the ideal "black-body" surface, as introduced usually in the Stefan-Boltzmann law. Radiation falling on a surface is partly absorbed and partly reflected. Moreover, the radiation emitted through the small orifice of a cavity at certain temperature is much more a characteristic of the temperature alone than of the emissivity of the cavity walls. The possible presence of condensed water on the surface has two important consequences: i) it saturates the pore system of the adjacent material layers, ii) it affects the emissivity of the surface. Regardless of the above sketched complexity of the heat transfer by radiation, the surface emissivity is a crucial parameter in the Stefan-Boltzmann law; therefore the practical validity of any results from computational simulations without its proper setting is low.

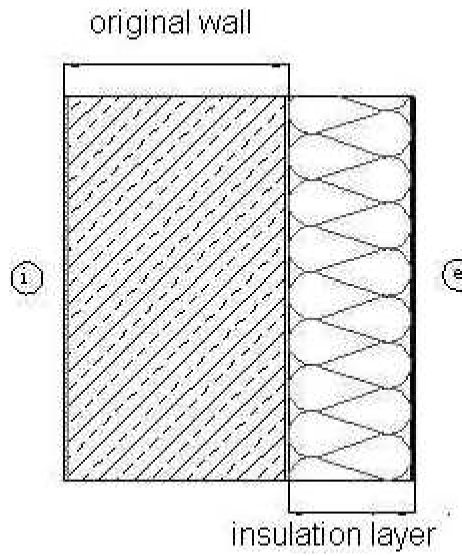

Figure 1: Typical approach to the reconstruction of buildings with insufficient thermal insulation

Fig. 1 shows the simplified scheme of a relatively inexpensive reconstruction of building objects, especially of block of flats in the "panel quarters of real socialism": one or more new insulation layer is added to existing constructions. The letter "i" denotes the interior room, the letter "e" the external environment. The condensed water is observed frequently as an unwanted consequence of such reconstruction activities; more references can be found in [4].

EXPERIMENTAL WORK

The inexpensive and precise measurement device for the identification of emissivity of various coatings, conditioning the process of thermal radiation, is not available. The surfaces of most coating materials are not perfect planar, they can be better characterized as rather ragged. Such insufficiency does not admit direct measurements, based on the monitoring of the intensity of rays, reflected from the surface. This difficulty can be avoided by the integral measurement of the reflected diffusive radiation from the surface, known as the "ball" method, implemented at the unique FTIR (Fourier transform infrared) spectrometer Bruker IFS-66/S. The gold-coated interior sphere of the measurement device handles the wide spectral range from the near infra-red domain (NIR) to the far infrared one (FIR), in practice the wavelengths from 5 to 20 μm; the spectral resolution is 0.15 cm^{-1}, for more technical details see [1]. Some necessary measurements for selected coating materials have been done at the National Institute of Chemistry in Ljubljana (Slovenia), as documented at Fig. 2: here the integral method has been applied to the high-reflectance aluminium surface and the graph presents its reflectance as a function of the wavelength. Let us remark that some other applications supported by Bruker FTIR spectrometers are referenced (mostly to papers in electronic journals) in [3].

However, the above described measurements are expensive and not available for common use. Therefore an indirect method for the identification of emissivity has been applied, based on the measurement of the thermal resistance of a plate which serves as a carrier of the analyzed coating. Such plate is inserted into the plate stationary measurement device Holometrix Lambda 2000 (U.S.A.). This device needs the specimens of size 300 × 300 mm, the distance between its plates is 50 mm. The mean temperature of measurement θ_{mean} and the thermal gradient between both plates $\Delta\theta_{delta}$ (this notation occurs in the following tables) can be adjusted; more technical information to the Holometrix Lambda 2000 supported measurements is contained in [5], p. 8. The measurement returns the information containing the thermal resistance of all layers (whose thickness is the same in all measurements) – namely of the plaster board with some surface coating and of the air gap. The differences between particular samples with various coatings can be detected, modified by the thermal changes caused by the heat conduction, convection and radiation, including the air flow.

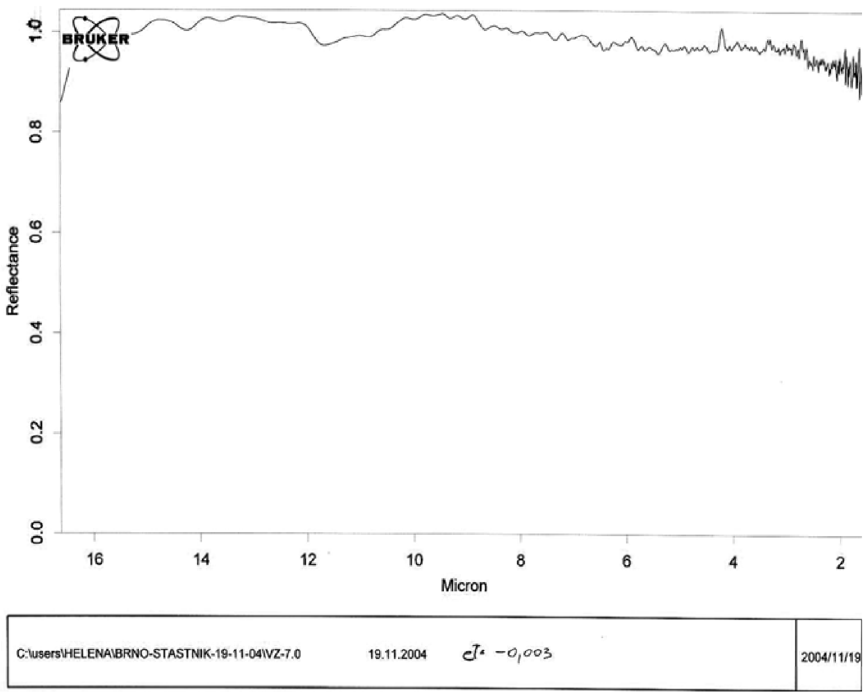

Figure 2: Example of an output from the measurement device BROKER

θ_{mean}	$\Delta\theta_{delta}$	λ	**R**	Presence
°C	°C	W/(m.K)	m^2.K/W	of condensed water
-0,04	-9,96	0,1710	0,290	No surface condensation
10,04	-9,94	0,1837	0,270	No surface condensation
20,13	-9,97	0,1956	0,254	No surface condensation
29,28	-9,94	0,2085	0,238	No surface condensation

Table 1: Plaster board, reference specimen – no surface modification

θ_{mean} °C	$\Delta\theta_{delta}$ °C	λ W/(m.K)	R m^2.K/W	R_{reflex} m^2.K/W	R_{reflex} %	Presence of condensed water
0,8	9,82	0,1721	0,29	0,00	**0,2%**	Surface condensation !
9,35	9,86	0,1610	0,31	0,04	**13,1%**	Surface condensation !
20,03	9,96	0,1662	0,30	0,06	**20,9%**	Surface condensation !

Table 2: Plaster board with the glued-on aluminium film, first specimen

θ_{mean} °C	$\Delta\theta_{delta}$ °C	λ W/(m.K)	R m^2.K/W	R_{reflex} m^2.K/W	R_{reflex} %	Presence of condensed water
20,25	10,43	0,0494	1,01	0,76	**74,9%**	No surface condensation
20,29	10,42	0,0496	1,01	0,75	**74,8%**	No surface condensation
29,51	10,42	0,0544	0,92	0,68	**74,1%**	No surface condensation

Table 3: Plaster board with the glued-on aluminium film, second specimen

θ_{mean} °C	$\Delta\theta_{delta}$ °C	λ W/(m.K)	R m^2.K/W	R_{reflex} m^2.K/W	R_{reflex} %	Presence of condensed water
19,78	10,01	0,1203	0,42	0,16	**39,0%**	No surface condensation
19,82	10,02	0,1202	0,42	0,16	**39,0%**	No surface condensation
30,1	9,96	0,1299	0,38	0,15	**38,1%**	No surface condensation

Table 4: Plaster board with the standard reflex aluminium coating

θ_{mean} °C	$\Delta\theta_{delta}$ °C	λ W/(m.K)	R m^2.K/W	R_{reflex} m^2.K/W	R_{reflex} %	Presence of condensed water
-0,13	9,95	0,1699	0,29	0,00	**1,0%**	No surface condensation
10,03	9,96	0,1717	0,29	0,02	**6,9%**	No surface condensation
20,18	9,97	0,1800	0,28	0,02	**8,3%**	No surface condensation
29,26	9,93	0,1914	0,26	0,02	**8,5%**	No surface condensation

Table 5: Plaster board with the grey reflex coating

θ_{mean} °C	$\Delta\theta_{delta}$ °C	λ W/(m.K)	R m^2.K/W	R_{reflex} M^2.K/W	R_{reflex} %	Presence Of condensed water
-0,15	-9,87	0,1817	0,27	-0,02	**-5,8%**	No surface condensation
10,02	-9,93	0,1894	0,26	-0,01	**-2,7%**	No surface condensation
20,12	-9,95	0,1990	0,25	0,00	**-1,3%**	No surface condensation
29,34	-9,92	0,2114	0,24	0,00	**-1,0%**	No surface condensation

Table 6: Plaster board with the black reflex coating

θ_{mean} °C	$\Delta\theta_{delta}$ °C	λ W/(m.K)	R M^2.K/W	R_{reflex} M^2.K/W	R_{reflex} %	Presence Of condensed water
-0,08	-9,94	0,1878	0,27	-0,02	**-9,4%**	No surface condensation
9,98	-9,95	0,1942	0,26	-0,01	**-5,3%**	No surface condensation
20,14	-9,98	0,2018	0,25	-0,01	**-2,7%**	No surface condensation
30,24	-9,94	0,2153	0,23	-0,01	**-2,9%**	No surface condensation

Table 7: Plaster board with the white reflex coating

The selected results of measurements are concentrated into seven tables. The reference material was the plaster board without any surface modification (Tab. 1), the remaining tables refer to the glued-on aluminium film (Tab. 2, Tab. 3) and to various types of a reflex coating (Tab. 4, Tab. 5, Tab. 6, Tab. 7). All tables contain the values of the heat transfer coefficient λ and of the thermal resistance R, including its part R_{reflex} related to the facultative surface coating.

CONCLUSION

The obtained values of the thermal resistance from the stationary device Holometrix imply that it is possible to evaluate the differences between the thermal resistance of particular materials with various surface modifications. These results have been applied to the quick estimate of the thermal emissivity of selected silicate materials and to the suitable choice of coatings for reconstructed building claddings.

The measurement results coincide with some known observations, e. g. that the colour of a surface has nearly no effect on the thermal radiation. The ideal surface seems to be the burnished metal surface, in the above presented tables the aluminium one.

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