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EXPERIMENTAL INVESTIGATION OF THE SPECIAL FEATURES OF HEAT TRANSFER THROUGH GLASS PACKETS

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We consider experimental procedures for determining the thermal resistances of certain types of commercial glass packets based on investigation of thermal and temperature fields on the outer packet surfaces at a stationary temperature head (~40°C), which corresponds to extreme climatic conditions of the middle belt. We evaluate the inhomogeneity of thermal losses over the glass-packet area caused by edge effects. The error in measuring the thermophysical parameters does not exceed ±3%.

Recent years have seen wide introduction of glass packets into civil and industrial engineering due to their heat-insulating properties, which exceed those of traditional sashes. This progressive innovation makes it possible to decrease considerably the heat losses through windows and thereby to resolve some problems in the field of energy saving. In this connection, extensive study of the processes of heat transfer through glass packets of various modifications is an urgent task for evaluating the saving of heat or cold in heat-engineering calculations of buildings that have translucent structures.

It should be noted that the process of heat transfer through a glass packet is complicated, since it includes three components: conductive, convective, and radiant. The exact solution of this problem with account for edge effects involves certain difficulties [1, 2], and therefore, in the present work we did not evaluate the contribution of every component. In this connection, certain assumptions were made, namely: a glass packet is considered to be a homogeneous infinite multilayer plate, and the principal heat-engineering parameter, namely, the effective thermal resistance, is introduced. This parameter characterizes comprehensively the heat-insulating properties of the glass packet and is very important in calculations of the heat transfer in building structures. We represent a glass packet in the form of a complex plane wall consisting of n layers packed close to each other, with different thickness δ_i and thermal conductivity λ_i (Fig. 1) and, naturally, with different thermal resistance R_i. Since there is good thermal contact at the boundary of two adjacent layers, the heat fluxes at their interface are identical, and the total thermal resistance of the glass packet will be equal to the sum of the resistances of the individual layers.

In structural thermal physics, there exists the concept of resistance to heat transfer, in which the heat-transfer coefficient on both sides of the glass packet is taken into account. Therefore, it is worthwhile to consider a glass packet to be an infinite plate, and then from the solution of the heat conduction problem with boundary conditions of the first and third kind [2, 3] in a steady-state regime it is possible to write the total heat-transfer resistance R_{eff} in the form

$$R_{\text{eff}} = \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_1} + \frac{1}{\alpha_2}, \qquad (1)$$

where δ_i and λ_i are the thickness and thermal conductivity of the i-th layer; α_1 and α_2 are the heat transfer coefficients on either side of the glass packet. We denote the first term in Eq. (1) by R and then obtain the following simplified relation for the effective thermal parameter:

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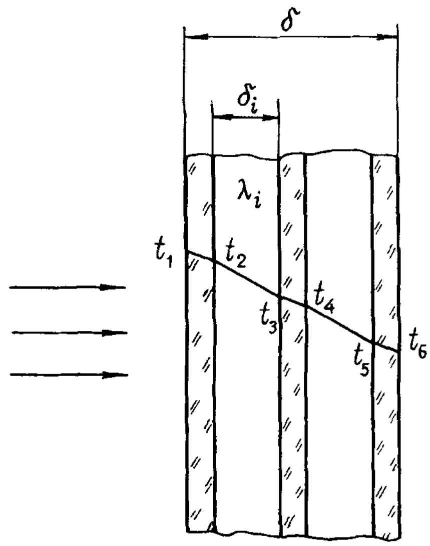

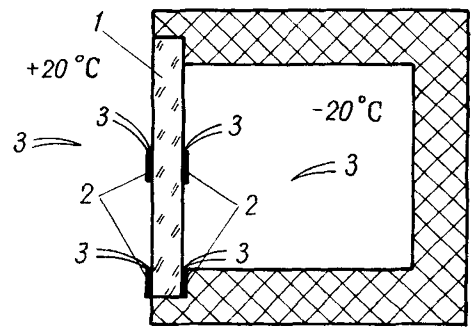

Fig. 1. Schematic of heat transfer through a multilayer plate.

Fig. 2. Climatic chamber: 1) glass packet; 2) HFSs; 3) thermocouples.

$$R_{\text{eff}} = R + \frac{1}{\alpha_1} + \frac{1}{\alpha_2}. \tag{2}$$

At large values of the heat-transfer coefficients α_1 and α_2 the total resistance of the glass packet will be $R_{\text{eff}} \approx R$. According to the Fourier law, the thermal resistance can be represented in terms of the specific heat flux q and the temperature difference:

$$R = \frac{\Delta t}{q}, \tag{3}$$

where $\Delta t = t_1 - t_6$ is the temperature difference between the outer and inner glass-packet surfaces, while the heat-transfer coefficients are $\alpha_1 = \frac{q_1}{\Delta t_1}$ and $\alpha_2 = \frac{q_2}{\Delta t_2}$ (Δt_1 and Δt_2 are the temperature difference between the surface on either side of the glass packet and the surrounding medium).

Finally, we obtain a simple expression for determining the effective resistance of the glass packet to heat transfer:

$$R_{\text{eff}} = \frac{\Delta t}{q} + \frac{\Delta t_1}{q_1} + \frac{\Delta t_2}{q_2}. \tag{4}$$

Expression (4) allows us to calculate the local R_{eff} in terms of the measured heat fluxes and temperature differences.

The thermal resistance is not identical over the entire glass-packet surface [3]. At the places of fastening the glass, i.e., in the edge region along the perimeter of the glass packet, the conditions of heat transfer will undoubtedly differ from the heat-transfer conditions in the central translucent structure. Therefore, it is of practical interest to determine the influence of the edge effect on the total heat transfer through a glass packet. For this purpose, an experimental setup similar to a climatic chamber [4] was created in which during the experiment we maintained a constant temperature head that corresponded to the extreme winter conditions of the middle belt.

Figure 2 presents the schematic setup. As objects of investigation we selected different glass packets: one-, two-, and three-chamber ones with aluminum thrust frames and, for comparison, a two-chamber glass

TABLE 1. Thermophysical Parameters of Glass Packets

Type of glass packet			q_1	q_2	Δt	Δt_1	Δt_2	R_{eff},
			W/m^2		°C			deg·m^2/W
Metallic thrust frame	One-chamber	Center	76	59	12.5	8.5	7.5	0.402
		Edge	82	74	7.5	13.2	7.5	0.354
	Two-chamber	Center	53	37	18.5	4.3	5.3	0.573
		Edge	72	71	10	11.1	7.5	0.392
	Three-chamber	Center	35	30	19.5	5.0	4.3	0.843
		Edge	61	78	12.2	8.7	8.2	0.448
Wooden thrust frame	Two-chamber	Center	50	36	16,7	5.5	5.2	0.572
		Edge	38	38	13.6	11.2	7.4	0.837

packet with a wooden frame. The glass packet was tightly pressed into a chamber groove through heat-insulating spacers. On the glass surfaces we positioned heat-flux sensors (HFSs) and thermocouples: two HFSs were located in the central translucent region and two HFSs, along the edge (see Fig. 2), which we placed opposite each other on the outer (q_1) and inner (q_2) sides of the glass packet. Each glass packet had four HFSs and six thermocouples attached using Vaseline and a thin transparent insulating tape, which provided complete thermal information for determining local thermal resistances. Measurements of the heat flux density were carried out by means of an ITP-II digital device consisting of a primary thermal converter of the heat flux and an electronic unit with an indicating board. This converter is characterized by high sensitivity, low inertia, and low thermal resistance. Its dimensions allow one to measure local values of the heat flux density under conditions of a substantially inhomogeneous temperature field with an error of no more than 1% for a given range. The ITP-II device has been developed at the Institute of Engineering Thermal Physics of the Academy of Sciences of Ukraine [5] and has undergone metrological tests.

To measure temperatures, we used precalibrated copper-constantan thermocouples. The thermocouples were joined to a V7-23-type digital millivoltmeter. All the experiments were carried out in a steady-state thermal regime under natural convection. For each tested glass packet, we performed ten measurements, and this allowed us to process the experimental data statistically and to obtain reliable results of thermal measurements with a total error in calculating the thermal resistance of no more than 3%.

The following quantities were measured: the heat flux density (q_1, q_2) in the central translucent and edge regions of the glass packet; Δt, the temperature difference between the hot and cold surfaces in the central region; Δt_1 and Δt_2, the temperature difference between the hot (cold) surface and the surrounding medium, respectively.

The averaged measurement results of the thermophysical parameters are tabulated in Table 1 (the total heat flux Q was determined in the usual way).

Analysis of the experimental data of the specimens tested makes it possible to examine in detail the special features of heat transfer through glass packets and to evaluate them quantitatively. As seen from the table, the effective thermal resistance of the investigated glass packets with a metallic thrust frame differs strongly for the translucent and edge regions; here heat is transmitted more intensely through the edge portion than through the translucent one. We may speak of the presence of thermal bridges along the perimeter of the glass packet. This circumstance not only favors additional leakage of heat but also can create, under certain conditions, thermal stresses that lead to mechanical deformation of the glass packet until cracks and breaks of the airtightness appear. It should be noted that the higher the thermal resistance of the translucent portion of the glass packet, the greater the amount of heat that leaves through the edge region, which is especially typical of glass packets with metallic thrust frames. For example, for the same values of R_{eff} of the central translucent portion (see the table), for a two-chamber glass packet with a metallic frame the thermal resistance of the edge region is equal to 0.392 deg·m^2/W, while for a glass packet with a wooden frame, it equals 0.837 deg·m^2/W. This means that in the second case the outflow of heat through the edge region is half that in the first case.

The investigation data show that metallic thrust frames, most often aluminum ones, decrease the heat-proof properties of glass packets, and their replacement by frames made of another material of lower thermal conductivity will favor an increase in R_{eff} of the translucent structure as a whole. Along with other constructive measures such as deposition of a heat-reflecting coating on the glass, evacuation of the chambers [6], filling of the chambers with an inert gas, etc., this will permit a considerable improvement in the heatproof properties of glass packets.

Thus, new experimental data on the thermal resistances of a number of glass packets are obtained. The principal thermophysical parameters are systematized and tabulated in Table 1. An analysis of the investigation results showed nonuniformity of the heat and temperature fields on the glass-packet surface. The leakages of heat in the edge region for one-, two-, and three-chamber packets with metallic and wooden thrust frames between the glasses were evaluated. The investigation data obtained can be useful for further improvement of the technology of manufacturing domestic glass packets, which is an important energy-saving indicator in heat-engineering calculations of industrial and civil engineering.

NOTATION

δ, thickness, m; λ, thermal-conductivity coefficient, W/(m·deg); α, heat-transfer coefficient, W/(m^2·deg); t, temperature, $^{\circ}$C; R, thermal resistance, deg·m^2/W; q, specific heat flux, W/m^2; R_{eff}, heat-transfer resistance, deg·m^2/W.

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