THERMAL REGIME IN AIR-PERMEABLE JOINTS

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Results are given of an investigation of the thermal regime in air-permeable joints by an electrothermal analog method.

One of the factors governing the temperature field of a joint is its permeability with respect to air.

Building codes recommend that the permeability of joints should not be less than the value corresponding to the condition that the additional heat loss due to infiltration shall not exceed 5% of the main heat loss from the room. This recommendation is difficult to apply: firstly, because in every form of jointed construction the joints acquire a definite permeability, depending on the construction conditions; secondly, because the additional heat loss due to the infiltration of air through the joint cannot be a criterion for estimating its thermal quality. It is shown below that in this case the determining factor is the temperature τ_x at the inside surface.

The movement of air through an outside wall is caused by a difference in air pressure between the two sides of the wall. This pressure difference depends on many factors: the velocity and direction of the wind, the aerodynamic coefficients of the building, the permeability of the external and internal building materials, the temperature of the outside and inside air, the size of the building, and the ventilation system. To determine the effective pressure difference, it is necessary to solve a system of air balance equations with components for all the rooms of the building, with numerous factors taken into account.

However, an accurate value of the air pressure difference Δp is necessary only in calculating the leakage through windows, since in this case there is a considerable increase in the additional heat loss. Calculations of the amount of infiltrating air can be approximate where only joints or building panels are concerned.

The criterion for choosing the thermal quality of an outside wall should be the temperature of its inside face. When infiltration occurs, this temperature falls in the neighborhood of the joint. In engineering calculations this fact must be taken into account, and the joint must be checked for condensation, in the same way as other heat-conducting elements.

In order to separate the influence of infiltration on the temperature conditions at the wall from the other factors and to derive quantitative relations, let us consider a joint between two similar panels.

There are two types of joint: an open joint (crack) and a closed joint formed by a highly permeable mixture. The first type is typical of walls that have stood for two or three years.

These two types differ only with respect to the conditions of heat transfer between air moving through the joint and the surface material. In the first case this is the surface of the crack, and in the second it is the surface of the pores and capillaries of the jointing mixture.

Open joints: We can represent the panel adjoining the crack as a semi-infinite plate. The temperature distribution in a section of the panel is described by the Laplace equation

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} = 0. \tag{1}$$

At the edge of the plate we get conditions of the third kind:

$$x = 0, \quad \alpha_o(\tau_o - t_o) = -\lambda \left.\frac{\partial t}{\partial x}\right|_{x=0}; \tag{2}$$

$$x = \delta, \quad \alpha_i(t_i - \tau_i) = -\lambda \left.\frac{\partial t}{\partial x}\right|_{x=\delta}; \tag{3}$$

$$y = 0, \quad \alpha_c(\tau_c - t_c) = -\lambda \left.\frac{\partial t}{\partial y}\right|_{y=0}. \tag{4}$$

The boundary conditions at the outside and inside faces are the usual ones. The boundary conditions at the third boundary have been examined in [2].

The similarity criteria determining heat transfer are:

$$\mathrm{Bi} = \frac{\alpha_o \delta}{\lambda}, \quad \mathrm{Bi}_i = \frac{\alpha_i \delta}{\lambda}, \tag{5}$$

$$\mathrm{Bi}_c = \frac{\alpha_c \delta}{\lambda}, \quad \mathrm{Bi}_b = \frac{\alpha_c \delta}{L(c\gamma)_i},$$

$$\mathrm{Bi}_b = \frac{\alpha_c \delta}{w_x (c\gamma)_i \delta_c} = \frac{\mathrm{Nu}_c}{\mathrm{Pe}_c} \frac{\delta}{\delta_c}. \tag{6}$$

Here $\alpha_c / w_x(c\gamma)_i$ is the conventional convection parameter, equal to the ratio of the Nusselt and Peclet numbers and characterizing the ratio of the heat transfer intensity to the specific enthalpy of the air stream.

In examining the temperature field of the wall, it is convenient to use the ratio $\mathrm{Bi}_b/\mathrm{Bi}_c$ instead of Bi_b:

$$K_1 = \mathrm{Bi}_b / \mathrm{Bi}_c = \lambda / L(c\gamma)_i. \tag{7}$$

K_1 characterizes the ratio of the intensity of the heat supply to the surface of the crack inside the wall to the intensity of the heat drain.

Closed joints. In this case the temperature distribution in the joint is complicated, since the joint and the part of the wall adjacent to the joint form a two-layer structure with the layers arranged in the direction of heat flow. If $\lambda < \lambda_j$, the joint should be regarded as an open, thermally conducting wall element, and if $\lambda > \lambda_j$, as a non-conducting wall element. The solution of problems of this kind is familiar to heating engineers.

In our case the problem is complicated by the fact that outside air moves across the joint, affecting the temperature field of the part of the wall adjacent to the joint.

In the steady state, heat transfer through the joint is described by a system of two differential equations. We have the Laplace equation giving the distribution of the temperature t over a section of the wall adjacent to the joint:

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} = 0 \quad \text{when} \quad y > \frac{\delta_j}{2} \tag{8}$$

and the Laplace equation with an additional term (heat "drain"):

$$\lambda_j \left(\frac{\partial^2 t_1}{\partial x^2} + \frac{\partial^2 t_1}{\partial y^2} \right) - w_x (c\gamma)_i \frac{\partial t_1}{\partial x} = 0 \quad \text{when} \quad y < \frac{\delta_j}{2}, \tag{9}$$

giving the distribution of the temperature t_1 over a section of the joint.

The conditions at the boundary between the two zones (λ and λ_j) are:

$$\lambda \left. \frac{\partial t}{\partial y} \right|_{y = \frac{\delta_j}{2}} = \lambda_j \left. \frac{\partial t_1}{\partial y} \right|_{y = \frac{\delta_j}{2}}; \tag{10}$$

$$t \Big|_{y = \frac{\delta_j}{2}} = t_1 \Big|_{y = \frac{\delta_j}{2}}. \tag{11}$$

Let us examine the remaining conditions of uniqueness of the equations:

$$\text{When } x = 0 \quad y > \frac{\delta_j}{2}, \quad \alpha_o(\tau_o - t_o) = -\lambda \frac{\partial t}{\partial x}; \tag{12}$$

$$y < \frac{\delta_j}{2}, \quad \alpha_o(\tau_{oj} - t_o) = -\lambda_j \frac{\partial t_1}{\partial x}. \tag{13}$$

$$\text{When } x = \delta \quad y > \frac{\delta_j}{2}, \quad \alpha_i (t_i - \tau_i) = -\lambda \frac{\partial t}{\partial x}; \tag{14}$$

$$y < \frac{\delta_j}{2}, \quad \alpha_i (t_i - \tau_{ij}) = -\lambda_j \frac{\partial t_1}{\partial x}; \tag{15}$$

$$y = 0, \quad \lambda_j \frac{\partial t_1}{\partial y} = 0. \tag{16}$$

The quantity $w_x(c\gamma)_i$ is the heat capacity of the air stream filtering through 1 m^2 of joint. The whole of the last term in (9) represents the intensity of the heat drain, uniformly distributed over the section of the joint.

The simultaneous solution of (8) and (9) with known uniqueness conditions determines the temperature field in the wall with air filtering through the joint.

Analysis of the equations shows that here the temperature distribution is determined by the relation between the following similarity criteria:

$$K_2 = \frac{\lambda}{\delta_j \, w_x (c\gamma)_i}, \quad K_\lambda = \frac{\lambda}{\lambda_j}, \quad \mathrm{Bi}_o = \frac{\alpha_o \delta}{\lambda},$$

$$\mathrm{Bi}_i = \frac{\alpha_i \delta}{\lambda}, \quad \mathrm{Bi}_{oj} = \frac{\alpha_o \delta}{\lambda_j}, \quad \mathrm{Bi}_{ij} = \frac{\alpha_i \delta}{\lambda_j}. \tag{17}$$

The parameter K_2 is similar to K_1 examined above, and is the ratio of the intensity of the heat supply inside the wall to the surface dividing the panel from the joint to the intensity of the heat drain. It can be calculated thus: $K_2 = \lambda / L(c\gamma)_i$, where $L(c\gamma)_i$ is the heat capacity of the air stream filtering through 1 lin. meter of joint.

Thus, this case differs from the previous one only in that the temperature distribution over the wall section at the inside face and the heat loss are determined not only by the thermal resistance of the wall R_0 and K_2, but also by the ratio of the thermal conductivities of the panel and joint materials.

The influence of infiltration was investigated further by solving the equations on an electric integrator.

The analog method of solution using an electric model, and the results for an open joint (crack) have been published previously [2] and will not be examined here.

The results obtained for the closed joint are given below. As with the open joint, analog computations gave the relations

$$\bar{\tau}_x = f_1(R_0 K_2), \quad A_L = f_2(R_0 K_2), \quad A_\tau = f_3(R_0 K_2)$$

with the correction b_λ for the different value of K_λ.

The quantity $\bar{\tau}_x$ represents in dimensionless form the minimum temperature τ_x of the inside of the wall panel in the immediate vicinity of the joint.

$$\bar{\tau}_x = (t_i - \tau_x)/(t_i - t_o). \tag{18}$$

Figure 1 gives this quantity as a function of R_0 and K_2. From the graph the value of τ_x may be determined, if the thermal resistance of the wall and the permeability of the joint to air are known:

$$\tau_x = t_i - b_\lambda \bar{\tau}_x (t_i - t_o). \tag{19}$$

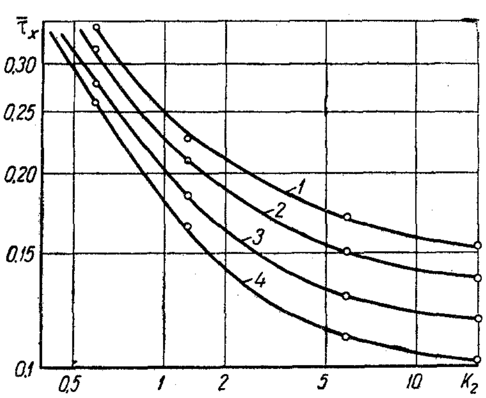

Fig. 1. Dimensionless temperature $\bar{\tau}_x$ as a function of K_2 for a closed joint with δ_j = 10, δ = 160 mm: λ/λ_j = 1.0; 1 - R_0 - 0.88; 2 - 1.0; 3 - 1.3; 4 - 1.6.

The correction b_λ may be determined from Fig. 2.

With the help of the graph (Fig. 1) we can also select the required value of the wall resistance for a given minimum permissible value of τ_x, which is usually found from the condition $\tau_x < t_{d.p.}$ (dew-point temperature of room air).

Analysis of the results obtained allows certain conclusions to be drawn.

It is impossible to estimate the permeability of joints from additional heat loss alone. Infiltration of air causes a sharp drop in temperature at the inside face of the joint, which can lead to the condensation on this surface of water vapor from the air of the room.

The temperature drop at the inside face depends equally on the amount of air filtering through the joint and on the thermophysical properties of the joint material. The more effectively the wall is heated, the more pronounced is the temperature drop at the inside surface.

To avoid condensation, the joint must be checked by determining the value of τ_x (as for thermally conducting wall elements). For this purpose the graph in Fig. 1 may be used, or a calculation may be performed on an electric model by the method referred to above.

Calculation of joints of various types by this method makes it possible to reduce the effect of infiltrating air by applying a thermally conducting layer to the inside face of the wall (e.g., plaster or a layer of structural material).

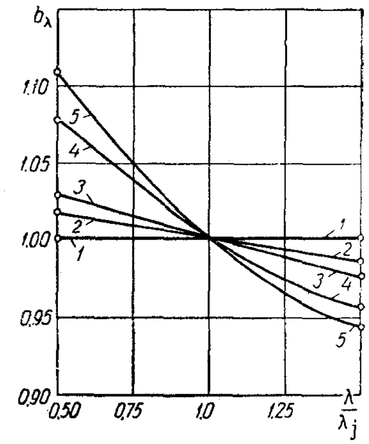

Fig. 2. Curve determining correction b_λ: 1 - K_2 = 0.56; 2 - 0.80; 3 - 1.40; 4 - 5,6; 5 - ∞.

NOTATION

α_o, α_i and α_c, τ_o, τ_i, and τ_c – heat transfer coefficients and temperatures at outside and inside faces of wall and at the surface bathed by air filtering through the joint: t_o, t_i, and t_c – temperature of the outside and inside air and of the air in the joint; λ, λ_j – thermal conductivities of the wall and joint materials; w_x – velocity of air in crack, equal to $1/\delta_c$; δ_c – height of crack; δ/δ_c – dimensionless ratio of crack length (wall thickness) to crack height; τ_o, τ_{oj}, τ_i, τ_{ij} – temperatures of outside and inside wall panel and joint.

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