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Air jet protection to prevent window surface condensation from air moisture

Alexander L. Naumov[a], Iurii A. Tabunshchikov[b], Dmitry V. Kapko[a], Marianna M. Brodach[b,*]

[a] Central Scientific Research Institute for Industrial Buildings and Structures – TSNIIPROMZDANII, Moscow, Russia
[b] Moscow Architectural Institute (State Academy), Moscow, Russia

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ABSTRACT

One of the methods to protect a building with a high indoor moisture content and structural glazing from vapour condensation is to use energy-efficient windows [1,2], but often, it is not sufficient. Another method is to blow air with a relatively low water content over a glazing. Such systems are designed to cope with critical conditions, i.e., the lowest temperature of the external air and the highest water content in the indoor air; therefore, they are extremely energy-consuming. The authors propose to use demand-controlled ventilation systems [3–6] that can adjust air consumption according to the actual temperature and indoor air humidity. The efficiency of air jet protection depends on the air stream range, conditions of heat exchange on the surface, and changes in the moisture content in the boundary layer of the air stream. The article [7] describes the method for the determination of the dew point temperature on the glazing surface that accounts for the characteristics of the air stream flowing out of the slotted outlet. This article analyses a refined statement of the problem that accounts for the change in the heat-exchange conditions in the initial and main parts of the air stream.

Protecting external windows from water vapour condensation is a challenge in buildings with high air humidity, such as swimming pools, waterparks and bathhouses: in the cold season, the temperatures on the inner surface of windows, atriums and skylights can drop below the dew point of the humid indoor air.

One of the ways to control vapour condensation on external windows is to blow relatively dry air over the glass surface.

Below is a description of the features of a flat non-isothermal stream of air that is blowing over a glass surface.

The air stream with initial excessive temperature υ_0 °C, and humidity d_0 g/kg of fresh air, flows out of the slotted outlet of width b m at the rate of U_0 m/s (Fig. 1).

The initial excess of the temperature is the difference in the temperature of the air flowing from of the slotted outlet t_0 °C and the room air temperature t_r °C:

$$\upsilon_0 = t_r - t_0$$

The air stream flows over the glass with heat resistance R m^2 °C/W. On the outside, the glass is cooled by the external air with temperature t_{ext} °C and the heat exchange coefficient α_{ext} W/m^2 °C.

The indoor air with temperature t_r °C, and moisture content d_r g/kg of fresh air, replenishes the stream.

To protect the inner surface of external glazing, its temperature must be higher than the dew point temperature of ambient air. Fig. 2 shows the relationship between the dew point temperature and air humidity.

Note that as the air stream advances, its features change: the rate U_x and excessive temperature υ_x decrease as well as the moisture content in the stream d_x and the heat exchange ratio α_x; therefore, the dew point temperature on the glass surface τ_x changes. Fig. 1 shows the behaviour of the parameters in question.

Another essential prerequisite for protecting the glazing from the formation of condensate is that the air stream must ‘adhere’ to the surface.

A nonisothermal stream affected by the gravitational force can come off the glass surface and start blowing downwards. Let us use the Archimedes number to determine the relationship between the gravitational force and the inertial force that affects the stream through the stream breakaway criterion [8]:

$$Ar = \frac{g \times b \times (t_x - t_r)}{T_r \times U_0^2} \qquad (1)$$

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* Corresponding author. Tel.: +7 916 1725736.
E-mail address: brodatch@abok.ru (M.M. Brodach).

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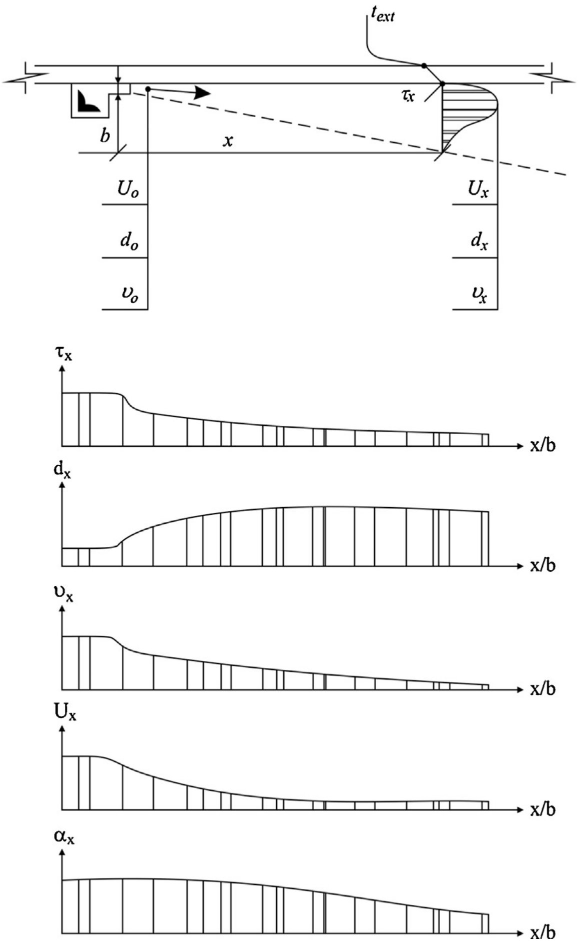

Fig. 1. Protection of the glass surface from vapour condensation with a stream of air.

where g, free fall acceleration, m/s^2; T_r, room air temperature, K; t_x, air temperature in the stream at the distance x from the stream outflow point,°C.

Fig. 3 shows the relation between the Archimedes number, Ar, and the current stream position describing the breakaway zone. As the graph demonstrates, when Ar reaches a value in the range of 0.5–0.6, the air stream comes off the glass plane immediately upon leaving the outlet. Stable stream adherence at the relative distance $x/b = 100–150$ is described by the Archimedes number $Ar < 0.02$.

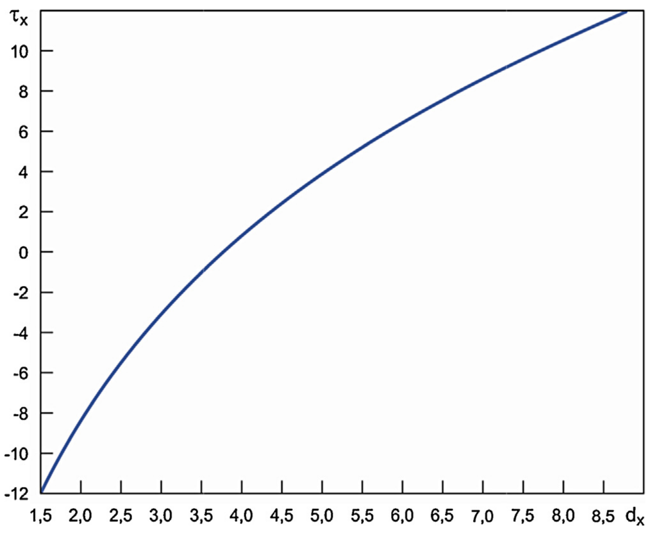

Fig. 2. Relationship between the dew point temperature and the air humidity.

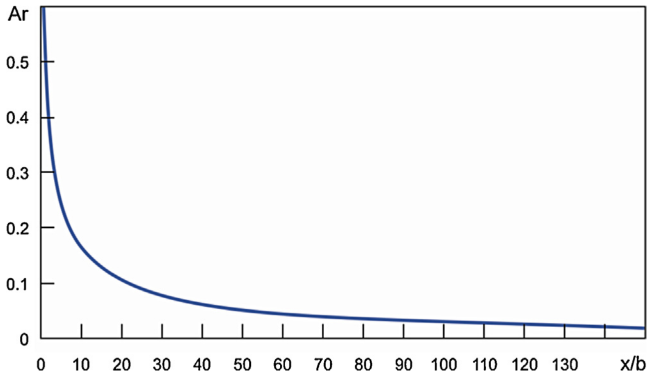

Fig. 3. Relationship of the stream breakaway distance and the slot width to the Archimedes number.

The moisture content and velocity remain unchanged at the initial level over the entire initial stretch of the air stream, the length of which is 13 calibres of the slot. This distance depends on the so-called stream core. After the initial stretch, the room air starts to "contaminate" the stream, thus changing the humidity of the room air. The relation [9] provides a fairly accurate picture of the dependence of the moisture content during the main stretch of the stream:

$$d_x = d_r - 3.51 \times (d_r - d_0) \times \left(\frac{b}{x}\right)^{0.5} \qquad (2)$$

Fig. 4 shows the relation between the dew point temperature at the current stream position with initial moisture content $d_0 = 2$ g/kg of fresh air to different room air moisture content values. During the initial stretch, the dew point temperature depends exclusively on the initial moisture content in the air stream, and not on the room air humidity. We observe the sharpest rise in the dew point

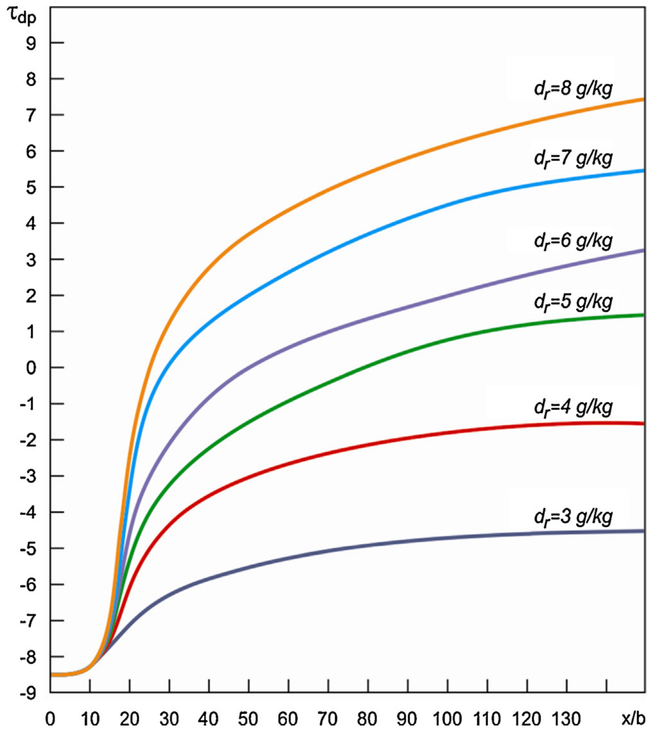

Fig. 4. Dew point temperature values along the stream at the initial moisture content of 2 g/kg of fresh air.