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CONDENSATION BETWEEN THE PANES OF DOUBLE WINDOWS†

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THE VALUE of double windows in reducing heat transmission through window areas and in permitting higher inside relative humidities during the winter, without excessive condensation on inside glass surfaces, is well known. Some form of double-window arrangement is used in most houses in regions having low winter temperatures. There is an increasing use of double windows in commercial and industrial buildings, particularly when year-round air conditioning is employed.

Condensation of water vapor between the panes, and on the inside surface of the outer pane, is a common occurrence with most types of double windows except the factory-sealed variety. A small amount of such condensation is accepted generally as inevitable. When it begins to obstruct seriously the view through the window for long periods, however, or when the run-off contributes to the deterioration of surrounding materials, there is reason for concern.

Condensation will occur on the inside surface of the outer pane whenever the temperature of that surface at any point is below the dew-point temperature of the air-vapor mixture in the space between the panes. This ultimately will occur, with outside temperatures lower than inside, if the gain in water vapor to the space is greater than the loss.

In this paper the factors involved in the transfer of water vapor to and from the space between the panes of double windows other than the factory-sealed type are considered. A relatively simple approach is developed for determining under what conditions condensation will occur in a given window, or alternately, for designing a window to be free of condensation under given conditions.

WATER VAPOR TRANSFER BY DIFFUSION

Water vapor generally moves in to and out of the air space of a double window under two forces. It moves through the materials and cracks in the window assem-

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Available experimental records for residences[1] suggest that the actual levels are considerably higher than would be predicted on the basis of the vertical distribution of window and door cracks. In single-story houses, the neutral zone may be above first floor windows, while in two-story houses it may be at the level of second story windows. Recently published information on pressure differences across entrances of tall buildings suggests that the neutral zone location in such structures may be well above mid-height.[2]

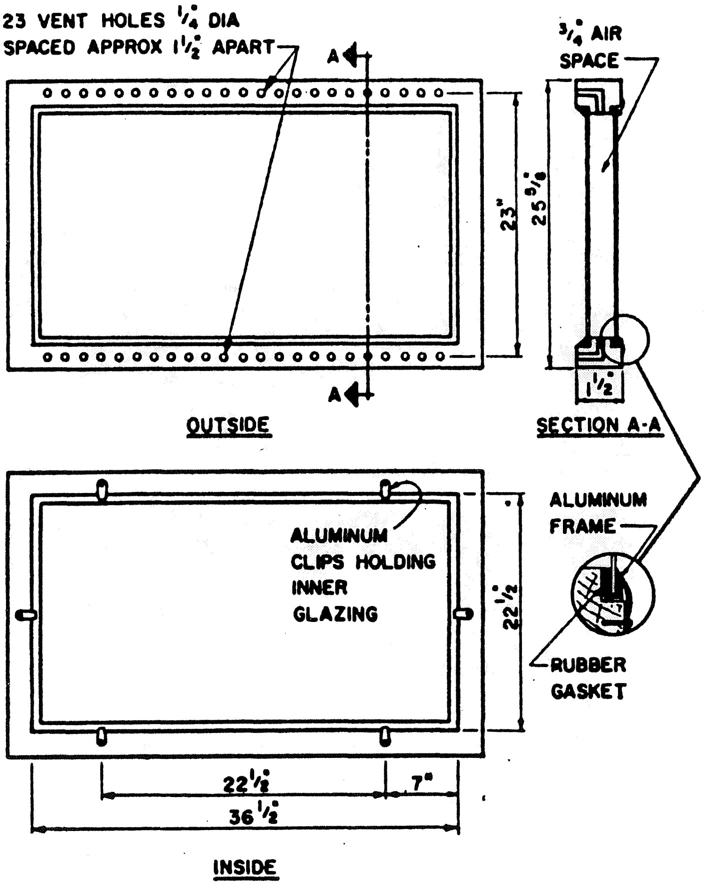

FIG. 3....DETAILS OF CENTER WINDOW

Since flow from the building to outside occurs only above the neutral zone, the level of the neutral zone is significant in connection with condensation between the panes, windows above the neutral zone being much more likely to exhibit such condensation. Any factor tending to raise the neutral zone, such as venting or mechanical exhaust systems, will reduce the possibility of window condensation; any factor tending to lower the level of the neutral zone, such as pressurizing of buildings, will have the opposite effect.

The order of the inside-outside pressure differences resulting from chimney effect can be seen in Table 3 which gives pressure differences per ft of distance from the

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[1] Exponent numerals refer to References.

of the window. Under this condition, the air space will interchange air with the inside, the amount of air flow through the outer pane being equal to the difference in inflow and outflow past the inner glazing.

WATER VAPOR TRANSMISSION BY AIR FLOW

The foregoing discussion of pressure distributions across double windows has shown that, with the air-flow resistance of the inside pane sufficiently higher than that of the outside pane, and with the openings in the outside pane located at the top and bottom of the window, the air space can interchange air with the outside even when an overall flow from inside to outside occurs. The relationship between these air flows and condensation between the panes can be shown by a simple mass balance.

If vapor flow by diffusion is neglected, the net gain of water vapor by the air space as a result of air flow from the inside is approximately equal to

$$Q_i d_i (W_i - W_s) \quad \ldots\ldots\ldots\ldots \quad (1)$$

where

Q_i = volume rate of flow into the air space from the inside.
d_i = density of inside air.
W_i = humidity ratio of inside air.
W_s = humidity ratio of air in space between panes.

The net loss of water vapor by the air space as a result of air flow from the outside is approximately equal to:

$$Q_o d_o (W_s - W_o) \quad \ldots\ldots\ldots\ldots \quad (2)$$

where

Q_o = volume rate of flow into the air space from the outside.
d_o = density of outside air.
W_o = humidity ratio of outside air.
W_s = humidity ratio of air in space between the panes.

To prevent condensation the net gain in water vapor by the air space must equal the net loss of water vapor by the air space.

Equating Equations 1 and 2 it can be shown that,

$$R = \frac{Q_o}{Q_i} = \frac{d_i}{d_o}\frac{(W_i - W_s)}{(W_s - W_o)} = \frac{T_o(W_i - W_s)}{T_i(W_s - W_o)} \quad \ldots\ldots \quad (3)$$

where

R = minimum ratio of outside to inside air to prevent condensation between panes.
T_o = absolute temperature of outside air, Rankine degrees.
T_i = absolute temperature of inside air, Rankine degrees.

The values of the minimum ratio of outside to inside air to prevent condensation at different outside temperatures will depend on inside temperatures and relative humidities. Values given in Table 4 are based on humidity ratios for inside, air space, and outside corresponding to saturation at the temperature of the inner and outer panes and of outside air respectively, using the same conductances as for Table 1. The value of the minimum ratio increases with decreasing outside temperature.

Another factor that produces total pressure differences between the air space and outside is a change in air-space temperature. If the window is not sealed this presor openings around the inner and outer panes. Flow from outside to the air space occurs through the openings around the outside pane below level l_1. This volume, together with the air flow through cracks around the inner pane, flows through openings around the outer pane above level l_1. If the ratio of outside air to inside air is that defined by Equation 3 then,

$$Q_T = Q_o + \frac{Q_o}{R} \quad \ldots \ldots \ldots \ldots \quad (8)$$

where

Q_T = flow through cracks around outer pane above level l_1.

But Q_T and Q_O can be expressed in terms of measured flow characteristics. For the test window the relationship is simple since, as shown in Fig. 7, flow is directly proportional to pressure difference at the small pressure differences produced by chimney action and the vent holes are located only at top and bottom. Thus,

$$Q_o = C_o(d_o - d_s)l_1 g/g \quad \ldots \ldots \ldots \ldots \quad (9)$$

and

$$Q_T = C_o(d_o - d_s)(l - l_1)g/g_o \quad \ldots \ldots \ldots \ldots \quad (10)$$

where

C_o = flow coefficient for vent holes.
l_1 = distance from the bottom vent holes to the level where air space and outside pressures are equal, feet.

Substituting Equations 9 and 10 in Equation 8

$$l_1 = \left(\frac{R}{2R + 1}\right) l \quad \ldots \ldots \ldots \ldots \quad (11)$$

It follows, with reference to Fig. 2*b* that

$$h'_o = \left(\frac{2R}{2R + 1}\right) h_o \quad \ldots \ldots \ldots \ldots \quad (12)$$

where

h'_o = pressure difference across bottom of outer pane with window above neutral zone, inches of water.

Also

$$h'_i = h - h_o \left(\frac{1}{2R + 1}\right) \quad \ldots \ldots \ldots \ldots \quad (13)$$

where

h'_i = pressure difference across center of inner pane with window above neutral zone, inches of water.
h = inside-outside air pressure difference across center of window, inches of water.

COMPARISON OF VAPOR TRANSFER BY DIFFUSION AND AIR FLOW

To assess the relative rates of vapor flow by diffusion and air flow in to and out of the air space of the test window, outside conditions of 0 F and 85 percent relative required becomes 2 and 4½, with the neutral zone at the center and bottom edge respectively.

There is fair agreement between the cold room observations and the estimated amount of venting of the air space required to overcome condensation between the panes. The cold room tests were not ideal for such a comparison because of the quite small total pressure differences provided, when accurate measurements of pressure and flow become difficult. Furthermore, small changes in the location of the neutral zone will lead to relatively large changes in the venting requirements.

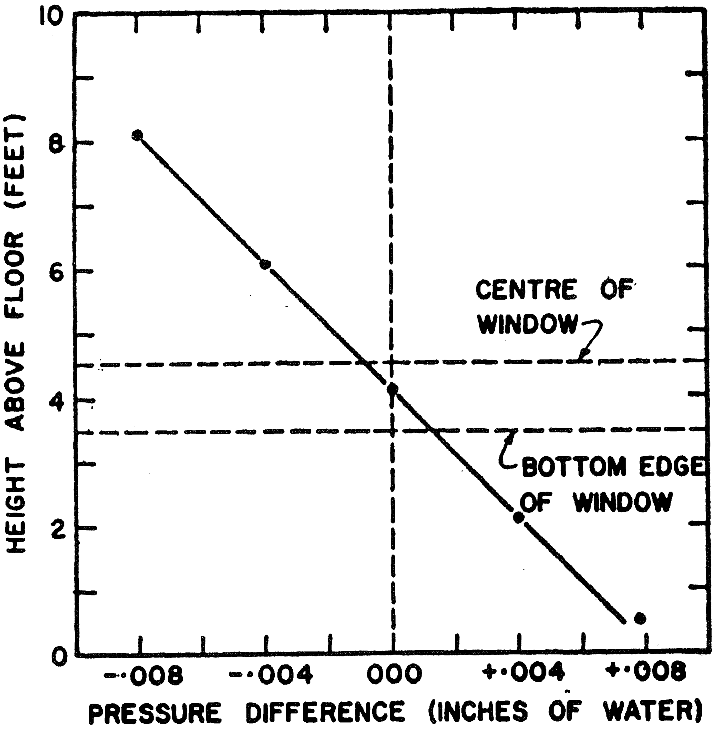

FIG. 9....PRESSURE DIFFERENCE BETWEEN WARM AND COLD ROOMS *vs.* HEIGHT

It is clear that cold room studies of condensation between the panes of double windows are of little value unless the total pressure differences across the window are measured. Even then, the observations are of use only in confirming some other approach for determining condensation performance, unless the total pressure differences correspond to those for which the window is being considered.

APPLICATION OF VENTING TO WINDOW CONDENSATION CONTROL

It has been shown that venting of the air space to outside through chimney action is an effective means of controlling condensation between the panes of double windows. It will be recognized, however, that excessive venting will lower the mean temperature of the air space and increase overall heat transmission. Taking the air space as equivalent to 2 surface conductances its mean temperature can be