

## AIR INFILTRATION THROUGH STEEL FRAMED WINDOWS

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**T**HE rate of air infiltration through a window depends to a great extent upon the quality of construction of the window. For this reason, only the approximate magnitude of the leakage can be estimated from test data on similar windows. Experiments conducted at the University of Wisconsin<sup>3</sup> in cooperation with the A. S. H. V. E. Research Laboratory indicate a variation of leakage of from 50 to 90 cu ft per hour per foot of sash perimeter at a pressure equivalent to 25 mph wind velocity, for nine double-hung wood sash windows of similar workmanship. The width of crack perpendicular to the direction of air flow, the window size, and thickness were the same for these windows.

The A. S. H. V. E. Research Laboratory tested steel double-hung windows actually installed in a building.<sup>4</sup> The results of the University of Wisconsin experiments and those of the A. S. H. V. E. Research Laboratory, supplemented by further tests on swing and hung steel windows made at the University of California by the authors, are shown in Fig. 3. The leakage curves are designated by letters indicating the corresponding cross section through the leakage path. The infiltration rate for a window is specified as the volume of air leakage per minute per linear foot of crack for a given wind velocity normal to the window. The curves show the leakage as a function of the wind velocity. It may be seen that there exists a very wide variation in the performance of these windows.

Certain other variables not controllable by the manufacturer must be considered in performing tests on windows. The results given in the aforementioned papers<sup>3-4</sup> indicate a variation in leakage rates for latched and unlatched windows. It is an object of this paper to show that the test results obtained on steel swing windows depend upon the manner in which the window is closed and latched. Further, it has been noted that the leakage through felt

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<sup>3</sup> Air Infiltration Through Double-Hung Wood Windows, by G. L. Larson, D. W. Nelson and R. W. Kubasta, A. S. H. V. E. TRANSACTIONS, Vol. 37, 1931, p. 571.

<sup>4</sup> Air Leakage Studies on Metal Windows in a Modern Office Building, by F. C. Houghton and M. E. O'Connell, A. S. H. V. E. TRANSACTIONS, Vol. 34, 1928, p. 321.

Presented at the 39th Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Cincinnati, Ohio, January, 1933, by P. D. Close.

weatherstripped steel swing windows depends upon the humidity of the air. Test results will be presented which indicate that for the window tested, the leakage was at least 130 per cent greater for dry air than for saturated air.

#### APPARATUS

The apparatus used for the tests, which were conducted in the Mechanical Laboratories of the University of California, is shown in Figs. 1 and 2. The

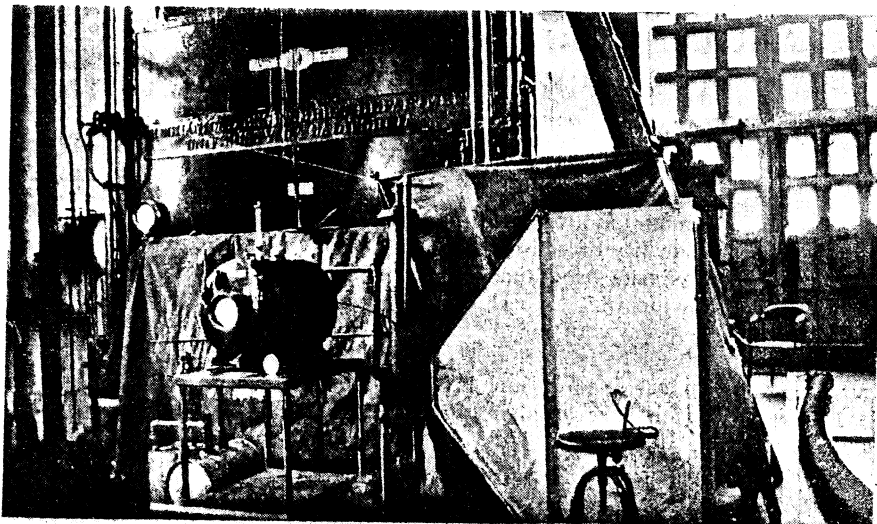


FIG. 1. ARRANGEMENT OF APPARATUS FOR INFILTRATION TESTS

windows and casings were mounted in a steel hood with the weather side of the windows facing the air inlet, which was located at the back of the hood.

The equivalent wind velocity in miles per hour was computed from the expression

$$V = K \sqrt{\frac{2gh}{w}} = K' \sqrt{\frac{h}{w}}$$

where

$K$  = a conversion factor = 1.55 or  $K' = 12.45$ .

$w$  = density of the air chosen as standard.

$h$  = the pressure head in the hood acting upon the window in inches of water. The head was obtained by means of an inclined manometer attached to the hood.

The equivalent velocity was calculated as the velocity of dry air normal to the window, at a pressure of 30 in. of mercury and at 60 F, corresponding to the actual pressure head acting across the window. Similarly the infiltration rate was calculated from the actual weight of air (and water vapor) flowing per unit time per linear foot of leakage space, as the volume of dry air at 30 in. of mercury and 60 F.

The air was supplied from a tank charged by a compressor. A wet test

meter was used to measure air quantity for the lower flow rates. This necessitated saturation of the air to prevent loss of water from the meter. A Venturi tube was used for the higher flow rates.

The piping from the meter to the hood was so arranged that the air could be passed directly, or through a calcium chloride container, to the hood. The humidity of the air was considered as a variable for the felt weatherstripping tests only.

Four steel swing windows and one steel double-hung window with brass weatherstripping were tested. One of the swing windows was felt weatherstripped. The felt seal was effected by cementing a strip of felt into a groove

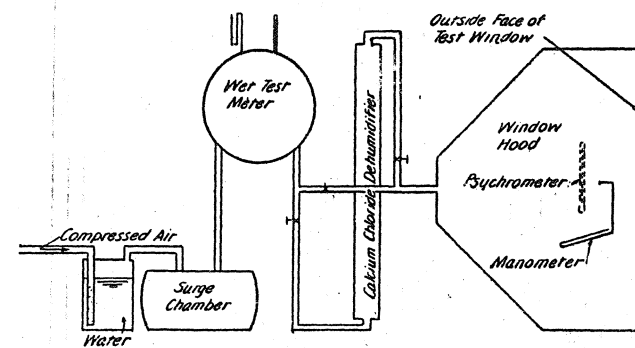


FIG. 2. DIAGRAM OF TEST APPARATUS

in such a manner that the window, when closed, was pushed tightly against the felt. The steel frame and casing formed the seal for the windows tested without weatherstripping. Figs. 3 and 4 show the cross section of the leakage path and the general location of the latches.

#### RESULTS OBTAINED

The effect of varying the method of closing and latching the door is shown in Fig. 5 for a non-weatherstripped window. Since the equivalent wind velocity is often used in specifying the infiltration rate of a window, the leakage rate ( $Q$ ) is plotted against wind velocity for two conditions:

1. Window closed by action of lock only.
2. Window pulled tightly closed and locked.

It may be seen that, as the pressure on the window is increased, the window is closed tighter and remains in position as the pressure is reduced. The leakage for the first case is 10 per cent to 30 per cent greater than for the second case, which shows that the manner of closing the window has an important influence on the leakage. It was also observed that improper application of paint at the cracks materially changed the leakage rate.

Tests on the felt weatherstripped window were made at three different humidities. For 100 per cent relative humidity, the air from the meter was assumed to be saturated. Practically dry air was obtained by the use of the

calcium chloride, while an intermediate humidity resulted from the use of calcium chloride not entirely dry. The humidities were measured by wet- and

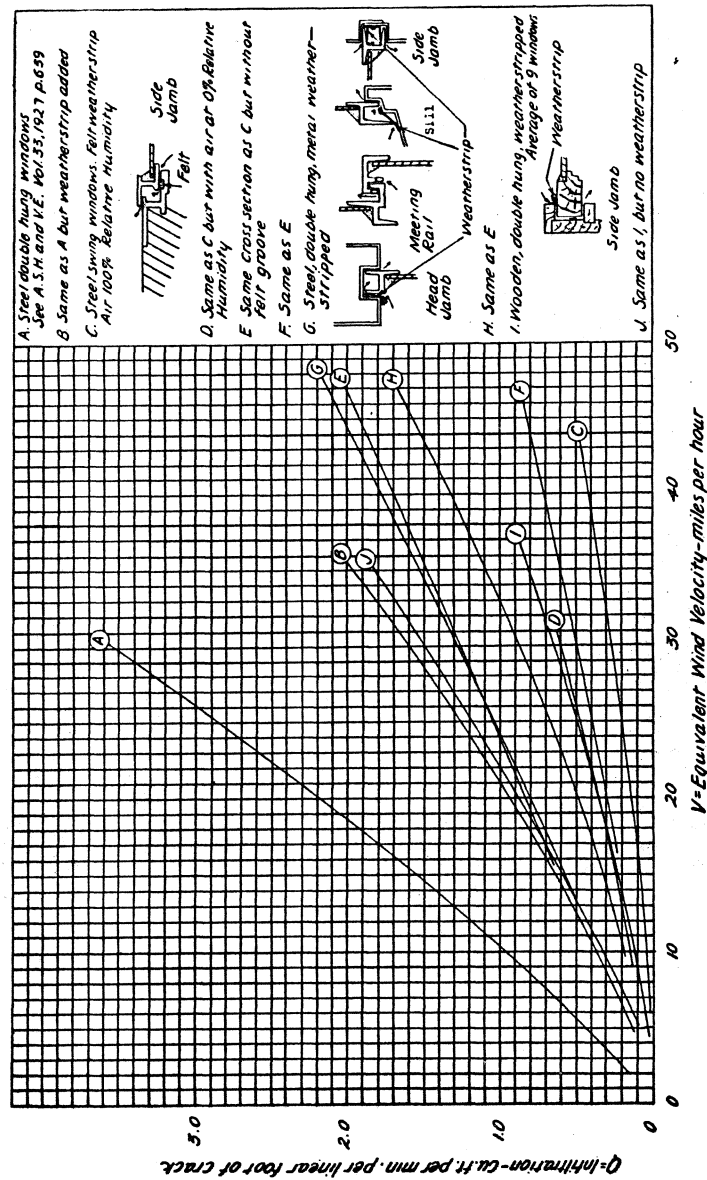


FIG. 3. INFILTRATION THROUGH VARIOUS KINDS OF WINDOWS

dry-bulb thermometers suspended in the hood. At each humidity, the flow of air for a particular pressure difference across the window was maintained until the infiltration rate became constant, which indicated that the moisture content

of the felt was approximately at a maximum (corresponding to the equilibrium moisture content).

The effect of humidity on leakage through felt weatherstripping, arranged as in Fig. 4, is shown in Fig. 6. Air leakage, in cubic feet per minute per linear foot of crack, is plotted as a function of equivalent wind velocity, in miles per hour. The air leakage at an equivalent wind velocity of 25 mph as a fraction of the leakage for saturated air is shown as a function of relative

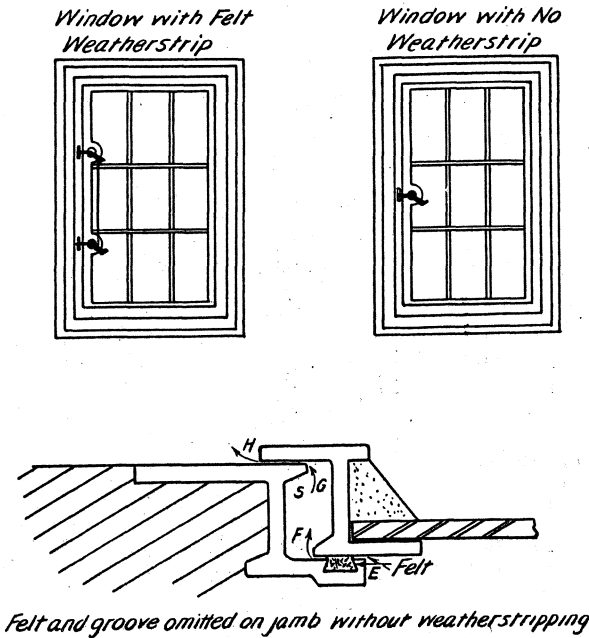


FIG. 4. METHOD OF MOUNTING WINDOWS IN HOODS AND CROSS SECTION OF JAMBS ON WEATHERSTRIPPED WINDOWS

humidity in Fig. 6a. It will be noticed that for this equivalent velocity, the leakage for dry air is 240 per cent of the leakage for saturated air.

If the air leakage per unit time as a function of pressure head across the window is plotted on logarithmic paper, the straight lines indicate a relation of the form:

$$Q = CAh^a$$

where

- Q = quantity flowing in cubic feet per minute per foot of crack.
- C = discharge coefficient.
- A = effective area for flow through crack in square feet.
- h = pressure head in inches of water.
- a = exponent depending on the moisture content of the felt.

The exponent a was found to vary from 0.63 for dry air to 0.79 for saturated air. Since the leakage decreases with wet air, it is seen that the flow ap-

proaches that of the viscous type for the lower rates of flow, that is, higher humidities. In the viscous<sup>6</sup> region the leakage  $Q$  is proportional to the head

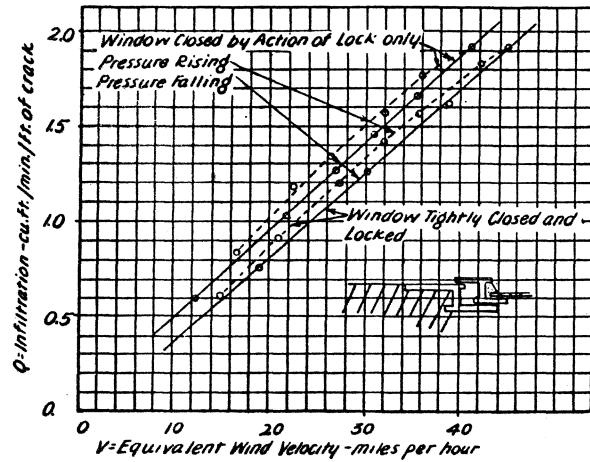
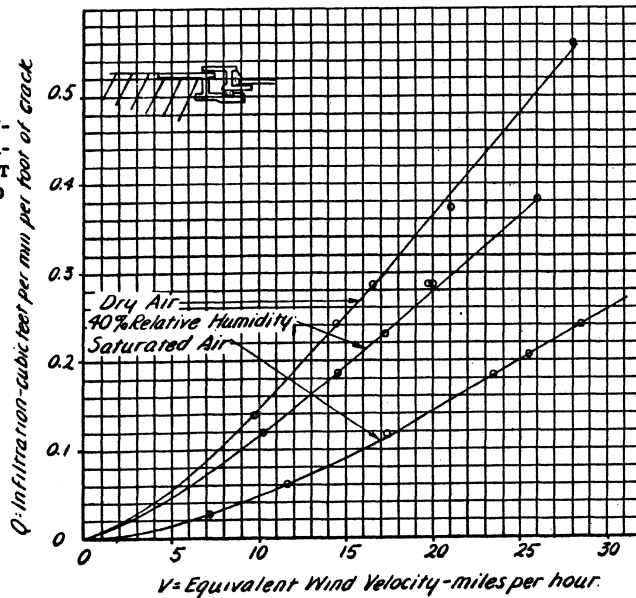


FIG. 5. EFFECT OF TIGHTNESS OF CLOSING OF WINDOW ON LEAKAGE OF AIR (WINDOW NOT WEATHERSTRIPPED)

FIG. 6. EFFECT OF HUMIDITY ON INFILTRATION THROUGH FELT WEATHERSTRIPPED METAL WINDOWS



$h$  while in the turbulent region  $Q$  is proportional to the square root of the head, ( $h^{1/2}$ ).

Plotting  $\frac{Q}{h^a}$  against the equilibrium moisture content of felt (obtained from Fig. 8) yields an approximately straight line as shown in Fig. 9. The moisture

<sup>6</sup> Gibson, Hydraulics and Its Applications, page 45.

content<sup>6</sup> of wool felt plotted in Fig. 8 was taken from the International Critical Tables, Vol. 2, pages 222-25.

The results plotted in Fig. 9 indicates that  $CA (= \frac{Q}{h^a})$ , the product of the discharge coefficient ( $C$ ) and the cross sectional area ( $A$ ) of the leakage path, and consequently the area ( $A$ ), is influenced by the moisture content of the felt. This curve is plotted with but three points and therefore should only be interpreted as indicating a general trend.<sup>7</sup>

The leakage path is shown by the arrows in Fig. 4. The resistance to flow may be regarded as consisting of an entrance loss at  $E$ , friction loss through the path bounded by metal, friction loss through the felt, friction through the remainder of the first crack, expansion loss at  $F$  into space  $S$ , the friction loss

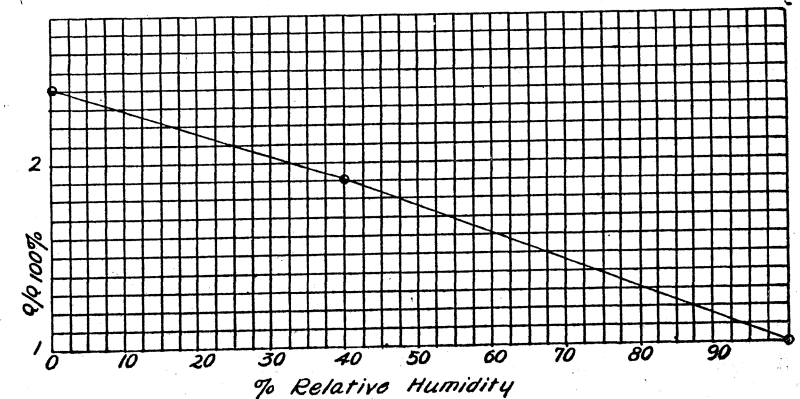


FIG. 6a. RATIO OF INFILTRATION OF PARTIALLY SATURATED AIR TO INFILTRATION OF SATURATED AIR THROUGH A FELT WEATHERSTRIPPED WINDOW. (EQUIVALENT WIND VELOCITY, 25 MPH)

due to flow through space  $S$  (which is small), entrance loss at  $G$ , friction loss through  $GH$  and exit loss at  $H$ . The change in the product of the coefficient of discharge ( $C$ ) and the effective cross sectional area ( $A$ ) of the leakage path for a given flow rate is partly due to the variable moisture content of the felt corresponding to various air humidities.

The actual variation in  $CA$  as the relative humidity is changed from 0 per cent to 100 per cent may be partially obscured by the decrease of frictional losses other than that through the felt. This would be due to the smaller infiltration rate and the consequent decrease in velocity through the leakage path. The loss in head due to sudden expansion<sup>8</sup> may be shown to vary with the square of the difference of the velocities before and after the expansion.

By means of the law of continuity it may be shown that the head loss is proportional to the square of the velocity through the smaller cross section. Similarly the head loss due to sudden contraction may be shown to be propor-

<sup>7</sup> See also Hougren and Watson, Industrial Chemical Calculations, page 168.

<sup>8</sup> Further tests are being conducted in which the diameter of a felt thread, the equilibrium moisture content, and the pressure drop through felt at various compression pressures are being determined for different humidities.

<sup>8</sup> Gibson, Hydraulics and Its Applications, pages 91 and 99.

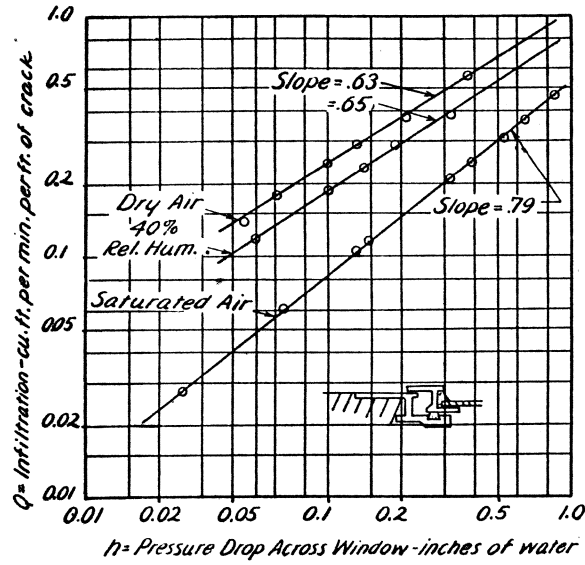
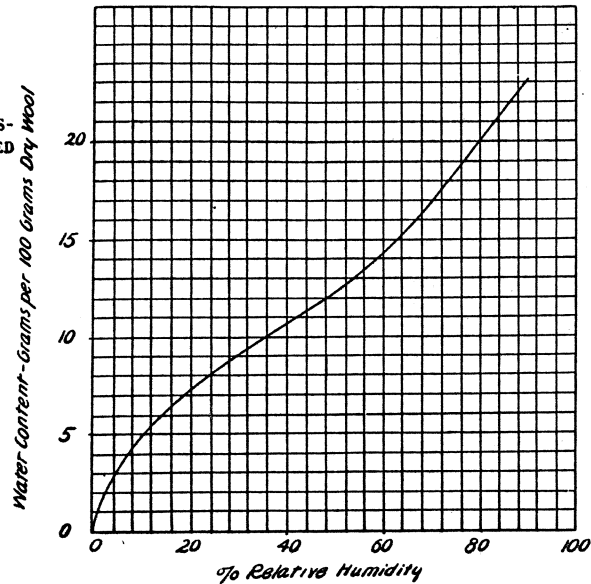


FIG. 7. EFFECTS OF HUMIDITY ON INFILTRATION THROUGH FELT WEATHER-STRIPPED METAL WINDOWS

FIG. 8. EQUILIBRIUM MOISTURE CONTENT OF WORSTED WOOL AT 25 C\*



tional to the square of the velocity in the smaller cross section. These two head losses (the latter being the smaller of the two) partly explain the deviation of the flow from the viscous flow law.

Replotting the equilibrium moisture content curve, Fig. 8, of wool felt in

\* International Critical Tables, Vol. 2, pp. 222-225.

accordance with the method outlined by Bray and Draper,<sup>9</sup> assuming the relative humidity to be directly proportional to the partial pressure of the water vapor, yields Fig. 8a. This curve indicates that for relative humidities less than 50 per cent the phenomenon is one of adsorption, while above 50 per cent relative humidity, capillary condensation (absorption) occurs.

From Fig. 9  $\frac{Q}{h^2}$ , that is the product  $CA$ , varies from 1.02 to 0.52. If  $C$  is assumed constant, then the variation of cross sectional area of flow, due to the change of moisture content of the felt, is 49 per cent. This would

FIG. 8a. EQUILIBRIUM MOISTURE CONTENT OF WORSTED WOOL AT 25 C

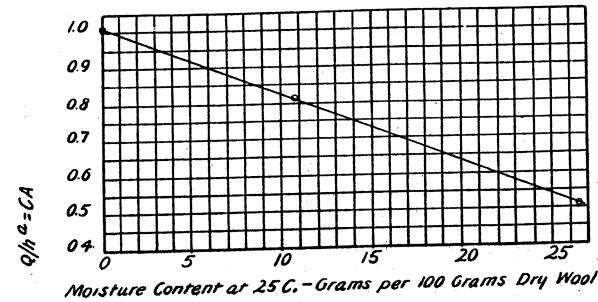
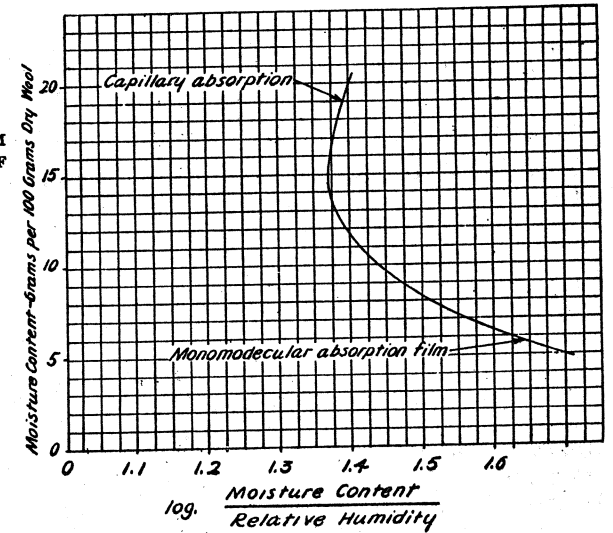


FIG. 9. EFFECT OF EQUILIBRIUM MOISTURE CONTENT ON FLOW OF AIR THROUGH WOOL FELT

represent the magnitude of the change of leakage rate, if the flow did not become more viscous as the area decreased. However, from Fig. 6, at an equivalent velocity of 25 mph, the air leakage rate falls from 0.48 to 0.20 cfm per foot of crack with the change from dry to saturated air. This decrease of 58 per cent is due both to the loss of area and change of the character of flow.

<sup>9</sup> Capillary Condensation and Absorption, Bray and Draper, Proceedings, National Academy of Sciences, Vol. 12, No. 5, 1926.

CONCLUSIONS

1. A wide variation in the infiltration rate of well constructed windows may be expected. Fig. 3 shows variation of 1400 per cent at an equivalent velocity of 25 mph (compared to the smallest leakage shown).
2. Test results on windows differ widely depending upon the method of closing and latching. Variations of 15 per cent at 25 mph are indicated in Fig. 5.
3. The air leakage for steel swing windows is found to differ when determined with ascending and descending pressure differences because the window is closed more tightly after completion of the ascending pressure difference tests.
4. Test results on felt weatherstripped windows vary widely with air humidities. A 140 per cent increase is shown for dry as compared with saturated air at an equivalent air velocity of 25 mph.
5. It would seem desirable that the specifications for window tests include reference to the preceding Items 2, 3, and 4.