No. 816

THE WEATHERTIGHTNESS OF ROLLED SECTION STEEL WINDOWS

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MEMBERS

Information is presented in this paper on the weathertightness of rolled section steel windows, as a contribution to the general subject of infiltration, and is based upon laboratory tests and field surveys of various types of windows of this class. Results show that steel windows manufactured of solid rolled sections are, on the average, more weathertight than wood windows, notwithstanding a rather widespread opinion to the contrary. Former papers presented before the Society on the subject of infiltration have been based chiefly upon tests of double hung wood and metal windows. (See bibliography at end of this paper.)

Factors Influencing the Weathertightness of Windows

Infiltration is dependent upon two things, *viz.*, the leakage opening, and the pressure difference that causes flow.

The leakage opening is determined by the length and width of crack between the fixed and movable contact surfaces. It is something that depends upon the type, design, manufacture and installation of the window.

The difference in pressure between the inside and outside faces of a window is a function of the aerodynamic forces that prevail in and about the building.

Outside of any frame crack that may exist, the length of the leakage opening is usually the total perimeter of the movable portions of the window. The double hung window always presents the same length of crack for leakage, *viz.*, approximately twice the height of the window plus three times the width. In the rolled section type of steel window with pivoted or swinging ventilators, the ratio of ventilating area to window area is adaptable to the needs of the installation, and the crack length varies with the ventilation area provided. For a ventilating area equal to 50 per cent of the window area, the crack perimeter of a steel window will vary between 60 per cent and 90 per cent of the crack perimeter for double hung windows.

The width of crack is dependent upon the type and construction of the window and care in installation. The sidewall factory type, for instance, will be expected

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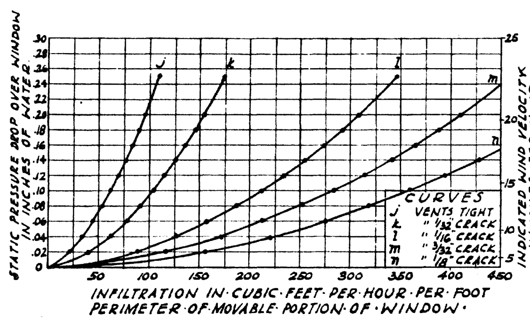

FIG. 3. INDUSTRIAL HORIZONTALLY PIVOTED STEEL WINDOWS

sidewall mullion over the coat of shop paint reduced the leakage about 15 per cent. In general, it can be said that painting has a considerable effect in reducing leakage when leakage cracks are small, but of course would have much less effect upon larger eakage cracks.

The curves were obtained from tests in the laboratory, and as such, will serve to furnish the heating engineer some general idea of the relative merits of the different types of rolled section windows for various pressure differentials as expressed in inches of water or equivalent wind velocity.

The curves for different crack openings show the relative values of different degrees of weathering or lack of weathering of the ventilators, and are to be associated with the data of Table 1, or other data similarly obtained.

By means of these curves, the engineer can compare windows of the same type

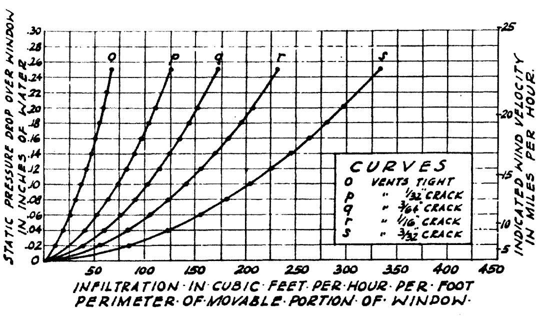

FIG. 4. COMMERCIAL AND ARCHITECTURAL PROJECTED STEEL WINDOWS

as built by different manufacturers, based upon his knowledge of their design and manufacture of such windows, or upon his general experience and observation of such windows actually installed in buildings. Furthermore, he can compare the data of these curves with similar data available on wood windows, plain or weather-

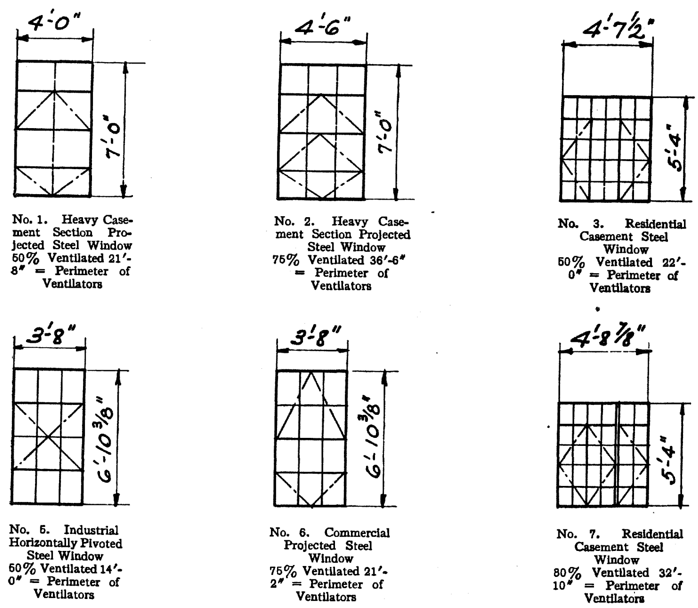

FIG. 5. TYPES AND SIZES OF SOLID SECTION STEEL WINDOWS TESTED

stripped, and with double hung steel windows or with other types of windows which have been tested or may be tested in the future. Incidentally, the testing of windows based on one condition of crack opening has little value for comparisons.

In using the data of the curves, it must be remembered that the leakage is given per foot of crack. The total window leakage must be figured upon the entire crack perimeter, to which is to be added such mullion and frame leakage, when the window is installed in steel, as may be determined from the curves of Fig. 6. The tests indicate that when steel windows are calked with mastic, as is the common practice with residential casements, heavy section casements, heavy casement section projected, and possibly architectural projected, or grouted with cement, as is the common practice with industrial pivoted windows, the frame leakage is negligible.

In figuring wood windows, the frame and elsewhere leakage is to be added to the crack leakage to obtain the total.

As stated above, in the steel window there will be little or none of the frame leakage often found in wood windows, because the steel framing is usually installed in the opening with grout or mastic, and the coefficient of expansion of steel is so near that of building construction that the bond is maintained intact. Cracks at mullions and at contacts where the windows are attached to the steel framework are found to give negligible leakage if even ordinary care is exercised in installation.

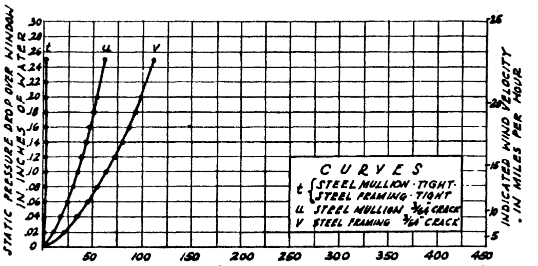

FIG. 6. VERTICAL STEEL MULLIONS, HORIZONTAL IMPOSTS AND CONTACT WITH STEEL

Some heating engineers allow the same leakage per foot of crack at mullions and contacts with steel frame work, as for ventilator perimeter, but this does not seem justifiable in the light of the tests. Poor installation in fixed steel work represents less leakage per foot of crack than that from $^1/_{32}$-inch crack of an industrial pivoted ventilator; and poor installation of mullions about one-half as much. Mastic is sometimes used to decrease this amount.

Measured Crack Widths Found in Rolled Section Steel Windows

Crack width is a quantity that is capable of being readily inspected and measured, and serves as a means of checking up on the manufacture and installation, whereas it is practically impossible to check up an installed window on any specification of air leakage.

In order to ascertain what crack widths might be expected in steel windows of the class included in this paper, a number of measurements were made in eight buildings at the University of Michigan and in a few buildings in Detroit. No attempt was made to examine all of the windows of a building, but only such as were readily accessible and in sufficient number to give fairly representative figures. Several types and makes of windows were measured as they were found in the building. The measurements are presented in Table 1. These figures, while not advanced as representative of steel window construction throughout the country, give some idea of what crack widths are found in practice.

TABLE 1. MEASURED CRACK WIDTHS OF STEEL WINDOWS IN SERVICE

Building Designated by Letter	Type of Window	Number of Ventilators Having Crack Width Indicated Which Represent the Average of a Number of Trials at Edges of Ventilators							
		0.006"	1/64"	1/32"	1/16"	1/8"	1/4"	Total No.	Avg. Crack
A (U. of M.)	Heavy section casement	7	28	25	4	4	...	68	1/32"−
B (Detroit)	Residential casement	56	39	6	1	...	...	102	1/64"−
C (U. of M.)	Heavy casement section projected	..	8	12	9	7	...	36	3/64"+
D (U. of M.)	Heavy casement section projected	58	214	6	10	2	...	290	1/64"
E (U. of M.)	Heavy casement section projected	77	127	10	..	...	...	214	1/64"−
F (U. of M.)	Industrial pivoted	..	7	19	30	35	6	97	3/32"−
G (Detroit)	Industrial pivoted	16	45	46	27	11	15	160	1/16"−
C (U. of M.)	Commercial projected	..	...	..	..	128	103	231	3/16"
H (U. of M.)	Commercial projected	..	80	24	6	...	...	110	1/64"+
I (U. of M.)	Architectural projected	43	41	5	21	...	...	110	1/64"+
J (U. of M.)	Architectural projected	6	53	13	10	6	...	78	1/32"−
K (U. of M.)	Architectural projected	76	90	13	..	...	...	180	1/64"−

It is hoped that other investigators may contribute similar data on crack widths, so that in due time there will have been accumulated a sufficient amount of statistics to enable the engineer to specify maximum crack width on any given installation.

Use of Curves in Determining Infiltration

Guided by data like those of Table 1, an estimate of probable crack width can

TABLE 2. CALCULATED INFILTRATION FOR VARIOUS TYPES OF WINDOWS, APPROXIMATELY 4 FT. x 7 FT. FOR A PRESSURE DIFFERENCE CORRESPONDING TO A WIND VELOCITY OF 20 MILES PER HOUR, AND FOR A VENTILATION AREA OF ABOUT 50% OF THE WINDOW OPENING

Type of Window	Crack Width (Chosen)	Crack Length		Leakage Cubic Feet per Hour per Foot of Crack			
		Frame	Sash	Frame	Sash	Elsewhere	Total
Residential casement, Fig. 1	1/32"	20	22	None	99	None	2180
Heavy casement, section projected, two ventilators, Fig. 2	1/32"	22	22	None	68	None	1500
Industrial pivoted, one ventilator, Fig. 3	1/16"	22	14	None	300	None	4200
Architectural, projected, two ventilators, Fig. 4	3/64"	22	14	None	146	None	2040
Double hung steel, unlocked not weatherstripped, Houghten & O'Connell, Nov., 1927 JOURNAL, Curve *D*, p. 650	..	22	26	None	...	...	3420
Double hung steel, unlocked and weatherstripped, Houghten & O'Connell, Nov., 1927 JOURNAL, Curve *B*, p. 650	..	22	26	None	...	...	1500
Wood, average, plain, uncalked frame, Houghten & Schrader, Feb., 1924 JOURNAL, Table 2, p. 132	..	22	25	38.8	202	456	6350
Wood, rib weatherstripped, Houghten & Schrader, Feb., 1924 JOURNAL, Table 2, p. 132	..	22	25	38.8	48.5	456	2520

be made for any chosen type of window. Referring then to the appropriate curve for that type of window and using the crack width considered as representative, the infiltration per foot of crack for any pressure difference can be determined, and after the crack length has been determined, the total leakage for the window can be computed.

The tests from which the curves were plotted were not carried beyond a pressure difference corresponding to an equivalent wind velocity of about 25 miles per hour. This includes the range of pressures most usually met with, and it seemed better to represent this range by a reasonably large scale rather than to minimize it by presenting results over a wider range within the same limits of space available for

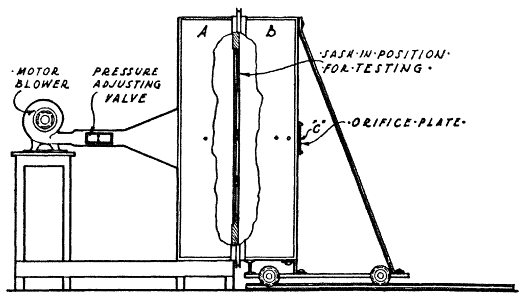

FIG. 7. DIAGRAM OF APPARATUS

the curves. Inasmuch as the curves become practically straight lines in the regions of higher values, they may be readily extended to cover extreme cases.

As an example of the computation of leakage, and to serve somewhat as a comparison among different types of windows, Table 2 has been prepared. The calculations are for a pressure difference corresponding to an indicated wind velocity of 20 miles per hour. Computations for a double hung metal window and for double hung wood windows, both weatherstripped and plain, from data available, have been included in this Table.

As will be noted, the figures for double hung wood windows have been arrived at by using the paper by Houghten and Schrader in the February, 1924 JOURNAL, instead of THE GUIDE, since the latter does not give the values for rib-stripped windows, and apparently does not include elsewhere leakage. Computations, based on Part I of Table 14, p. 47 of the 1928 GUIDE, would give a figure of 5880 cu. ft. per hour for the average plain wood window with uncalked frame, and 1940 cu. ft. per hour for the average weatherstripped wood window with uncalked frame.

Pressure Difference

The force that causes infiltration is the difference between the pressure against the inside face of the window and that against the outside face. It is a very complex quantity arising out of a combination of a number of influences including the wind velocity and direction with respect to the window, the proximity of other structures as they affect the wind, the temperature inside and outside, the height of building, the distance of the window from the ground, the interior construction whether single or multiple story, the freedom of air communication between stories

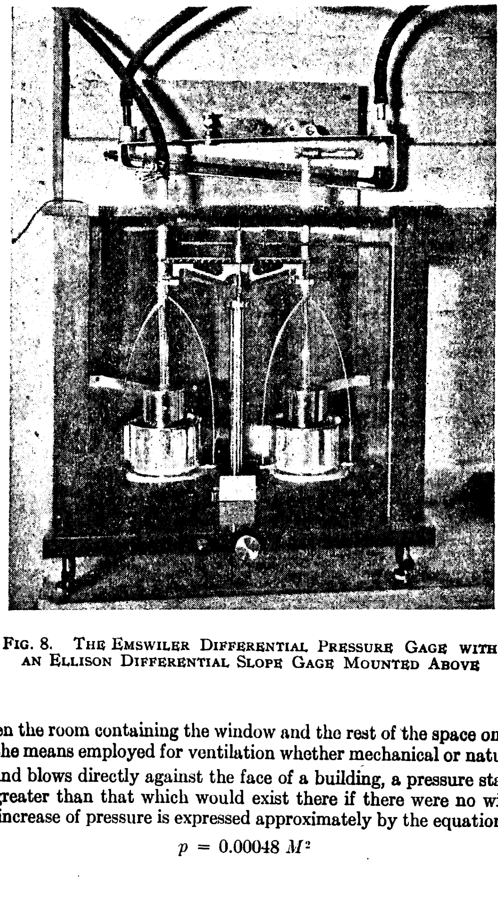

FIG. 8. THE EMSWILER DIFFERENTIAL PRESSURE GAGE WITH AN ELLISON DIFFERENTIAL SLOPE GAGE MOUNTED ABOVE

and between the room containing the window and the rest of the space on the same floor, and the means employed for ventilation whether mechanical or natural.

If the wind blows directly against the face of a building, a pressure state will be produced greater than that which would exist there if there were no wind. The maximum increase of pressure is expressed approximately by the equation

$$p = 0.00048\ M^2$$

where p is in inches of water and M is wind velocity in miles per hour. The pressure of the wind will vary considerably over the face of the building, being usually greatest toward the top and in a zone midway between the corners.

If the wind comes obliquely against a surface, the pressure will be greatest near the corner that splits the wind and will diminish along the face.[3] Thus it would be possible in a building that was perfectly air tight on all sides except the one against which the wind is blowing obliquely, to have inflow through windows in the vicinity of the windward corner, and outflow through those near the leeward corner. The mean pressure of the wind upon a surface against which it blows at an angle may be roughly considered as varying with the sine of the angle, until the angle becomes about 10 deg. when the state changes from pressure to suction.

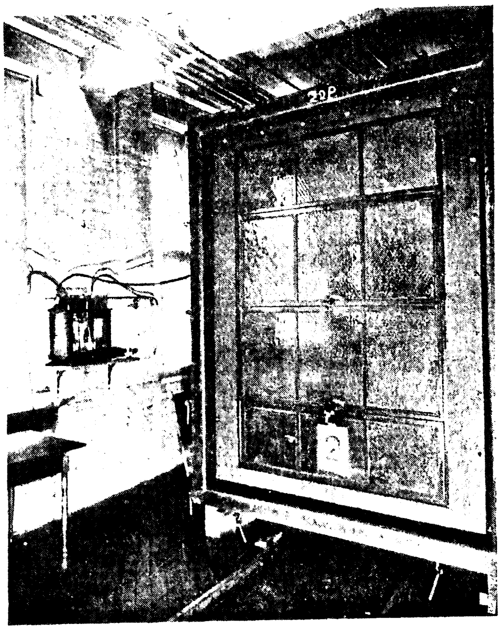

FIG. 9. WINDOW WITH WOODEN FRAME IN POSITION FOR TESTING

[3] See paper by W. C. Randall, "Airation of Industrial Buildings," TRANSACTIONS OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 34, 1928, p. 159.

On sides or roof adjacent to the corners from which the wind leaps away from the building, there will be a suction or partial vacuum, of a magnitude of approximately 75 per cent of the value given by the equation above for pressures. Where the wind blows parallel to a surface, the pressure state is neutral, that is it is equal to what it would be if no wind were blowing. There will be some slight suction at the leeward end or side of a building.

The wind, therefore, operates to create regions of pressure or vacuum about the exterior of a building, as compared to the normal or neutral barometric pressure state that would exist in those regions if the air was still. These pressures or suctions are not necessarily the forces that produce infiltration, since it is the difference of pressure on the inside and outside of an opening that causes flow—not the external state alone.

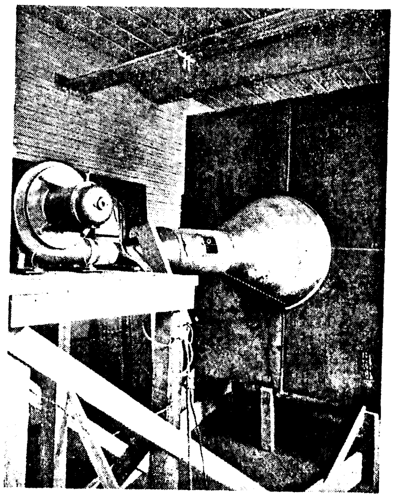

FIG. 10. VIEW SHOWING BLOWER, PRESSURE CONTROL VALVE AND ARRANGEMENT FOR OPERATING THE VALVE BY REMOTE CONTROL

Other structures in the proximity of a building may greatly modify the action of the wind, particularly in reducing the maximum intensity of the pressure and suction.

Even without any wind, a difference of temperature inside and outside will cause the pressure state inside to be less than that outside at the ground, and greater near the roof, and inflow will occur at lower windows and outflow at upper windows.[4] If the building is tall and open throughout from bottom to top, or if arranged in stories in free communication from one to another, and if the temperature difference is great, the pressure difference created at a point near the ground and also at a point near the roof may be considerable. Thus, in a building 200 ft. high with 70 deg. fahr. difference in temperature, this force alone causing inflow at the ground and outflow at the top, may easily exceed 0.20 in. of water, which is the equivalent of a twenty-mile wind. If the building is multiple storied and there is absolutely no communication between stories, then the force of temperature difference is effec-

FIG. 11. ASSEMBLY OF WINDOWS TESTED

tually nullified, or rather reduced to an amount proportional to the height of a single story. However, there is always some communication by means of stairs and otherwise, so that the force of temperature difference is always operative in some degree.

If the wind blows against a window of a building that is tightly sealed at all other points of possible ingress or egress of air, there will be no continuous infiltration at the window, because the temporary excess of pressure outside will soon be equalized by a momentary inflow. If the building has an outlet of exactly the same area as the presumed infiltration area of the window, and this outlet opens into a region of neutral pressure, then the pressure in the room will be half as much as that produced by the wind outside. Infiltration will take place through the window, but

[4] See paper by J. E. Emswiler, "The Neutral Zone in Ventilation," TRANSACTIONS OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 32, 1926, p. 59.

with only half the force of the wind pressure. Something like this is what occurs in any building. Whatever air gets in at inflow points must escape somewhere else. In order to force the air out, there must be a greater pressure inside somewhere than that which prevails immediately outside. The inside pressure automatically assumes a value that will give the necessary head for outflow through openings available, so that the outflow quantity always balances the inflow.

A weatherstripped inside door in an apartment will effectively retard infiltration through windows, because it makes it more difficult for the air to get out, and thus automatically increases the inside pressure opposing the wind. On the other hand,

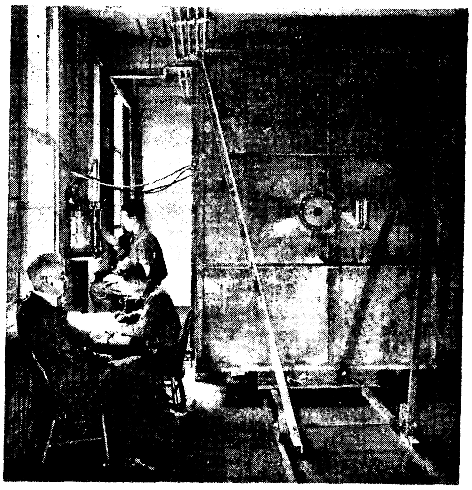

FIG. 12. THE TEST IN PROCESS

an open louver or transom in the door will increase infiltration. A fan in the kitchen, exhausting air, will tend to increase infiltration.

If a building is exposed to wind, a considerable part of the exterior is in a suction state. But it is probable that in a building not equipped with roof openings, as in the factory type, the interior pressure is usually higher than neutral, so that the force causing infiltration is less than that of the computed wind pressure.

As between wind and temperature difference, the wind is, no doubt, the more powerful agent in the extreme. But in a tall building, the outflow tendency at the upper levels caused by temperature difference is a factor of importance operating to greatly reduce infiltration at the top floors. On the other hand, at the lower levels, the wind and temperature difference cooperate to increase infiltration. However, the wind is usually much less effective near the ground because of the presence of other structures.

This whole question of pressure difference is fundamental to the problem of infiltration. Some excellent data on infiltration for all possible ranges of pressure difference are being accumulated, but much information about what pressure difference should be used in determining the probable amount of infiltration for any given case has not as yet been advanced. It would seem then that further research on the general subject should be directed at least in part toward this phase of the problem.

While numerous factors contribute in a very complex way to determine pressure difference, the actual measurement of it in a building is a simple thing. What is needed is a recording device that can be set up in various places in different buildings to operate more especially during the season of extreme weather conditions. The accumulation of records from a number of instruments would in time furnish definite information on pressure difference which, taken in conjunction with laboratory data now available, and crack widths guaranteed by manufacturers, would make it possible to definitely determine infiltration.

Following a suggestion received from the paper by Messrs. Houghten and O'Connell in the November, 1927 JOURNAL, a number of observations were made during April of this year, of the actual prevailing pressure difference as found in the University Hospital at Ann Arbor. These data have been taken chiefly for the purpose of ascertaining the feasibility of the plan, and represent manual observations for periods of about 20 minutes at each station, at one-minute intervals. The readings obtained do not represent extreme conditions of either wind or temperature difference, although on one day a wind velocity of over 20 miles per hour was recorded by the anemometer at the University Observatory. Some of the averages of the readings are given in Table 3.

TABLE 3. AVERAGES OF SOME READINGS, OF PRESSURE DIFFERENCE ACROSS WINDOWS OF UNIVERSITY HOSPITAL, ANN ARBOR, AS OBSERVED ON THREE DIFFERENT DAYS AT CORRESPONDING STATIONS AT 2ND AND 6TH FLOORS

Date	Average Wind Velocity	Station *A*		Station *B*		Station *C*	
		2nd Floor	6th Floor	2nd Floor	6th Floor	2nd Floor	6th Floor
Apr. 17	5.3	+0.009	+0.013	+0.020	+0.003	+0.024	−0.036
Apr. 18	11.3	+0.006	−0.007	+0.054	+0.001	+0.010	−0.037
Apr. 19	21.0	+0.516	+0.380	+0.060	+0.037	+0.159	+0.099

In the above table the plus (+) sign indicates tendency for inflow, and (−) sign, outflow.

The different floors of the hospital were not in open communication. The readings at Station *C* were taken at windows in the stairwell, and are naturally influenced to a greater degree by temperature difference than are those of Stations *A* and *B*.

It will be noticed that the pressure difference varies widely, the values ranging all the way from −0.037 to +0.516, the latter value corresponding to an equivalent wind velocity of about 33 miles per hour. It is significant that in every case, except one in Table 3, the inflow tendency at the second floor was always greater than that at the sixth floor, indicating the activity of temperature difference, and probably also the influence of a fan ventilation system serving a part of the building. The height between the second and sixth floors is about 45 ft., and the outside temperature was about 40 deg. fahr. A recording device is being made whereby more extensive observations can be carried on.

Due to the fact that there is not a constant definite relation between the difference in pressure between the outside and inside face of all windows and the velocity of the wind, as measured at some observation point, one must hesitate to use the definite pressure difference as being equivalent to the assumed wind velocity. This is particularly true if this is transferred to infiltration and in turn to B.t.u.'s. In other words, one cannot assume with accuracy that there is always an actual saving in B.t.u.'s required to heat the infiltering air comparable to the difference in leakages shown on the curves.

Relation of Infiltration to Heating and Ventilation

It is common practice, to provide additional direct heating surface to supply the heat necessary to warm the cold infiltrating air to room temperature and to charge up the installation of extra radiation and the heat consumed therein, as a loss attributed to infiltration. But infiltration is ventilation and, within reasonable limits, it would seem that this heat should be charged to ventilation. This is exactly what is done automatically in naturally ventilated buildings. With considerable wind, the ventilators on the windward side are closed; and inflowing air on that side is reduced to infiltration which then becomes the only means of ventilation. The heat employed in warming the incoming air is not a loss but is chargeable to ventilation. In a building that is mechanically ventilated, there appears to be no good reason why the amount of cold air drawn in by the fan and heated up should not be reduced as infiltration increases on a windy day.

Every building should have adequate ventilation which usually means exchanging inside for outside air. If a naturally ventilated building had windows perfectly air tight against infiltration, some windows would then have to be opened to provide the necessary air for ventilation during the hours of occupancy. In a mechanically ventilated building it is equally true that if windows were perfectly air tight, the fans would have to draw in more outside air to be heated up to compensate for the loss of ventilation by infiltration.

Steel windows, particularly some types, can be made weathertight to almost any practical limit desired, but in view of what has been said, there would seem to be no economic justification in seeking to secure too great a degree of weathertightness. How far it is desirable to go depends upon the service of any given building. In office buildings and schools, ventilation is not necessary during the hours of non-occupancy and infiltration then represents a heating loss, although, as has been pointed out, it may not represent a loss during the hours of occupancy. In a factory building, which may be operated 24 hours a day, and where temperatures are usually lower, infiltration in moderate amounts will mean no heat loss. In dwelling houses and apartments, where sleeping room windows are open during the night, infiltration in such rooms represents no loss during those hours, while in the daytime in cold weather, the only means of ventilation is by infiltration, of which there must be some; otherwise windows would have to be opened for that purpose. The point to be made is that infiltration in a moderate degree is in many cases a necessity, and not a source of heat loss, and amounts representing heat savings by reduction of infiltration should be considered with considerable caution.

Apparatus and Method of Testing

The apparatus used in these tests is shown in Fig. 7 and is very similar to that developed by the Laboratory at Pittsburgh. It is built of 20-gage sheet iron over an angle iron frame. The chamber *A* is stationary, while chamber *B* is constructed upon a wheeled carriage which allows it to be easily moved back, giving access to the window. All of the windows that were to be tested were installed in wooden frames of the same over-all dimensions, so that window and frame were handled as a unit and could be mounted in the tester or removed quickly and conveniently. The wooden frame was bolted to a stationary steel frame in chamber *A*. This joint between the window and wooden frame, and that between the wooden frame and stationary steel member were sealed with mastic. Fig. 9 shows a window bolted to the stationary frame of chamber *A* and Fig. 11 shows an assembly of the windows tested and referred to in this paper.

Care was taken to make chamber *B* as tight as possible. All of the fixed joints are welded and painted, while the joint between *A* and *B* is sealed with a soft sponge rubber packing. Experiment showed that chamber *B* was not absolutely air tight, but a method was developed for determining the slight leakage that did occur, and the corrections have been applied.

A static air pressure equivalent to any desired wind velocity is produced in the pressure chamber *A* by a small motor blower and the air that leaks through the window or other construction is collected in chamber *B*, and, as it passes through the orifice *C*, its volume is determined by the well-known orifice method established by R. J. Durley (*A.S.M.E. Transactions*, Vol. 27, p. 193) and others.

The pressure drop through the orifice was determined by an extremely sensitive differential type of gage designed particularly for this research work. Fig. 8 illustrates the Emswiler gage and suggests the principle of operation. The fixed chambers or cylinders on the two sides, to which are connected the rubber tubing at the top of the instrument, have their lower open ends dipping into liquid contained in corresponding cups which rest upon the pans of the sensitive balance. It will thus be seen that the pressure difference is virtually weighed by means of a chemical balance. The gage will respond to variations in pressure as small as 0.0002 in. of water.

The pressure drop through the window was measured by an Ellison differential slope gage graduated to 0.01 of an inch of water.

A slide over the intake of the blower was used as a primary control of the pressure drop through the window, while the pressure adjusting valve, shown in Fig. 10, served as a vernier regulation of the same pressure. An arrangement of rope and pulleys enabled the observer at the two gages to adjust and hold with ease any desired pressure drop through the window at an absolute value, while the pressure drop through the orifice was being determined.

The test of each window was made by regulating the pressure controls to give the desired pressure drop through the window as indicated by the slope gage, and while this pressure was maintained by manipulation of the adjusting valve, the pressure drop through the orifice was determined by the sensitive differential gage. By repeating the test for a large number of pressure differences through the window, data were obtained for plotting a curve showing air leakage through the window in cubic feet per hour, for pressure differences in inches of water or equivalent wind velocity. As readings were taken, the pressure readings of one gage were plotted against the pressure readings of the other and a curve constructed through the points. If some points did not fall on the general smooth curve, the readings of these points were checked by repeating that particular point. All velocities and volumes given in this report are for air under standard conditions of 29.92 in. of mercury, a dry-bulb temperature of 68 deg. fahr. and 50 per cent relative humidity.

The authors wish to acknowledge the work of L. W. Leonhard and J. A. Grant, who conducted the laboratory work and made the field survey.

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DISCUSSION

F. H. BURKE (WRITTEN): The paper presented by Messrs. Emswiler and Randall is an excellent example of practical and timely research. From first to last, this paper is packed with valuable data and logical conclusions, all of which are admirably presented.

Mention is made of the rather widespread opinion that rolled steel sections for windows are less weathertight than window sections of wood. The Standard Radiation Estimating Table of the *Heating and Piping Contractors National Association* tabulates the infiltration of double hung steel sash and fenestra as twice that of double hung wood sash. It would appear that this widespread opinion has, to some extent, received the stamp of authority, though I doubt that any engineer of experience would be misled.

The authors' observations regarding frames distorted in shipment and handling, and of steel windows with excessive crack widths due to the hardened mortar and plaster chunks should be given heed by architects as well as by engineers. Nor is it out of reason to conclude from these observations, that the engineer should inspect those factors outside his work which may affect the proper working of a heating and ventilating system, and call the architect's attention to faulty construction.

That portion of the paper under the heading Relation of Infiltration to Heating and Ventilation merits special consideration. It is to be hoped that the deduction set forth will bear fruit and be widely applied. Of late we have been strenuously advocating the insulation of walls and roofs to save heat loss. This is as it should be. But here we have a warning that we should not carry the stoppage of heat loss to extremes by stopping altogether the infiltration loss at windows, lest we also stop much needed ventilation.

At the end of the paper the Bibliography on Infiltration through Windows will have added value by including also the paper of Messrs. Emswiler and Randall.

EDWIN S. HALLETT (WRITTEN): This paper is a valuable contribution to the literature now so rapidly appearing on the subject of infiltration. The table on p. 533 especially represents a great outlay of time in compiling the data on actual cracks, in the various types of steel windows.

In making use of these tables the architect and engineer will discover the wide variation in the crack, especially in the industrial pivoted and the commercial projected. This does not properly represent the present state of the manufacturing process but rather the product of several firms some of which do not use precise methods in the manufacture. Steel sash will be made tight when the demand for it becomes insistent. This demand must come from engineers who have learned of its value in other branches of research of this Society.

The comparison of the crack leakage of steel sash with wood does not make a good showing for steel in the table on p. 533. The calculated infiltration of wood sash and rib weatherstrip is 48.5 cu. ft. per hour, the lowest reported. However attention should be called to the fact that steel sash has been designed generally for setting in mortar, and there is seldom any frame leakage, whereas wood frames are not generally calked at all. The advantages gained by steel frames set in mortar are more than the losses from greater crack of the steel sash as shown. Evidently the choice of steel or wood sash will be made upon other reasons than that of weathertightness.

The paragraph devoted to the relation of infiltration to heating and ventilation calls for most emphatic protest. Infiltration is not ventilation. Infiltration whether inward or outward is injurious to ventilation and produces a loss. Ventilation places a house under fan pressure and leakage at the window in still outside air increases the air delivered to the room from the fan. If a wind is blowing the leakage will be inward and the fan delivery will be reduced and the air distribution in the room disturbed and the temperature reduced. Inleakage brings dirt, sulphur gas and the street odors, so that infiltration in any degree is a defect in the building construction.

Those architects who still build vent stacks on their buildings for wasting all the air of ventilation will not be interested in small window cracks nor frame calking. The owner will however be compelled to shut it all down to save fuel.

It is not probable that there is an inherent advantage of steel over wood or wood over steel in designing perfectly tight windows. The refinements of weather strips for wood sash has placed that temporarily in the lead, but the enterprise shown in steel sash industry points to the production of a sash practically perfect and proof against all infiltration.

PROF. G. L. LARSON: I feel that this paper is a very excellent contribution to our data on infiltration. We have lacked information as far as THE GUIDE is concerned on the matter of steel windows and especially on steel casement windows.

There are a number of points that occurred to me that might well be brought out here in order that we may make the paper a little more valuable in working it up for future use in THE GUIDE.

Referring to p. 534 where Table 14 of THE GUIDE 1928 is referred to, I think the authors will find on further investigation that Table 14 does include elsewhere leakage. Perhaps Mr. Houghten can check me on this: I think Table 14 also gives an average of interlocking and rib strip rather than just rib strip alone. These items are not clear in THE GUIDE, but I think the authors will find them to be true on further investigation.

I also note that the authors make their comparisons with wood windows, not calked. I think it is true nowadays that practically all wood windows put in brick walls are calked, and it would give more nearly the right conditions of comparison if comparisons had been made with calked frames set in brick walls.

I also want to refer to the statement on the first page where the author states "for a ventilating area equal to 50 per cent of the window area, the crack perimeter of a steel window will vary between 60 per cent and 90 per cent of the crack perimeter for double hung windows."

I think a comparison made on the basis of light area instead of ventilating area would bring different results. For instance, take a given window opening in a wall and it is decided to put in a casement window in that opening rather than a double hung window. In such a case I think it will be found that the perimeter of the crack openings for the casement window is greater than it would be for the double hung window. This is true for steel as well as wood casements.

I would like to ask how the windows were closed before the tests. I got the impression that in each case the window was adjusted so that it fitted equally all around, being pressed against the space gages so that it had an equal opening through the entire perimeter. It has been my experience with casement windows that they are closed by a lock near the middle of the window and may fit very closely near the lock and have a very poor fit at the corners away from the lock.

I think it would clear up the paper a little bit to have a statement as to how they were arranged before the tests were made.

One other point I wish the authors had brought out a little more clearly, and that is, just what in their opinion and experience is the maximum crack that should be allowed for in designing calculations of these types of windows. I think they purposely avoided it and put it up to the designer to choose, but I am thinking in terms of the chairman of the Infiltration Committee of THE GUIDE as to what values should be used there, and that is what I am being asked so I am passing the responsibility to the authors, to develop a table that will give us results that will be workable for the average man that is trying to use THE GUIDE.

J. E. EMSWILER: In reference to one point that Mr. Hallett has made, *viz.*, that infiltration is not ventilation: of course, it is not contended that infiltration in any excessive degree is ventilation, but the point that the authors have attempted to make is that it is not only uneconomical to attempt to reduce infiltration below a certain point, but in many circumstances it would not be desirable to do so, even with the question of economy not under consideration. For instance in naturally ventilated buildings, of which nearly all dwelling houses are examples, there must be some air let in from the outside, and the only air that gets in from the outside is by way of infiltration or through the natural opening of doors, inlets and outlets, for ingress and egress to the building. In fan ventilated buildings, of course, infiltration tends to disturb the fan system, but even there infiltration to a degree is certainly not harmful and so long as air gets in and does not disturb the system, it seems to me it is legitimate to consider it as a portion of the ventilation.

W. C. RANDALL: With reference to the rib type of weather stripping used in the comparisons, as questioned by Professor Larson, we made investigations of the general types of weatherstripping generally used, and we found in checking up with the representatives of four manufacturers that over 80 per cent of the weatherstripping was ribbed strip, not the interlocking strip. That is why we preferred to think it was a little more practical to use the ribbed strip figures.

In reference to the calking of windows, we checked with people who make a specialty of calking windows in Detroit, and found that less than 10 per cent of all wood windows which are manufactured and installed are calked. I would say that in brick construction referred to by Professor Larson, if 25 per cent of the windows were calked, that is a very high figure at the present time. I don't think enough is known of the infiltration of air through the windows that people realize the advantage of calking at the present time. I think the paper by Professor Larson will go a long way toward correcting that situation. We therefore felt it more practical to use uncalked frame figures.

With reference to the crack, and something which can be used in THE GUIDE, I presented a table of the typical figures as we found them. In the comparison which we made with other types of windows, we used a $^1/_{32}$-in. crack for residential casements, $^1/_{32}$-in. crack for heavy casement section windows, $^3/_{64}$ in. for the architectural projected, $^1/_{16}$ in. for the industrial windows and I would say so far as the steel window manufacturers, the equivalent of that at least should be guaranteed, particularly if the window is installed by the manufacturer. At least that can be expected, and I think the figures as represented by those particular curves could be used with the provision possibly that the installation in the building has got to come within those limits of crack opening because the crack opening can be very easily checked to and measured.

With reference to Mr. Hallett's discussion on this paper, I think that he has referred particularly to schools. After all, there is a wide general application of steel windows to residential and industrial conditions that are quite different than we normally have in the school, and while his criticism was probably perfectly in order in reference to schools, the authors had in mind a little broader general application where the point made might a little more logically be true.

Incidentally with reference to the leakage of rolled section steel windows, I was talking to Mr. Hallett and they have a school in St. Louis called Lincoln School. It was referred to in White Sulphur in the discussion of Mr. Armstrong's paper and is published information. That is this: there is less leakage in this rolled section steel window installation than any other in St. Louis, and incidentally, he said the heating equipment on that school, which is for 1800 pupils, is about the same as they normally use for the 1200-pupil schools. His experience, and I am sure I interpret it correctly, more or less consolidates the conclusions of the authors that despite widespread opinion and certain authorities on the subject, there is not greater leakage through rolled section steel windows than through wood windows.