No. 686

AIR LEAKAGE THROUGH THE OPENINGS IN BUILDINGS

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MEMBERS

HEAT is lost from buildings in two ways: *First,* by transmission and *Second,* by infiltration. Both sources of heat loss are of vital concern to the heating and ventilating engineer, the architect and the owner. Both are difficult of exact measurement and determination of constants which may be used in practice with the desired engineering accuracy. As a result, the calculation of heat loss from buildings probably involves a greater element of chance than any other engineering problem.

Heat loss by transmission was one of the first problems to receive the attention of the Research Laboratory. Total heat loss by infiltration for a room as a unit has also received considerable attention. (JOURNAL AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, January and September, 1921.) In January 1916, a paper on Window Leakage by Stephen F. Voorhees and Henry C. Meyer Jr., was presented at the Annual Meeting of this Society (TRANSACTIONS, A.S.H. & V.E., 22, 1916, p. 183).

The great need for information regarding infiltration led to the present investigation of the leakage of air through and around all types of windows and doors by the Research Laboratory of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, in cooperation with the *American Institute of Architects* and the U. S. Bureau of Mines. The architect is interested in the relative leakage of air through various types of windows and doors, with and without weatherstripping, in order that he may design a building with the lowest heat loss consistent with other considerations. The heating engineer needs the actual leakage through and around all types and sizes of windows and doors, or better, through a unit length of crack around such openings, in order to more accurately calculate the heat loss from any room or building and supply radiation accordingly.

This report deals with the method employed in the investigation of and results obtained for double hung windows, 2 ft. 8 in. x 5 ft. 2 in. x 1$^3/_8$ in., in a 13 in. brick wall, plastered on the inside with cement plaster. Results are given for the leakage,

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through such a window without weatherstripping with two types of weather stripping, around the frame, and through the brick wall itself.

Leakage of air through cracks around windows and doors, cracks in walls, and through the porous materials of which walls are made, takes place in accordance with two physical laws. *First*, there is an interchange of air through the wall by diffusion; *Second*, there may be a current of air through the wall caused by a pressure difference set up by the impingeing wind. The first goes on at all times, is independent of wind velocity, and is probably negligible. The second takes place only when there is a pressure difference between the two sides of the wall. Such a pressure difference exists whenever the wind blows against the surface of the wall or whenever the direction of the wind toward the wall is changed. For any given velocity of wind striking the wall at right angles, there is always a definite pressure produced at the surface which tends to cause leakage of air through cracks.

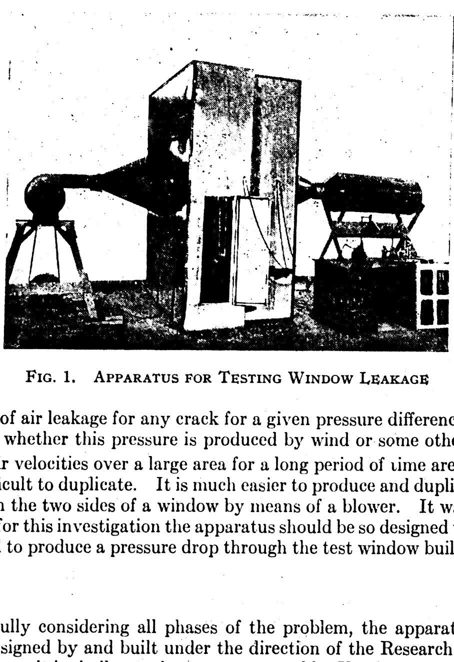

Fig. 1. Apparatus for Testing Window Leakage

The amount of air leakage for any crack for a given pressure difference is the same regardless of whether this pressure is produced by wind or some other cause.

Uniform air velocities over a large area for a long period of time are hard to produce and difficult to duplicate. It is much easier to produce and duplicate pressure differences on the two sides of a window by means of a blower. It was, therefore, decided that for this investigation the apparatus should be so designed that a blower could be used to produce a pressure drop through the test window built in a section of wall.

Apparatus

After carefully considering all phases of the problem, the apparatus shown in Fig. 2 was designed by and built under the direction of the Research Laboratory. In many respects it is similar to the apparatus used by Voorhees and Meyer in the work previously mentioned. The apparatus is built of 18 gage galvanized iron, and consists of a pressure chamber *A* and an air collecting chamber *B* separated by a section of wall including the particular window or door to be tested. Air pressure is produced in the first chamber by means of a motor driven blower, and the volume of air passing through the wall is measured by the orifice box *C*. The test wall,

10 ft. high x 6 ft. 6 in. wide, is built in the collecting chamber section flush with its outer edge and the pressure chamber section of the apparatus bolted on later. The desired pressure is produced in *A* by varying the inlet of the blower, and by means of a butterfly damper and relief slide in the connection between the blower and *A*. Chamber *A* is substantially air-tight although the requirements of the investigation do not demand that it be absolutely so. A door, 4 ft. x 1 ft. 6 in., allows entrance into this chamber to make any changes in the opening under study. The present blower has a capacity of 1100 cu. ft. per min., at 5 in. water pressure. Chamber *B* must be air-tight so that all air passing through the test wall

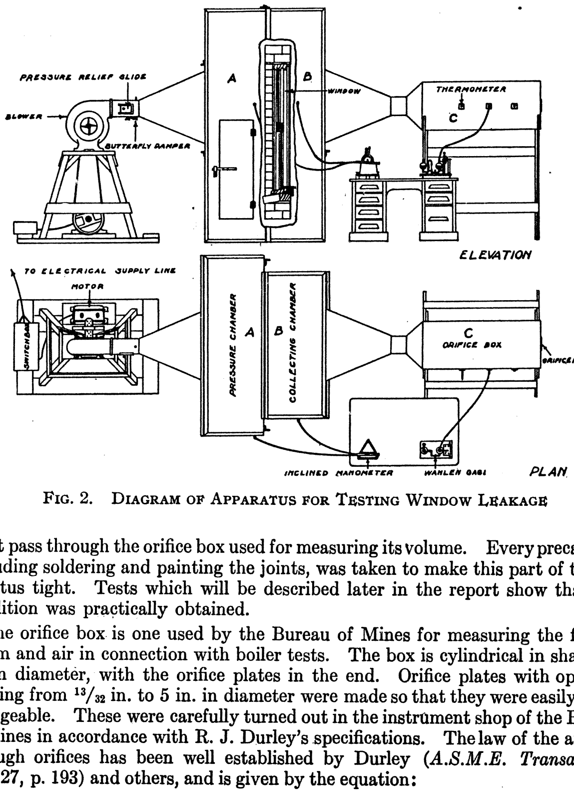

Fig. 2. Diagram of Apparatus for Testing Window Leakage

must pass through the orifice box used for measuring its volume. Every precaution, including soldering and painting the joints, was taken to make this part of the apparatus tight. Tests which will be described later in the report show that this condition was practically obtained.

The orifice box is one used by the Bureau of Mines for measuring the flow of steam and air in connection with boiler tests. The box is cylindrical in shape, 24 in. in diameter, with the orifice plates in the end. Orifice plates with openings varying from $^{13}/_{32}$ in. to 5 in. in diameter were made so that they were easily interchangeable. These were carefully turned out in the instrument shop of the Bureau of Mines in accordance with R. J. Durley's specifications. The law of the air flow through orifices has been well established by Durley (*A.S.M.E. Transactions*, Vol. 27, p. 193) and others, and is given by the equation:

$$Q = 1096.5\, C\, A \sqrt{\frac{p}{w}} \tag{1}$$

Q = quantity of air, cu. ft. per min.
A = area of orifice in sq. ft.
p = pressure head in inches of water causing flow through the orifice
w = weight of air in pounds per cu. ft.
C = coefficient of discharge

The coefficient of discharge used is 0.6 because it approaches this value at the pressures obtained for all the orifices used.

The pressure drop through the orifice which in this case is the difference between

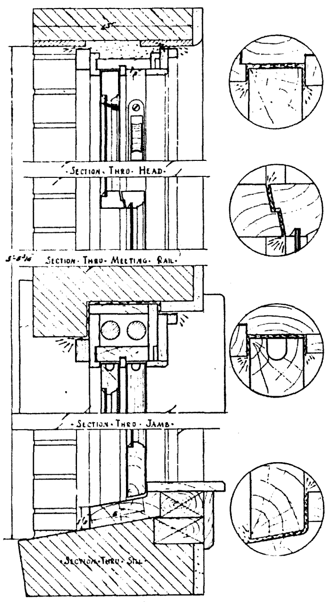

FIG. 3. DETAILS OF WINDOW WITHOUT WEATHERSTRIPPING

the pressure in the orifice box and the atmosphere, was measured by a Wahlen gage accurate to 0.0001 in. of water. This gage was developed at the University of Illinois and is fully described by A. C. Willard in the University of Illinois Engineering Experiment Station Bulletin 112.

While the accuracy of the orifice method of measuring air flow is well accepted by those familiar with its use, it was thought desirable to compare it with some other method. The orifices in the box as used in the tests were compared with a dry gas meter used as a standard in the meter testing laboratory of the Equitable Gas Co., Pittsburgh. These tests showed that the results for the orifices using the equation

given above were more consistent than those for the gas meter with which it was compared. As a further check of the relative readings of the various sized orifices they were compared with each other and with duplicate orifices by placing a second orifice in the window opening in the test wall in series with the box. This was done when the total leakage through the wall was reduced to a negligible but known value.

The pressure drop through the test wall was measured by an inclined U-tube gage of a particularly accurate type designed and built by the Bureau of Mines.

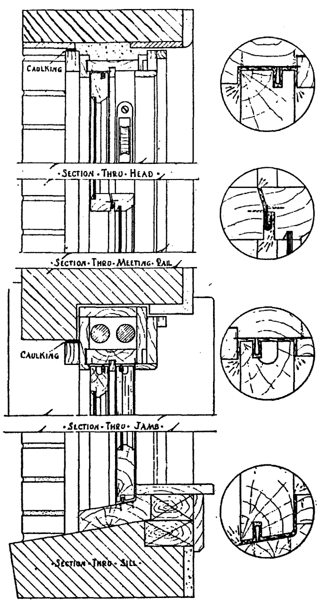

FIG. 4. DETAILS OF WINDOW WITH RIB TYPE WEATHERSTRIPPING

It was compared with the Wahlen gage and found to be accurate to 0.003 in. of water. The two legs of this gage are connected by rubber tubing to chambers A and B.

A test of any particular window was made by regulating the blower pressure so as to give the desired pressure drop through the window indicated by the differential gage. The size of the orifice chosen for any test was such as to give a pressure in the orifice box of from 0.3 to 0.7 in. of water. When these conditions were maintained for a sufficient time to insure equilibrium, the two pressure gages were read simultaneously. By repeating the tests for a large number of pressure differences through the window, data was obtained for plotting a curve giving leakage through the wall in cu. ft. per min. against pressure differences in inches of water or wind velocity. All velocities and volumes given are for air weighing 0.07488 lb. per cu. ft. corresponding to air having a barometric pressure of 29.92 in. of mercury, a dry bulb temperature of 68 deg. fahr. and 50 per cent relative humidity. Many

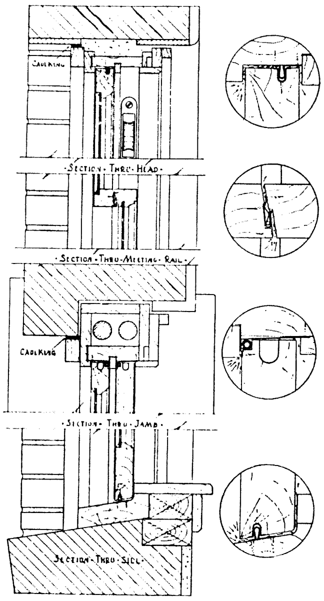

FIG. 5. DETAILS OF WINDOW WITH INTERLOCKING TYPE WEATHERSTRIPPING

tests in such a series were repeated after opening and closing the window and also after taking the sash out of the frame and replacing it.

Data and Results

The results given in this paper are for a double hung window, 2 ft. 8 in. x 5 ft. 2 in. x $1^3/_8$ in. in a 13 in. brick wall plastered on the inside with cement plaster. The brick wall was built, the plastering was done and the window hung by mechanics in the employ of large contracting firms in the city of Pittsburgh. The work was done according to specifications supplied by and under the direction of S. F. Heckert, representing the Structural Service Committee of the *American Institute of Architects*. All changes in the window, such as hanging new sash and applying weatherstripping, were made also by mechanics under his direction. Every precaution

was taken to make the wall and window represent work done by the ordinary contractor under the supervision of an architect. The sash and frame were given three coats of paint. Fig. 3 is a vertical section through the unweatherstripped window with a horizontal section through one side of the frame.

For convenience in presenting, the results are given in two sections. *First,* those obtained in a preliminary series of tests on the unweatherstripped window in the wall as built, and with certain changes such as calking the frame, sealing cracks, and painting the wall; *Second,* results obtained from a large number of tests with various sash hung under different conditions with and without weatherstripping.

Preliminary Tests

Preliminary tests were made in order to study the working of the apparatus itself and in order to differentiate between the various channels of leakage through the

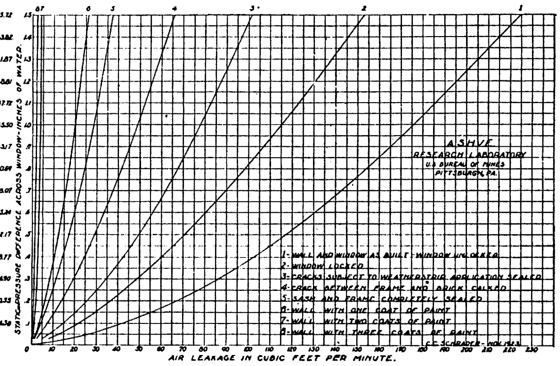

FIG. 6. RESULTS OF TESTS OF LEAKAGE THROUGH VARIOUS PARTS OF WINDOW AND WALL

window and wall. Leakage through the window may be divided into the following parts. *First,* that which passes through the cracks, around the sash perimeter which are subject to weatherstrip application; *Second,* that which passes through the cracks between the frame and the brick and can be eliminated by calking under the staff bead or brick mold. This may be called the frame leakage. *Third,* leakage through other cracks in the frame or sash which cannot be eliminated by either weatherstripping or calking and may be called the "elsewhere" leakage.

Before making the first series of tests, the joint between the brick and the chamber wall was calked so that all leakage would take place through the wall or window. In all other respects, the wall and window were in the condition in which they were left by the mechanics, the sash having been fitted as tight as would allow free sliding, though probably tighter than would be allowable in actual construction because of swelling in rainy or damp weather. The window was left unlocked. A large number of tests were made with various pressure drops through the wall, many of them being duplicated several times after opening and closing the window, in order to determine the variation due to the way in which the window was closed. No care was taken to close the window in any particular way other than to see that the lower sash was pushed down against the sill and the upper sash raised until the meeting rails were even. Curve 1, Fig. 6, shows the leakage for this condition for various pressures or wind velocities. The shape of the curve is characteristic of all curves obtained with the various conditions of the window and, as would be expected, shows the same characteristics as the curve for the flow of air through an orifice. For a pressure difference of 0.1 in. of water through the wall corresponding to a wind velocity against the wall of 14.4 miles per hr., 42 cu. ft. of air per min. passed through the window and wall. With a pressure drop

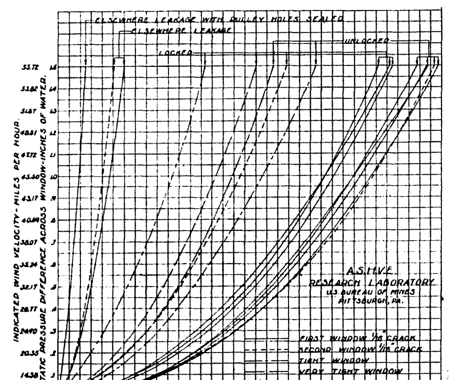

FIG. 7. RESULTS OF TESTS ON WINDOWS WITH VARIOUS CRACKS, SHOWING VARIATION IN LEAKAGE FOR DIFFERENT TESTS ON SAME WINDOW

through the wall of 1 in. of water, corresponding to a 45.5 mile wind velocity, 174 cu. ft. per min. passed through.

The second series of tests was made under the same conditions as the first series excepting that the window was locked. Curve 2 shows the leakage for various wind velocities for the locked window. Locking caused a reduction in leakage of 20 cu. ft. per min. with a 14.4 mile wind and 64 cu. ft. per min. with a 45.5 mile wind. The third series of tests was made with the cracks around the sash perimeter, which are subject to weatherstrip application, sealed with a rubberized adhesive tape. This tape was tested and found to be as effective as a plastic calking compound and was more easily and quickly applied and removed. The leakage for this series of tests is given in Curve 3, and the difference between this curve and Curve 1 or 2 indicates the maximum possible reduction in leakage by a perfect weatherstrip.

Before making the next series of tests the staff bead, or brick mold, was removed and the crack between the frame and the brick wall calked. The brick mold was then replaced. Calking was also applied between the frame sill and the brick. The leakage for this condition is given in Curve 4 and the difference between Curve

4 and Curve 3 gives the leakage between the frame and the wall, commonly called the frame leakage.

In order to determine the elsewhere leakage, a sheet of galvanized iron was fastened by screws over the entire frame and the edges were sealed with calking compound. The leakage for this condition is given in Curve 5. The difference between Curve 4 and Curve 5 is the leakage stopped by the galvanized iron and is the elsewhere leakage.

Curve 5 shows a considerable leakage which does not go through the window opening, but through the brick wall and the plaster. To prove that this leakage was really through the brick wall, the wall was painted one coat with asphaltum paint and another series of tests made. The result of this series is shown in Curve 6. The difference between Curves 5 and 6 represents the leakage stopped by one coat of paint. The wall was then thoroughly inspected and any visible cracks in the mortar closed with calking compound and given second and third coats of paint after each of which additional series of tests were made resulting in Curves 7 and 8, respectively. These curves show the reduction in leakage through the wall by each coat of paint. Another coat of paint was applied later and the leakage through the wall was further reduced to one half of that shown in Curve 8. The total leakage through the entire wall had been reduced by the various processes from 4.5 cu. ft. per min. to 0.2 cu. ft. per min. for a 14.4 mile wind, and from 28 cu. ft. per min. to 0.9 cu. ft. per min. for a 45.4 mile wind. No doubt further painting would have reduced the leakage still more, but that shown by Curve 8 was so small that it was considered negligible.

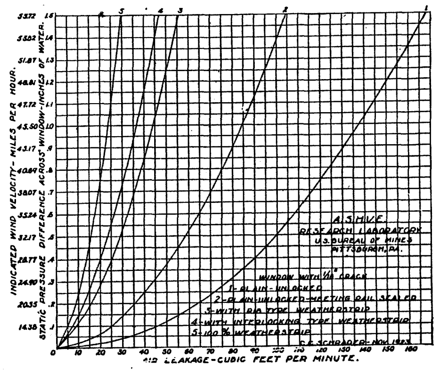

FIG. 8. RESULTS OF TESTS ON WINDOW WITH $^1/_{16}$" CRACK AROUND PERIMETER

With the leakage through the window and wall reduced to a minimum, some special tests were made in order to determine the magnitude of any leakage which might occur from chamber *B*. The leakage through the wall and window as indicated by the orifice reading is too small by the amount of the leakage from chamber *B*. While every precaution was taken to eliminate this leakage, it was not possible to do so entirely. However, as shown by the following tests, it was negligible.

When the leakage through the wall as shown by the orifice reading was reduced to a minimum, a pressure drop of 1.5 in. of water through the wall, gave a pressure difference of 0.066 in. between the second chamber or orifice box and the atmosphere when a $^5/_8$ in. orifice was used. That is, 1.41 cu. ft. per min. passing through the orifice and an unknown amount which we will call x was leaking from the second chamber. The leakage through the wall was then 1.41 + x cu. ft. per min. We wish to determine the value of x for all pressures. Since x cu. ft. per min. were passing through minute openings with an orifice pressure p, x is given by the orifice formula as:

$$x = 1096.5\ C\ A \sqrt{\frac{p}{w}} \tag{2}$$

where the various symbols have the same significance but probably not the same values as given in equation (1). A and C are not known but are constant for the

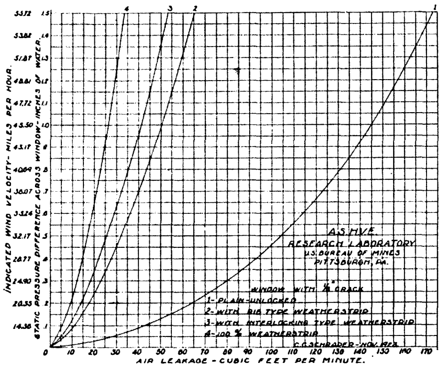

FIG. 9. RESULTS OF TESTS ON WINDOW WITH 1/8" CRACK AROUND PERIMETER

same conditions and w is also constant; $A\ C$ and w can therefore be included with the numerical constant 1096.5 as K. Our equation then becomes,

$$x = K \sqrt{p} \tag{3}$$

and the leakage from the second chamber for an orifice pressure of 0.066 in. becomes:

$$x = K \sqrt{.066}$$

The leakage through the wall for any pressure drop may likewise be expressed as:

$$y = K_1 \sqrt{p} \tag{4}$$

and for a pressure drop of 1.5 in. as,

$$y = K_1 \sqrt{1.5} = 1.41 + K \sqrt{.066} \tag{5}$$

The orifice was eliminated by using a plate without a hole and the leakage through the wall became equal to that from the second chamber. The pressure drops observed through the wall, and between the second chamber and atmosphere were 0.045 in. and 0.701 in., respectively; therefore,

$$y = K_1 \sqrt{.045} = x$$

$$= K \sqrt{.701} \tag{6}$$

Solving equations (5) and (6) simultaneously gives $K = 0.308$ and the leakage from the second chamber for all pressures becomes,

$$Q = 0.308 \sqrt{p} \tag{7}$$

This gives a leakage from the second chamber of 0.258 cu. ft. per min. for an orifice pressure of 0.7 in. of water, the maximum used in the tests. This leakage is entirely negligible in comparison with the results obtained.

When the galvanized plate and the tape were removed from the sash perimeter cracks, tests were made in order to check the decrease in leakage resulting from their application. The calking around the frame and the paint on the wall was not removed after having been applied, so that the curves in all figures after Fig. 6 do not include the frame and wall leakage, and show only the leakage through the window.

Tests on Windows with and without Weatherstripping

After completing the preliminary series or tests, a large number of tests were made with a number of sash with and without weatherstripping and with various width of crack around the sash perimeter. As was mentioned before the preliminary tests were made with a sash too light for practical purposes. Tests were made with cracks of 1/16, 1/8, 3/16 and 1/4 in. on both sides, top and bottom of the sash, without weatherstripping and with two types of weatherstripping. The size of the crack was increased to approximate the condition of windows that become loose, as is found in old buildings.

In these tests the sash were often changed and at least two different sash were fitted and tested for each condition. Figs. 4 and 5 show vertical sections of the window with the two types of weatherstripping together with horizontal sections through one side of the sash and frame, and also detailed sections of the various weatherstripped cracks.

The curves in Fig. 7 show the variation in data obtained for different windows fitted in the same way, for the same sash removed and replaced several times; also the leakage for tight windows and the effect of sealing the pulley holes. The five curves for the unlocked window with 1/16 in. crack show the variation which can be obtained for the same window under different conditions and for a second window fitted as nearly the same as could be done by a carpenter. The greatest variation from the mean of the five series of tests is about four per cent. The variation in the leakage of the same window locked shows the effect that locking may have. The main effect of locking is on the leakage through the meeting rail crack. The lock on the sash giving the three solid line curves was put on by the carpenter in the usual manner. The lock on the sash giving the curve with the short dashes was put on by a member of the laboratory staff in such a manner as to draw the meeting rails together as tightly as possible. The locks on the weatherstripped windows were put on by the carpenter. Locking caused no reduction in leakage for these windows.

The tight window was fitted so as to allow opening without great difficulty. The very tight window required considerable effort in opening.

In the tests for "elsewhere" leakage the cracks around the upper sash were sealed on the inside because the weatherstripping was put on the inward side of the pulley holes and thus would not reduce the leakage through these holes. The cracks around the lower sash were sealed on the outside because the weatherstripping was applied near this side of the sash. A series of tests was made in order to determine the percentage of the elsewhere leakage which passed through the outer pulley holes into the weight box and out through the inner holes or through cracks in the frame. Curves in Fig. 7 show that more than half of the elsewhere leakage occurred through these holes.

Figs. 8 to 11 give the results for the various sized cracks without weatherstripping, with two types of weatherstripping, and with 100 per cent weatherstripping, that is, with the cracks subject to weatherstrip application sealed up thus allowing only the "elsewhere" leakage. In each case the curve given is the average of several tests.

The curve for the unlocked window with the 1/4 in. crack as obtained from the test data shows less leakage than the same condition with smaller cracks. While this is contrary to what might be expected it can be explained and corrected as outlined in the following paragraphs.

In testing the windows without weatherstripping, the lower sash was pushed down against the sill and the upper sash raised until the meeting rails were even. Be-

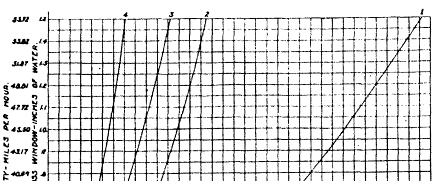

FIG. 10. RESULTS OF TESTS ON WINDOW WITH 3/16" CRACK AROUND PERIMETER

cause of the construction of the meeting rails, raising the upper sash beyond this point would reduce the crack between them. With the 1/4 in. crack and the meeting rails even, it was found that the upper sash would just come up to the edge of the outside stop on the head of the frame. This stop extended 1/2 in. from the frame. Also, if the sash were not planed off parallel to the head stop, there would be a visible crack. In order to get a test, the conditions of which would compare with the conditions of the preceding tests, the upper sash was raised until it was above the edge of the head stop. By doing this, the crack between the meeting rails was decreased and the resultant leakage was less than that for the smaller cracks. In order to correct for this decrease, a series of tests was made with the crack between the meeting rails sealed. The results of this series are shown in Fig. 11. Curve 2 shows the leakage with the crack between the meeting rails not sealed and Curve 3 the leakage with the same crack sealed. The windows with the 1/16 in., 1/8 in., and 3/16 in. cracks were then tested with this crack sealed to determine the leakage between the meeting rails with the members even. The leakage thus found, sub-

tracted from that found without this crack sealed, represents the leakage through it. This proved to be much greater than that found in the tests on the window with 1/4 in. crack with the meeting rails uneven. Also it was found to be practically the same for all three windows. An average was taken and the leakage for the window with 1/4 in. crack corrected accordingly. Curve 1, Fig. 11, shows the corrected values. The difference between Curves 1 and 2, Fig. 8, shows the leakage between the meeting rails for the window with 1/16 in. crack. These tests also showed that the leakage for all the windows with the crack between the meeting rails sealed was practically the same.

An examination of the curves for a plain window with different size cracks shows only a small variation for the three smaller ones. Various factors must be taken into consideration to account for this. The thickness of the sash is 1 3/8 in. and it slides in a 1 7/16 in. groove. If the sash were held in the middle of this space between the stops there would be a crack 1/32 in. wide on either side. In this position the smallest crack around the edge of the sash through which air must pass is a maximum. The moment the wind strikes the window it tends to move it against the inside stops, thus increasing the crack on the outside but decreasing the crack on the inside. Since leakage depends largely upon the minimum width of crack around the sash perimeter, it is limited by the tightness with which the sash is forced against the stops. Increasing the width of crack around the edge of the window does not increase the minimum crack width and hence the leakage is not increased measurably.

When weatherstripping is used the window is held in the middle of the groove. The cracks between the members are so much smaller in comparison with the unweatherstripped window that a small variation in this crack will cause a measurable variation in the leakage. The curves for the weatherstripped windows show a corresponding increase with size of crack.

Tables 1 and 2 contain data taken from the curves Figs. 6 to 11 or resulting therefrom. Table 1 gives the leakage in cubic feet per minute for the whole window and per linear foot to crack, for wind velocities of 14.4 and 24.9 miles per hour. It is of interest to note that for a plain window with crack varying from 1/16 to 1/4 in. the leakage is 46 cu. ft. per min., while for the two types of weatherstripping tested it varies from 9 to 18 and 7 to 10 cu. ft. per min. respectively. The heat loss is given for two temperature differences. The heat loss for any temperature difference varies directly as the leakage. The radiation required to supply this heat loss is given for the higher temperature difference only, since it must be supplied for the maximum condition. With a 14.4 mile wind based upon the above temperature difference the unweatherstripped windows with cracks varying from 1/16 to 1/4 in. required 14.6 sq. ft. of radiation, while the same windows with the two types of weatherstripping require only from 2.8 to 5.7 and 2.2 and 3.2 sq. ft. respectively. Basing the cost of radiation on $2.00 per sq. ft. installed, the two types of weatherstripping will show a resulting decrease in first cost of radiation of about $18.00 and $23.00 per window respectively. The further saving in coal per year based upon a seven month heating season with an average temperature difference of 35 deg. is also given.

Table 2 gives the "elsewhere," wall, and frame leakage, and also the leakage through with the window with and without weatherstripping for various wind velocities.

Perhaps the most surprising fact brought out by this table, if not by the whole investigation, is the leakage per square foot of wall. With a 15 mile wind each

TABLE 1. DATA ON TESTS OF WINDOWS UNDER VARIOUS CONDITIONS

	Leakage C.F.M. Crack Perimeter 18′ 4″				B.t.u. per Hour								Radiation on Sq. Ft. 240 B.t.u. per Sq. Ft. per Hour				Lb. of Coal 13,000 B.t.u. and 50% Efficiency at Radiator 35°–70°Fahr. for Seven Months			
					0–70°Fahr.				20–70°Fahr.				0–70°Fahr.							
	For total window		Per ft. crack		For total window		Per ft. crack		For total window		Per ft. crack		For total window		Per ft. crack		For total window		Per ft. crack	
Wind velocity, M.P.H.	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24 9
Plain window—very tight—unlocked	19.0	40.0	1.04	2.18	1445	3040	78.7	166.0	1033	2170	56.3	118.5	6.02	12.67	0.328	0.692	560	1180	30 50	64.3
Plain window—tight—unlocked	22.0	46.0	1.20	2.53	1673	3500	91.3	192.5	1195	2500	65.2	137.5	6.97	14.60	0.381	0.802	648	1357	35.40	74.5
Plain window—$^1/_{16}$″ to $^1/_4$″ crack—unlocked	46.0	75.0	2.53	4.08	3500	5700	192.5	310.0	2500	4075	137.5	222.0	14.6	23.80	0.802	1.290	1357	2213	7.45	120.5
Rib Strip $^1/_{16}$″ Crack	9.0	20.0	0.49	1.09	685	1522	37.3	83.0	488	1087	26.6	59.2	2.86	6.34	0.155	0.346	266	590	14.45	32.2
Rib Strip $^1/_8$″ Crack	11.0	22.5	0.60	1.25	837	1710	45.6	95.1	598	1223	32.6	67.9	3.48	7.12	0.190	0.396	324	663	17.70	36.9
Rib Strip $^3/_{16}$″ Crack	15.0	30.0	0.82	1.63	1141	2282	62.2	124.4	815	1630	44.4	88.8	4.75	9.50	0.259	0.518	442	884	24.10	48.5
Rib Strip $^1/_4$″ Crack	18.0	36.0	0.98	1.96	1370	2740	74.7	149.4	978	1956	53.3	106.6	5.71	11.42	0.311	0.622	531	1062	28.95	57.9
Interlocking Strip $^1/_{16}$″ Crack	7.0	16.0	0.38	0.87	533	1218	29.0	66.3	380	870	20.7	47.3	2.22	5.07	0.121	0.276	207	472	11.23	25.7
Interlocking Strip $^1/_8$″ Crack	8.5	18.0	0.46	0.98	647	1370	35.3	74.7	462	978	25.2	53.3	2.69	5.71	0.147	0.311	251	531	13.66	29.0
Interlocking Strip $^3/_{16}$″ Crack	9.0	19.5	0.49	1.06	685	1483	37.3	80.9	489	1060	26.6	57.8	2.85	6.18	0.155	0.337	266	575	14.45	31 4
Interlocking Strip $^1/_4$″ Crack	10.0	20.5	0.55	1.12	761	1560	41.4	85.0	543	1114	29.6	60.7	3.17	6.50	0.173	0.354	295	605	16.08	32.9

TABLE 2. LEAKAGE IN C.F.M.

Wind Velocity M.P.H.	Frame 17 Ft. Perimeter		Wall per Sq. Ft.	Elsewhere	Window with $^1/_{16}$ In. Crack				Perimeter 18 Ft. 4 In.	
					Plain		Rib strip		Interlocking Strip	
	For total window	Per ft. crack			For total window	Per ft. crack	For total window	Per ft. crack	For total window	Per ft. crack
5	0.50	0.0294	0.0111	0.7	15.0	0.818	1.3	0.071	1.0	0.0546
7.5	2.3	0.1325	0.0289	1.8	24.0	1.31	3.0	0.164	2.2	0.1200
10	4.0	0.2350	0.0512	2.8	32.5	1.77	5.0	0.273	4.0	0.2180
15	8.0	0.4710	0.1110	5.2	47.5	2.59	9.7	0.529	7.8	0.4260
20	11.0	0.6470	0.1780	7.6	61.5	3.36	14.8	0.808	11.8	0.6440
30	19.0	1.1180	0.3330	13.6	89.0	4.86	25.5	1.390	20.0	1.0920
40	25.5	1.5000	0.5250	20.0	118.0	6.44	37.0	2.020	30.0	1.6380
50	31.5	1.8530	0.7150	26.0	149.0	8.13	48.5	2.650	41.0	2.2400

square foot of the 13 in. wall, plastered on the inside, allowed the passage of 0.111 cu. ft. of air per min., while the leakage through the window and frame for the same wind velocity was 47.5, 9.7, and 7.8 cu. ft. per min. for the plain window and two types of weatherstripping respectively. The area of the window and frame is 16.25 sq. ft. giving a leakage of 2.82, 0.597 and 0.48 cu. ft. per min. per sq. ft. of window without and with the two types of weatherstripping. Based upon these figures the leakage through the window and frame varies from 4 to 28 times that through the same area of wall. When we take into consideration the usual greater area of wall to window, it is evident that the leakage into a room is usually greater through the wall than through the window if weatherstripped, and not many times less if not weatherstripped. It is of interest to compare the heat loss through windows and walls by transmission and by leakage. The leakage for the plain window and

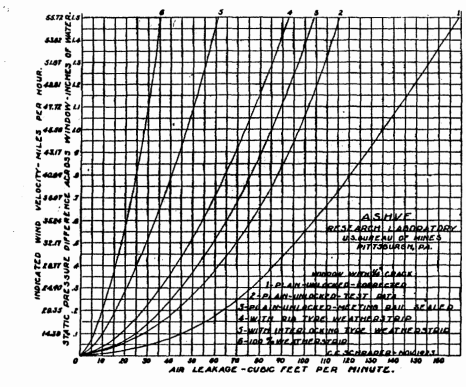

FIG. 11. RESULTS OF TESTS ON WINDOW WITH $^1/_4$″ CRACK AROUND PERIMETER

with two types of weatherstripping all for $^1/_{16}$ in. crack and a 15 mile wind is 47.5, 9.7, and 7.8 cu. ft. per min. respectively, representing a heat loss of 2580, 527, and 423 B.t.u. per hr. respectively for a 50 deg. temperature difference. A leakage of 0.111 cu. ft. per min. per sq. ft. of wall represents a heat loss of 6.03 B.t.u. per hr. for a 50 deg. temperature difference. Taking the transmission through the wall as 0.28 B.t.u. per hr. per sq. ft. per degree temperature difference, this loss is 14 B.t.u. per hr. for the same temperature difference. The heat loss as thus indicated by infiltration is 43 per cent as great as the heat loss by transmission as indicated by the constant used.

The values given in the table are from the tests and are probably somewhat higher than those actually found in practice. They represent the leakage when the pressure drop through the window is a certain value which represents a definite wind velocity at right angles to the window. If the wind strikes the window at an oblique angle the component of the velocity at right angles to the window must be considered. Pressure difference between the outside and the inside surfaces of the window for an actual wind will be slightly less for a given velocity because of a building up of pressure within the room before the air leaks out the opposite side of the building. Attention is called to the fact that air leaks in on the windward side of the building and out on the leeward side and, since wind will blow from various directions at different times, heating for any room having only one exposure must be based on the maximum loss. The heating plant, however, need not be figured on the sum of all maximum leakages but in general only half of the total. However, the tables give accurate comparative figures which are probably not much too high for actual practice. In order to apply these values, a further study of the overall results as found in practice should be made, and the figures modified, if necessary, to fit practical conditions.

DISCUSSION

W. H. CARRIER: About 15 years ago, I believe, we had a paper presented before this Society on window leakage. It would be very interesting to compare the work that was done at that time with what we have tonight.

E. S. HALLETT: I have been talking tight windows for several years, because they affected my work so much. When we went to recirculate all of the air, it became necessary to have tight windows in order to obtain good results. The fact that caulking frames and the improved window strip has done so much good is amazing.