No. 779

SOME STUDIES OF INFILTRATION OF AIR THROUGH WINDOWS

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NON-MEMBER

THIS paper is concerned principally with the problem of infiltration of air through windows as it pertains to the present-day high buildings as used for hotels, apartment houses, office buildings and lofts. The tendency toward higher buildings increases exposure and it is quite evident that present-day construction has a tendency to provide a larger window area per square foot of wall surface than structures of several years ago. Both of these conditions increase the importance of the subject under discussion.

Since approximately 30 per cent of the heat loss in this type of building is due to the window installation, excessive infiltration of air through windows and its prevention, is a problem of interest to architects, building owners and heating engineers. Especially to the heating engineer, as he is responsible for the proper heating of the completed building and if the windows do not function properly the building might very readily be a failure as regards this item. The heating engineer, if not properly advised as to the quality of the windows to be used in a proposed building, might so design his heating plant as to obtain any one of the four following results:

Window Condition	Heating Plant	Result
A—Weatherproof windows	Heating plant suitable for weatherproof windows	Economical
B—Weatherproof windows	Heating plant suitable for leaky windows	Uneconomical
C—Leaky windows	Heating plant suitable for weatherproof windows	Insufficient heat
D—Leaky windows	Heating plant suitable for leaky windows	Sufficient heat but uneconomical combination of windows and heating plant

A results in good engineering and requires no further consideration.

B results in the owner paying for an excessive heating plant which is obviously uneconomical.

C results in insufficient heat and would be considered a failure.

D results in sufficient heat, but on any building of a character similar to that under discussion, it can be shown that the cost of leaky windows plus the cost of a heating plant in proportion to the same is more expensive than a weathertight window installation plus its required heating plant. In order to emphasize this a hypothetical computation follows:

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COMPUTATION FOR TYPICAL HOLLOW METAL WINDOWS

1000 typical hollow metal 24 gauge windows which allow 100 cu. ft. infiltration per minute in a 25-mile wind, at $30.00 each....................	$30,000
40,000 sq. ft. of radiation assumed for this building at $2.00 per sq. ft. (of which 40,000 × 30 per cent = 12,000 sq. ft. is on account of infiltration)........	80,000

Cost of typical metal windows and heating plant corresponding $110,000

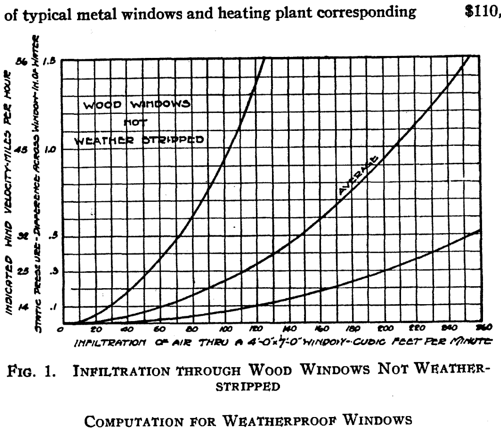

FIG. 1. INFILTRATION THROUGH WOOD WINDOWS NOT WEATHER-STRIPPED

COMPUTATION FOR WEATHERPROOF WINDOWS

1000 weatherproof windows which allow only $12^1/_2$ cu. ft. infiltration per minute in a 25-mile wind at $38.00 each.................................. $38,000

Since the weatherproof window allows only $\frac{12.5}{100}$ as much infiltration as the typical hollow metal 24 gauge window, the 12,000 sq. ft. allowed for infiltration can be reduced. If we reduce it by a like amount, $12{,}000 \times \frac{12.5}{100} = 1500$ sq. ft. required for infiltration with weatherproof windows, which represents 12,000 − 1500 = 10,500 sq. ft. at $2.00 per sq. ft. = $21,000 saving.

Cost of heating plant for typical hollow metal 24 gauge windows..........	$80,000	
Reduction in cost because of reduction in infiltration........................	21,000	
Cost of heating plant for weatherproof windows		$59,000
Cost of weatherproof windows and the corresponding heating plant		$97,000
Saving		$13,000

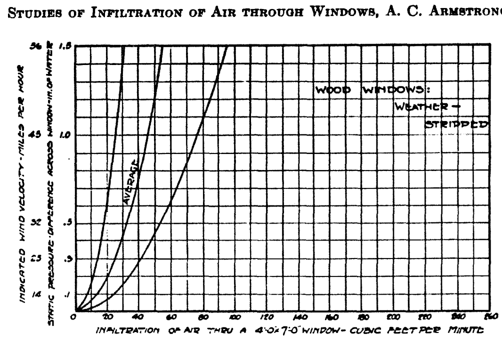

FIG. 2. INFILTRATION THROUGH WOOD WINDOWS WEATHERSTRIPPED

Furthermore, the quality of the windows as regards infiltration influences to a decided extent the cost of operation of the heating plant, especially in the type of building being considered here. It may be noticed that it is possible to reduce the radiation in the problem cited, 10,420 sq. ft. by reducing the infiltration to a minimum. Again resorting to a very approximate operating cost figure of 25¢ per square foot of radiation per season, this case would show a yearly saving of $2625.00, which, if capitalized at 5 per cent, would amount to $52,500.00.

Many cases can be cited where the above proportion of square feet of radiation to the number of windows would be at wide variance, but this has been found to be an average for a number of large office buildings. The cost per square foot of radiation will, of course, vary with the type of construction and the nature of the

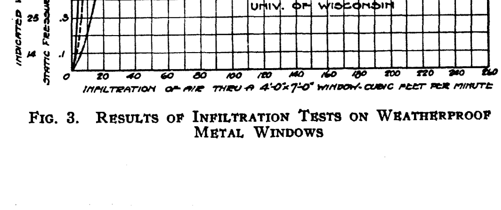

FIG. 3. RESULTS OF INFILTRATION TESTS ON WEATHERPROOF METAL WINDOWS

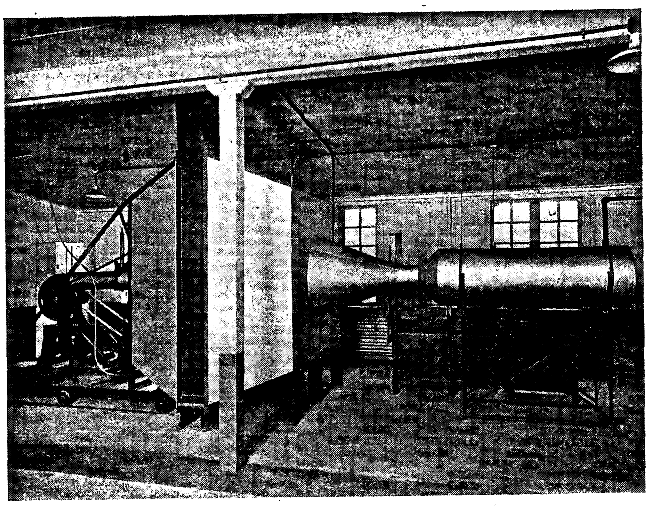

FIG. 4. WINDOW TESTING APPARATUS

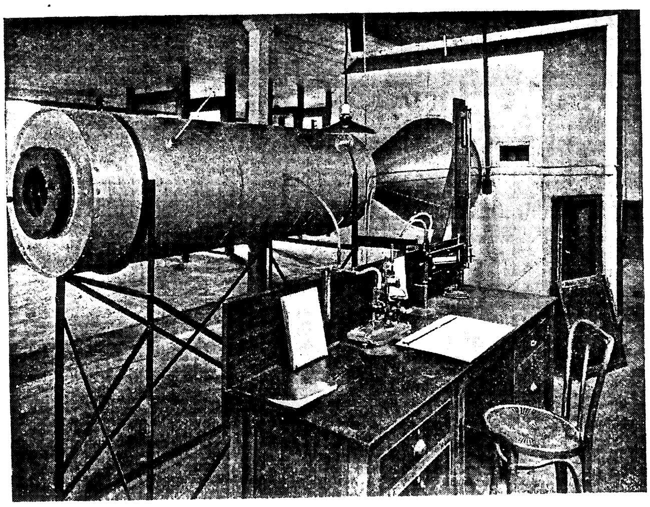

FIG. 5. RECORDING TEST DATA IN WINDOW TESTING LABORATORY

installation. Also, engineers are at variance as to what percentage of the total radiation is on account of infiltration. Many conditions influence this percentage and it may readily vary from 25 to 35 per cent, depending upon the particular problem.

Of course, the figures representing operating cost per season per square foot of radiation will vary with the type of building and its location. But, in spite of the variables in the problem, the computations given have been cited to show the relation of window installations to the first cost and operating cost of the heating plant and to emphasize the necessity for making this comparison on every building project in order that economical building construction will be accomplished.

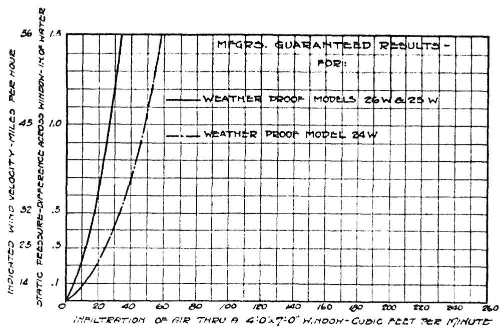

FIG. 6. PERFORMANCE CURVES FOR SEVERAL WEATHERPROOF METAL WINDOW TYPES

The matter of infiltration should be considered at the time the building specifications are being written. If not, it must be taken up at a later period and in a different manner.

Practically all the important items entering into the construction of a building are so specified as to definitely require them to perform their functions in a qualified manner. For instance, the specifications say the boilers must deliver a certain horsepower, the pumps must deliver so many gallons per minute, the elevators must operate at a required speed under a given load with proper power consumption. Certainly it is not asking too much to have the building specifications so written that they will require the windows to allow only a definite amount of infiltration and thus enable the engineer to economically design his heating plant. It is strongly recommended to the Society that it use its influence to have inserted in building specifications a clause that will definitely fix the quality of the windows. Window installations in a number of buildings have been so specified and it is becoming more universal. Messrs. Meyer and Voorhees, also Schrader and Houghten, in their previous investigations on the subject of infiltration, have established a yardstick by which the relative quality of windows may be measured. Their method of testing windows by means of creating a static air pressure on one side of a window and measuring the amount of air leaking through is well known to all who are interested in the subject. Bearing in mind their methods of testing, it is suggested that all window specifications incorporate the following, irrespective of the type, kind or make of windows:

The amount of infiltration of air through standard double hung windows shall not be more than ...... cubic feet of air per foot of sash perimeter per minute when subjected to a static air pressure equivalent to the air pressure exerted by a wind of 25 miles per hour.

The window manufacturer shall submit for test before shipment a quantity of

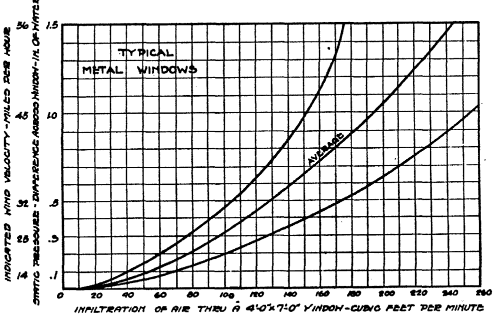

FIG. 7. TYPICAL INFILTRATION CURVES FOR METAL WINDOWS

windows as selected by the architect from regular production in order to assure compliance with the above.

Tests to be conducted under the supervision of the architect at any laboratory in a manner similar to that described in the TRANSACTIONS of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 30, 1924.

In the specification given, the amount of infiltration has been left blank. It has been found by experience in dealing with a great number of large buildings that certain conditions require finer treatment than others. For instance, it is recommended for severe exposures, and hotels, and apartment houses, a window allowing no more than $^1/_2$ cu. ft. of infiltration per foot of sash perimeter per min. when subjected to a pressure equivalent to the pressure exerted by a wind of 25 miles per hour be specified. For average exposures and for buildings in which comfort is not the principal consideration, a window allowing no more than 1 cu. ft. of infiltration per foot of sash perimeter per min. when subjected to a pressure equivalent to the pressure exerted by a wind of 25 miles per hour will be satisfactory.

In following the suggestion outlined the specifications put the responsibility squarely up to the person who should really carry it, that is, the window manufacturer if it be a window of metal, or the weatherstrip contractor if it is a matter of weatherstripping wood windows or metal windows after they have been installed.

The preceding statements outline a means of properly advising the heating engineer if the subject is considered when the building specifications are written. Frequently this subject receives no consideration at that time, but at some period during the designing of the plant the heating engineer can advise himself as to the kind and type of windows to be used. With this knowledge there is sufficient information available to estimate the infiltration in order that the heating plant can be economically designed.

The information consists of a long series of laboratory tests on windows as made by Messrs. Meyer and Voorhees and Messrs. Schrader and Houghten, both recorded in the Society's TRANSACTIONS, and tests made by the writer. It has been pointed out by the former investigators that it is doubtful if the windows leak just as much under the wind pressures on buildings as they do under the equivalent static pressures created in the laboratory, but they have concluded that the windows will perform in proportion to the laboratory tests, *i. e.*, a window that leaks twice as much as another in laboratory tests will leak twice as much when installed in the building. At the expense of some repetition there has been incorporated a number of results formerly reported with the hope that bringing together all this information in one article will make the subject more comprehensive.

All the tables hereafter introduced show the infiltration of air in cubic feet per minute through windows 4 ft. x 7 ft. in size, with a sash perimeter of 25 ft., this being the average window size for buildings of the class under discussion. The results in the tables are derived from data recorded by other investigators or they are the results of tests on windows of the size above mentioned. The curves are in all instances plotted from the data in their corresponding table of results and they also show the infiltration through windows 4 ft. x 7 ft. in size with sash perimeter of 25 ft. Should it be desirable to obtain this information in terms of infiltration per foot of sash perimeter, it is only necessary to divide the infiltration figure by 25.

The data hereafter gathered together pertain to double hung windows only and to give it the proper treatment the windows should be separated into four classes:

A—Wood windows not weatherstripped.
B—Wood windows weatherstripped.
C—Weatherproof metal windows.
D—Typical metal windows.

Each one of these classes will be discussed and existing data presented.

TABLE 1. INFILTRATION OF AIR THROUGH 4 FT. x 7 FT. WINDOWS

Sash Perimeter 25 ft.

Type of Windows—Wood Windows Not Weatherstripped

Wind Velocity	14	25	32	45	56
Equiv. Static Press.—In. of Water	0.1	0.3	0.5	1.0	1.5
Window condition	Infiltration—Cu. ft. per minute				
$^1/_{16}$ to $^1/_4$ Crack—0.035 Clearance	29	52	74	101	125
$^1/_{16}$ to $^1/_4$ Crack—0.055 Clearance	36	67	89	127	155
$^1/_{16}$ to $^1/_4$ Crack—0.090 Clearance	51	87	113	154	186
$^1/_{16}$ to $^1/_4$ Crack—0.125 Clearance	65	113	157	198	237
$^1/_{16}$ to $^1/_4$ Crack—0.187 Clearance	96	161	202	286	369
$^1/_{16}$ to $^1/_4$ Crack—0.250 Clearance	123	202	258	383	464

A—Wood Windows Not Weatherstripped: Table 1 gives results calculated from the very complete investigation of wood windows not weatherstripped carried on by Messrs. Schrader and Houghten. The experiments leave nothing in the way of doubt as to the relative value of this type of window in its various conditions. The writer has checked these results by laboratory tests with satisfactory accuracy.

Fig. 1 gives the infiltration curves for the best condition, the worst condition and the average, and the heating engineer should be able to use this information with confidence.

B—Wood Windows Weatherstripped: Wood windows weatherstripped have received the same careful investigation by Messrs. Schrader and Houghten. Table 2 shows the infiltration of air through weatherstripped wood windows with various types of weatherstrip and with various cracks and clearances. It is believed that these particular tests from Messrs. Schrader and Houghten's investigations represent the average conditions.

Fig. 2 gives the usual infiltration curves of the best result, poorest result and the average. The relative value of wood windows weatherstripped should be considered amply and sufficiently treated by the investigation referred to. From these data the heating engineer can most assuredly work with confidence and economy.

TABLE 2. INFILTRATION OF AIR THROUGH 4 FT. x 7 FT. WINDOWS

Sash Perimeter 25 ft.

Type of Windows—Wood Windows Weatherstripped

Wind Velocity		14	25	32	45	56
Equiv. Static Press.—In. of Water		0.1	0.3	0.5	1.0	1.5
Window condition		Infiltration—Cu. ft. per minute				
Type A Weather Strips						
1/32 Clearance	1/16 Crack	8	14	18	25	31
1/8 Clearance	1/16 Crack	10	18	22	32	39
1/4 Clearance	1/16 Crack	10	18	23	33	40
1/32 Clearance	1/8 Crack	10	17	22	31	38
1/8 Clearance	1/8 Crack	11	20	26	36	45
1/4 Clearance	1/8 Crack	11	21	26	37	46
1/32 Clearance	3/16 Crack	9	17	21	30	38
1/8 Clearance	3/16 Crack	11	20	26	36	45
1/4 Clearance	3/16 Crack	11	21	27	38	48
1/32 Clearance	1/4 Crack	11	19	24	34	42
1/8 Clearance	1/4 Crack	13	23	30	42	52
1/4 Clearance	1/4 Crack	14	25	32	45	56
Type B Weather Strips						
1/32 Clearance	1/16 Crack	13	24	31	43	54
1/8 Clearance	1/16 Crack	16	28	36	50	63
1/4 Clearance	1/16 Crack	16	28	36	50	63
1/32 Clearance	1/8 Crack	14	24	31	44	54
1/8 Clearance	1/8 Crack	15	28	35	50	62
1/4 Clearance	1/8 Crack	16	28	36	51	63
1/32 Clearance	3/16 Crack	17	31	39	55	68
1/8 Clearance	3/16 Crack	19	34	44	62	77
1/4 Clearance	3/16 Crack	20	35	45	63	79
1/32 Clearance	1/4 Crack	21	37	47	66	82
1/8 Clearance	1/4 Crack	22	40	51	72	90
1/4 Clearance	1/4 Crack	24	43	54	77	95

TABLE 3. INFILTRATION OF AIR THROUGH 4 FT. x 7 FT. WINDOWS

Sash Perimeter 25 ft.

Type of Windows—Weatherproof Metal Window

Wind Velocity	14	25	32	45	56
Equiv. Static Press.—In. of Water	0.1	0.3	0.5	1.0	1.5
Window model		Infiltration—Cu. ft. per minute			
Weatherproof Metal Window Model 26-W	2	3	4	7	11
Weatherproof Metal Window Model 25-W	2	5	7	12	16
Weatherproof Metal Window Model 24-W	6	12	17	28	37

C—Weatherproof Metal Windows: Table 3 shows results determined by Professor Larson, Mechanical Engineering Department, University of Wisconsin, on

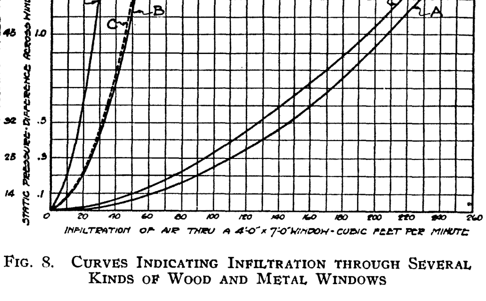

FIG. 8. CURVES INDICATING INFILTRATION THROUGH SEVERAL KINDS OF WOOD AND METAL WINDOWS

a type of weatherproof metal windows, designated as Models 24-W, 25-W and 26-W. These tests reported check many tests made by the writer and his associates in perfecting this type of window.

Fig. 3 shows the curves plotted from the results of Professor Larson.

It might be interesting for the members to know that the inspiration to develop these present weatherproof models resulted from the research investigations previously carried on by the Society. These investigations pointed out the desirability of development in this direction, and showed how results could be tabulated and compared and described in detail how to construct the necessary testing apparatus shown in Figs. 4 and 5. This indicates that the work of the Society has a very beneficial effect upon the allied industries. The problem was experimented with over a period of about two years. Piece by piece, and item by item, the parts that go to make up a window were tested, resulting in the introduction of the present models with the guarantee that these models will perform as shown by the curves in Fig. 6. These curves naturally give results considerably over those shown by the curves in Fig. 3 by Professor Larson and in excess of what can readily be reproduced. This excess is the margin of safety desirable when guaranteeing a performance of any kind. In developing the weatherstrips as used on these windows certain difficulties had to be overcome. A number of types were made that successfully resisted infiltration, but it was noted that they would bind the window and make it difficult to operate, which is prohibitive. Other types were exposed on the surface of the jambs and therefore would be subject to damage, especially during the building construction. Another type was inferior because the painting operation after the windows were installed would fill up the running joints and cause difficult operation.

The type finally developed allows considerable leeway as to adjustment. For instance, during the above-mentioned tests at the University of Wisconsin, the windows were adjusted both loose and tight, then they were taken apart and they were put together again, but the results as shown by the tests were always safely within the guaranteed figures. In other words, these weatherstrips are so adjustable that they will function properly in spite of the variations as usually found in the manufacture of such an article as a window and in spite of the very severe treatment afforded the windows during the construction of the building.

D—Typical Metal Windows: In experimenting with the weatherproofing of windows it was desirable to investigate other makes of windows, so a very complete series of tests on other metal windows was carried on and the data shown in Table 4 resulted. Incorporated in these data are also five tests, Nos. 1, 2, 3, 4, 5, performed by Messrs. Meyer and Voorhees in 1916. It is worthy of note that typical metal windows have not changed since their investigation. From an engineer's point of view it would be desirable to give in this table designating names or marks to the windows but it is not deemed ethical to do so. The investigation, however, was quite broad and includes the popular types of windows available today.

TABLE 4. INFILTRATION OF AIR THROUGH 4 FT. x 7 FT. WINDOWS

Sash Perimeter 25 ft.

Window Type—Typical Metal Windows

Wind Velocity		14	25	32	45	56
Equiv. Static Press.—In. of Water		0.1	0.3	0.5	1.0	1.5
	Window type	Infiltration—Cu. ft. per minute				
1	Typical Metal Window	63	131	175	256	325
2	Typical Metal Window	75	144	184	266	331
3	Typical Metal Window	44	81	113	163	206
4	Typical Metal Window	63	125	169	238	288
5	Typical Metal Window	55	100	131	191	235
6	Typical Metal Window	44	83	117	173	216
7	Typical Metal Window	52	99	132	178	220
8	Typical Metal Window	73	126	165	222	290
9	Typical Metal Window	41	77	106	153	187
10	Typical Metal Window	42	61	107	152	176
11	Typical Metal Window	48	72	123	168	208
12	Typical Metal Window	65	81	137	209	236
13	Typical Metal Window	67	128	155	217	300
14	Typical Metal Window	58	87	108	142	181
15	Typical Metal Window	54	95	145	207	270
16	Typical Metal Window	40	75	110	168	193
17	Typical Metal Window	50	85	146	216	275

Fig. 7 gives the typical infiltration curves showing the worst, the average and the best of this class.

Having presented and discussed all the data in connection with the four classes of double hung windows, it is now interesting to gather together, for the purpose of comparison, the average curves of each class as shown on Fig. 8.

CC—Infiltration through weatherproof metal windows Models 25-W and 26-W guaranteed.

C—Infiltration through weatherproof metal windows Model 24-W guaranteed.

B—Infiltration through weatherstripped wood windows. Averaged from the above-recorded tests.

D—Infiltration through typical metal double hung windows. Averaged from the above-recorded tests.

A—Infiltration through wood windows not weatherstripped. Averaged from the above-recorded tests.

From Fig. 8 it will be seen that the relative value for resisting infiltration of the four classes of windows under a pressure corresponding to that caused by the wind at 25 miles per hour is as follows, arranged in the order of their quality:

Class *C*—Weatherproof metal windows 25-W and 26-W guaranteed, Curve *CC*—$12^1/_2$ cu. ft. per min.

Class *C*—Weatherproof metal windows 24-S guaranteed, Curve *C*—25 cu. ft. per min.

Class *B*—Weatherstripped wood windows, Curve *B*—25 cu. ft. per min.

Class *D*—Typical metal windows, Curve *D*—95 cu. ft. per min.

Class *A*—Wood windows not weatherstripped, Curve *A*—115 cu. ft. per min.

At best the infiltration of air through windows is not a problem that can be solved with mathematical accuracy due to the various conditions that prevail in different buildings. Elevators, partitions, concentration of heat in various portions of the building, arrangement of courts and many other conditions have some influence on the problem. Therefore, an engineer is justifiably conservative if he makes use of Fig. 8 in estimating the infiltration in any proposed building using double hung windows.

It is hoped that the above remarks point out the relationship between the problems of the window manufacturer and the engineer. The questions of heat losses, fuel consumption, radiation and heating plant belong rightly in the hands of the engineer and, so, wherever possible they have been eliminated from this discussion. But if on any building project the problem of infiltration of air through windows is not given proper consideration, if the cost of good windows and poor windows with their necessary economical or excessive heating plants are not balanced one against the other, the matter is not receiving sound engineering treatment.

DISCUSSION

W. C. RANDALL: This question of air infiltration through steel windows is a problem that has been apparently neglected by the manufacturers of steel windows in so far as any contact with the Society has been concerned. It seems most of the work along these lines has been done by people outside the window manufacturing industry. I am here today, however, because of the awakened interest of our industry in the activities of the Society.

We have made some infiltration tests, used a testing apparatus similar to the one used by the author of this paper. So far as I know there are only three apparatuses of this nature, one in the Laboratory of the Society, one in St. Louis and one at the University of Wisconsin. All of these apparatuses, I understand, are relatively small. If there is an apparatus readily available to manufacturers which will test full-sized window openings, I am not acquainted with the fact. These tests which we made were chiefly on metal casement windows. That is of vital interest to the home owner, especially since there is a development toward the metal casement, in homes as well as in apartment houses. Tests were also made on our standard industrial type windows as well as a window of a type which has recently been developed by several makers of rolled sections for use in offices, called projected windows. These tests which we made were on small windows but did give us a general idea of the infiltration of the air, for a variety of wind velocities per foot crack of perimeter of the movable portion of the ventilator, and other leakages, for instance, through the putty and possibly through other portions of the window that is not represented by the crack perimeter of the ventilator, such as between the framing member and the building construction.

Without quoting figures, our tests show that it is perfectly possible and practical in a steel window to equal or better the results obtained from the average weather-stripped wood window. I agree with the author of this paper to this extent: that the window manufacturers, especially the steel window manufacturers, should handle the problem of air infiltration. As far as our company is concerned, I imagine others would feel the same way, since the matter of infiltration is a problem of the heating and ventilating engineer, it should be seriously considered and we should not only know the results which are obtained, but the ways and means of improving these results. I am agreeable to the other suggestion that perhaps some sort of a specification on the part of the architect is perfectly within reason. Some sort of a test, to check compliance with the specification at the present time, however, may be difficult.

I would like, Mr. Chairman, to make the following suggestion:

First: that some committee which is either acting at the present time, such as the infiltration committee, or could be appointed would take charge of this whole proposition and approve a testing apparatus. It seems to me, however, before that apparatus can be standardized and the results used, it should closely approximate the field results which would be obtained in an actual installation. In all of the research work which our company has been doing, we find that highly important.

Second: It would seem to me that the tests should include not only the crack leakage of double hung windows or any other form of a steel window which is used, but the frame leakage and the so-called elsewhere leakage referred to by Mr. Schrader. The tests should be carried through which include the installation features, because after all it is the window installation that the heating engineer and the owner is vitally interested in rather than possibly the laboratory test of a bare window.

Third: It would seem, also, that there should be included the factors to be used for the glass, as a part of the window opening.

Fourth: I am not so sure, but feel that doors might logically be included with the story of windows, because they are openings somewhat similar to windows.

Fifth: The last suggestion is going to be a little bit more difficult to handle possibly, but it seems to me that there should be determined the minimum requirements for air since there is a possibility of the windows and the door manufacturers going beyond a certain point which is logical to go. In other words, there is quite a possibility if the window is so tight that air won't come in, the window will simply be opened and therefore a lot of the effect of the tightness of the window might be dissipated. It would seem to me that very logically the window manufacturer should have a measuring stick which would indicate the low and high values of infiltration between which he should work.

H. W. Whitten: In talking this matter over with Mr. Armstrong last evening there were several points which came up, but one of them was the very thing Mr. Randall mentioned and that was that there were probably only about three plants available for the testing of windows according to the methods employed by the Research Laboratory. I have for the past three years been using a very simple method of testing window leakage, which consisted of a pressure box connected to the window frame in which the window is set, a blower, and between the blower and the pressure box a calibrated meter, calibrated for air up to a capacity of 6000 cu. ft. per hr. It had its limitations of course, because you cannot measure the large volume that comes through an unstripped window, but after a window had been weather-stripped or weather-proofed, as Mr. Armstrong or his company has devised for their double unsealed window, the amount of leakage that you would get on say a 3 × 6 window or a 4 × 7 would not be anywhere near up to the capacity of a 6000 cu. ft. meter, and it is very simple to operate because you don't have the collector box on the opposite side of the window or what would naturally be the inside of the window. The leakage is all measured by a simple reading of the meter. You set your gauge and your manometer for the desired static head and then you sit down and take your stop watch and watch the needle go round. At the same time the window is readily accessible. It can be opened and closed at will and frequently it is found that the mere opening and closing of a window changes the result.

It was rather difficult to get a meter of that capacity because meters of that character are not a stock article. They are supplied to public service corporations and are not for sale, but through the kindness and courtesy of the American Meter Co., we were enabled to get one of them, which is our property. We were able to borrow one for a time at the architectural exposition in New York two years ago this last spring and it was very interesting, interesting particularly because the visiting engineers and architects could have ready access to the window. They didn't have to take off the collector apparatus in order to see what was going on. It may be that some device of that kind can be used so as to give it a more general distribution or a more general accessibility. I believe that the work done by Mr. Armstrong is very remarkable. I have studied his paper quite closely and it seems to me to be a step in the right direction; that is, that the manufacturer has awakened to the fact that it is up to him to make his windows practically weather-proof within a reasonable range and not have to call in a doctor after he has his job up.

E. S. Hallett: Evidently the testing of windows for the infiltration has been brought about by these people who have developed improved windows and window stripping and the like. When I began to study school ventilating a number of years ago I found that our architects said, "What is the use of making windows tight when you are throwing all the air away through the ventilation in the stack?" and I guess those who have not come to the matter of recirculating the air are not very much interested in whether you get so much leakage or ten times that much.

My experience is that the standard method of constructing window frames will admit of very much more infiltration around the frame than you can ever get in the poorest construction of unstripped windows. We have found tremendous openings around them. They were covered up, of course, by the trim, so that you couldn't see them, but when you took the trim off you found out how big an opening there was around it. Immediately we put into all of our specifications a requirement that the window frame be calked with oakum and when plastered —filled up full—and that has been done with all of them recently. We have made our windows tight and of course we are using window strips on the double hung windows. I suppose the metal sash is the tightest window that we have. I am not advertising any product. I am not interested in anybody's product at all, but evidently our Lincoln School has the tightest window we have ever built because the metal frame is set in mortar and we don't have very much opening because we are not interested in having windows open, and therefore the portion of the window that opens is relatively small. When it is closed, it is closed relatively tight and it is a good job.

Another thing that concerns the casement window—we have casement windows that have stood the severest test that I know of. They are closed under pressure, they are always tight; this is the bellows type of window that is sprung into place and we have tried all kinds of water tests on them. We have played a hose against them for a long period of time trying to get a drop of water through. They are absolutely proof against anything of that kind. A casement window has that weakness, as you know. Now we haven't put Mr. Lane's patent testing box on that. I have no doubt at all from looking at it that ordinary horse-sense applied, it would stand up as one of the very best windows that can be made. We insist upon the windows being as nearly 100 per cent tight as possible.

MR. WHITTEN: In regard to what Mr. Hallet said about frame leakage, we have found that to be a very important part of our business. Some few years ago it was a very incidental part, but last year in round figures at least one million dollars worth of calking of frames was done and our curve of increase in that class of business is very pronounced. We consider it perhaps as important as any of our business, because eventually it looks as if it might over-shadow any other part of the business that we are doing.