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No. 803

AIR LEAKAGE STUDIES ON METAL WINDOWS IN A MODERN OFFICE BUILDING

By F. C. Houghten and M. E. O'Connell

SYNOPSIS

In this report, the Research Laboratory of the American Society of Heating and Ventilating Engineers presents information concerning the leakage of air through metal windows in a modern office building, and the effectiveness of weatherstripping in its reduction. The reasons for the investigation, method of attack, instruments used and the magnitude and significance of the results are discussed.

A STUDY of air infiltration through metal windows in a modern office building and the effect of weatherstripping in reducing this leakage was made possible by cooperation between the Research Laboratory of the American Society of Heating and Ventilating Engineers and other organizations. The Southwestern Bell Telephone Co., through its architects, Mauran, Russell, and Crowell, and associate architect, I. R. Timlin, made available space and other facilities for the study in its new building in St. Louis. The Athey Co., The Campbell Metal Window Corp., The Chamberlain Metal Weatherstrip Co., and The Monarch Metal Products Co., each equipped one window with its weatherstripping, or leakage retarding improvement, and furnished other equipment necessary for the tests. Arrangements for the investigation were completed* by S. R. Lewis, chairman of the Committee on Research of the Society, and representatives of the other organizations. The investigation was made by the staff of the Laboratory during May and June.

Type of Building Studied

The Southwestern Bell Telephone Building in St. Louis, Fig. 1, is a modern skyscraper of the setback type, partly occupied by the telephone company for its exchange and office requirements. The other space in the building is leased for

* Late in April, 1927.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, N. Y., January, 1928.

office purposes. The building is 32 stories high and contains 514,380 sq. ft. of floor space.

Windows having a northern exposure in the northwest corner of the eleventh floor were chosen for test. These windows are indicated by x-x in Fig. 1, while

FIG. 3. SOUTHWESTERN BELL TELEPHONE BUILDING, ST. LOUIS, MO.

Fig. 2 shows a plan of the eleventh floor. Windows 1, 2, 3, 4 and 5 were tested. Window 6 was used for collecting wind pressure data and for other observations.

Probable Value of Results of Study

The investigation was of particular interest to engineers, architects, and building owners.

1. It gave an opportunity to study infiltration through metal windows on which little or no data have been available.

2. It offered information on the average effect of various types of leakage retarding devices in reducing infiltration through such windows.

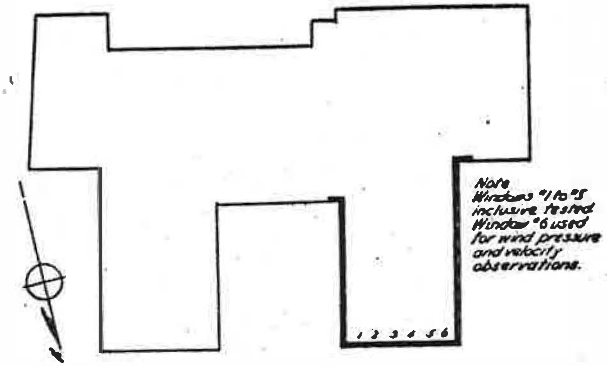


FIG. 2. ELEVENTH FLOOR PLAN, SOUTHWESTERN BELL TELEPHONE BUILDING

3. It offered an opportunity to demonstrate the feasibility of making infiltration tests on windows in an actual building.

4. It was hoped that the findings would give an indication of the reliability of results on air leakage through windows collected under laboratory conditions where an artificial wind pressure is created by fans.

Proposed Apparatus

The investigation offered difficulties as well as opportunities not encountered in the Laboratory. Originally, it was planned to measure the air leakage through the windows by the orifice method in a manner similar to that developed and used by the Laboratory in its infiltration studies in Pittsburgh. Fig. 3 is the apparatus developed and used by the Laboratory for determining leakage through windows. A static pressure equivalent to any desired wind velocity is maintained in the pressure chamber *A*, and the air leaking through the window or other construction is collected in chamber *D* and measured as it passes out through the orifice *E*.

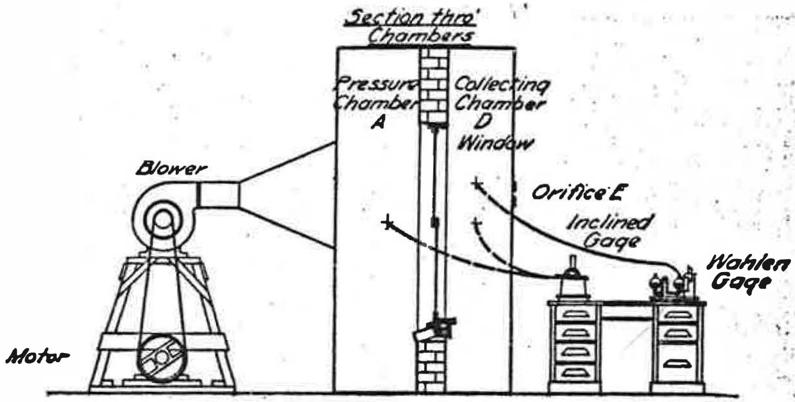


FIG. 3. LABORATORY APPARATUS FOR STUDYING AIR LEAKAGE THROUGH BUILDING CONSTRUCTION

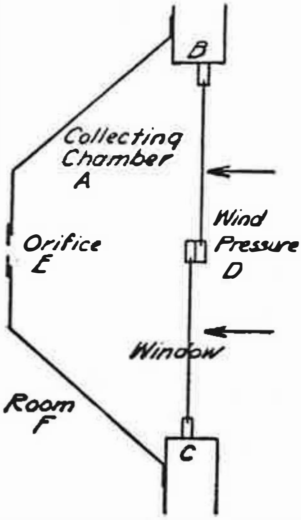


Fig. 4. Orifice Method Proposed for Measuring Infiltration through Windows

Fig. 4 is a modification of the Laboratory apparatus which it was thought could be used for determining leakage through actual windows. The collecting chamber *A* is clamped against the wall *BC* containing the window. Air leaking through the window due to a wind pressure on the outside is collected in chamber *A* and measured as it passes out through orifice *E*.

There are two fundamental difficulties with this method of procedure. *First,*

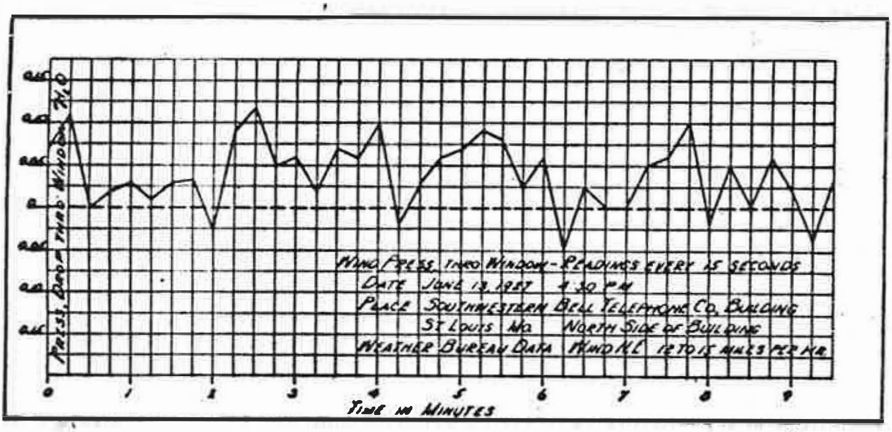


Fig. 5. Variation in Wind Pressure

measurement of the air leaving the collecting chamber by the orifice method requires a pressure drop through the orifice and hence a higher pressure in the collecting chamber than in the surrounding room *F*. Since the pressure in the collecting chamber will be greater than the pressure in the room, the full pressure of the wind against the window will not be effective in causing leakage through it. The observed infiltration under such test conditions would necessarily be less than normally taking place. *Second*, wind pressure is extremely variable and hence the rate of infiltration through the window will vary over a wide range. Since the orifice method of measurement gives only the instantaneous rate of flow at the time of observation, it is not easily adaptable for measuring variable flow.

Fig. 5 shows variation in wind pressure against a window in the Southwestern

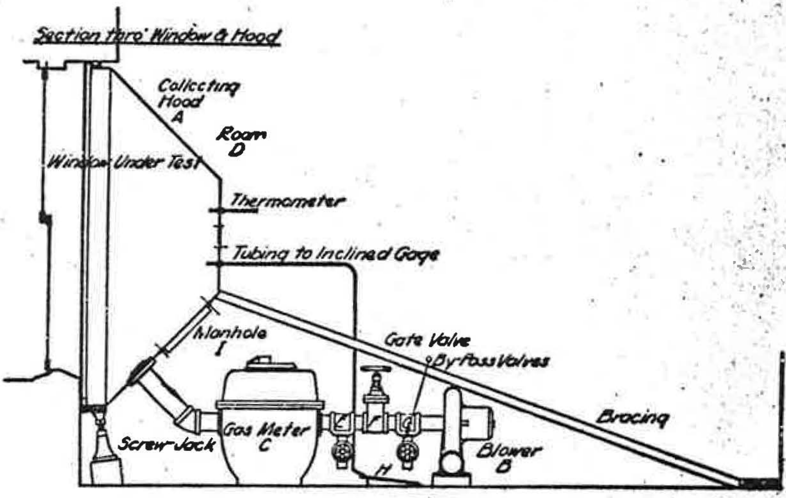


FIG. 6. APPARATUS USED FOR MEASURING INFILTRATION THROUGH WINDOWS

Bell Telephone Building over a period of 10 minutes while the Weather Bureau reported a northeast wind of 12 to 15 miles an hour. Observations were made and the pressure plotted every 15 seconds. It will be noted that the pressure was extremely variable, changing several times from a maximum positive to a small negative value over a very short period. If an orifice method were used for measuring the leakage, the orifice pressure observed would show the same cycles of variation, although the magnitude of variation would probably be much less. It would be necessary to take frequent readings and integrate the area under such a curve in order to determine the quantity of air leaking through the window over a period of time. Obviously this would be impossible without considerable error.

Apparatus Used

Because of these difficulties the method shown in Fig. 6 was finally adopted and used throughout the tests. The collecting hood *A* was clamped to the wall around the window under test. Air was exhausted from the collecting chamber by means of the blower *B* through the gas meter *C* so as to maintain zero pressure difference between the collecting chamber *A* and the room *D*. This insured the same leakage through the window at any wind velocity as would take place if the collecting chamber was not clamped to it. In other words, it insured normal leakage through the window.

A calibrated gas meter was used for measuring the air taken from the collecting chamber. The exhaust fan used had a capacity in excess of the estimated requirement for exhausting all of the infiltering air through the meter. Valves *E*, *F*, and *G* made it possible to control the flow so as to maintain a constant pressure in the collecting chamber equal to that in the surrounding room, as indicated by

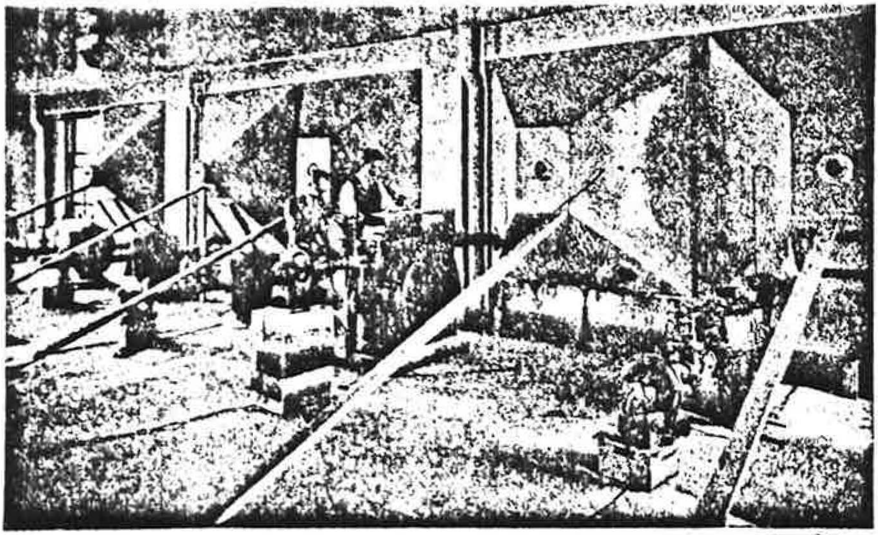


FIG. 7. TEST SET UP FOR MEASURING INFILTRATION THROUGH WINDOWS IN SOUTHWESTERN BELL TELEPHONE BUILDING

a sensitive inclined pressure gage *H*. Meters having a capacity of 5000 cu. ft. per hour were used for testing the weatherstripped windows. A 10,000 cu. ft. meter was used for testing the non-weatherstripped window. Standard 4-in. pipe was used for the duct between the collecting chamber and meter, and 3-in. pipe between the meter and blower. A 3-in. gate valve was used for main control, and 2-in. valves for bypass control.

The five meters were lent for the tests by the Pittsburgh Equitable Meter Co., and were calibrated at the factory before shipment. To insure that after applying the calibration correction they all read alike after shipment, they were compared at the scene of the tests before they were installed. All five meters were connected in series with one of the exhaust blowers, and air was drawn through them at various rates. After taking into consideration the difference in pressure of the air passing through the different meters due to the pressure drop through the series, and after

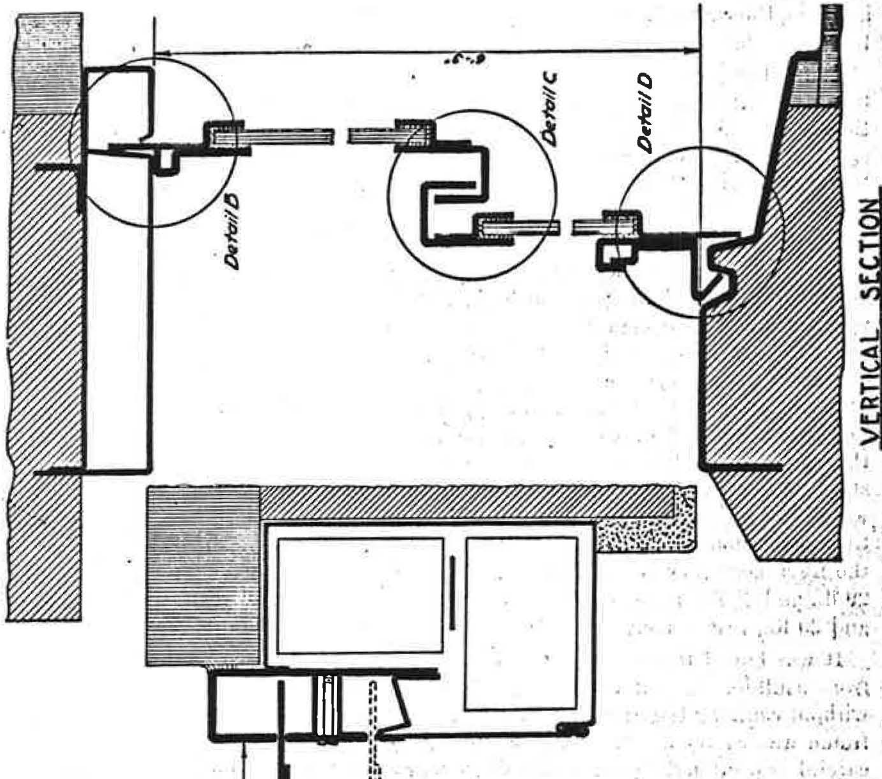


Fig 8. Campbell Metal Window without Weatherstripping

applying the calibration correction to each, all meters read alike at all rates of flow to within plus or minus 1 per cent.

Fig. 7 shows the collecting chambers, meters and other test equipment attached to the 5 windows under test. The windows were all of the same size and construction. The choice of windows for the different leakage retarding devices was decided by lot. From the reader's right to left, they are in the following order—the *Athey* stripped window, the non-weatherstripped window, the *Chamberlain* stripped window, the *Campbell* improved window, and the *Monarch* stripped window.

The windows as found in the building were Campbell metal frame and a sash of that firm's standard specification of 1925. The unstripped window was tested without any adjustment or change from the condition in which it was found. Before the windows which were to be weatherstripped were altered, the force necessary to open each of the five windows was determined. A spring balance was attached by cords to the two hand grips on the sash and a force of increasing magnitude was applied until the sash began to move. The force was then reduced so that the sash continued to move with uniform velocity. The force necessary to start the sash and that necessary to continue it in uniform motion after starting were both recorded. The forces necessary to start and open the windows after the application of the weatherstripping were also determined. The averages of the force necessary to start the six sash before and after weatherstripping were 29 lb. and 35 lb., respectively. After the sash were started, average forces of 14 lb. and 20 lb., respectively, were necessary to continue their uniform motion.

It was hoped that data could be obtained on the decrease in leakage resulting from caulking around the frame. Therefore, it was planned to make tests first without caulking the frames and again after the crack between the masonry and the frame was caulked. The windows tested, however, were so well caulked that a careful inspection did not reveal a single hair crack between the frame and masonry. It was not necessary, therefore, to caulk the frames.

To make certain that no leakage took place between the glass and the sash, all such joints were sealed where it seemed the least bit possible that leakage could take place.

Fig. 8 shows the frame and sash as found in the building. Figs. 9 to 12 show details of the application of the different leakage retarding devices. The Campbell improved window was changed by that firm in accordance with the present specification of its standard equipment, which includes a leakage retarding feature built into the window. Each of the other windows was equipped with weatherstripping by representatives of the respective companies participating in the studies. The test equipment was then installed and made ready for operation with the exception of closing the man-hole opening *I*, Fig. 6. Representatives of the different improved windows were then allowed to inspect, finally, their respective windows, immediately after which the windows were inspected by a committee of three, representing the architects, the Bell Telephone Co. and the Research Laboratory. After inspection both the upper and lower sash of each window were run up and down several times, closed tightly and locked. As soon as this was accomplished, the man-holes were closed and sealed.

The sixth window left, Fig. 2, was fitted with a tube leading outside, flush with the window surface, and connected by rubber tubing to an inclined pressure gage for observing wind pressure against the window. The corner window at the reader's left, Fig. 2, having a western exposure, was likewise fitted with a tube leading to the outside, so that the wind pressure on this exposure could be observed.

A Tycos electric cup anemometer was placed on top of a pent-house on the roof of the Majestic Hotel, across the street from the windows under test. At that point, the anemometer was about 100 ft. in front of, and about 20 ft. below the windows tested, and clear of all obstructions for about a block on all sides, with the exception of the Bell Telephone Building. The anemometer was of the electrical contact indicator type. Observation of the change in reading of the indicating instrument, which was in the test room, over a given period, gave the wind travel and the average wind velocity could be calculated. The St. Louis station of the U. S. Weather Bureau is 4 blocks east and 1 block north of the Southwestern Bell Telephone Building, and meteorological readings for any period were available.

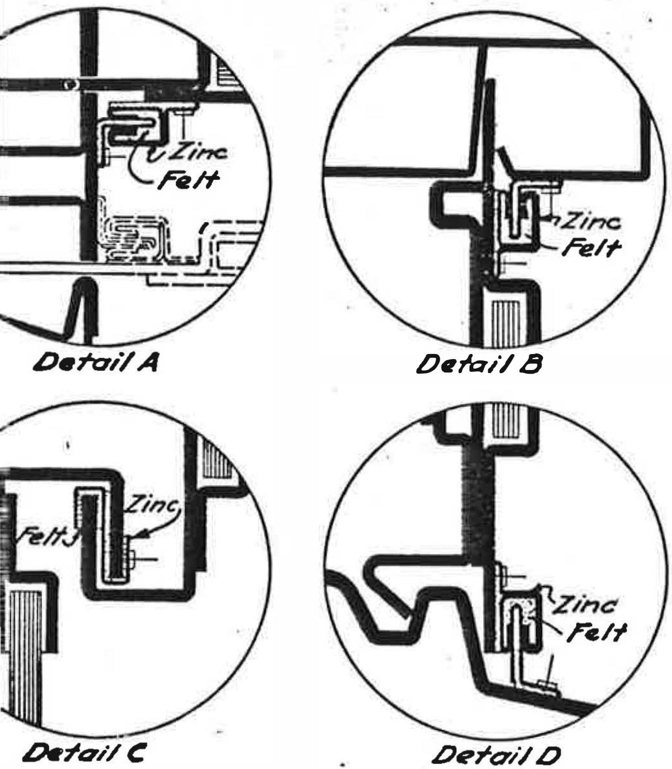
Test Manipulation

In making a test, an observer manipulated the valves so as to maintain a zero pressure drop between the collecting chamber and the room, as indicated by the sensitive pressure gage before him. An observer was required for such manipulation for each window under test. If sufficient observers were not available for making simultaneous tests on all windows, tests were made on at least two windows one of which was always the non-stripped window. Another observer made frequent observations of the anemometer indicator, pressure gages, meters, and wind direction. The wet- and dry-bulb temperatures were also recorded. The wind direction and velocity and barometric readings were later obtained from the w eather bureau for the period of the test.

It was hoped to obtain tests with wind velocities perpendicular to the window ranging up to 30 miles an hour but it was soon found, however, that satisfactory wind was not to be had excepting at very infrequent intervals, and then the velocity was never very high.

A large number of tests were made with pressure drops through the window created by exhausting air from the collector chambers. Pressure drops equivalent to various wind velocities could easily be maintained for such tests. One observer controlled the pressure drop through each window under test by manipulating the valves while another observer recorded other observations. A few tests were also made by reversing the process—that is, by blowing air into the collecting chamber through the meter so as to give a desired positive pressure in the collecting chamber and a pressure drop through the window.

After an extended series of tests with the locked windows had been made, the seal on the man-hole covers in the collecting chambers was broken, and the covers were removed. The windows were unlocked, opened and closed several times, and then closed tightly after which the man-holes were again closed and sealed. A short series of tests was then made on the unlocked windows with artificial wind pressures only—that is, by maintaining a pressure drop through the window by exhausting air from or blowing air into the collecting chamber.



Campbell Metal Window with Athey Weatherstripping

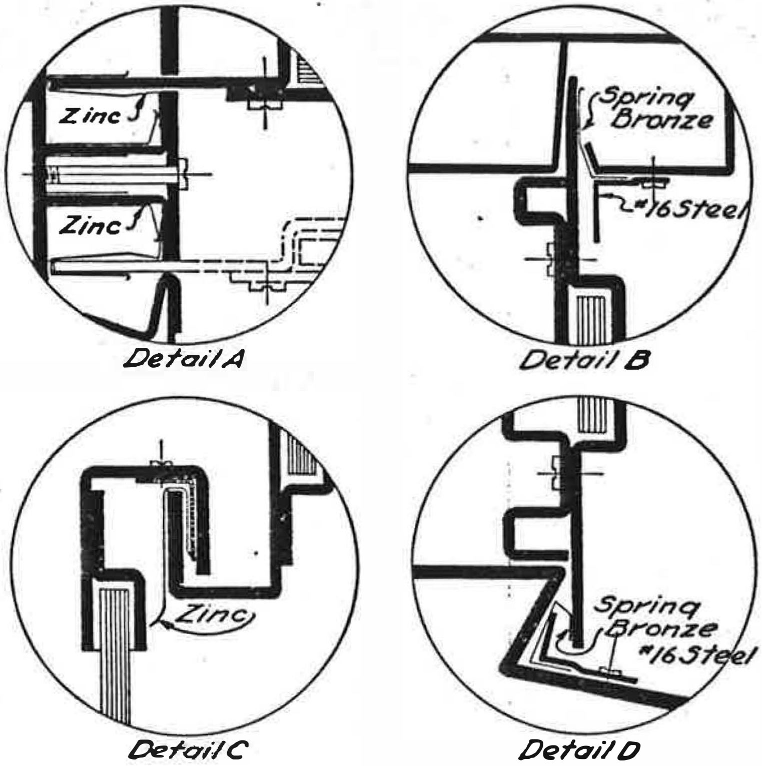


Fig. 10. Campbell Metal Window with Campbell Leakage-Retarding Improvement

Test Data

The object of the comparison of leakage through weatherstripped and non-weatherstripped windows was to establish data regarding reduction in leakage, which might be expected from the application of any good weatherstrip, and was not to establish the relative merits of the four strips studied. This report is only concerned with the average leakage through the different weatherstripped windows and the numerical value of such averages only are given. It is, however, desirable in this report to illustrate the consistency of the data collected on the different windows, and for this purpose, all data collected on one weatherstripped window is shown. However, the scale showing the magnitude of the leakage is purposely omitted so that a direct comparison is not possible, even though the particular make of weatherstrip be ascertained.

Points on curves *C* and *D*, respectively, Fig. 13, are the results of tests with artificial wind pressures on the non-weatherstripped window, locked and unlocked.

The curve in Fig. 14 is a reproduction of curve *C*, Fig. 13, with the test points for natural wind pressures against the locked, non-weatherstripped window, plotted on it. The leakage is plotted against the pressure drop resulting from natural winds as observed at the sixth window.

Curves *A* and *B*, Fig. 15, show the leakage through one of the weatherstripped windows, locked and unlocked, respectively. The test points are for artificial wind pressures only, and are plotted to an unknown scale in order to avoid direct comparison.

Fig. 16 is a comparison of artificial wind pressure data and natural wind pressure data for a weatherstripped window. The curve is based on data obtained with artificial wind pressures; the indicated test points are for natural wind pressures. All points are plotted to an unknown scale.

Curves *A* and *B*, Fig. 13, are the averages of curves for all four weatherstripped windows for the locked and unlocked conditions, respectively.

Discussion of Results

The data in the curves, Figs. 13 to 16, indicate that consistent results can be obtained from tests on windows in an actual building. The data collected when artificial wind pressures were produced show a very consistent curve, even though tests were made under varying conditions and over a period of several weeks. The test points for natural wind pressures, Figs. 14 and 16, show that practically the same leakage results from a given pressure drop regardless of whether it is produced artificially or by a natural wind. Curves *A* and *B*, Fig. 13, the averages of all weatherstripped windows tested, show that the average of the leakage retarding devices decreased the leakage about 56 per cent for a 30 mile wind.

Although a direct comparison of the leakage through the various stripped windows is not possible in this report, it should be added that the maximum variation of any strip from the averages as given in curves *A* and *B*, Fig. 13, is little greater than might be expected by the application of the same strip to two different windows by different mechanics. The variation in leakage through the different stripped windows tested is of minor importance when compared to the great reduction in leakage resulting from the application of any of the strips tested.

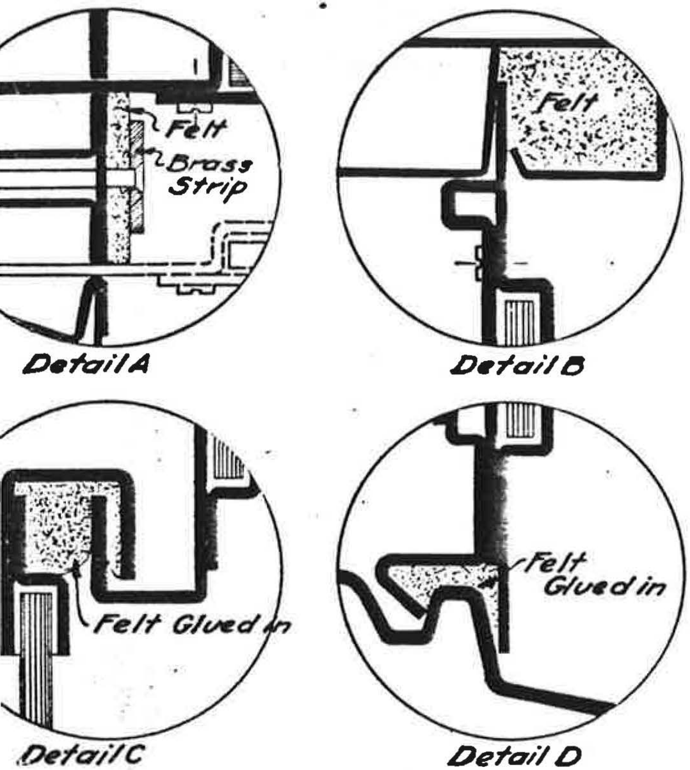


FIG. 11. CAMPBELL METAL WINDOW WITH CHAMBERLIN WEATHERSTRIPPING

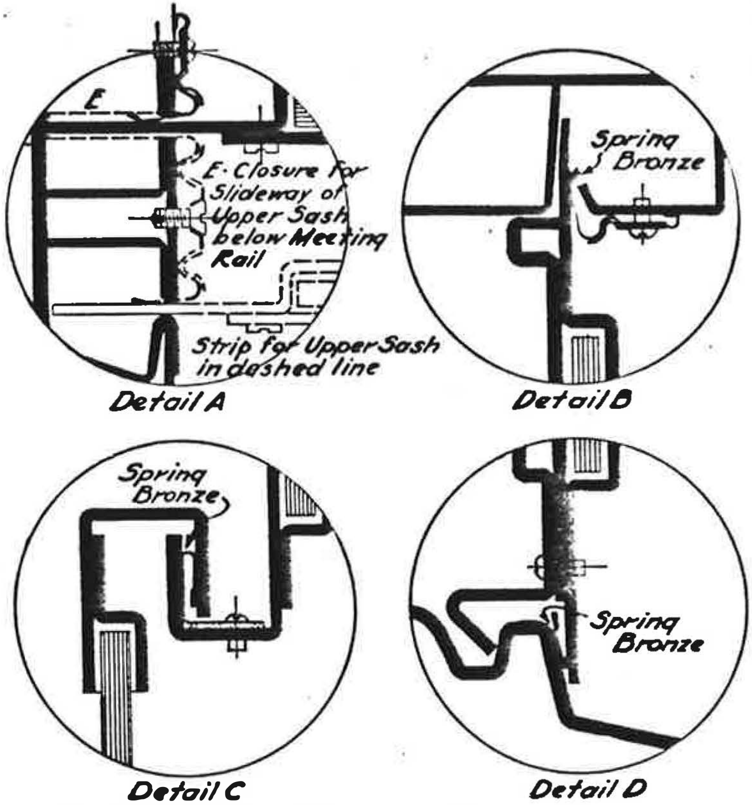


FIG. 12. CAMPBELL METAL WINDOW WITH MONARCH WEATHERSTRIPPING

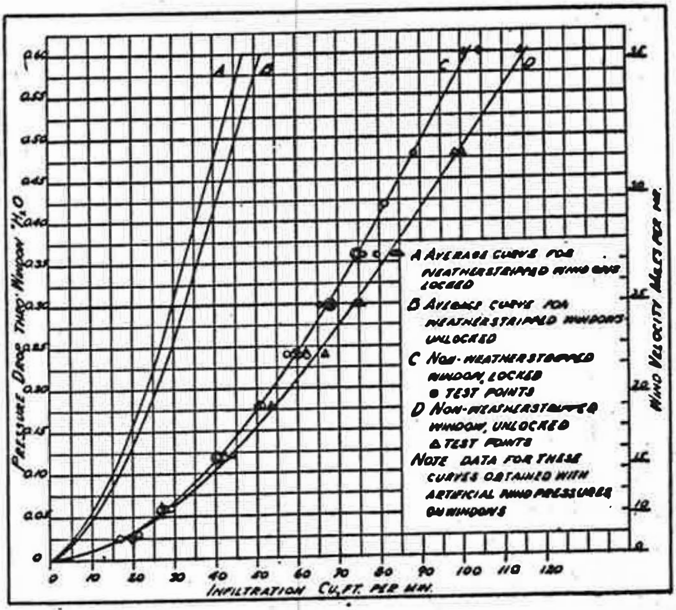


FIG. 13. INFILTRATION THROUGH METAL WINDOWS WITH AND WITHOUT WEATHERSTRIPPING

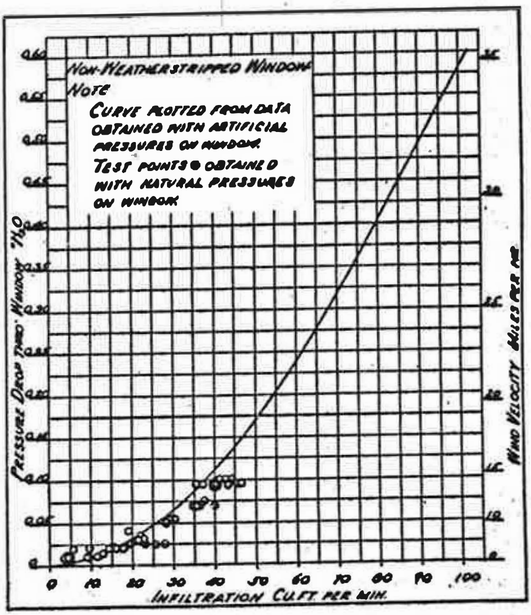


FIG. 14. INFILTRATION THROUGH METAL WINDOWS WITH NATURAL AND ARTIFICIAL WIND PRESSURES

Curves *C* and *D*, Fig. 13, show the reduction in leakage resulting from locked windows. This fact is of some importance in the conservation of heat, and is a factor worthy of consideration in meeting the heating requirements of a large building in severe weather. The heat loss by infiltration through windows of the type tested is reduced about 10 per cent by locking with a 30 mile wind.

Conclusions

1. The investigation establishes the heat loss by infiltration through the metal windows tested for different conditions as given in Tables 1 and 2. It indicated that infiltration loss through such metal windows can be reduced about 10 per cent by locking an unweatherstripped window, and an average additional 56 per cent by applying weatherstripping of the types studied to the locked window.

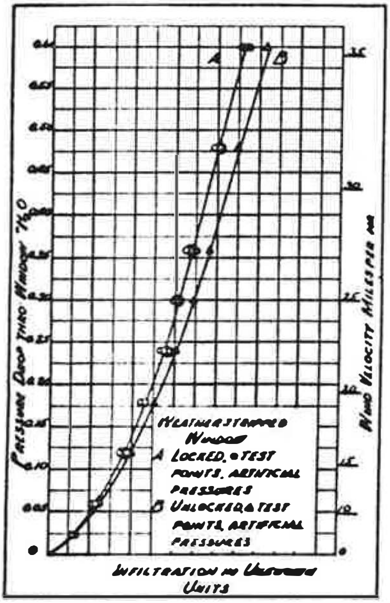


FIG. 15. CHART INDICATING INFILTRATION THROUGH WEATHERSTRIPPED METAL WINDOW LOCKED AND UNLOCKED

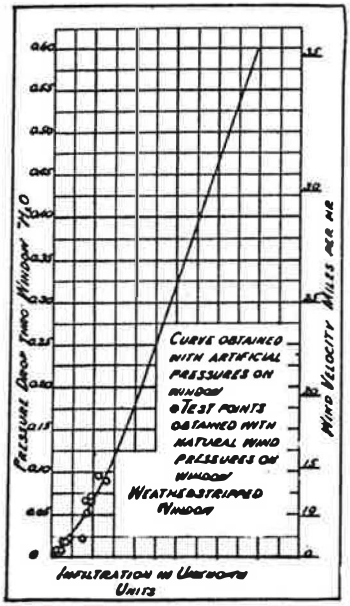


FIG. 16. INFILTRATION THROUGH WEATHERSTRIPPED METAL WINDOW WITH NATURAL AND ARTIFICIAL WIND PRESSURES

2. Application of leakage retarding devices to metal windows of the type studied can be accompanied by an average reduction in radiation installed to meet the heating requirements in zero weather with a 15 mile wind of 0.28 sq. ft. per foot of crack around the sash or a reduction of 7.2 sq. ft. per window of the particular size investigated.

3. Determination of infiltration through windows in actual buildings is quite

feasible although much more difficult than making similar tests under laboratory conditions.

4. Data collected under natural wind pressures in an actual building are practically the same as those collected for artificial wind pressures. It may be assumed, therefore, that data collected under laboratory conditions with artificial wind pressures are quite satisfactory.

TABLE 1. INFILTRATION THROUGH METAL WINDOWS

Wind Velocity	Non-weatherstripped Window, Locked			Non-weatherstripped Window, Unlocked			Weatherstripped Window, Unlocked		
Miles per hr.	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0-70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0-70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0-70° F.	Sq. ft. Radiation
5	660	832	3.5	660	832	3.5	210	265	1.1
10	1470	1852	7.7	1530	1928	8.0	600	756	3.2
15	2280	2872	12.0	2400	3025	12.6	1020	1285	5.4
20	3120	3932	16.4	3360	4235	17.7	1488	1875	7.8
25	4050	5105	21.3	4440	5595	23.3	1950	2458	10.2
30	4980	6275	26.2	5520	6960	29.0	2460	3100	12.9
35	6060	7640	31.8	6870	8660	36.1	3060	3858	16.1

TABLE 2. INFILTRATION THROUGH METAL WINDOWS PER FOOT OF CRACK

Wind Velocity	Non-weatherstripped Window, Locked			Non-weatherstripped Window, Unlocked			Weatherstripped Window, Unlocked		
Miles per hr.	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0-70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0-70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0-70° F.	Sq. ft. Radiation
5	25.5	32.1	0.13	25.5	32.1	0.13	8.1	10.2	0.04
10	56.8	71.5	0.30	59.1	74.4	0.31	23.2	29.2	0.12
15	88.0	110.8	0.46	92.5	116.8	0.49	39.4	49.6	0.21
20	120.4	151.8	0.63	129.7	163.4	0.68	57.5	72.4	0.30
25	156.3	197.0	0.82	171.4	216.0	0.90	75.3	94.9	0.40
30	192.2	242.2	1.01	213.0	268.7	1.12	95.0	119.9	0.50
35	233.8	294.9	1.23	265.0	334.3	1.39	118.1	148.8	0.62

DISCUSSION

G. B. NICHOLS: I think this paper is very timely on account of the number of skyscrapers being built at the present time throughout the country. There is one phase of the paper that is still unfortunate. I think the paper carries a little too much of an advertising nature and you might get the idea (not that I have anything against it) that the Campbell window is the best window to use in skyscraper work. The title of the paper is not quite covered by the material of the paper. It only touches one phase, that of infiltration through windows. I recently have been connected with several skyscrapers and have my office in one. I was led to make some studies around that building, the Tribune Tower in Chicago. There was a paper several years ago at one of our Atlantic City meetings on the neutral zone in skyscrapers. I think it has been a subject that has been little thought out. I had my office on the 19th floor of the Tribune Tower in Chicago. It was almost impossible to keep that room at 70 deg. Most of the time it varied from 55 to 60. I had thermometers in the room continuously in winter weather. In other words, that office appeared to be in the neutral zone. On the bottom floors we had the infiltration of air and on the upper floors the outgoing air.

There are no papers in existence that in any way approach that subject of how much radiation shall be put into the bottom floors of a skyscraper, how much on the top floors with the same type of rooms.

To add to this information, in a recent skyscraper that has been built in Chicago and nearing completion at the present time, the building was laid off with the usual metal windows. That building contains approximately 50,000 square feet of radiation. Campbell windows were put in that building. One of the great arguments was that the saving in radiation would be more than offset, or would more than offset the extra cost of the Campbell windows. The extra cost in that building was approximately $5000. The engineers were asked to revise the plans, the radiation to meet the Campbell window infiltration. The reduction on the plans was about 10 per cent in radiation. The actual cost of the reduction was about 28 cents a square foot which amounted to about $1300. So that the extra cost of the windows was approximately $3700. They cannot substantiate the special windows and their extra cost on the saving in radiation. There is no leg to stand on at all. The leg to stand on is the saving in fuel.

There was one other point that is well worth considering bringing under this head, the argumentative point of having a control on the downfeed riser. Generally speaking skyscrapers are downfeed system and at the top of each riser inserting a control valve, an air control valve, and having that operate by air pipes to the boiler room. There are a number of buildings in Chicago that have been built along that line. The engineer turns off the risers on the sunny side of it during the daytime. In other words, he follows the sun around the building. If the sun is in the east he will cut off a few of the risers on the east side and as the sun goes around the buildings he will cut off other risers. There is quite a chance for saving along that line and it should come under this head.