No. 817

EFFECT OF FRAME CALKING AND STORM WINDOWS ON INFILTRATION AROUND AND THROUGH WINDOWS

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THE subject of infiltration has given rise to much discussion as to the amount of air which finds its way into buildings through and around the windows and other openings. This report is the result of a series of tests which have been carried on at the University of Wisconsin during the past year. It is the first work which has been conducted under the cooperative agreement with the American Society of Heating and Ventilating Engineers.

These tests have been made to show the effect of calking the crack between the brick wall and window frame, and the effect of applying storm sash to the window. Each group was divided into two parts. The infiltration was determined through the crack for a window set in a plain 13-in. brick wall and for the same crack after the wall had been plastered. The storm sash was applied in two methods to a window which had a very small crack and clearance and to a window with a crack and clearance of more or less average size.

Description of Apparatus

The apparatus used to determine the air leakage or infiltration is very similar to that used in the Research Laboratory at Pittsburgh. Fig. 1 shows the location of the equipment with reference to the storage space for windows, doors and walls, and also illustrates the apparatus set up for a test run. The machine is built of eighteen gage galvanized iron, and consists of two main parts: the pressure chamber *A* and the collecting chamber *B*. Each of these chambers is fitted with an opening so that entrance may be had into either chamber to make adjustments after the two parts of the machine have been fastened to the wall. To facilitate setting up a wall for testing, the collecting chamber *B* and the orifice box *C* have been mounted on a small four-wheel truck which can be moved back about 10 ft. from the pressure chamber on a narrow gage track upon which it operates. This provides sufficient space to place the wall between the two halves of the machine for the tests. Chambers *A* and *B* are fastened to the bottom of the wall by means of two eye bolts

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The results of cooperative research between the University of Wisconsin and the American Society of Heating and Ventilating Engineers.

Presented at Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, West Baden, Ind., June, 1928.

hinged to the bottom side of the pressure chamber. These bolts extend through two holes in a channel bar which is attached to the bottom side of the collecting chamber and are secured by two nuts. The sides and top of the pressure and collecting chambers are fastened to the channels of the steel frame containing the wall by means of *C*-clamps. To insure that no air will escape from the joint between the steel frame and the pressure and collecting chambers, sponge rubber approximately 1 in. square in cross section has been attached to the lip of these chambers. The rubber on the collecting chamber is indicated by *A*, Fig. 2.

The artificial wind pressure is produced by a small motor-driven blower, rated at 340 cu. ft. of air per minute against a static pressure of 3 oz. of water, which is

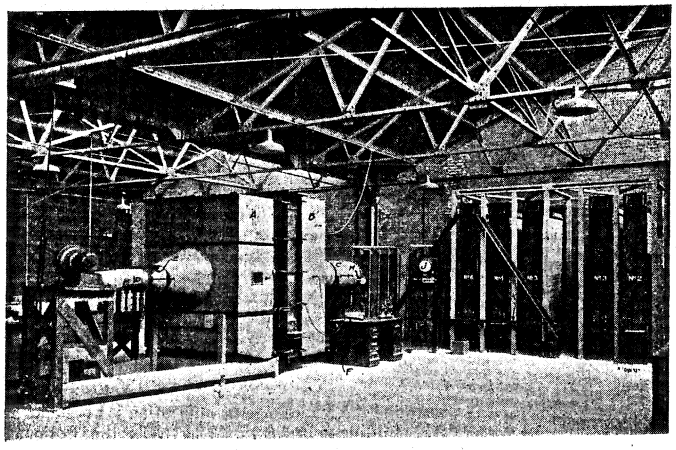

FIG. 1. GENERAL LAYOUT OF TEST EQUIPMENT

connected to the pressure chamber. The pressure drop through the wall may be regulated by means of a damper on the inlet of the blower, a relief slide, *D*, and a sliding damper, *E*, located in the connection between the blower and the pressure chamber. This pressure is measured by an ordinary inclined draft gage, *F*, the ends of which are connected to the pressure and collecting chambers.

The orifice box *C* is fitted at one end with eight $^1/_4$-in. stud bolts equally spaced on the circumference of an 11-in. circle, to which the orifice plates are secured by means of wing nuts. The orifices, varying in diameter from $^3/_8$ in. to 8 in., are accurately machined in these plates. A rubber gasket is placed between the end of the orifice box and the orifice plate in order to eliminate any possibility of leakage at that joint.

The pressure drop through the orifice, which is the pressure differential existing

between the orifice box and the atmosphere is measured by a Whalen gage, *G*. The atmospheric pressure is determined from an aneroid barometer, and the relative humidity of the air is calculated from the readings taken from a chart on the wet- and dry-bulb recording thermometer. These instruments are designated by *H* and *J*, respectively, in Fig. 1.

The steel frames in which the walls are built were specially designed for the conditions which are encountered in this test. The frame is made of 15-in. channel iron reinforced at the corners with angles which are riveted into place. The construction was changed slightly after the first frame had been completed. Instead

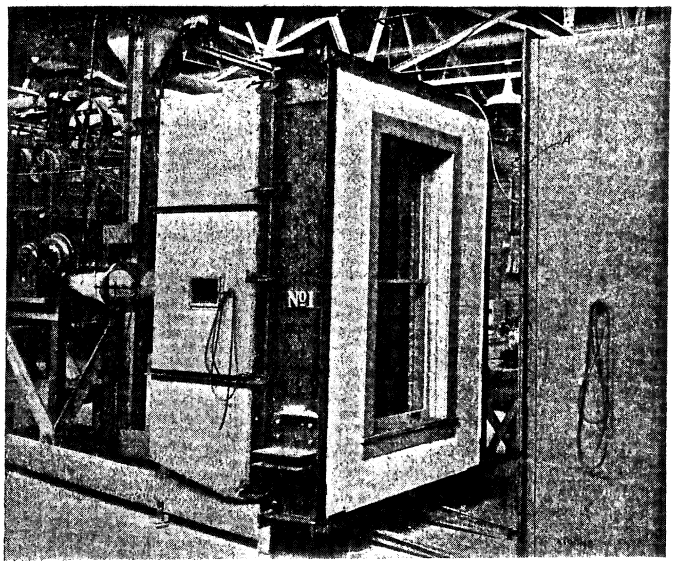

FIG. 2. MACHINE OPEN WITH PLASTERED WALL IN PLACE

of the side members resting on the bottom channel which is supported by two ball bearing rollers, the side members were lengthened so that they rest on the floor, carrying the entire load of the frame and wall. The top and bottom members are butted against the side members, and are riveted to reinforcing angles. These changes are clearly shown by comparing the wall in the machine with those in the storage rack, Fig. 1. Provision was made on the frame for attaching the moving equipment. This consists of an *A* frame mounted on rollers, and a single steering roller. The construction of the frame and method of attaching it to the

wall frame is shown in Fig. 1. Tightening the nuts at the two ends of channel iron *K* draws the two legs of the frame together, lifting the wall off the floor. The steering roller is attached at the opposite end of the wall. That end is lifted by a screw jack thread cut on the vertical shaft to which the steering roller is fastened.

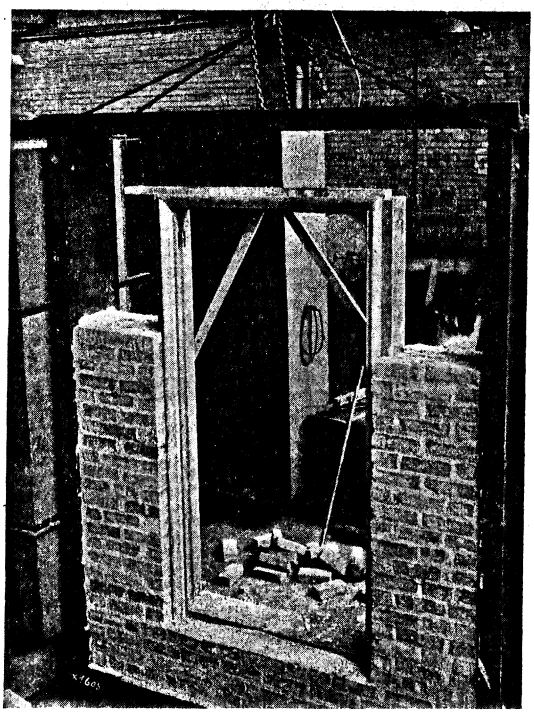

FIG. 3. WALL NUMBER ONE UNDER CONSTRUCTION

This arrangement works out very well and is a very great improvement over the two ball bearing rollers which were placed under the first frame. The *A* frame is very stable and eliminates the chances of sudden shock which might cause cracks in the completed walls.

Description of Wall and Window

The wall used in this series of tests is wall Number 1 of the proposed program of tests to be carried out at the University of Wisconsin. A box type double hung wood window frame, with sash 3 ft. x 6 ft. x $1^3/_8$ in., was built in a section of 13-in. brick wall. A porous type of brick commonly known as the Chicago clay brick and ordinary lime mortar were used for the construction of this wall. These materials are used very extensively for construction purposes, and it was decided upon as one of the combinations of masonry wall to be tested. The manner in which the window frame was built into the wall is shown in Fig. 3. This picture

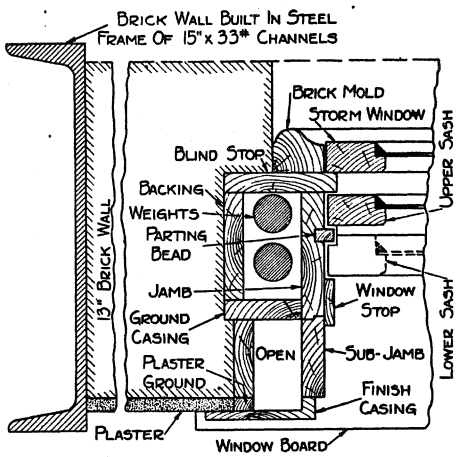

FIG. 4. HORIZONTAL SECTION THROUGH WALL AND WINDOW FRAME

was taken during the process of construction and shows the steel frame work which contains the wall section, the manner in which the brick are laid, and the small amount of mortar that was used to slush the joints between the brick.

Provision was made for applying storm sash to the window frame after the wall had been placed in the machine for test. Two types of fastenings for the storm sash were tested: one in which the storm sash was suspended from the top of the window frame by the ordinary hook and eye arrangement and held at the bottom by the arm type clamp, and the other in which the storm sash was held in place by four turn buttons screwed onto the window frame itself. The former type of fastening permits the storm sash to be opened slightly for ventilating purposes, while the latter does not permit any movement of the storm sash after it has been secured in place.

Fig. 4 is a cross section through the steel frame, brick wall and window frame showing the general type of construction of the wall under test. The first series of tests were run on the plain wall. A coat of gypsum base plaster was then applied to the wall, allowed to dry for a week, and then the second series of tests were made.

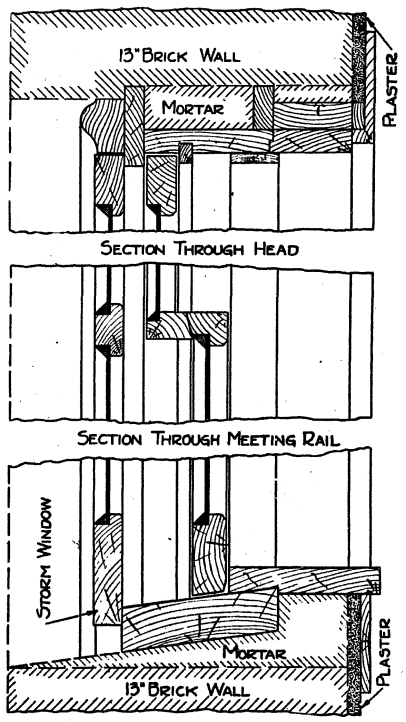

FIG. 5. VERTICAL SECTION THROUGH WINDOW FRAME

Fig. 5 is a cross-section view of the head, meeting rail and sill of the window tested. Fig. 2 shows the type of finish used on the window after the plaster had been applied.

Every precaution possible was taken to insure that the wall and window frame would represent conditions which would be comparable to those used in the actual construction of buildings. The window frame and sash were purchased from a local

lumber company, the sash were fitted and the brick wall laid by the service department of the University of Wisconsin. Any changes which were made during the test were done by the same department. Having the work done in this manner duplicated ordinary building practice very closely.

Procedure

The wall was placed in the machine, the machine clamped into place, and several preliminary runs were made to ascertain if there was any leakage through the various parts of the machine itself. When all of the leaks had been stopped, the joint between the steel frame and the brick wall was calked to insure that all the

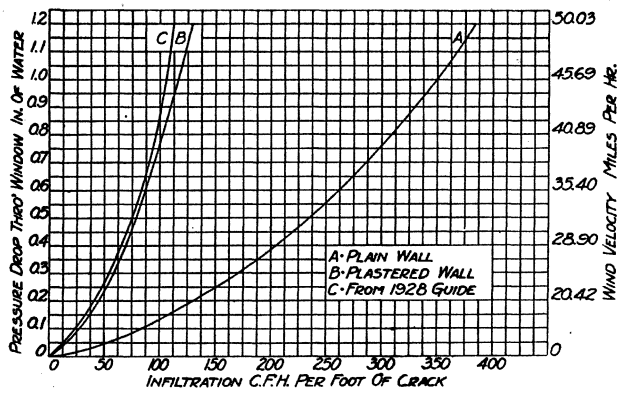

FIG. 6. INFILTRATION THROUGH CRACK BETWEEN BRICK WALL AND WINDOW FRAME

leakage must take place through the brick, through the window frame or through the sash perimeter of the window. In all cases of calking adhesive tape was first placed over the crack and this covered with a plastic calking compound. In this manner the calking could be easily removed and insured against the calking compound entering very small cracks which could not be cleaned out when a duplicate test was desired. This method proved very satisfactory and was employed during the entire series of tests.

Test data were obtained at pressure drops through the wall corresponding to increments of wind velocities of 5 mi. per hour over a range from 10 to 50 mi. per hour, inclusive. This pressure drop was controlled by varying the amount of air allowed to enter the pressure chamber from the blower. Readings of the wet- and dry-bulb temperatures and the atmospheric pressures were taken during the progress of each run. The inclined gage and the Whalen gage were read

simultaneously for each pressure after the air conditions in the machine had sufficient time to become stable.

Check runs were made on each set of conditions so that the curves represent the average of at least six separate runs, and in some cases as many as twenty-four runs. After each set of two runs the window was opened and closed several times to insure that an average value for the window closing would be obtained.

To obtain the infiltration through any one crack a series of runs were made to determine the total leakage through the wall and window as it was placed in the machine. The crack was then calked in the manner previously described and another series of runs were made. The actual leakage for the crack in question was determined by subtracting the leakage found in the second test from that in the first for a

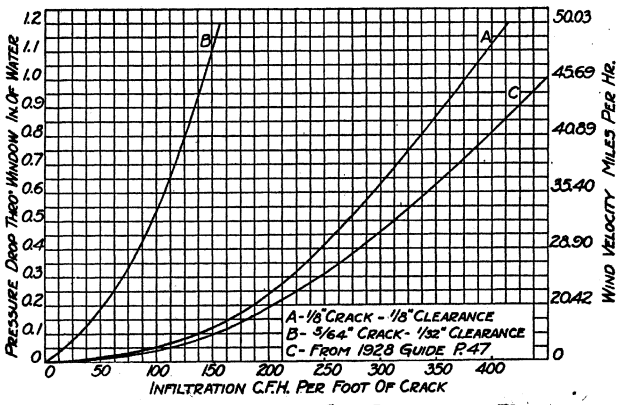

FIG. 7. INFILTRATION THROUGH SASH PERIMETER OF WINDOW

given pressure drop through the wall. In this manner each leakage could be isolated and determined in the easiest manner. During the entire test care was taken to see that the setting of the wall was not disturbed and all calking was carefully inspected to insure against leaks.

Discussion of Results

The data taken during the tests supplied the necessary information to determine the leakage through the various parts of the window and wall. All infiltration was measured in cubic feet per minute by the orifice method. These data were then reduced to infiltration in cubic feet of air at standard conditions, 29.92 in. of mercury, 70 deg. fahr. and 50 per cent relative humidity per hour per foot of crack. This gives a factor which may be multiplied by the number of lineal feet of crack in the room for which the heat loss is to be figured.

Fig. 6 shows the infiltration through the crack between the brick wall and the

window frame, *A* for the plain brick wall, *B* for the plastered wall and *C* is plotted from the data given on page 47 of the 1928 GUIDE. There is a considerable reduction of this leakage by plastering the wall, but all of the leakage may be stopped by calking the window frame in the brick wall during construction or even later at a very slight expense.

The curves plotted in Fig. 7 show the infiltration through the sash perimeter of the window, *A* for the window fitted with $^1/_8$-in. crack and $^1/_8$-in. clearance, *B* for the window fitted with $^5/_{64}$-in. crack and $^1/_{32}$-in. clearance, and *C* for the average window from data given on page 47 of the 1928 GUIDE. These curves show very

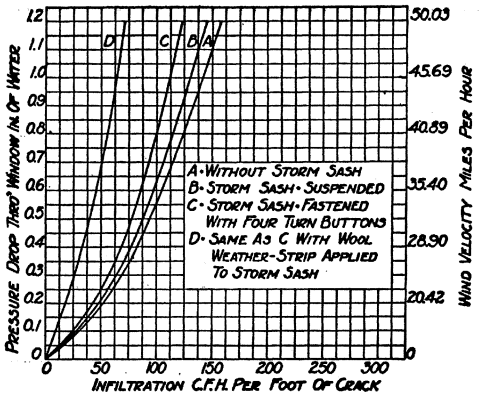

FIG. 8. INFILTRATION THROUGH SASH PERIMETER OF WINDOW WITH AND WITHOUT STORM SASH—$^5/_{64}$" CRACK AND $^1/_{32}$" CLEARANCE

clearly the increase in infiltration which accompanies an increase of the crack and clearance.

The curves on Fig. 8 show the infiltration through the sash perimeter of a window with $^5/_{64}$-in. crack and $^1/_{32}$-in. clearance before and after storm sash have been applied. Curve *A* is for the window without storm sash, *B* for the window with storm sash suspended by the hook and eye arrangement, *C* for the window with storm sash fastened with four turn buttons, and *D* is the same as *C* except a felt strip was placed between the storm sash and the window frame. This last condition could be used to advantage where the windows are fastened by means of the turn buttons.

The curves on Fig. 9 correspond to curves *A*, *B* and *C* of Fig. 8 except the window is fitted with an $^1/_8$-in. crack and $^1/_8$-in. clearance.

The storm sash used for both series of tests was fastened so that it rested against

the window frame as tightly as possible. A crack of $^3/_{64}$ of an inch was left between the storm sash and window frame. This was considered to be a conservative size although some storm sash very probably have a crack which is larger than this.

The infiltration through the window after the storm sash had been applied was figured on the basis of the sash perimeter of the window and not the perimeter of the storm sash. This point should be noted as there is considerable difference between the two perimeters.

Care was taken during the entire test that conditions in the machine would be

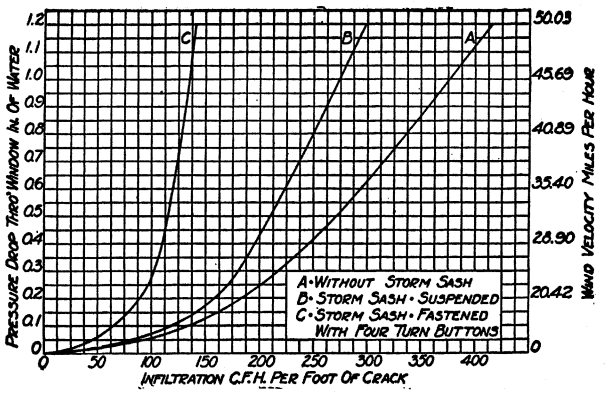

FIG. 9. INFILTRATION THROUGH SASH PERIMETER OF WINDOW WITH AND WITHOUT STORM SASH—$^1/_8$" CRACK AND $^1/_8$" CLEARANCE

constant for a given series of runs or the check runs. As stated previously the window was opened and closed several times for each test to insure an average closing. In closing the window, the only thing that was duplicated was to have the meeting rails flush. No effort was made to have the lower sash resting upon the sill of the window frame. The machine was watched and precautions were taken to see that no leaks developed in the collecting chamber. The manner in which some of the latter test data checked, previously collected data proved that no leaks had developed in the collecting chamber during the time tests were made.

Results

The pressure drop through the wall gave artificial wind velocities of desired values. The tests of windows in the Southwestern Bell Telephone Co. Bldg. at St. Louis, as reported by F. C. Houghten and M. E. O'Connell in the November, 1927, JOURNAL OF THE AMRICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS,

established the fact that data collected under conditions of artificial wind pressure checked very closely with those taken under conditions of actual wind pressure. It is, therefore, reasonable to assume that the result obtained from this series of tests applies to conditions existing in actual buildings.

Table 1 gives the leakage, heat loss and square feet of radiation per foot of crack between the brick wall and the window frame. These are average values from a number of test runs.

Conclusions

The infiltration through the crack between the brick wall and window frame is a very important factor in calculating the infiltration into a room. However,

TABLE 1. INFILTRATION IN CUBIC FEET PER HOUR BETWEEN BRICK WALL AND WINDOW FRAME PER FOOT OF CRACK AND SQUARE FEET OF RADIATION NECESSARY TO HEAT SUCH LEAKAGE FROM 0 TO 70 DEG. FAHR.

	Plain Wall			Plastered Wall		
Wind Velocity Miles per Hour	Leakage Cubic Feet per Hour	Heat Loss B.t.u. per Hour	Square Feet Radiation	Leakage Cubic Feet per Hour	Heat Loss B.t.u. per Hour	Square Feet Radiation
5	20.0	25.2	0.11	4.0	5.0	0.02
10	52.0	65.5	0.27	15.0	18.9	0.08
15	89.0	112.0	0.47	28.0	35.3	0.15
20	127.5	160.5	0.67	44.0	55.4	0.23
25	170.0	214.0	0.89	58.5	73.7	0.31
30	216.0	272.0	1.13	73.0	92.0	0.38
35	258.5	325.5	1.36	86.5	109.0	0.45
40	302.0	380.5	1.59	100.0	125.9	0.52
45	344.5	434.0	1.81	114.0	143.5	0.60
50	384.0	484.0	2.02	128.0	161.3	0.67

this source of leakage can be practically eliminated by the application of some type of calking compound to the crack.

The application of storm sash does not materially decrease the infiltration of a tight fitting window, but does give a large saving if the crack and clearance of the window is large. The application of a wool strip between the frame and storm sash reduced the infiltration appreciably.

The storm sash applied by means of the four turn buttons reduced the infiltration much more than those applied by means of the hook and eye suspension arrangement.

The infiltration through the crack between the brick wall and window frame for a plastered wall is about 40 per cent of that through the same crack on a plain wall. This leakage may be as great as the leakage through the sash perimeter of the window.

Data on runs which duplicate previous tests made at the Research Laboratory check very closely with the data from that laboratory.

DISCUSSION

L. B. LENT (WRITTEN): I would like to call attention to a statement at the top of p. 551, which statement might be misleading to some not well acquainted

with construction work. This statement is as follows: "A porous type of brick commonly known as the Chicago clay brick and ordinary lime mortar were used for the construction of this wall. These materials are used very extensively for construction purposes, and it was decided upon as one of the combinations of masonry wall to be tested."

It is hardly true that this type of construction is *used very extensively* and, therefore, does not represent anything except a very small part of the brick construction done in this country.

In the first place, Chicago brick are used almost entirely within the Chicago district. Brick produced in all other states are very largely consumed in a local market.

Lime mortar is not recommended or used where the better type of construction is required. In this case either cement mortar or cement mortar with a small part of added lime is the preferred kind. It might be well to recall that the investigation at the University of Wisconsin is not yet completed, and that the full program was intended to discover the effect of what might be called the extremes of brick quality, kind of mortar and grade of workmanship.

The test reported in the paper merely represents the poorest grade of these three factors. It should not, therefore, be taken to represent what might be called an average grade of brick masonry, although there is no such thing as an average grade. The paper might well mention these facts and further state that further investigation will, no doubt, show that with better grades of brick, mortar and workmanship the resulting infiltration might be materially reduced.

It is also a fact that in better construction, window frames are usually set in mortar all around and calked at the same time.

E. C. EVANS: I want to ask if the wall that is going to be continued in the test was built by an ordinary brick layer or whether particular attention was paid to the mortar that was placed when the wall was being built. I think this is most important. The curves show it, to compare with THE GUIDE. We find that same factor coming up. I think particular attention should be paid to that. It ought to be built at present, and then similar curves made, go through the same items of test, repeated after the wall was torn down, and another wall built by the same man, but supervised for the amount of mortar used. Definite records should be made of what the difference was, calking costs, together with cost of extra mortar, extra labor, and time, for only in that way will we get information that we can put back through the Committee of the American Institute of Architects. Let that come back for the benefit of those who have to build houses.

E. K. CAMPBELL: Continuing that same thought, I want to bring out this fact: that there is one factor that can never be determined in the laboratory; that is, shrinking of wood frames from a brick wall. In one instance in Kansas City it took half a bale of cotton to fill the crack after the building was 10 or 15 years old. The statement has been made that most buildings are having the windows calked. That is not true in the Kansas City territory.

W. C. RANDALL: I want to refer to one statement on p. 557. "It is therefore reasonable to assume that the result obtained from this series of tests applies to conditions existing in actual buildings."

There are two points involved, as I see it. First of all, as Mr. Campbell in his discussion has indicated, the authors have not taken into account the expansion and shrinkage of the wood windows in actual installation over a period of time. I think certain cracks develop in wood windows that probably are not common to a relatively new window in test conditions.

The second point that I again want to emphasize, is that they have run the pressures up to the equivalent of fifty-mile wind velocities, and the evidence which we and others have obtained would indicate that such pressures are not normally found and are probably much lower than that. A great deal more work has to be done to properly evaluate the drop in pressure to approximate actual conditions.

W. M. RICHTMANN: In reply to Mr. Evans' question on the construction of the wall, the window frame and storm sash were bought at a local lumber company, the brick from the local brick dealer, and the work was done entirely by the service department of the University of Wisconsin. This department does all the repair work around the university, and I believe is practically what you might call ordinary or common labor; the fact that the wall was to be used for testing did not change the kind of workmanship.

As time goes on we may find that leakage will develop from the shrinkage of the window frame and sash. This wall is going to be put in the storage rack and tested from time to time as the work proceeds. This is merely the result of our first year's work, and a good many things can't be brought out which may come up with the time element.

Mr. Campbell's question of shrinkage: that again is rather hard to determine in this first test, due to the fact that the window is stored in a building and is not subjected to outside weather conditions. It is a new window and consequently a certain time must elapse to give the frame and sash an opportunity to shrink.

In reply to Mr. Randall's statements we have found from the other men working on infiltration tests that we are carrying the curves into too high a range and intend in the following work to reduce our high pressures and get more data at the pressures which seem to be those under which the windows are subjected. Of course, it is rather hard, as was brought out in the previous papers, to know what a 15-mile wind velocity as recorded by the Weather Bureau is going to be in connection with the window itself; and we have merely tried to follow the practice as used in THE GUIDE and reduce our results to the same basis so they may be used in the future GUIDE Tables.