No. 888

AIR LEAKAGE THROUGH VARIOUS FORMS OF BUILDING CONSTRUCTION

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THE study of infiltration through masonry walls was undertaken at the Research Laboratory of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS in 1925. The tests were made in two pieces of apparatus (Fig. 1) designed for that purpose. Early in the investigation it was discovered that the rate of infiltration through masonry walls increased for several months after building, and as a result, the testing of different types of construction in the available apparatus in the Pittsburgh Laboratory became a very slow process.

In 1927 the major portion of the infiltration studies of the Laboratory was transferred to the University of Wisconsin under a cooperative agreement. Profiting by the earlier experience in Pittsburgh, the apparatus at Wisconsin was so designed that a large number of walls could be built in steel frames which could later be moved into the testing machine from time to time as the walls aged. This made possible a more rapid testing program, since the testing apparatus was not tied up by a single wall during the aging process.

Since 1926, the two pieces of apparatus at the Laboratory have been kept in constant use with the result that there has now accumulated data on several types of construction which are made the basis of this report. These data will help in extending the knowledge of the infiltration through different types of construction and will also serve to indicate variations which may be found in the rate of air leakage through different walls of the same type built by different mechanics under different conditions.

All the walls tested at the Laboratory since 1926 and here reported were built by Prof. C. W. Larkin, Head Instructor of Masonry at Carnegie Institute of Technology. In building these walls an attempt was made to follow as nearly as possible the practice of the building industry.

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The method of conducting the tests was identical with that previously used and reported in detail in earlier Laboratory reports [1,2]. The wall to be tested was built as a partition between the pressure chamber and the collecting chamber of the test apparatus (see Fig. 1). Except in cases where edge losses were the subject of investigation, the joint between the apparatus and the wall was carefully sealed with calking compound and then painted with an asphalt base paint so as to limit the leakage measured to that through the 6 x 10 ft. section of wall under test.

The desired wind pressures were produced in the pressure chamber by means

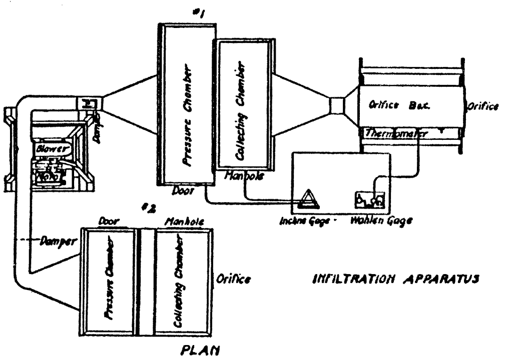

FIG. 1. ARRANGEMENT OF APPARATUS FOR MEASURING LEAKAGE OF AIR THROUGH WALLS

of a blower and the air leaking through the wall into the collecting chamber was measured as it passed out through the calibrated orifice. A Wahlen gage was used to measure the pressure drop through the orifice and a sensitive inclined gage was used to measure the pressure drop through the wall. In analyzing the data, the leakage per square foot of wall or per linear foot of crack was plotted against pressure drop through the wall and the equivalent wind velocity.

Data are given in this paper on the following types of construction:

1. A 13-in. brick wall after plaster had been removed from the wall and the joints repointed.
2. Same as (1) with the application of paint.
3. A frame wall consisting of siding, sheathing, paper, lath and lime plaster.
4. Same as (3) with gypsum plaster.
5. Same as (4) with sizing and paper.
6. Leakage per foot of crack between plaster or stucco and wood frame.

[1] *Air Leakage Through the Openings in Buildings*, by F. C. Houghten and C. C. Schrader. (A. S. H. V. E. TRANSACTIONS, Vol. 30, 1924).

[2] *Infiltration Through Plastered and Unplastered Brick Walls*, by F. C. Houghten and Margaret Ingels. (A. S. H. V. E. TRANSACTIONS, Vol. 33, 1927).

TABLE 1. RESULTS OF TESTS SHOWING AIR INFILTRATION IN CUBIC FEET PER HOUR PER SQUARE FOOT OF WALL SURFACE FOR VARIOUS WIND VELOCITIES

Fig. No.	Curve	Types of Construction	Age in Days	Wind Velocity Miles per Hour					
				5	10	15	20	25	30
2	A	13-in. plain brick wall	22	1.80	4.90	9.35	14.50	20.30	25.50
2	G	Same as 2A, with plaster on brick	183	0.006	0.016	0.031	0.054	0.084	0.121
2	B	Same as 2G, plaster removed, wall repointed	384	1.35	3.25	6.15	10.20	14.95	20.00
2	C	Same as 2B, with one coat paint	387	1.25	2.85	5.10	8.00	11.60	15.65
2	E	Same as 2B, with three coats paint	398	1.05	2.45	4.50	7.00	9.60	12.50
2	F	Same as 2B, with six coats paint	406	0.02	0.06	0.10	0.15	0.20	0.25
4	C	Frame wall siding, paper, sheathing, studs, lath and lime plaster	156	0.25	0.60	1.10	1.90	2.95	4.10
4	D	Frame wall siding, paper, sheathing, studs, lath and gypsum plaster	145	0.25	0.45	0.75	0.95	1.10	1.35
4	E	Same as 4D, with sizing and paper	266	0.10	0.22	0.42	0.60	0.75	0.95
7	B	⅞ in. sheathing, studding, paper, metal lath and stucco		0.12	0.25	0.40	0.50	0.70	0.90
7	D	13 in. brick and tile wall...		1.05	2.90	5.55	8.60	12.15	16.15
				Infiltration in cfh per foot of crack					
8	H	Average, crack between frame and plaster or stucco		0.06	0.135	0.236	0.360	0.50	0.65

7. A stucco wall consisting of sheathing, paper, metal lath, and stucco (without inside plaster finish).
8. A 13-in. brick veneer hollow tile wall.

Figs. 2, 4, 7 and 8, and Table 1 indicate the infiltration rates found for these types of construction.

RESULTS OF TESTS

Brick Wall

The brick wall on which leakage values for both the plastered and plain wall were reported in an earlier Laboratory report was tested after the plaster had been carefully removed and the joints had been repointed. The leakage is given in curve *B*, Fig. 2. This leakage is found to be somewhat lower than that reported for the same plain brick wall before plastering which leakage is shown in curve *A* for comparison. This reduction is probably due to better pointing of the joints after the plaster was removed. One coat of paint was then applied to the inside brick surface with the result shown in curve *C*. Curve *E* gives the results after the application of three coats of paint. It was rather astonishing to those conducting the tests that the paint did not have a greater effect in reducing the leakage, but upon careful inspection of the surface, it was found that the paint did not fill up and seal over the larger cracks and crevices in the wall and it was apparent that the greater portion of the leakage took place through these openings. The wall was then carefully examined and calking material placed in all visible cracks or crevices, followed by an application of paint. This was repeated three times, resulting in leakage indicated by curve *F*. It is apparent that careful calking and painting of brick walls will give a reduction in leakage comparable to the reduction found for plastering. Curve *G* indicates the leakage earlier reported for the plastered brick wall and is included for the sake of comparison. It should be emphasized, however, that this result was obtained only through a very laborious process of searching out all cracks and crevices and seeing that they were sealed up and covered with paint. It is doubtful if this is a practical procedure.

Curves *H*, *I* and *K*, resulting from tests by Larson and Nelson [3] are also included for purposes of comparison. These are for 13-in. brick walls of the following types: *H*, poor workmanship, lime mortar and porous brick; *I*, good

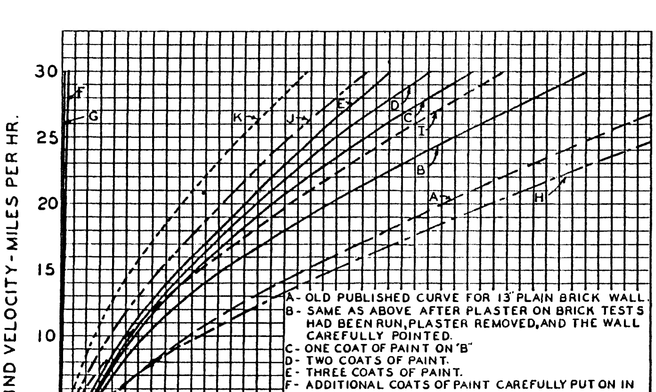

FIG. 2. INFILTRATION THROUGH 13-IN. BRICK WALL

workmanship, cement lime mortar, and porous brick; *K*, good workmanship, cement lime mortar and hard brick. Curve *J* indicates the leakage reported for the *I* wall after the application of three coats of paint.

Frame Wall

The details of construction of the frame wall are shown in Fig. 3. The outside construction consisted of ⅞ in. x 8 in. sheathing, building paper, and lap-siding. The sheathing was purchased on the local market for this purpose and was applied immediately with the butt edges firmly against each other so as to allow no visible cracks. After removing the first coat of plaster

[3] *Air Infiltration Through Various Types of Brick Wall Construction*, by G. L. Larson, D. W. Nelson and C. Braatz, A. S. H. V. E. TRANSACTIONS, Vol. 36, 1930.

several months later, it was observed that the sheathing had shrunk showing cracks from ⅛ to ¼ in. in width.

The interior of the wall was lathed and plastered with two coats of rough lime plaster and one lime skim coat. After aging, the frame wall with this plaster showed the leakage indicated by curve *A*, Fig. 4. However, a considerable portion of this leakage took place through the joint between the plaster and the surrounding wood frame as indicated by the infiltration shown by curve *C*, found after sealing the joint. Fig. 5 is a cross section of the construction showing this crack. The frame construction on which the lath and plaster was applied was built in a 1½ x 8-in. board frame placed in the channel iron frame forming part of the apparatus. The joint between the wood frame and the channel frame was carefully calked so that no leakage took place

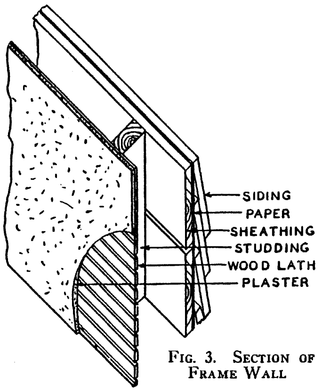

FIG. 3. SECTION OF FRAME WALL

through this joint. The leakage through the frame wall with gypsum plaster before sealing the crack between plaster and wood frame is given by curve *B* and that taking place after this crack was sealed is given by curve *D*. This wall was then sized and papered and again tested giving the leakage indicated by curve *E*.

Stucco Wall

The details of construction of the outside stucco finish is shown in Fig. 6. The ⅞ x 8 in. unmatched sheathing was again purchased on the local market and immediately applied to the studding so as to give as small cracks as possible. Paper and metal netting was applied to the sheating on which two coats of cement plaster and one coat of finish stucco were applied. By using special spacing nails the paper was held firmly against the sheathing and the wire netting was held about ¼ in. away which resulted in the netting becoming completely imbedded in the stucco. By the time the stucco had aged sufficiently for testing, it was again observed that the sheathing had shrunk so as to leave from ⅛ to ¼ in. cracks between boards.

The stucco wall was built in the same board frame discussed under the plastered wall and curve *A* (Fig. 7) gives the leakage after aging but before the crack between the stucco and the wood frame was sealed up while curve *B*

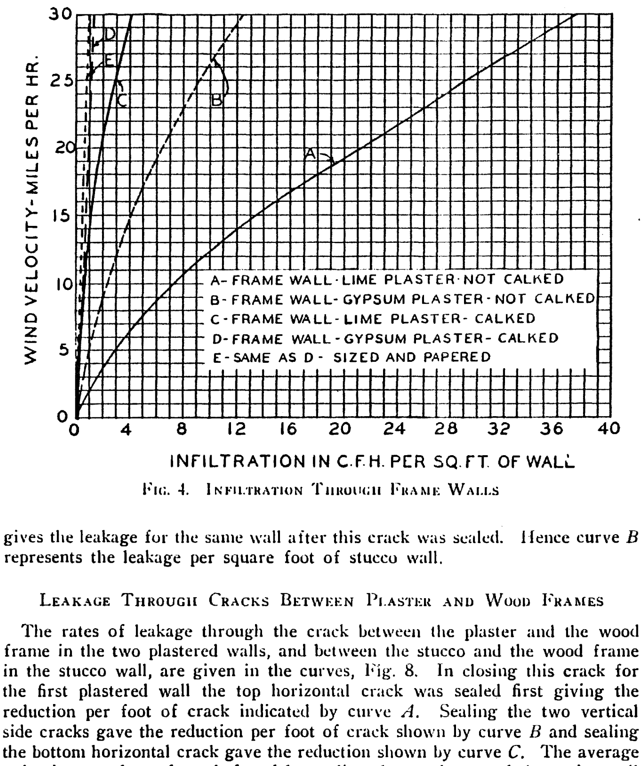

FIG. 4. INFILTRATION THROUGH FRAME WALLS

gives the leakage for the same wall after this crack was sealed. Hence curve *B* represents the leakage per square foot of stucco wall.

LEAKAGE THROUGH CRACKS BETWEEN PLASTER AND WOOD FRAMES

The rates of leakage through the crack between the plaster and the wood frame in the two plastered walls, and between the stucco and the wood frame in the stucco wall, are given in the curves, Fig. 8. In closing this crack for the first plastered wall the top horizontal crack was sealed first giving the reduction per foot of crack indicated by curve *A*. Sealing the two vertical side cracks gave the reduction per foot of crack shown by curve *B* and sealing the bottom horizontal crack gave the reduction shown by curve *C*. The average reduction per foot of crack found by sealing the crack around the entire wall is given by curve *E*.

Sealing the crack around the second plastered wall gave the average reduction per foot of crack shown by curve *F* and sealing the entire crack around the stucco wall gave the reduction shown by curve *G*. Curve *D* gives the average leakage per foot of crack between plaster and wood frame or the average of

curves *E* and *F*. Curve *H* gives the average leakage per foot of crack for the two plastered walls and the stucco wall or the average of curves *E, F* and *G*.

It is the opinion of the authors that the leakage shown by the curves obtained by the reduction of the leakage for the walls after sealing the joints is fairly representative of the leakage through the joint between plaster or stucco and the frame work of doors and windows and around the floor line of plastered

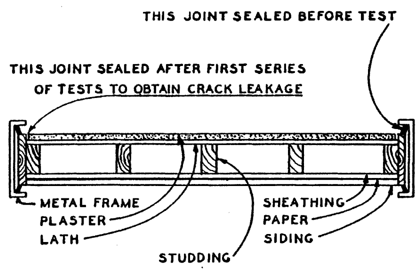

FIG. 5. CROSS-SECTION OF FRAME WALL SHOWING CRACKS

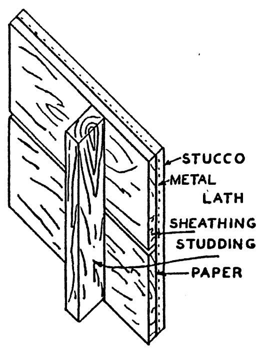

FIG. 6. SECTION OF FRAME STUCCO WALL

walls. A very definite crack always appears at these points during the drying and aging process. It should be pointed out, however, that in most types of construction the finish trim is applied in such a way as to cover this crack. While such trim will always reduce the leakage through the crack to some extent, it rarely eliminates it entirely unless special pains are taken to close the joint between the plaster and trim.

BRICK VENEER HOLLOW TILE WALL

Details of construction of the brick veneer hollow tile wall are shown in Fig. 9. The joints between brick and tile were only partially filled with mortar in

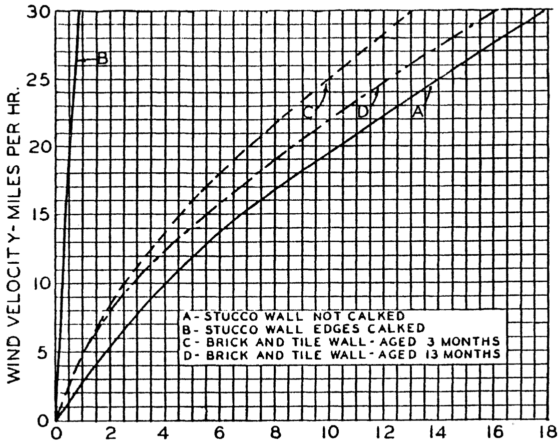

FIG. 7. INFILTRATION THROUGH FRAME STUCCO, AND BRICK AND TILE WALLS

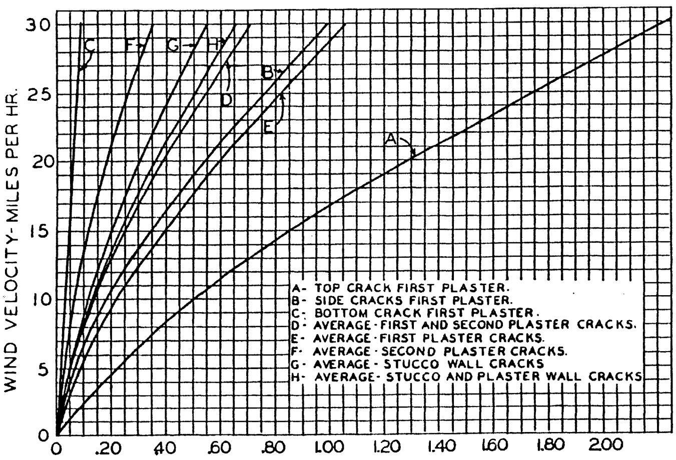

FIG. 8. INFILTRATION THROUGH CRACKS IN FRAME AND STUCCO WALLS

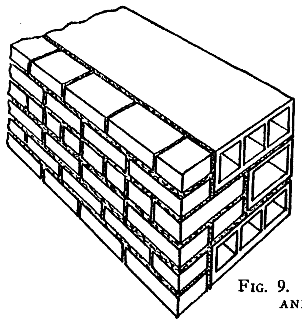

FIG. 9. SECTION OF BRICK AND TILE WALL

a manner similar to common practice. The leakage for this wall three months after construction is given in Fig. 7 by curve *C*, and the leakage after 13-months aging is given by curve *D*.

DISCUSSION

MARGARET INGELS (WRITTEN): I was especially glad to see the information in this paper concerning the air leakage around the edges of plastered walls.

It should be borne in mind that the air leaking through a given wall of a building may not be the product of the cubic feet of air per square foot times the area of the wall. If there is a space within the wall where an air current may be set up, the infiltration may be considerably more than figured from the unit area value. Plaster is practically air tight but a plastered wall may not be, if there is a space between the plaster and the outside portion of the wall which permits a circulation of air within the wall. The air leaking in through the outside portion enters this space and may flow into the interior of the building over baseboards, or escape into the space between ceilings and floors to leak in around interior door frames.

The infiltration of a wall is the sum of 3 factors:

(1) Infiltration due to cracks of windows in the wall. (This factor may be obtained from the data published by the Research Laboratory of the Society.)

(2) Infiltration through walls. This factor may be obtained for several types of walls; also from the data of the Research Laboratory.

(3) Infiltration due to space within the wall which permits air flow between portions of the wall. If there is no air space, or if the air space is sealed, this factor becomes zero.

The curves in Fig. 4 show the effect of the air circulating back of the plaster and finding an outlet around the edges of the plaster. Curve *A* shows the leakage through a frame wall with lime plaster, the crack between the plaster and wood frame not calked. Curve *C* shows the leakage through the same wall with the cracks calked. The difference in these two curves may be called the infiltration around the edges of plaster. Such edges would occur in actual installations at the base boards, window frames and door casings. At 15 miles wind velocity the difference in infiltration is shown as 12.5 cu ft per hour per square foot of wall. When estimating the leakage through a wall of this construction, should the wall area be multiplied by 13.5 cu ft per hour, or 1.0 cu ft per hour to get a fair estimate of the infiltration through the wall?

In the data for stucco walls the edges of plaster leaks are shown, the top, side and bottom edges each having a different factor. The average cubic feet per hour per foot of crack shown in Fig. 8, Curve *H*, is quite valuable in obtaining the third factor for this type of wall for the total infiltration through it.

The air space, not being sealed, tends to increase the infiltration; the amount of increase depending on the probable length of plaster edges, which may be the perimeter of external wall times the number of floors (each baseboard) plus the sum of the perimeter of all window frames and outside door casings. The additional infiltration due to the plaster edges would be the total length of the edge crack times the cubic feet per hour per foot for the given wind velocity and divided by 2, as the possible maximum crack, exposed to the wind will be ½ of total for home.

The consideration of the space which permits air circulation within the walls is also of importance in determining the heat transfer through the wall.

In buildings with large volume in comparison to external wall surface this third suggested factor is not so important. But, in figuring the heat load for residences it is important because there are usually large amounts of outside wall in comparison to enclosed volumes.

L. B. Lent[4] (Written): It might be helpful to those who might use these data in design problems to point out that the use of *average* values derived from laboratory experiments may not fit the case in hand and might be a source of error in exact calculations.

To be more specific, conditions found in actual structures may be quite different from those present in the laboratory.

For example, it is stated that in building the brick walls, attempt was made *to follow as nearly as possible the practice of the building industry*. But this practice varies widely in different parts of the country and even in the same city, and the character and performance of brick masonry is known to be greatly influenced by this matter of workmanship. Also aged brick walls seemed to pass more air than new ones.

Again, it was found that, in the frame wall panels, after several months, "the sheathing had shrunk showing cracks from ⅛ to ¼ in. width."

And, that "leakage took place through the joint between the plaster and the surrounding wood frame."

It would therefore appear that, in all of the types of construction examined, conditions which might greatly influence air infiltration in actual structures or structural parts might vary greatly as between similar types and as between different ages of the same type.

In other words, the condition of a brick, frame or stucco wall, a few years after construction might be entirely different (as it affects air leakage) than when newly constructed; or, quite different from the conditions described in these tests.

Hence, a logical conclusion would seem to be that the data given in this paper should be used with caution. The use of *average* values is sometimes dangerous.

In this matter of air leakage through walls, however, the saving feature is that the amount of leakage through the conventional types of walls is practically negligible and may be even desirable as furnishing the necessary ventilation. The usual application of plaster or stucco on the wall surface confines air leakage to the cracks. It is these cracks, either structural cracks around wall openings or undesirable cracks in the walls themselves which really merit our consideration.

[4] Chief Engineer, *Common Brick Manufacturers' Association of America.*

D. W. Nelson (Written): It is interesting to those of us at the University of Wisconsin who are engaged in infiltration testing, to review the excellent work done in the Research Laboratory of the Society that is reported in this paper. This paper gives valuable additional data on the subject and shows what variations may be expected from different constructions built under different circumstances by different mechanics.

The 13-in. plain brick wall tested after removing the plaster and repointing shows a leakage somewhat less than that of the poorest wall but more than that of the better walls built at Wisconsin. The fact that repointing reduced the leakage seems to bear out the belief that most of the air finds its way through the mortar joints and that this is probably through a hair-line crack at the contact between the brick and the mortar. This crack is caused by a shrinking away of the mortar during the hardening period. A second application of mortar as in repointing, reduces the leakage through this crack.

The application of 3 coats of paint to this brick wall showed about the same reduction in leakage as we found for brick wall No. 4. The application of 2 coats to this wall No. 4 ordinarily applied resulted in a 9 per cent reduction. The third coat was applied with exceptional care in an attempt to fill all pores and hair-line cracks. The result was a total reduction of 28 per cent for 3 coats of paint. This comparatively small reduction for careful application of paint seems to be due to the paint not having sufficient body when dry to clog these hair line cracks.

The application of 3 more coats, 6 in all, to the Pittsburgh wall put on with special care and the use of calking material in all visible cracks reduced the leakage to a negligibly small value just as plastering would do. Due to the expense of this procedure from both the material and labor standpoint such reduction of leakage could not be obtained at a reasonable building cost.

Probably the application of hot asphalt to the brick wall would be effective in the reduction of air infiltration as well as in the prevention of moisture entrance for which reason alone, it is usually justified. The application of such a coat to the brick surface of a furred wall is to be recommended due to the loss of effectiveness of the plaster by leakage at the edges of the plaster sheet at window and door openings and at the baseboard.

The tests at Wisconsin on brick wall No. 7, which was equipped with a standard baseboard applied to the usual furred and plastered construction, showed that the efficiency of the plaster sheet in stopping air leakage was only about 50 per cent due to the crack at the baseboard. The crack at the baseboard allowed the passage of 12 cu ft per hour per foot of length and if it had offered no resistance would have passed 22.5 cu ft per hour per foot of length at 15 mph.

This leakage is much larger than that found at the Pittsburgh Laboratory and reported in this paper for the crack around the plaster and stucco sheets. The average of all was 0.25 cu ft per hour per foot of crack and the maximum was 0.85 cu ft per hour per foot of crack at 15 mph.

Should the baseboard be made exceptionally effective by running the plaster entirely to the floor or by using calking material between the baseboard and the plaster, there would still be the chance for air to enter into the floor and ceiling construction from the wall space and find its way into the room through openings such as around the steam pipes. There is also the chance for air to reach window frames in furred masonry and in frame walls. At this location, entrance to the room is not effectively resisted. In fact, the pulley holes and sash weight door cracks offer easy entrance. In our opinion the effectiveness of the plaster in furred masonry and in frame walls should not be over 50 per cent.

Because of the opportunity for air leakage at the edges of the plaster sheet, especially at the baseboard and window openings, building paper must be largely relied upon for infiltration effectiveness in frame construction. The tests at Wisconsin reported to the Society in June, 1930, showed that all of the half dozen walls of sheathing, paper and siding or shingles and without plaster had a negligible leakage. The air resistance is due to the paper which was effectively clamped between the 2 thicknesses of boards.

The leakage through the finished frame walls was less than ½ cu ft per square foot per hour at 15 mph. The values secured in Pittsburgh as shown in Fig. 4 are about 1.10 and 0.75 cu ft. These leakages are extremely small and in either case would be neglected in ordinary heat loss calculations. This difference, though negligible, may be due to a difference in method of calking. At Wisconsin, a recess was made in the 2 x 4s against the 4 x 8 wood members of the frame into which the walls were built. This was filled with calking compound. In addition a space of ⅛ to ¼ in. was left on the 4 sides of the outer wall against the frame and this space was filled with calking compound against the siding, paper and sheathing down to the 2 x 4s, so that air could not enter at the ends of the test panel.

Fig. 5 of this paper does not show calking at these locations and the slight additional leakage secured may be accounted for by this condition. It is a question which method of calking comes nearest to representing building conditions. In preliminary tests on frame walls *2B* and *3B* at Wisconsin, one of these end joints of siding, paper and sheathing was left uncalked and the leakage resulting was 1.70 cu ft as compared to 0.30 cu ft when sealed. This was considered to represent the condition at the corner of a house or against an opening. This crack leakage amounted to 0.20 cu ft per foot of crack per hour, which is close to that of the average plaster and stucco cracks found at the Pittsburgh laboratory.

The 13-in. brick and tile wall reported in this paper had an air leakage of about 5.0 cu ft per hour per square foot of wall at 15 mph arrived at by taking an average from the 2 curves shown in Fig. 7. An 8-in. hollow tile wall tested at Wisconsin had a leakage of 9.8 cu ft per square foot per hour at 15 mph. The tile itself then seemingly allows the passage of twice the air that the combined brick and tile wall does. There seems to be a great variation in workmanship on tile walls and some would have a much greater leakage than the foregoing figures would indicate.

The test on this brick and tile wall at the end of 13 months showed something over 20 per cent more leakage than did the test at 3 months. There was no indication in the brick wall tests at Wisconsin that there was any change in leakage attributable to aging. The tests were made at 5 months and then 2 months later. It would be interesting in the near future to again test these brick walls and the tile wall to look for an aging effect.