No. 868

AIR INFILTRATION THROUGH VARIOUS TYPES OF WOOD FRAME CONSTRUCTION

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MEMBERS

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

Introduction

FOR the past three years, a program of cooperative research has been under way sponsored by the *University of Wisconsin* and the American Society of Heating and Ventilating Engineers for the purpose of determining the relative air tightness of various types of building construction. The initial work of this program was confined to brick wall construction, the results of which are presented in the paper entitled, Air Infiltration Through Various Types of Brick Wall Construction, p. 99.

In the Summer of 1929, work was begun on a series of tests pertaining primarily to wood frame construction under a cooperative agreement between the Society, the University and the *National Lumber Manufacturers' Association*. It is the results of the latter program with which this paper is concerned.

Description of Test Apparatus

The test apparatus shown in Fig. 1 consists briefly of the pressure chamber *A*, and the collecting chamber *B*, between which the panel to be tested is secured by means of *C*-clamps. Air tight seals are obtained between the two sides of the panel frame and chambers *A* and *B* by means of a sponge rubber gasket attached to the perimeter of the chamber openings. Artificial wind pressure is produced by a small motor-driven blower, shown at the extreme left of Fig. 1. The blower is in communication with the pressure chamber through an adjustable damper *E* by means of which the pressure drop through the wall is controlled. Other control dampers are provided at *D* and on the intake to the blower itself. The pressure difference in chambers *A* and *B*, which is the pressure drop through the wall panel, is measured with an inclined draft gage, *F*.

The amount of air passing through a wall panel is measured by a set of interchangeable orifices ranging in size from 3/8 in. to 6 in. in diameter, mounted on the end of orifice box *C*. The pressure drop through the orifice is determined

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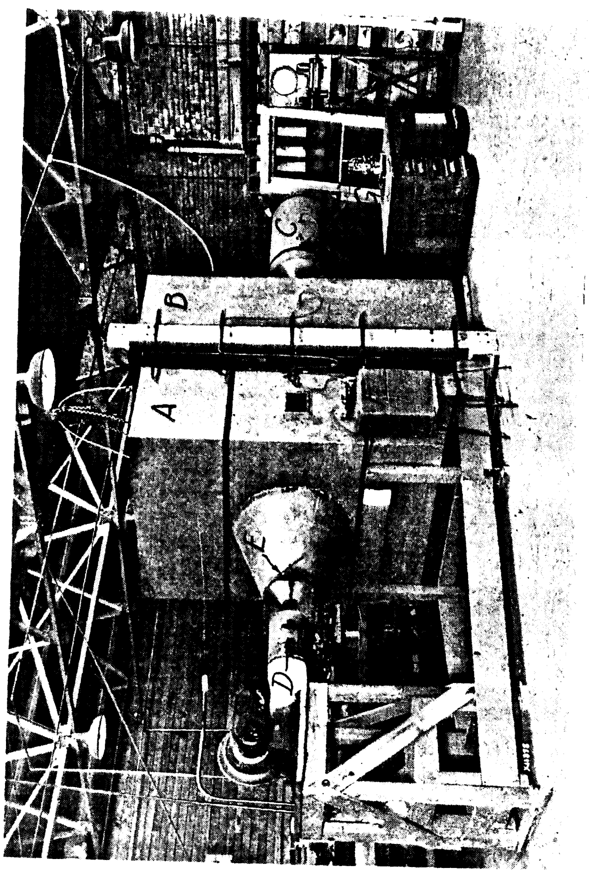

FIG. 1. GENERAL LAY-OUT OF TEST EQUIPMENT

by a Wahlen gage, *G*. To facilitate examination of a wall panel after it has been clamped in place, without disturbing the seal between the test machine chambers and the wall frame, a manhole is provided in each chamber on the side opposite that shown in Fig. 1.

DESCRIPTION OF TEST PANEL FRAMES

The test panels, described briefly in Tables 1 and 2 and in detail in the appendix of this paper, were built into rectangular frames constructed of four 4 × 8 air-dried Douglas fir timbers, in the manner shown in Fig. 15. The frame members were secured at the four corners by means of 6 × 6 × ½ in. angle irons, and the joints at these corners were thoroughly sealed with a plastic calking compound.

All construction work was done by a local contractor, under the supervision of L. V. Teesdale of the *U. S. Forest Products Laboratory*, who also passed upon the suitability of all construction material, with reference to specifications drawn by the *National Lumber Manufacturers' Association*. Every effort was made to have all construction comparable to that in actual building practice.

TEST PROCEDURE

Each test panel was subjected to wind pressure ranging from about 5 to 30 mph, for each of the test conditions as outlined in Tables 1 and 2. Except in the case of Panels *2B* and *3B*, the crack between the frame members and the test panel perimeter was completely sealed with plastic calking compound, leaving only the surface of the panel, 51 sq ft, open to leakage.

With the exception of the panel described in Item 34 of the appendix, all seasoning periods took place indoors at a temperature of approximately 70 F. The seasoning period for panel *6D*, Item 34, consisted for the most part of sub-zero weather together with one light snowfall and several days of sunshine.

DESCRIPTION OF TABLES 1 AND 2

A brief description of the different constructions built and tested is given in Tables 1 and 2. Cross-sections of the constructions listed in Table 1 are shown in Fig. 2 and for those listed in Table 2 in Fig. 3. More complete descriptions of the constructions built are given in the appendix. The description in the appendix for any particular panel number may be located by referring to the number in the column headed *Index to Specifications*.

Tables 1 and 2, in addition to giving a brief description of the constructions made and tested, list the standing periods from the date of construction to the date of test. Figs. 4 to 15 are photographs of typical wall constructions that were built. The columns headed *Index to Figures* in Tables 1 and 2 list the panel constructions for which photographs are included in this paper. These are the numbers appearing before the dash.

DISCUSSION OF RESULTS

The results of the tests on each one of the constructions made are given in Tables 1 and 2 under the heading of *Air Infiltration in Cubic Feet per Hour per Square Foot of Wall*. The results are given at wind velocities from 5 to 30 mph by 5-mile intervals. These wind velocities correspond to drops in pressure in inches of water across the wall as observed during the tests. The relation

TABLE 1. DESCRIPTION OF TEST PANELS AND SUMMARY OF RESULTS OF AIR INFILTRATION TESTS

Panel No.	Description of Construction: Outside Construction: Sheathing	Bldg. Paper	Siding	Inside Construction	Standing Period in Days	Air Infiltration in Cubic Feet Per Hour Per Square Foot of Wall — Wind Velocity—Miles Per Hour: 5	10	15	20	25	30	Panel No.	Index: To Figures	To Spec.
1A	1x6 Green Dressed and Side Matched No. 1 Common	None	None	None	29	16.3	47.0	81.2	115.0	149.9	188.0	1A	4	3
1A1	As in 1A except knot hole plugged	None	None	None	29	16.3	46.5	78.6	111.8	145.8	182.0	1A1	16	3
1B	1x6 Air Dried Butt-Edged No. 1 Common	Bldg. Paper B	1x10 Bevel Siding Air Dried	None	70	0.04	0.13	0.28	0.45	0.62	0.78	1B	20	22
1B1	As in 1B	As in 1B	Paint Added to Siding in 1B	None	6	0.03	0.10	0.18	0.27	0.35	0.43	1B1	20, 22	22
1C	As in 1B	As in 1B	As in 1B1	Wood Lath and 3 Coats Gyp. Plaster	68	0.03	0.09	0.16	0.23	0.29	0.33	1C	22, 24	23
1D	1x6 Air Dried Dressed and Side Matched No. 1 Common	None	¾x2 Expanded Metal 1⅛ in.—3 Coats Stucco	None	29	0.02	0.05	0.08	0.12	0.14	0.15	1D	25	15
2A	1x6 Air Dried Dressed and Side Matched No. 1 Common	None	None	None	28	2.4	8.0	15.3	23.3	32.5	42.3	2A	5,-16, 25	4
2B	As in 2A	Bldg. Paper A	1x6 Drop Siding Air Dried	None	14	0.04	0.13	0.28	0.45	0.62	0.78	2B	7,-20, 21	6
2B1	As in 2A	As in 2B	Paint Added to Siding in 2B	None	6	0.03	0.12	0.27	0.43	0.59	0.75	2B1	20	6
3A	1x6 Air Dried Dressed and Side Matched No. 1 Common	None	None	None	28	1.3	4.6	9.3	15.1	21.5	28.8	3A	6,-16, 25	4
3B	As in 3A	Bldg. Paper A	1x6 Bevel Siding Air Dried	None	14	0.04	0.13	0.28	0.45	0.62	0.78	3B	7,-20, 21	6
3B1	As in 3A	As in 3B	Paint Added to Siding in 3B	None	6	0.02	0.06	0.11	0.17	0.22	0.27	3B1	20	6
3C	1x4 Boards on 5-in Centers No. 2 Common	None	5/2-16 in. Red Cedar Shingles—5-in. Exposed	None	69	13.4	39.5	69.5	101.1	135.0	172.0	3C	19, 25	16
3D	As in 3C	Bldg. Paper B	As in 3C	None	69	0.07	0.22	0.38	0.54	0.70	0.84	3D	19	21
4A	1x6 Air Dried Dressed End and Side Matched No. 1 Common	Bldg. Paper A Studs Vert.	None	None	29	0.05	0.16	0.31	0.50	0.69	0.90	4A	8,-18	5
4A1	As in 4A	Cut Out	None	None	None	20.0	48.5	80.3	114.1	148.2	184.5	4A1	16	5
4B	1x8 Air Dried Ship-lap No. 2 Common	None	5/2-16 in. Red Cedar Shingles — 5-in Exposed	None	14	2.1	7.5	15.3	24.8	34.9	45.3	4B	9, 10-19	17
4D	None	Bldg. Paper B Studs Vertical	1x6 Air Dried Select Drop Siding Painted	None	4	0.06	0.15	0.23	0.31	0.38	0.45	4D	....	31
4E	None	As in 4D	As in 4D	1x6 Sheathing End and Side Matched	6	0.06	0.15	0.23	0.31	0.38	0.45	4E	24	32
4F	1x6 Air Dried Dressed End and Side Matched No. 1 Common	None	None	None	None	3.6	13.4	28.3	45.5	63.8	82.7	4F	16, 25	33

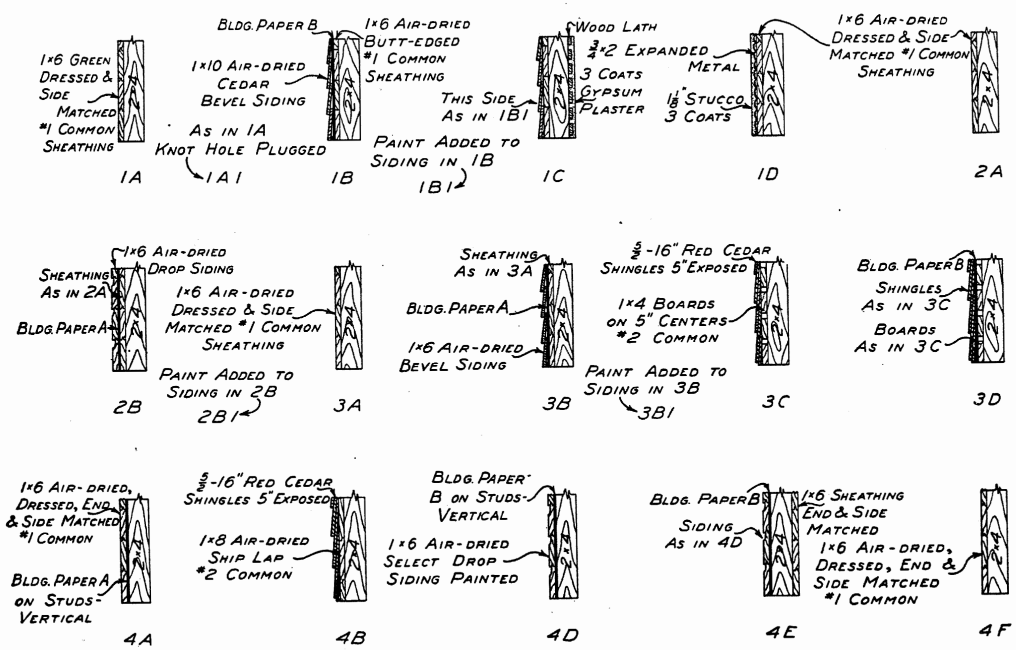

FIG. 2. CROSS-SECTIONS OF PANELS

TABLE 2—DESCRIPTION OF TEST PANELS AND SUMMARY OF RESULTS OF AIR INFILTRATION TESTS

Panel No.	Description of Construction: Outside Construction: Sheathing	Bldg. Paper	Siding	Inside Construction	Standing Period In Days	Air Infiltration in Cubic Feet Per Hour Per Square Foot of Wall: Wind Velocity—Miles Per Hour: 5	10	15	20	25	30	Panel No.	Index: To Figures	To Spec.
6A	Insulation A Sheathing Board	None	None	None	30	3.8	9.8	16.1	22.5	29.2	36.4	6A	11,-16	7
6B	None	None	Corrugated Steel	None	14	9.0	26.2	45.4	65.1	85.2	106.7	6B	12,-25	9
6C	1x8 Air Dried Ship-lap No. 2 Common	None	24 in. Red Cedar Shingles 11 in. Exposed	None	14	7.2	23.1	43.8	67.1	90.9	116.7	6C	19	19
6D	None	None	1x10 Boards — Spaced 1x4 Battens — Paint	None	14	16.3	49.0	86.9	126.5	165.8	206.0	6D	13,-25	34
7A	Insulation B Sheathing Board	None	None	None	30	1.6	5.0	9.1	13.2	17.8	22.8	7A	16	8
7B	1x6 Boards on 11-in. Centers No. 2 Common	None	24 in. Red Cedar Shingles 11 in. Exposed	None	15	22.1	68.0	122.5	180.4	240.6	307.1	7B	9, 10-19, 25	18
7C	As in 7B	Bldg. Paper B	As in 7B	None	67	0.02	0.07	0.13	0.19	0.23	0.25	7C	18	20
7D	1x6 Air Dried Ship-lap	Bldg. Paper B	5/2-16 in. Red Cedar Shingles — 7½ in. Exposed	None	7	0.03	0.10	0.17	0.25	0.33	0.42	7D	19, 22	29
7E	As in 7D	As in 7D	As in 7D	Wood Lath and 3 Coats Gyp. Plaster	14	0.02	0.06	0.12	0.18	0.25	0.31	7E	22, 24	30
9A	None	None	None	Wood Lath and 3 Coats Gyp. Plaster	15	0.02	0.08	0.17	0.28	0.40	0.52	9A	14-23	10
9B	None	None	None	As in 9A Plus Decorative Paper	10	0.01	0.05	0.10	0.15	0.20	0.26	9B	23	11
9D	None	None	Insulation A Lath and Stucco	None	29	0.07	0.27	0.39	0.56	0.73	0.90	9D	25	14
9E	1x6 Air Dried End and Side Matched No. 1 Common	None	None	None	2	3.6	13.4	28.3	46.3	64.7	83.8	9E	16, 17, 25	24
9F	As in 9E	Poor Grade Resin	None	None	None	0.4	1.5	2.9	4.3	5.3	5.9	9F	17, 18	25
9G	As in 9E	As in 9F	1x6 Drop Siding Painted	None	13	0.01	0.05	0.10	0.14	0.18	0.21	9G	17	26
10A	None	None	None	Metal Lath and 3 Coats Gyp. Plaster	14	0.03	0.12	0.23	0.35	0.47	0.60	10A	14,-23	12
10B	None	None	None	As in 10A Plus Sizing and Flat Paint	10	0	0	0	0	0	0	10B	23	13
10C	None	None	None	1x6 Sheathing End and Side Matched	7	8.3	26.5	48.8	72.0	96.7	122.8	10C	16, 25	27
10D	None	None	Corrugated Steel	As in 10C	4	1.2	4.0	8.1	12.7	17.4	22.2	10D	24	28
10E	None	None	As in 10D	None	63	1.4	4.7	9.1	13.8	18.5	23.6	10E	25	28

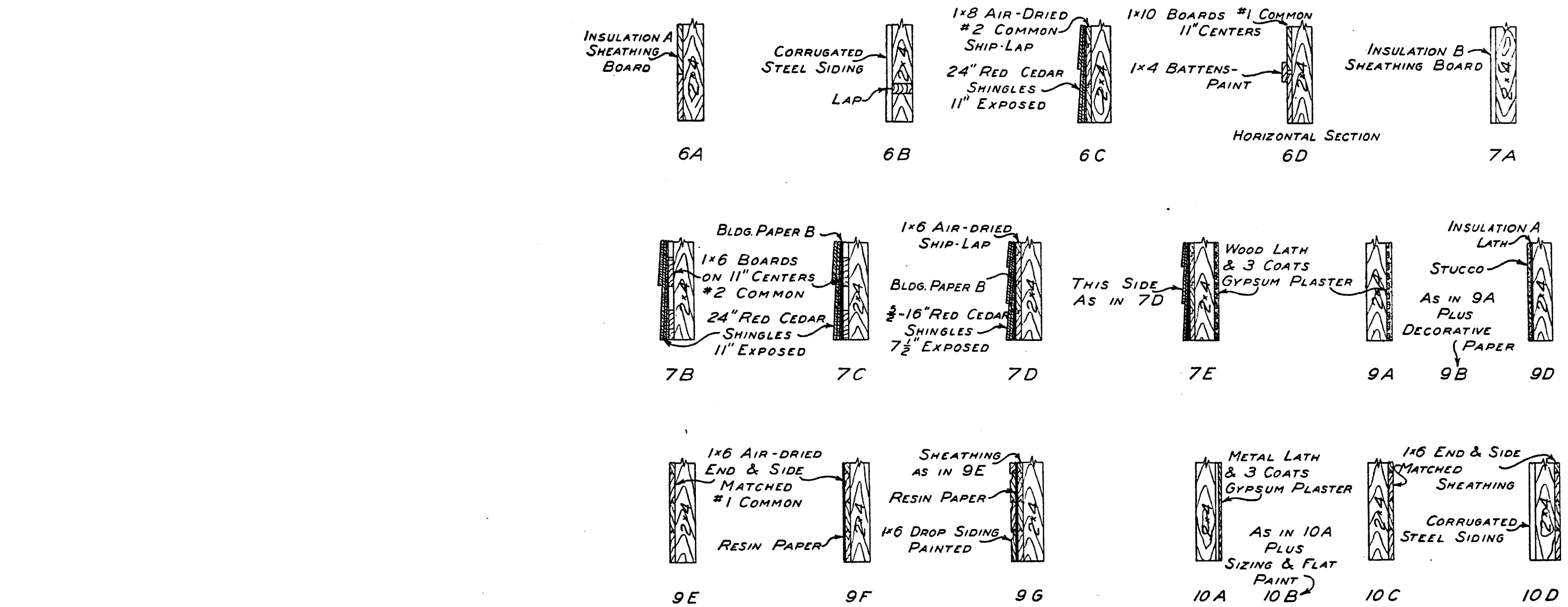

FIG. 3. CROSS-SECTIONS OF PANELS

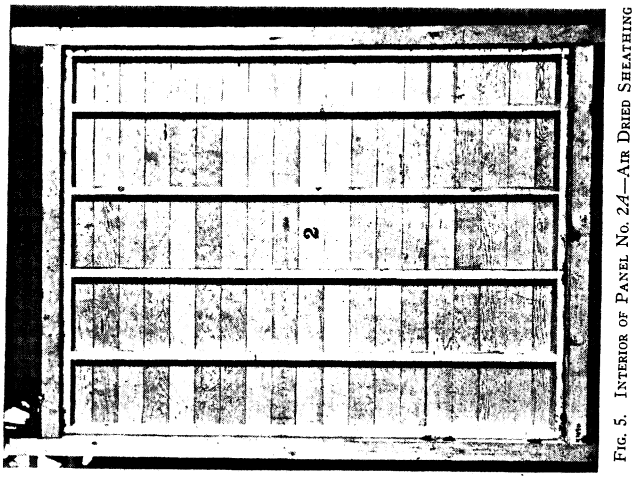

Fig. 5. Interior of Panel No. 2*A*—Air Dried Sheathing

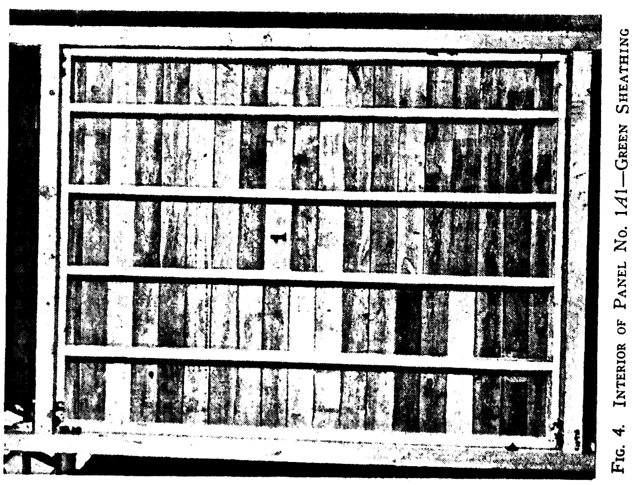

Fig. 4. Interior of Panel No. 1*A*1—Green Sheathing

between the drop in pressure in inches of water and the wind velocity is as follows:

Drop in Pressure in Inches of Water......	0.012	0.048	0.108	0.192	0.300	0.431
Wind Velocity in Miles per Hour	5	10	15	20	25	30

The test results are shown graphically in Figs. 16 to 25 grouped to show comparisons between various important features. The column headed ***Index to Figs.*** in Tables 1 and 2 shows the figures in which the test results of each panel number appear. The figure number before the dash is that of the photograph of the wall construction, if any is included, and the numbers after the dash refer to the figures showing the test results graphically. Not all of the test results have been plotted but only those most useful in making comparisons. Tables 1 and 2, however, show the results of all tests and any additional comparisons may be made by referring to the results as tabulated there.

Infiltration Through Sheathing Only

The results of tests on the various sheathings are shown grouped together in Fig. 16. The four tests on air-dried end and side matched sheathing show considerable variation. The average of the four tests shows a leakage of 46.4 cfh per square foot of wall at 15 mph. Of these four end and side matched sheathing panels, 4*F*, 9*E* and 10*C*, were of a uniform material and the average of these would be 35.1 cfh per square foot at 15 mph. As compared to this average, the leakage through Panel 4*A*1 which was of a less uniform material was 80.3 cfh. The lowest leakage secured for end and side matched sheathing was 28.3 cfh per square foot, the value obtained in tests of Panels 4*F* and 9*E*.

The air-dried side matched sheathing on Panel 2*A* showed a leakage of 15.3 cfh per square foot and on Panel 3*A* a leakage of 9.3 cfh per square foot of wall both at 15 mph. This is an average leakage at this wind velocity of 12.3 cfh per square foot. This figure of 12.3 cu ft for side matched sheathing is to be compared with the figure of 35.1 cu ft for end and side matched sheathing for the same material. In the case of side matched sheathing, all end joints are butted on the studding, whereas many joints with end and side matched sheathing come in between studding. The increase in leakage of end and side matched sheathing over side matched sheathing is considered to be due to greater leakage through the end joints. Figs. 5 and 6 show the air dried side matched sheathing used in Panels 2*A* and 3*A*. The end and side matched sheathing of Panels 4*F*, 9*E* and 10*C* was of this same material.

The leakage through green side matched sheathing, Panel 1*A*1, was 78.6 cfh per square foot at 15 mph. This is slightly less than the leakage through air dried end and side matched sheathing of like material. The comparatively low leakage secured indicates that even with green lumber the shrinkage is not ordinarily enough to pull the tongues and grooves apart and allow the free passage of air. A photograph of Panel 1*A*1 is shown in Fig. 4.

The leakage through fibre board as found in tests of Panels 6*A* and 7*A* was 12.6 cfh per square foot at 15 mph. This is about the same as through air dried side matched sheathing as determined on Panels 2*A* and 3*A*. The variation in the infiltration found in the two tests of fibre board was due to a variation in the width of the horizontal joints. The sheets were closely fitted together on Panel 7*A*, but a section of the joint on Panel 6*A* had a crack of an

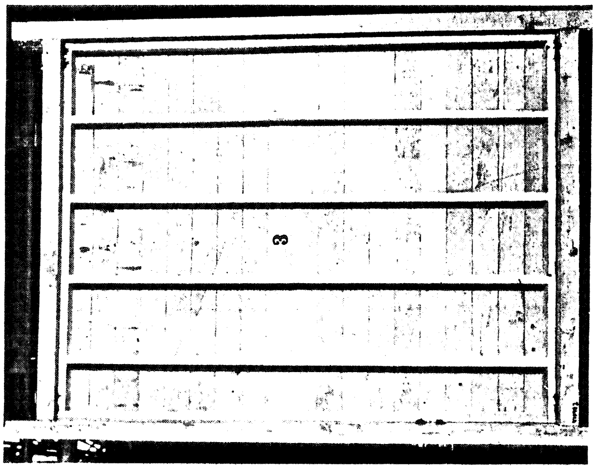

FIG. 6. INTERIOR OF PANEL NO. 3A, AIR DRIED SHEATHING

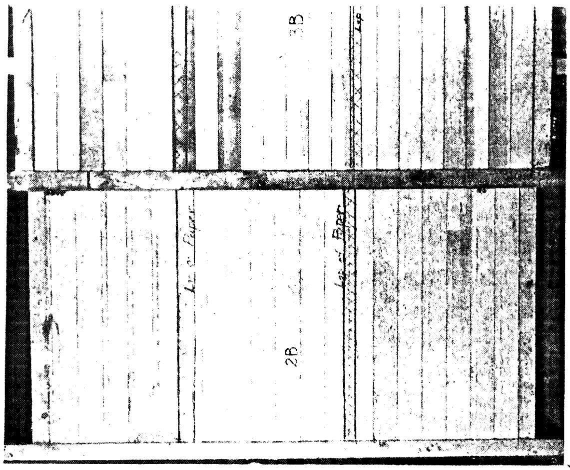

FIG. 7. EXTERIOR OF PANEL NO. 2B, SHEATHING, PAPER AND DROP SIDING. EXTERIOR OF PANEL NO. 3B, SHEATHING, PAPER AND BEVEL SIDING

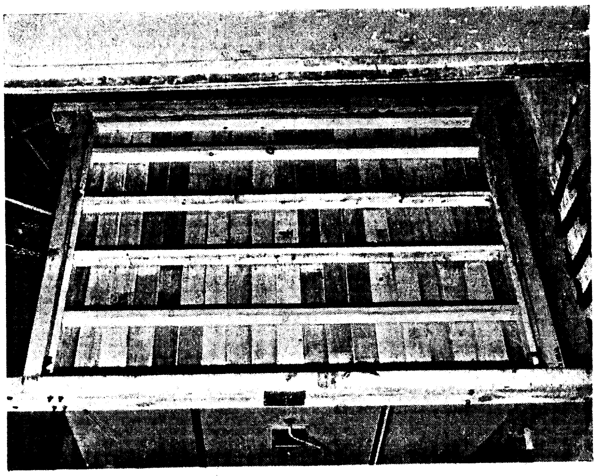

FIG. 8. INTERIOR OF PANEL NO. 4A—AIR DRIED SHEATHING

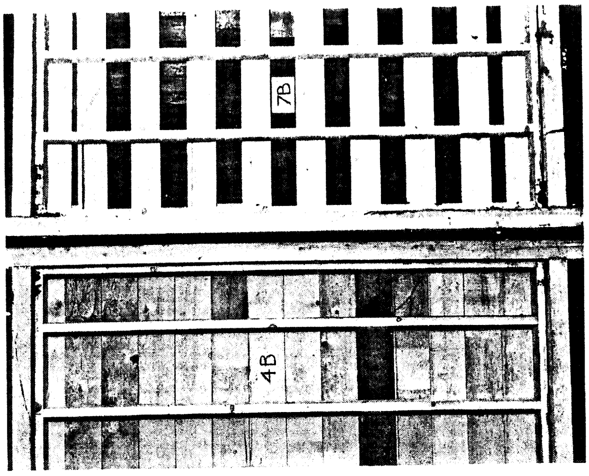

FIG. 9. INTERIOR OF PANEL NO. 4B, 16-IN. SHINGLES ON SHIPLAP. INTERIOR OF PANEL NO. 7B, 24-IN. SHINGLES ON SPACED BOARDS

appreciable width. Fig. 11 shows a photograph of Panel *6A*. When the horizontal joints were sealed the leakage for Panels *6A* and *7A* was the same. The leakage through a wall of fibre board depends largely on the fit of the horizontal joints and may be considerable with careless workmanship.

Addition of Building Paper, Drop Siding and Paint to Sheathing

Fig. 17 shows the infiltration resulting from tests of the various steps in the building of the outside construction of a wall. The leakage through the sheathing only in Panel *9E*, which was end and side matched was 28.3 cfh per square foot of wall at 15 mph. The application of ordinary resin-sized building paper over the sheathing with the seams nailed at 7-in. intervals reduced the leakage in Panel *9F* to 2.9 cfh per square foot of wall at 15 mph. The addition of drop siding and paint in Panel *9G* reduced the leakage to a negligibly small amount. This reduction is due not only to the resistance to air flow of the painted drop siding but also to the increased effectiveness of the sheathing paper because of being clamped between two thicknesses of boards.

Various Applications of Sheathing Paper

That the effectiveness of sheathing paper depends to a considerable extent on the method of application is shown by the curves in Fig. 18. Paper nailed on the sheathing with the laps nailed at approximately 7 in. intervals in Panel *9F* showed a leakage of 2.9 cfh per square foot of wall at 15 mph. Paper applied vertically between the studs and sheathing in Panel *4A* showed a leakage of 0.31 cfh per square foot at 15 mph. In Panel *7C*, paper was placed between two thicknesses of spaced boards and shingles which by themselves showed an extremely high leakage. The extremely low leakage of 0.13 cfh per square foot at 15 mph found in the test of Panel *7C* is attributable to the effectiveness of the paper when tightly clamped between two thicknesses.

The paper used on Panel *9F* was a poor grade of resin paper. In Panel *9G* drop siding and paint were added which reduced the leakage to a negligibly small amount just as was the case with a good grade of building paper. This is attributable to the reduction in leakage at the laps due to the clamping of the paper between the two thicknesses of sheathing and drop-siding. In the average building construction, a good grade of sheathing paper would probably have a greater resistance to air flow than would a poor paper because of less tearing in application due to its greater tensile strength. Also it probably would maintain its resistance to air leakage better over a period of years against the effects of aging and weathering.

In the construction of farm and other shelter buildings the application of paper in the proper way would seem to be worth while. There are two ways of applying the paper between the studding and the sheathing, horizontally and vertically. Horizontal application between studding and sheathing would correspond in leakage to the results secured in test of Panel *9F* where the sheathing paper was applied horizontally on the outside of the sheathing and nailed at intervals. Vertical application between studding and sheathing was made in Panel *4A* and showed considerably less leakage than horizontal application.

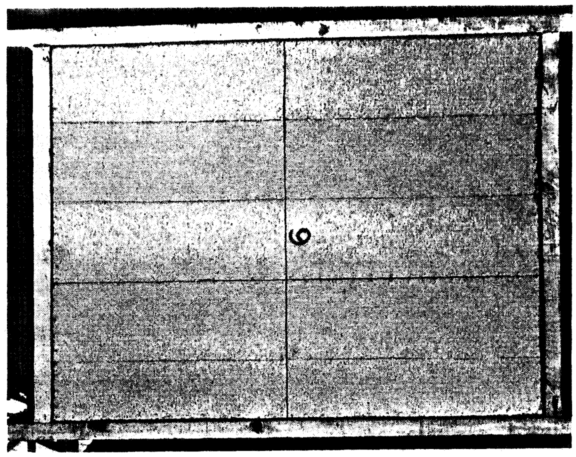

Fig. 11. Exterior of Panel No. *6A*—Fibre Sheathing Board

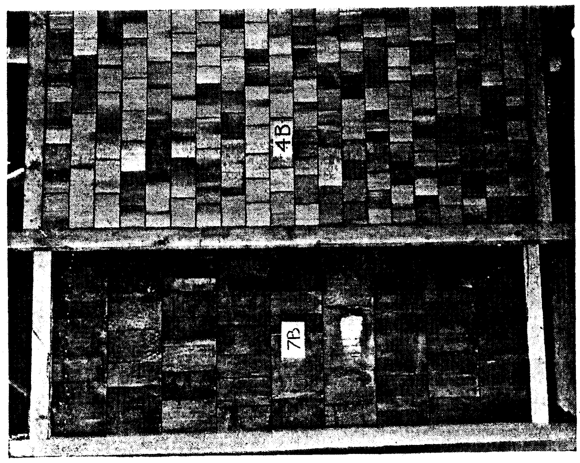

Fig. 10. Exterior of Panel No. *4B*, 16-in. Shingles on Shiplap. Exterior of Panel No. *7B*, 24-in. Shingles on Spaced Boards

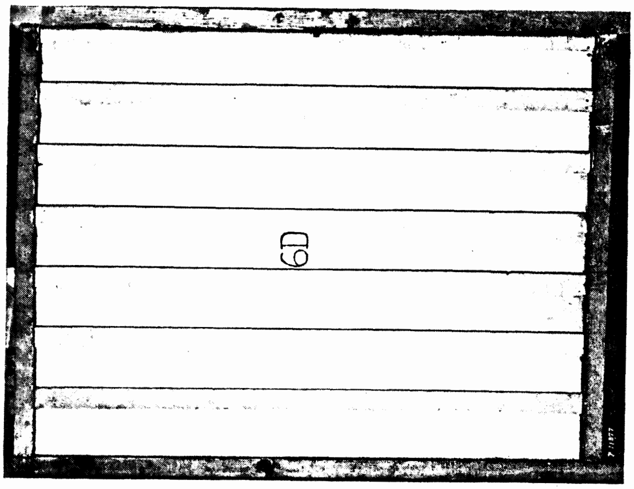

FIG. 13. EXTERIOR OF PANEL NO. *6D*—1x10 SPACED BOARDS WITH BATTENS

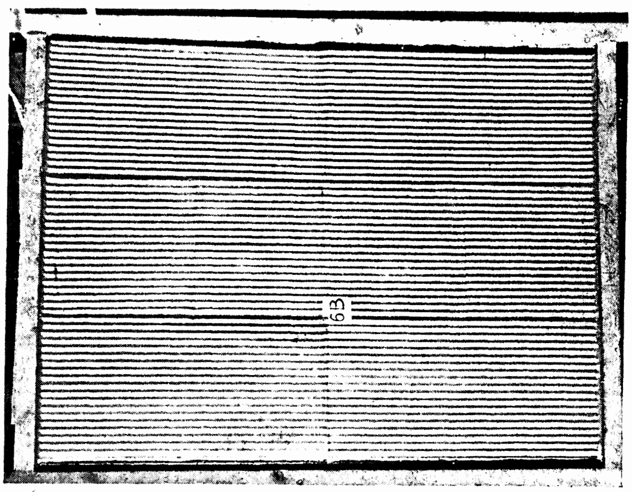

FIG. 12. EXTERIOR OF PANEL NO. *6B*—CORRUGATED STEEL SIDING

AIR INFILTRATION THROUGH VARIOUS TYPES OF SHINGLE CONSTRUCTION

Fig. 19 shows the results of tests on various shingle constructions. The greatest leakage was secured with 24-in. shingles nailed to 1x6 boards spaced on 11-in. centers in Panel *7B*. This leakage was 122.5 cfh per square foot of wall at 15 mph. The corresponding construction for 16-in. shingles and 1x4 boards on 5-in. centers in Panel *3C* showed a leakage of 69.5 cfh per square

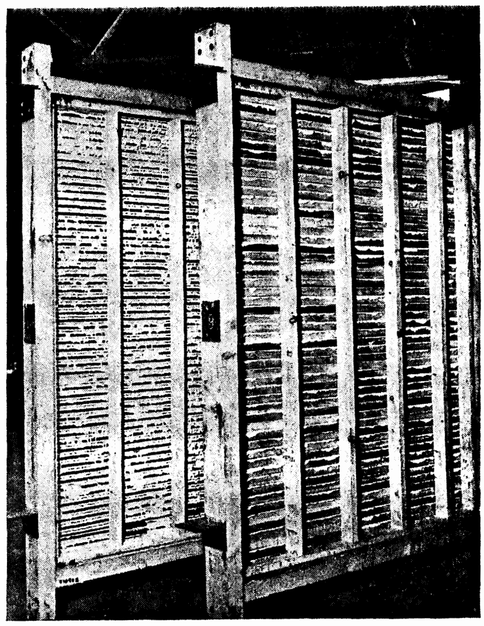

FIG. 14. EXTERIOR OF PANEL NO. *9A*, PLASTER ON WOOD LATH. EXTERIOR OF PANEL NO. *10A*, PLASTER ON METAL LATH

foot. In both of these constructions, the spaced boards act merely as pieces to nail the shingles to and play practically no part in the stopping of air leakage.

The replacing of the spaced boards with shiplap in the case of 24-in. shingles in Panel *6C* reduced the leakage to 43.8 cfh per square foot at 15 mph. The corresponding value for 16-in. shingle construction in Panel *4B* was 15.3 cfh per square foot. The use of shiplap in shingle roof and side wall construction would seem to be advisable in the reduction in infiltration.

The application of sheathing paper to a 16-in. shingle construction using

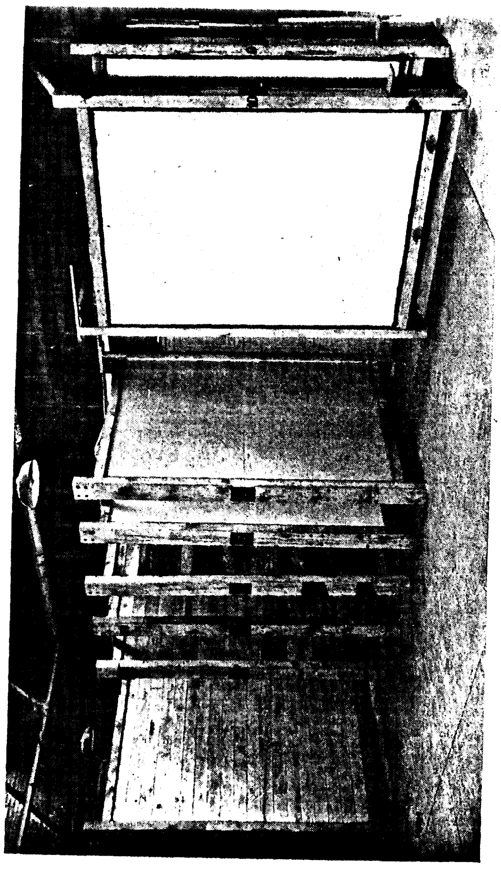

Fig. 15. Assembly of Test Panels

spaced boards in Panel *3D* and to a 16-in. shingle construction using shiplap in Panel *7D* reduced the air infiltration to the negligibly small amount of less than one-half cubic foot per hour per square foot of wall. The great reduction secured by the use of paper in a shingle wall would make its use advisable in any construction where infiltration is objectionable. One construction where the use of paper would be highly desirable is in shingle roof construction on residences.

Addition of Paint to Siding

The infiltration of air through a wall having building paper properly applied is negligibly small. This amount was 0.28 cfh per square foot of wall at 15 mph for Panels *1B*, *2B* and *3B*. Fig. 20 shows the results of these tests plotted to a very much enlarged scale. The application of paint to the siding on these panels resulted in a further reduction.

In the case of Panel *2B1*, having drop siding, the reduction was very slight, but was an appreciable amount in Panels *1B1* and *3B1* having bevel siding. This indicates that paint seals the joints in bevel siding better than in drop siding. This reduction in either case is extremely small since the sheathing paper clamped between the sheathing and siding by itself is very effective in preventing air infiltration. This reduction in leakage due to the addition of paint probably is not permanent since it would take very little movement due to weathering or to changes in humidity to break the paint film sufficiently to allow air to reach the sheathing paper quite freely as compared to its passage through the paper layer. Paint applied to a weathered siding would of course reduce the size of the cracks at joints in the siding.

A Study of Good and Poor Corner Constructions

In the case of Panels *2B* and *3B* tests were first made with the joint between the wall and the frame calked on only three sides. On the fourth side, the joint at the depth of the sheathing only was calked. This allowed air to get under the siding and under the paper from this uncalked end joint. This is considered to be approximately the condition at the corner of a frame building or against window or door openings with poor construction. Here there is a chance for air to get under the trim, then to get under the siding and seek out openings in the layer of paper. Unless the paper is very carefully applied, there would also be the chance for air to find its way under it directly at the corner or at the window or door frame.

Fig. 21 shows the results of these tests with one edge of the siding and paper not sealed. The results on Panel *3B* showed a leakage of 1.70 cfh per square foot of wall at 15 mph for a wall equipped with bevel siding. The corresponding results on Panel *2B* equipped with drop siding was 0.45 cu ft. This indicates that drop siding, since it presses down over the entire paper surface quite effectively, prevents air from getting under the paper from an end joint such as occurs at the corner of a building or at window or door frames. The bevel siding, since it makes only line contact with the paper, is not so effective in preventing air from getting under the paper. This points to the need for carefully wrapping the paper around the corner of a building and for the making of a tight seal in the paper layer at window and door openings. In the case of bevel siding with the best paper application at such locations, there is still the chance for air to travel horizontally in the air spaces under

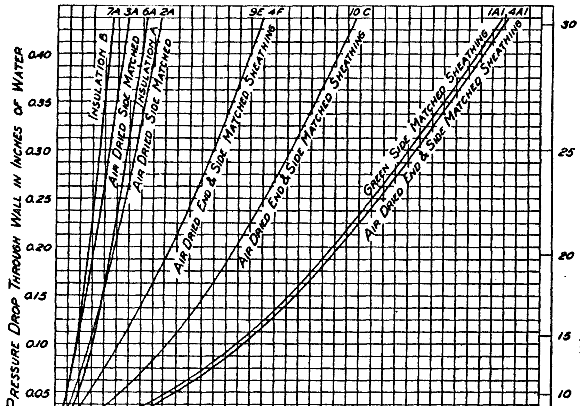

FIG. 16. INFILTRATION THROUGH SHEATHING ONLY

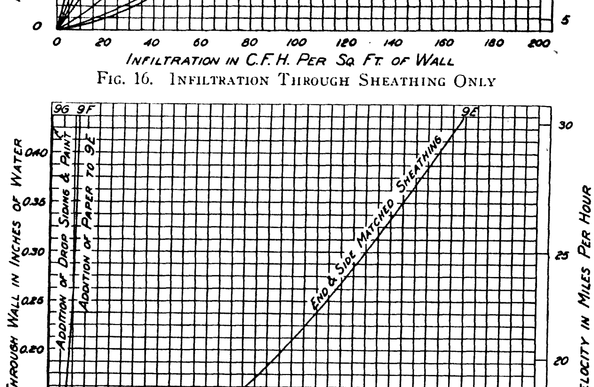

FIG. 17. ADDITION OF BUILDING PAPER, DROP SIDING AND PAINT TO SHEATHING

the siding and seek out defects in the paper. This calls for careful application not only at corners at openings but over the entire wall surface. It is also important that laps in the paper layer come under lines of contact when bevel siding is to be applied.

When the fourth side of Panels *2B* and *3B* was sealed, the leakage was reduced to the negligibly small amount of 0.28 cfh per square foot. Fig. 7 shows a photograph of these two panels.

ADDITION OF PLASTER TO WALLS HAVING SHEATHING PAPER

The results of tests on Panel 1*B*1 made of sheathing, paper and bevel siding and Panel *7D* consisting of shiplap, paper and shingles are plotted in Fig. 22 to a greatly exaggerated scale. The leakages for these two constructions were 0.18 and 0.17 cfh per square foot at 15 mph. These are extremely small leakages. The addition of plaster to these two constructions in Panels 1*C* and 7*E* resulted in a further reduction of this negligibly low leakage.

Tests on plaster constructions alone in Panels 9*A* and 10*A* showed the negligible leakage of 0.17 and 0.23 cfh per square foot at 15 mph.

Having practically air tight layers such as building paper and plaster at two points in a wall should reduce air movements within the wall and thereby exert a beneficial effect on heat losses by transmission.

ADDITION OF WALL PAPER AND PAINT TO PLASTER

Plaster by itself allows only a negligible amount of air leakage. The results of tests of plastered Panels 9*A* and 10*A* are plotted to an exaggerated scale in Fig. 23. The infiltration averaged 0.20 cfh per square foot at 15 mph. The tests were made with no cracks in the plaster and the panels were sealed completely on all four sides. Had cracks been present or had imperfect sealing been made at an edge of the plaster sheet corresponding to poor sealing at the baseboard or at a window opening in actual construction, the leakage would have been much greater. To obtain the effectiveness of plaster against air leakage good workmanship includes the proper sealing of the plaster sheet at the baseboard and window trim. The addition of wall paper in Panel 9*B* to the plaster in Panel 9*A* resulted in a considerable although unimportant reduction in air leakage. The addition of sizing and flat wall paint in Panel 10*B* to the plaster in Panel 10*A* made the wall practically air tight. The leakages of the plain plaster walls were negligibly small. The application of paint or paper under such circumstances would have to be justified by other reasons than a reduction in air infiltration. Probably the application of paint or paper to a badly cracked plaster wall would have a favorable effect on air leakage.

INFILTRATION THROUGH VARIOUS TYPES OF COMPOUND WALLS

A compound wall for the purposes of this paper is defined as one that has a finished construction on both sides of the studding. The results of tests on the four compound walls that were built are shown in Fig. 24. The three panels 1*C*, 4*E* and 7*E* all had in their construction sheathing paper and plaster, although different types of siding were used. The leakages secured were 0.16, 0.23 and 0.12 cfh per square foot at 15 mph or an average for the three walls of 0.17 cu ft.

Panel 10*D* contained neither sheathing paper nor plaster and had corrugated steel siding as the outside construction and end and side matched sheathing as the inside construction. The leakage at 15 mph was 8.1 cfh per square foot. Had paper been applied vertically between the studding and the boards as in Panel 4*A*, the leakage would have been less than 1 cu ft per hour per square foot of wall.

Infiltration Through Single-Surfaced Walls Used in Farm and Other Shelter Buildings

Fig. 25 shows the results of tests on panels having a single thickness. These

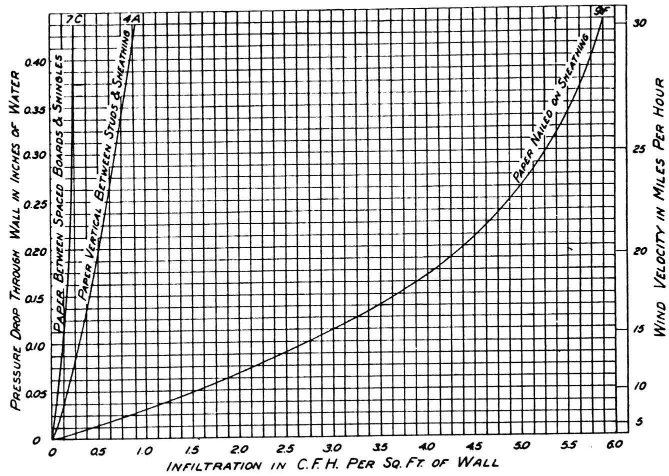

Fig. 18. Study of Various Applications of Sheathing Paper

include panels having tongued and grooved boards both butt ended and end matched, boards and battens and corrugated steel siding.

The largest leakage occurred with Panel 6*D* which was built of 1x10 in. boards spaced on 11 in. centers and the spaces covered with 1x4 in. boards. This leakage was 86.9 cfh per square foot of wall at 15 mph. Fig. 13 is a photograph of this panel.

The leakage through the three panels 4*F*, 9*E* and 10*C* of air dried end and side matched sheathing of a uniform material averaged 35.1 cfh per square foot of wall at 15 mph. The inclusion of the fourth panel of a different material, Panel 4*A*1, of end and side matched sheathing increased the average to 46.4 cfh per square foot of wall at 15 mph. Air dried side matched sheathing in Panels 2*A* and 3*A* showed an average leakage of 12.3 cfh per square foot at 15 mph.

Two panels, 6*B* and 10*E*, were tested having corrugated steel siding. The

leakage through Panel 6*B* was 45.4 cu ft and through Panel 10*E*, 9.1 cfh per square foot at 15 mph. The average of the two is 27.3 cfh per square foot. The large variation in results is explainable in a difference in the length and fit of

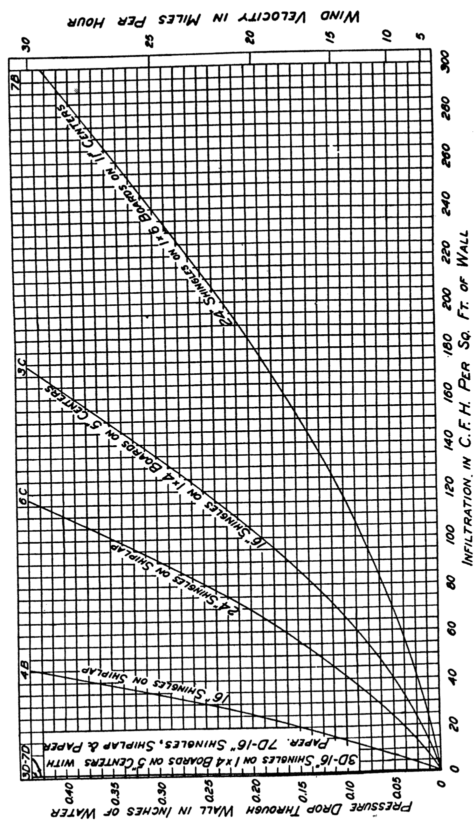

Fig. 19. Infiltration Through Various Types of Shingle Construction

the horizontal joints. Panel 6*B* had 1-1/3 horizontal joints and Panel 10*E* had only one horizontal joint. The fit of some of the horizontal joints on Panel 6*B* was poorer than that on Panel 10*E*.

Fig. 12 shows a photograph of Panel 6*B*. The joint between the steel siding

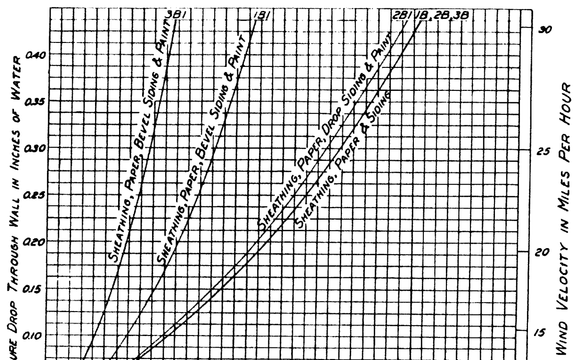

FIG. 20. ADDITION OF PAINT TO DROP SIDING AND BEVEL SIDING

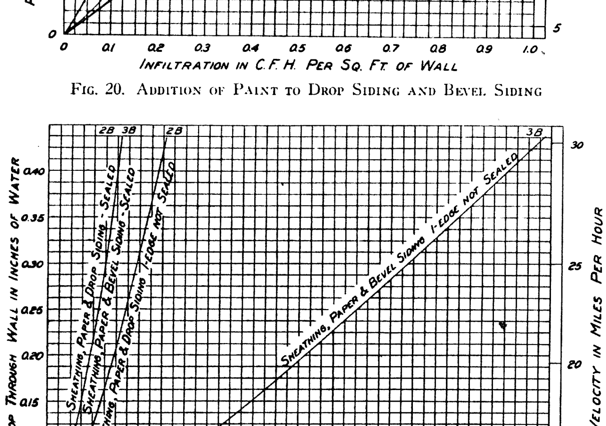

FIG. 21. STUDY OF GOOD AND POOR CONSTRUCTIONS

and the test frame was calked on all four sides during the tests. Had air been allowed to enter the ends of the corrugations at the top or bottom of the wall, the leakage would have been exceedingly large. Such would be the condition in actual building construction unless special care were taken in the application to butt the sheets against wood construction.

The tests on all of the single-surfaced walls show considerable leakage. The application of sheathing paper nailed vertically on the studding to any single-surfaced wall would greatly reduce the leakage. The leakage of such an appli-

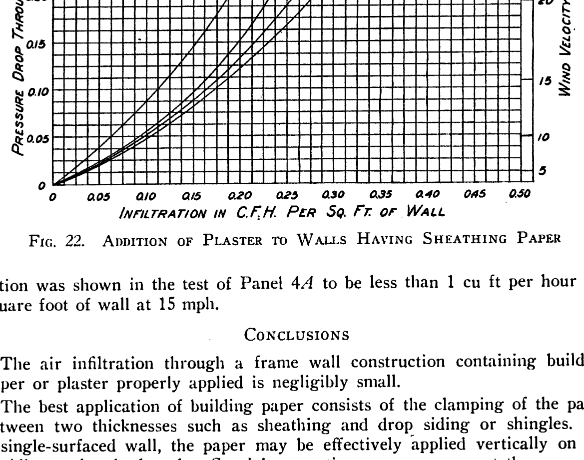

FIG. 22. ADDITION OF PLASTER TO WALLS HAVING SHEATHING PAPER

cation was shown in the test of Panel 4*A* to be less than 1 cu ft per hour per square foot of wall at 15 mph.

CONCLUSIONS

The air infiltration through a frame wall construction containing building paper or plaster properly applied is negligibly small.

The best application of building paper consists of the clamping of the paper between two thicknesses such as sheathing and drop siding or shingles. In a single-surfaced wall, the paper may be effectively applied vertically on the studding under the boards. Special precautions are necessary at the corner of a building or against door or window openings to make the paper effective.

While no difference has been found in the value of a high and a low grade paper on these infiltration tests, likely the good grade of paper will better maintain its efficiency against air infiltration over a period of years than will the poor grade of paper. A paper having considerable weight and strength should develop fewer defects in application than would a poor paper. The use of a poor grade of paper is particularly objectionable for a construction in which the paper is not firmly clamped between two thicknesses of material over its entire surface.

End and side matched sheathing has a somewhat greater leakage to air than has side matched sheathing. The difference is of no importance when sheathing paper is included in the construction. End and side matched sheathing presents

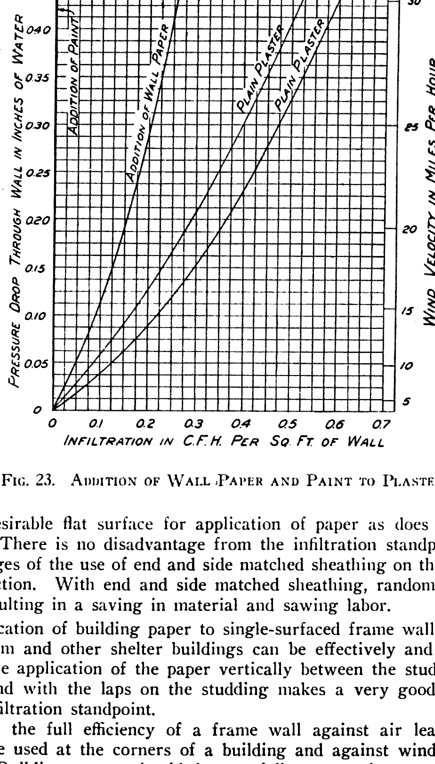

FIG. 23. ADDITION OF WALL PAPER AND PAINT TO PLASTER

the same desirable flat surface for application of paper as does side matched sheathing. There is no disadvantage from the infiltration standpoint to offset the advantages of the use of end and side matched sheathing on the usual building construction. With end and side matched sheathing, random lengths may be used, resulting in a saving in material and sawing labor.

The application of building paper to single-surfaced frame walls such as are used for farm and other shelter buildings can be effectively and cheaply performed. The application of the paper vertically between the studding and the sheathing and with the laps on the studding makes a very good construction from the infiltration standpoint.

To obtain the full efficiency of a frame wall against air leakage, special care must be used at the corners of a building and against window and door openings. Building paper should be carefully wrapped around the corner so as to prevent air getting through the wall construction at this point.

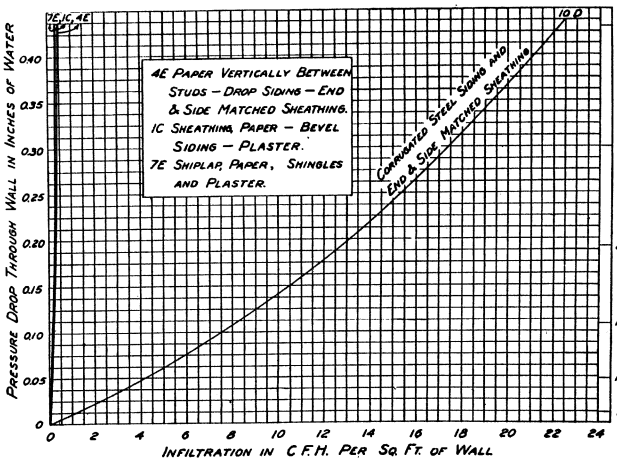

FIG. 24. INFILTRATION THROUGH VARIOUS TYPES OF COMPOUND WALLS

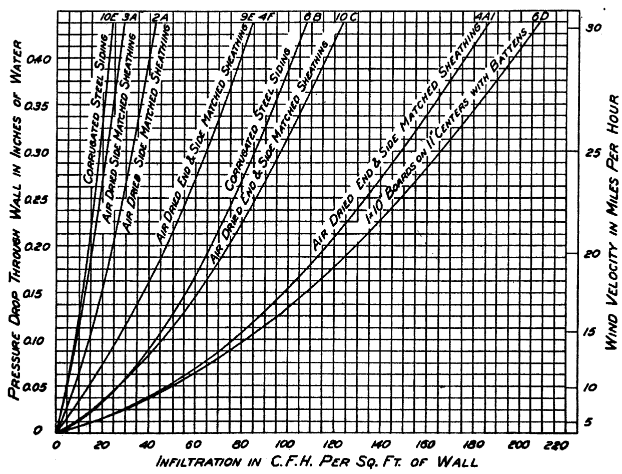

FIG. 25. INFILTRATION THROUGH SINGLE SURFACE WALLS USED IN FARM AND OTHER SHELTER BUILDINGS

In the case of bevel siding, there is the chance for air to enter at a corner construction and travel horizontally to seek out defects in the sheathing paper. This requires the careful application of the paper so as to prevent defects developing and the use of wide laps so as to bring them under the contact lines of the bevel siding. The use of a good grade of paper would be economical due to freedom from tearing during application and the maintaining of a high degree of effectiveness throughout the life of the building.

Drop siding does not present spaces for air travel over the surface of the sheathing paper and very effectively holds the paper against the sheathing. Poor corner construction is a less serious factor with drop siding than with bevel siding.

The use of building paper is justified from an infiltration standpoint in any shingle roof or side wall construction. The use of shiplap rather than spaced boards is desirable in the clamping of the sheathing paper securely over its entire surface. This minimizes the buckling of the paper from aging. In districts where heating seasons are mild, the inclusion of building paper and the use of shiplap rather than spaced boards would be justified by the reduction in infiltration.

Plaster by itself allows the passage of only a negligible amount of air when properly applied. Proper application means the sealing at the baseboard and against window and door openings by running the plaster tightly against the floor or frame construction of an opening. The full effectiveness of plaster is probably seldom obtained. The development of cracks reduces the efficiency of the plaster. The application of paint or wall paper is not justified from the standpoint of infiltration reduction on a plaster wall that is fully effective, but on a cracked plaster surface the application of either paint or paper may reduce infiltration considerably.

The effectiveness of plaster properly applied is no justification for the use of low grade building paper or of the poor construction of the wall containing it. Not only is it difficult to secure and maintain the full effectiveness of the plaster but also it is highly desirable to have two points of high resistance to air flow with an air space between them to keep heat transmission losses at a minimum.

APPENDIX

DESCRIPTION OF TEST PANELS

Items 1 *and* 2. Eight test panel frames were built of 4x8 timbers as described in the forepart of the paper. To the top and bottom members of each of these frames single 2x4 plates were nailed 1½ in. from the face of the frame and extending from end to end of the frame opening. Vertical 2x4 studs were installed between these plates on 16-in. centers, except that the end studs were spaced such as to bring end studs tightly against the vertical frame members. Studs were firmly toe nailed to plates and end studs to frame. A recess was made against the frame members in the 2x4 plates and end studs on both sides of the frame into which calking compound was packed to prevent air leakage at this joint.

Item 3. Over the stud frame in panel frame No. 1, 1x6-in. dressed and side matched sheathing was applied with ends butted over studs, fitted with ordinary care to secure tightness and face nailed twice at each stud with 8*d* nails. Joints were broken over studs in every third course. This material was green and of No. 1 Common grade. Green sheathing, in this test, consisted of air-dried sheathing that had been soaked in water for several days. The panel was allowed to season 29 days before testing.

Item 4. Over the studding in panel frames Nos. 2 and 3, 1x6-in. dressed and side matched sheathing was applied. Workmanship was in all respects similar to that of *Item* 3, except that the sheathing was thoroughly air-dried when applied. These panels were allowed to season 28 days before testing.

Item 5. Over the stud frame in panel frame No. 4, a good grade of sheathing paper termed, Building Paper *A*, was applied in vertical strips, lapped 2 in. over studs and tacked to studs with roofing nails. Over the building paper, 1x6-in. dressed, and end and side matched No. 1 Common sheathing was applied. Workmanship was similar in all respects to that required for ***Item*** **3**, except that no effort was made to have the end joints between boards occur over studs. End joints were made in not less than two-thirds of the courses, but each board spanned at least two studs. The panel was allowed to season 29 days before testing. Immediately after testing the paper and siding, the paper was cut out between studs with a knife and the panel re-tested.

Item 6. Over the sheathing on panel frames Nos. 2 and 3 after test, Building Paper *A* was applied in horizontal strips lapped not less than 2 in. and with one vertical joint one strip wide, also lapped, in the center of the panel.

Over the building paper on panel No. 2, 1x6 in. drop siding was applied. This siding was air dry to the satisfaction of the inspector, and was nailed in accordance with usual practice. The panel was allowed to season 14 days and then tested. Three coats of good commercial white lead and zinc paint were then applied to the siding at customary intervals, and 6 days after the application of the final coat, the panel was re-tested.

Over the building paper on panel frame No. 3, 1x6-in. bevel siding was applied lapped not less than 1 in. and nailed in accordance with usual practice. The panel was allowed to season 14 days and then tested. Three coats of good commercial white lead and zinc paint were then applied to the siding at customary intervals, and 6 days after the application of the final coat the panel was re-tested.

Item 7. Over the stud frame in panel frame No. 6, Insulation *A* sheathing board was applied, using one vertical joint butted over studding and one horizontal joint clear across panel. The panel was allowed to season 30 days before testing.

Item 8. Over the stud frame in panel frame No. 7, Insulation *B* standard sheathing board was applied in a manner similar to the Insulation *A* (see Item 7) nailed according to manufacturer's specifications. The panel was also allowed to season 30 days before testing.

Item 9. Insulation *A* sheathing board was removed from studding in panel frame No. 6 and 20-gage galvanized corrugated sheet steel siding applied. Sheets were about 27 in. wide and 60 in. long and were lapped and nailed on to the studding according to manufacturer's specifications for siding for farm or industrial buildings. No intentional standing period was allowed for the corrugated steel siding, but 14 days elapsed between the date of construction and the date of test.

Item 10. Over the studding in panel frame No. 9, wood lath and gypsum plaster were applied in accordance with the specifications given in the next paragraph. Lath was No. 1 grade, soft pine, spaced at least ¼ in. apart and nailed to each stud with a *3d* 16-gage wire nail. Joints were broken at every seventh course. Lath was thoroughly soaked before application and also well wetted down several hours before plastering. Wood grounds ⅞ in. thick were nailed around the stud frame and flush with the outside edges of the plates and the two outermost studs. The crevices between grounds and the panel frame were carefully calked with plasted calking compound. A seasoning period of 15 days was allowed before testing.

"Plaster shall be a good three-coat job of gypsum plaster applied as follows: Scratch coat shall be one part plaster, hair fibered, to not more than two parts (by weight) of dry sand. Brown coat shall be of similar materials and proportions, but unfibered. The finish coat shall be four parts gypsum plaster, one part finishing lime, and five parts clean dry sand."

Item 11. After the plaster in Item 10 on Panel No. 9 was tested, a good grade of wall paper was applied. This was allowed to dry for 10 days and the panel re-tested.

Item 12. Over the studding in panel frame No. 10, metal lath and gypsum plaster were applied in accordance with the following specifications: "The metal lath shall be expanded metal lath weighing not less than 2.5 lb per square yard, attached to each stud with *6d* nails spaced not over 6 in. apart. Clinch of nails to be upward. Lath to be lapped at sides not less than ½ in. with lower sheet over the upper. Grounds shall be ⅞ in. as for wood lath and plaster. There shall be at least one vertical and one horizontal lap in the metal lath joint entirely across the panel.

"Gypsum plaster shall be used and applied in three coats, as follows: Scratch coat shall be one part plaster, hair fibered, to not more than two parts (by weight) of dry sand. Scratch coat shall be applied with sufficient pressure to fill all meshes and obtain good key.

"Brown coat shall be one part plaster, unfibered, to not more than two parts (by weight) of dry sand. This coat shall be kept back sufficiently from grounds to allow for finishing coat and surface shall be roughened to receive finishing coat.

"The finish coat shall be four parts gypsum plaster, one part finishing lime and five parts clean dry sand."

Item 13. Over the metal lath and plaster on panel frame No. 10 (see *Item* 12) a coat of sizing and two coats of a good commercial flat wall paint were applied. A drying period of 10 days was allowed, after which the panel was re-tested.

Item 14. The wood lath and plaster were removed from panel frame No. 9 and the stud faces carefully cleaned. Over the stud frame Insulation *A* plaster lath was applied in commercial sheets; the sheets being broken over studs twice vertically and once horizontally. Lath was nailed according to manufacturer's specifications. Grounds were ⅞ in. as for wood lath and plaster. A scratch coat and finish coat of stucco were then applied.

Item 15. The bevel siding and building paper on panel frame No. 1 were removed. Over the matched sheathing, expanded metal stucco reinforcement of 20-gage thickness with openings ¾ in. by 2 in., and weighing 1.8 lb per square yard, was applied. Stucco reinforcement was placed horizontally and fastened to the sheathing with saddle nails spaced about 8 in. apart over the surface. Vertical laps were made over studs and horizontal laps laced with wire. Stucco was applied according to the following specifications:

"Scratch coat shall be of one part portland cement to three parts sand, applied ½ in. thick and troweled well through the reinforcement. It shall be thoroughly dry before the brown coat is applied. The brown coat shall be ½ in. thick, of the same proportions, and the finish coat from ⅛ in. to ¼ in. thick. Total thickness of stucco over sheathing shall be approximately 1⅛ in. and shall be established by 1⅛ in. grounds nailed around the outside of the stud frame." The panel was allowed to season 29 days before testing.

Item 16. The bevel siding, building paper and sheathing were removed from panel frame No. 3. Over the stud frame 1x4-in. butt-edged boards No. 2 common grade were applied spaced 5 in. on centers. Over the boards, edge grain 5/2-16-in. red cedar shingles were applied 5 in. to the weather using zinc coated shingle nails. The panel stood 69 days before testing.

Item 17. The sheathing and building paper on panel frame No. 4 were removed. Over the stud frame, 1x8-in. shiplap No. 2 common was applied butted over studs and face-nailed twice. Over the shiplap edge grain 5/2-16 in. red cedar shingles were applied 5 in. to the weather using zinc coated shingle nails. The panel stood 14 days before testing.

Item 18. The Insulation *B* standard sheathing board was removed from panel frame No. 7. Over the studs, 1x6-in. butt edged boards, No. 2 common grade were applied spaced 11 in. on centers. Over the boards, edge grain strictly clear 24-in. red cedar shingles were applied, 11 in. to weather. The panel was allowed to stand 15 days before testing.

Item 19. The corrugated sheet metal was removed from panel frame No. 6. Over the studding, 1x8 in. shiplap No. 2 common grade was applied. Over shiplap, 24-in. edge grain red cedar shingles, strictly clear, were applied, 11 in. to weather. The standing period was 14 days before testing.

Item 20. The 24-in. shingles were removed from panel frame No. 7. All remaining nails were pulled or driven flat to avoid any projections on the boards. Building Paper *B*, a good grade of paper, was then applied over boards according to manufacturer's instructions. Over the paper, strictly clear edge grain 24-in. red cedar shingles were applied 11 in. to the weather, using zinc coated nails. The panel was allowed to stand 67 days before testing.

Item 21. The 16-in. shingles were removed from panel frame No. 3. All remaining shingle nails were pulled or driven flat to avoid any projections on the boards. Building Paper *B* was then applied over the boards according to manufacturer's instructions. Over the paper, edge grain 5/2-16 in. red cedar shingles were applied 5 in. to the weather using zinc coated shingle nails. The panel stood 69 days before testing.

Item 22. The matched sheathing was removed from panel frame No. 1 and butt-edged 1x6-in. sheathing, No. 1 Common grade, was applied over studs. The lumber was air dry and fitted with ordinary care. Over the sheathing, Building Paper *B* was applied according to manufacturer's specifications. Over the building paper, 1x10 red cedar bevel siding, *B* grade and better, was applied, lapped $1\frac{1}{2}$-in., and double nailed with *8d* cement-coated box nails. The panel stood for 70 days before testing.

Two coats of good quality white paint were then applied to the bevel siding at the customary intervals, and 6 days after application of the second coat the panel was re-tested.

Item 23. On the reverse side of panel frame No. 1, finished as specified in *Item* 22, wood lath and gypsum plaster were applied in conformity to specifications for *Item* 10. The panel stood 68 days and was again re-tested.

Item 24. All previous construction was removed from the 2x4 studs in panel frame No. 9. Over studs air dry 1x6 No. 1 Common end and side matched sheathing was applied. The panel was allowed to stand 2 days and then tested.

Item 25. Over the sheathing in *Item* 24 ordinary red resin-sized building paper was applied with laps horizontal, nailed with No. 3 shingle nails spaced approximately 7 in. The panel was re-tested immediately.

Item 26. Over the building paper mentioned in *Item* 25, air dry 1x6 drop siding was applied, nailed in accordance with usual practice, and painted with three coats of good commercial white lead and zinc paint applied at customary intervals. The panel was allowed to season 13 days and again re-tested.

Item 27. All previous construction was removed from the 2x4 studs in panel frame No. 10. Over the studs 1x6 end and side matched sheathing was applied. The panel was allowed to season for 7 days and then tested.

Item 28. Over the other side of panel frame No. 10 corrugated steel siding was applied as in *Item* 9. The panel was re-tested four days later, the steel siding being exposed to the pressure side of test machine.

Item 29. All previous construction was removed from the 2x4 studs in panel frame No. 7. Over the studs 1x6 air dry shiplap, double nailed, Building Paper *B*, and 16 in. red cedar shingles 5/2 thickness were applied $7\frac{1}{2}$ in. to the weather. The panel was allowed to season 7 days and then tested.

Item 30. Over the other side of panel frame No. 7, wood lath and plaster were applied according to the specifications of *Item* 10. The panel was allowed to season 14 days and re-tested.

Item 31. All previous construction was removed from the 2x4 studs in panel frame No. 4. Over the 2x4 studs, Building Paper *B* lapped vertical on studs, and 1x6 air dry Select drop siding were applied. Siding was painted with two coats of commercial white lead and zinc paint. After the application of final coat of paint, the panel was allowed to dry for 4 days and then tested.

Item 32. Over the other side of panel frame No. 4, 1x6 air dry end and side matched sheathing was applied. Panel was allowed to season 6 days and then re-tested.

Item 33. Drop siding and building paper (*Item* 31) were removed from panel frame No. 4 and the panel immediately re-tested with the sheathing in *Item* 32 exposed to the pressure side of the test machine.

Item 34. All previous construction was removed from panel frame No. 6, including inside vertical studs, leaving only the 2x4 plates nailed to top and bottom frame members and the two end studs nailed to vertical frame members. Between the two end studs and perpendicular to them two 2x4 girts were toe-nailed on 33-in. centers. Over the studs and girts and perpendicular to the latter, 1x10 boards were applied with a one inch space between boards nailed with *8d* wire nails at each side and in the middle of the boards at each girt. One heavy coat of good commercial paint was then applied. Immediately after painting, 1x4 battens were applied over the one inch spaces between the 1x10 boards and nailed on one side only of the battens through one edge of the 10-in. boards into the girts but not at other points. After the first coat of paint had dried, an additional coat was applied to boards and battens. The panel was allowed to season 14 days out-of-doors before testing.

DISCUSSION

A. P. KRATZ: This paper, taken in conjunction with the previous reports on the same subject, emphasizes the importance of proper wall construction. It brings out the fact that the major part of air leakage results from improper or faulty construction, and that the proper use of building paper, plaster, and paint, reduces such leakage to a negligible amount.

Since it is impossible to standardize faulty construction, it is difficult to choose, in spite of a wealth of information, just what factors should be used in the case of a particular building, and the infiltration loss remains one of the most uncertain calculations in determining the predicted heat loss from a building. It would seem to the writer, from the evidence presented, that the next step in a future program should be a study of the actual infiltration in existing buildings in order to establish upper and lower limits for the factors to be used for given types of constructions in conjunction with the factors now established for known conditions.

D. R. BREWSTER: These tests emphasize the importance of building paper to such an extent that I thought it might be of interest in this connection to call attention to a study of building papers made by the Bureau of Standards, the results of which are recorded in a bulletin entitled A Study of Sheathing Papers, Research Paper No. 85, of the Bureau of Standards, published in the *Journal of Research*, Vol. III, July 1929. This can be bought separately.

The conclusions of the study made by the Bureau of Standards bear out the results reported in this paper to an interesting degree and point out that the importance of sheathing paper depends not so much upon its weight and thickness and cost as upon the method of application, the tightness of the joints and the care used in preventing tearing and damage to the paper in use. Thus the only justification for using a high grade paper in building construction is to provide a paper of sufficient strength so that in application it is not apt to tear and so that during the life of the building it will not be subject to deterioration from the influence of moisture and rain blowing in. It is evident that it really pays to use a high grade building paper from the standpoint of obtaining a maximum length of life of the effectiveness of the construction in preventing infiltration.

Among the conclusions of the U. S. Bureau of Standards study I might read the following sentences which are of interest: "The price range of sheathing papers is about ten-fold between the cheapest and the most expensive. There is no very definite relation between the price of such papers and their value as building papers." This brings out the importance of the method of application rather than the quality of the paper itself. "Strength sufficient to insure getting the material in place, whole, water resistance sufficient to insure against damage to plastering and inside finish, which sometimes occurs in severe storms, and impermeability to air, are apparently the requisite elements in a good sheathing paper." It is evident that high grade building papers will more nearly meet these requirements than cheap, low grade papers that are made to meet price competition rather than to give definite standards of quality and performance.