SOME CAUSES OF PAINT PEELING

FRANK B. ROWLEY, M.E.
PROFESSOR OF MECHANICAL ENGINEERING

MILLARD H. LA JOY, M.S. (M.E.)
ASSOCIATE PROFESSOR OF MECHANICAL ENGINEERING

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UNIVERSITY OF MINNESOTA
J. L. MORRILL, President

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A. F. SPILHAUS, Dean

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INTRODUCTION

The peeling and blistering of paint from the outside surfaces of wood structures is a common occurrence and often very costly to the home owner. There are many causes for paint failure, and it is often difficult to trace the failure to a single cause. It is known that excessive moisture in wood may cause the paint to peel off or blister from the surface, but, if the blistering is due to excess moisture, there are still several methods by which this moisture may have gotten into the wood. It may have been contained in the wood when it was placed in the building; it may have come from faulty outside construction and the direct entrance of water from the outside; or it may have come from excessive moisture within the structure. If it was caused by condensation of moisture, the condensation may have been caused by excessive humidities within the building or by the improper selection and use of materials within the wall. In most cases where the difficulty is due to the condensation of moisture, the direct cause can be traced either to operating conditions or to structural design and not to a given material. Thus, insulation, which has in recent years taken so much of the blame for condensation and the results from condensation, may not be a factor even though there are improper construction and severe operating conditions.

In the summer of 1947, a test house was constructed at the University of Minnesota and a series of experiments conducted to determine the extent to which insulation may be responsible for condensation and paint peeling even though approved operating and construction methods are not used.

The house consisted of a story-and-one-half bungalow substantially 21 feet square constructed in a temperature control room which was 30 feet square and 25 feet high. Various types of mineral wool insulation were used, and, during the test, they were subjected to high relative humidities inside the house and moderate temperatures outside the house. The results of this study, which are given in this bulletin, show that the first paint peeling took place on the uninsulated wall rather than on the insulated walls, which is contrary to the general opinion as to the effect of insulation on the condensation problem.

EQUIPMENT AND INSTRUMENTS

Test Room

The tests were conducted in a large temperature control room 30 feet square and 25 feet high. The air for controlling the temperature was conditioned in an air conditioning unit located in the basement under the room, delivered at the top along one corner, and discharged along the corner on the top at the opposite side. The test room surrounding the test house was insulated on the side walls with six inches of mineral wool. The temperature control room with the test bungalow in place is shown diagrammatically in the line drawing of Figure 1.

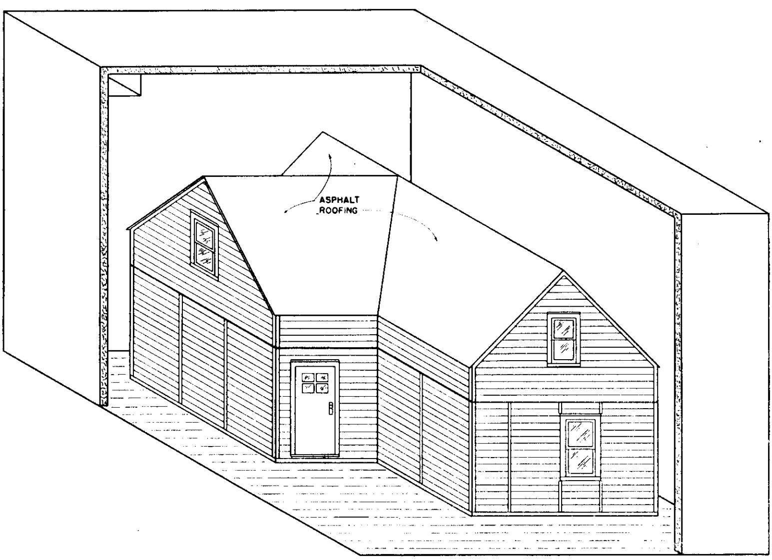


Figure 1. View of Test Bungalow in Place Within the Temperature Control Room

Temperature Control for Test Room

The low temperature in the test room was obtained from a 25-ton ammonia compressor and direct expansion cooling coils. Air was circulated through these coils by a 6000-cfm fan and distributed to the temperature control room. From here the air was taken back to the coils and recirculated to the room. The proper temperature was maintained by a system of by-pass dampers and direct expansion cooling coils. There was no humidity control for the low temperature air; however, as a result of operating conditions, the relative humidity averaged from 70 to 80 per cent.

Air Conditioning Control for Test House

The temperature and humidity of the air used in the test house were controlled by an air conditioning unit placed in the basement under the test house. This unit is shown in the line drawing of Figure 2. It consists essentially of a 1000-cfm fan for circulating the air through a chamber which contains both temperature and humidity control apparatus. The major part of the heating was accomplished by direct heating coils as shown, but the final temperature was controlled by electrical resistance heaters which in turn were controlled by the temperature of the air in the return ducts.

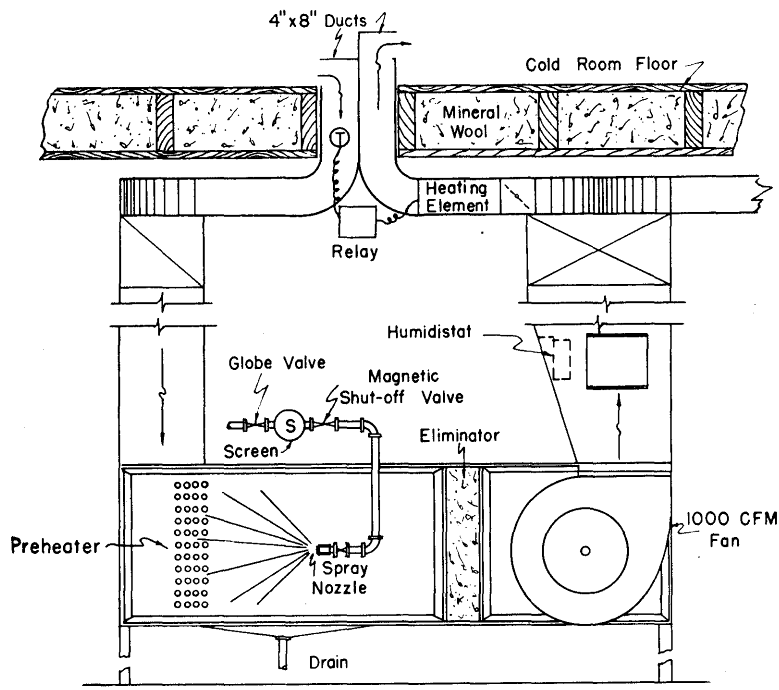


Figure 2. Sectional View of Air Conditioning Unit and Distribution Ducts

Temperature Measuring Equipment

All temperatures were taken with copper-constantan thermocouples. Readings were taken with both manually operated instruments and automatic recorders. All thermocouples were brought down to an operating panel which is shown in the photograph of Figure 3.

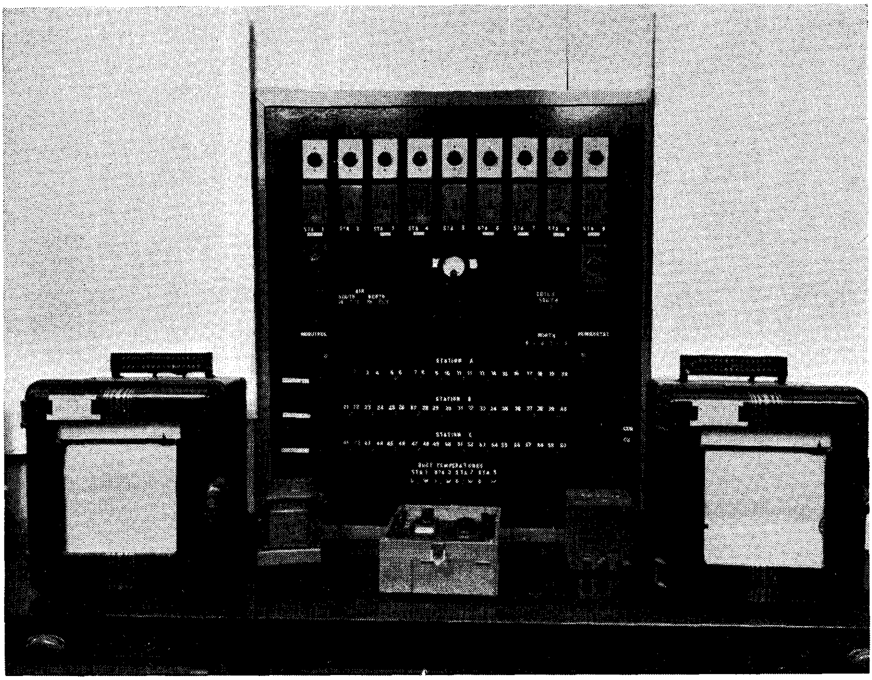


Figure 3. Control Panel and Automatic Recorders

Test House

The test house, which is shown diagrammatically in the control room in Figure 1, was essentially a one-and-one-half-story bungalow. The walls were all constructed with 2 x 4 studs spaced 16 inches on centers, those for the lower floor being eight feet in height. The first floor walls were all constructed in 4-foot-wide panels and so arranged that they could be taken apart during the test. The inside surface was finished with sheet rock 4 feet by 8 feet which was screwed to the studs. The finish on the outside surface of the studs consisted of ½-inch sheet rock sheathing and 6-inch pine lap siding. The sheathing was attached to nailing strips which fit snugly into grooves in the outside surface of the studs. The combined unit of sheathing and siding was attached to the studs with screws so that it could be readily removed during the test for inspection. The top, middle, and bottom siding boards were attached to the sheathing with screws so that they could be removed for inspection during the test.

Insulation was applied in the various test walls as described in detail under the heading Test Walls.

All of the siding was painted on the outside with two coats of outside white paint. The paint used was Federal Specification

TT-P-40. The paint was applied with a brush by one applicator. The first coat coverage was 330 square feet to the gallon, and the second coat coverage was 575 square feet to the gallon. Standard specifications were used throughout for the paint and for its application.

Special test walls were built into each of the outside 4-foot-wide panels.

Test Panels

The design and location of the test panels for the first floor are shown in Figure 4. Referring to this figure, the walls are numbered clockwise around the plan beginning at the lower left-hand corner. These are marked as "no insulation," "blown insulation," and "mineral wool batts," with the thickness of the batts and the location of the batts in the wall indicated on the plan. As will be noted, some of the batts are fitted snugly against

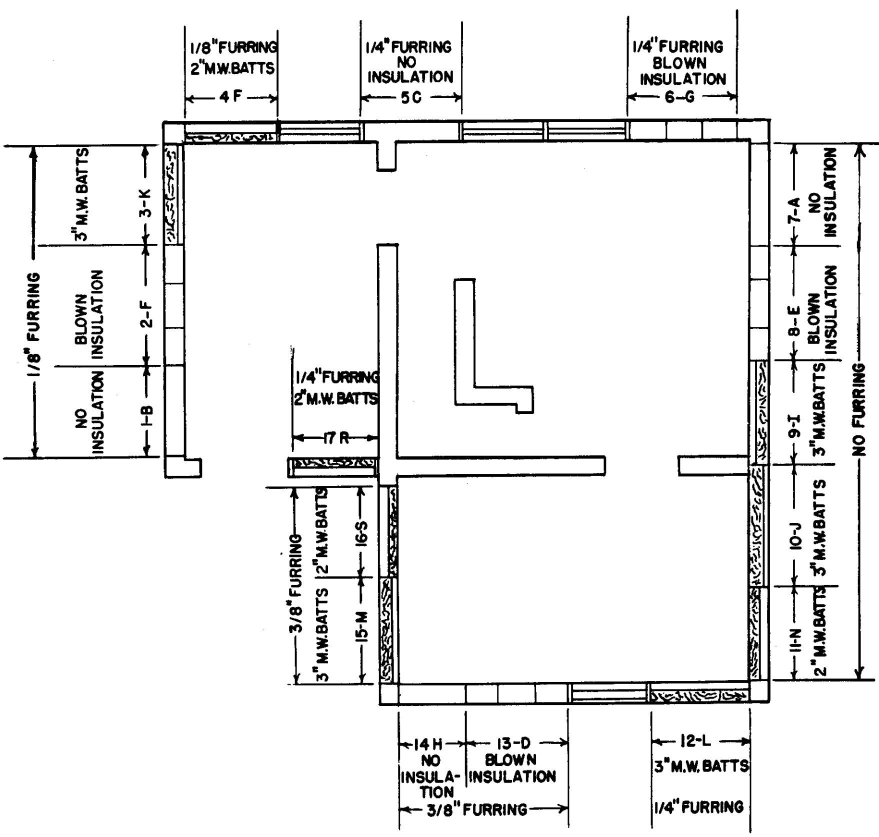


Figure 4. Plan View of Bungalow Showing Location of Wall Panels

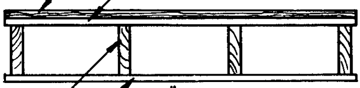
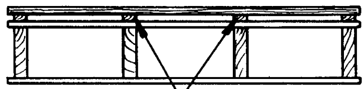
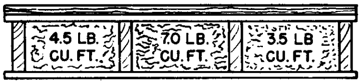
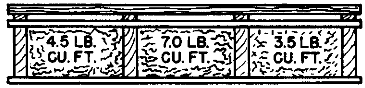
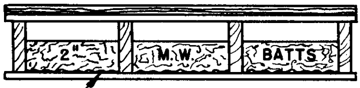
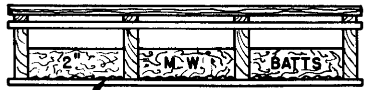
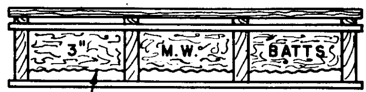
INSULATION	PANELS WITHOUT FURRING STRIPS	PANELS WITH FURRING STRIPS
NONE	WALL 7A SIDING — 1/2" GYPSUM SHEATHING  3/8" GYPSUM WALL BOARD 2"X4" FIR STUDS, 16" O.C.	1/8" FURRING STRIPS: WALL 1B 1/4" " " : WALL 5C 3/8" " " : WALL 14H  FURRING STRIPS
BLOWN	WALL 8E  MINERAL WOOL	1/8" FURRING STRIPS: WALL 2F 1/4" " " : WALL 6G 3/8" " " : WALL 13D  MINERAL WOOL
2 INCH M. W. BATTS	WALL 11N  ASPHALT COATED PAPER (CENTER STUD SPACE PERFORATED)	1/8" FURRING STRIPS: WALL 4P 1/4" " " : WALL 17R 3/8" " " : WALL 16S  ASPHALT COATED PAPER (CENTER STUD SPACE PERF.)
3 INCH M. W. BATTS	WALL 9I  ASPHALT COATED PAPER (CENTER STUD SPACE PERFORATED)	1/8" FURRING STRIPS: WALL 3K 1/4" " " : WALL 12L 3/8" " " : WALL 15M  ASPHALT COATED PAPER (CENTER STUD SPACE PERF.)
3 INCH M. W. BATTS	WALL 10J WALL CONSTRUCTION IDENTICAL TO WALL 11N ; 3" BATTS SUBSTITUTED FOR 2" BATTS.	

Figure 5. Construction of Wall Panels

the outside surface while others are fitted snugly against the inside surface. It will be noted further that the walls are indicated as having no furring strips, ⅛-, ¼-, and ⅜-inch furring strips. This refers to the width of the furring strips which were used between the sheathing and siding in the various walls.

Cross-sectional drawings of the various walls on the first floor are shown in Figure 5. These show the types of wool used and the locations of the batts with respect to the air spaces. As will be noted from the detail drawings of those walls in which the batts were used, the vapor barriers on the warm sides of the batts were perforated for the center stud section of each 4-foot-wide panel. These were perforated with holes ¼-inch in diameter and 6 inches apart to give three rows of holes in the center stud space only.

TEST PROCEDURE

Since the purpose of these tests was to determine the effect of high humidities within the house on exterior paint when no insulation and when various types of mineral wool insulation were used, the house was designed and built with different types and thicknesses of noninsulated and mineral wool–insulated walls. It was operated with inside air conditions of approximately 70° F and about 60 per cent relative humidity. It was the intention to maintain outside air of approximately 32° F throughout the test; however, at the end of a 10-day run, it did not appear that this temperature would produce tangible results within any reasonable length of time. For that reason, the temperature was then dropped to about 25° F for five days and then to 20° F for three days. It was then raised up to 30° F for eight days and again dropped to 25° F for four days. After this, and for the last half of the test, the outside air surrounding the test house was maintained at approximately 32° F. The relative humidity of the outside air varied from 70 per cent to 80 per cent throughout the test, the inside air remaining at substantially 60 per cent for the first half of the test and 65 per cent for the latter half of the test.

Observations were made throughout the test of the paint on the exterior of the various walls. The moisture gain in the siding and in various parts of the structure were taken with a commercial type of electric moisture meter which measures the comparative electrical conductivity of a wood or fiber material, which is an index of moisture content. The dates were noted at which blistering first occurred on the test walls. After test, the walls were disassembled and inspected, and the moisture through the various parts of the wall was noted. Photographs were also taken to show the blistering which had occurred on the painted siding.

TEST RESULTS

At regular periods throughout the test and at the end of the test, the siding was sampled by the moisture meter to determine moisture content. Figure 6 is a diagram of points at which moisture contents were taken for the sheathing and siding of the various walls. The numerals on this diagram will be carried

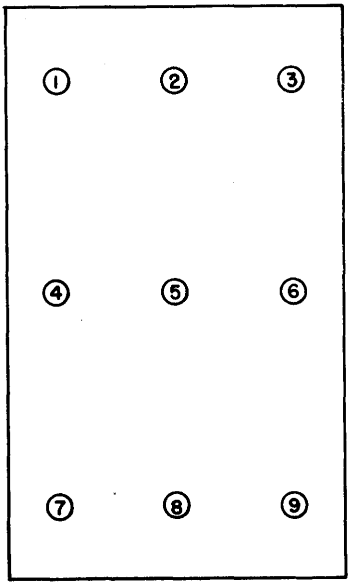


Figure 6. Locati•n Chart for Sampling of Siding, Sheathing and Insulation as Viewed from Outside

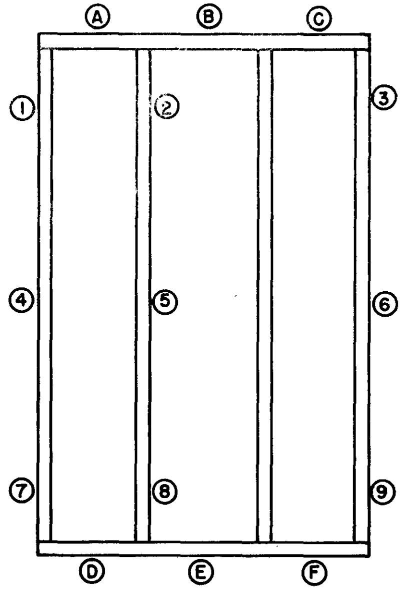


Figure 7. Location Chart for Sampling of Wall Framing as Viewed from Outside

through the tables indicating moisture content as given by the meter for the various periods of test. Figure 7 gives a diagram of the locations of points at which moisture contents were taken for the framing at the end of the test. The numerals and letters on this diagram are carried through the table giving moisture content of the framing.

Figures 8 and 9 show the general results of the tests from June 2 to August 5. The curves in the upper part of each chart show the air temperatures and humidities on the inside and outside of the test house, and the four sets of curves at the lower part of each chart show the average moisture pickup of the siding boards throughout the test. In Figure 8, the curves are grouped according to the type of insulation used in the wall; in Figure 9, they are grouped according to the thickness of the furring strips used on the wall between the sheathing and the siding.

Figures 10 to 23 inclusive are photographs taken near the end of the test to show the condition of the paint on the exterior surfaces of the different walls. The designating numbers of the walls photographed are shown in the titles beneath the photos.

Tables I to VIII inclusive give the results taken after the test was over for the various test walls on the first floor. Tables IX, X, and XI give a summary of conditions as observed for the first

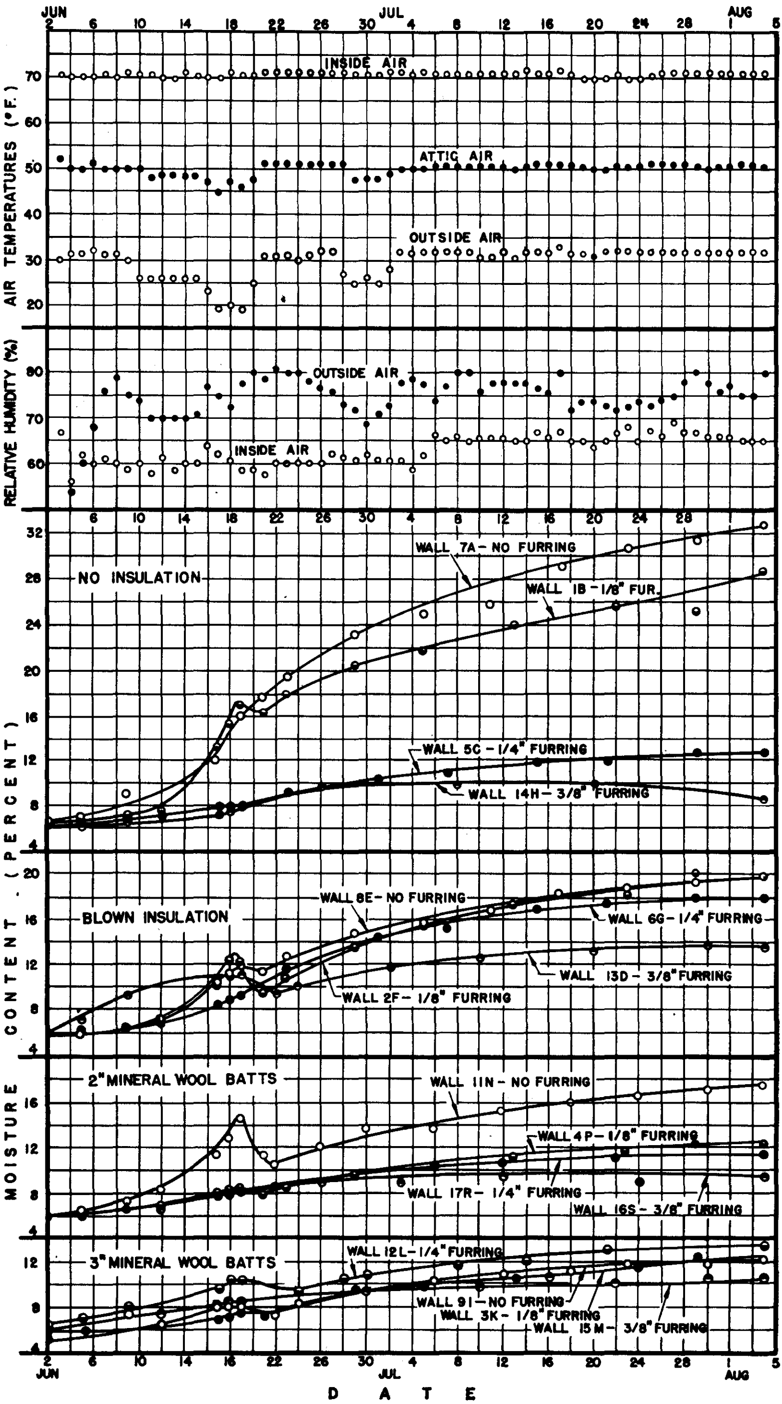


Figure 8. Summary Chart Showing the Average Moisture Content of the Siding Boards Throughout Test—Walls Grouped According to Type of Insulation

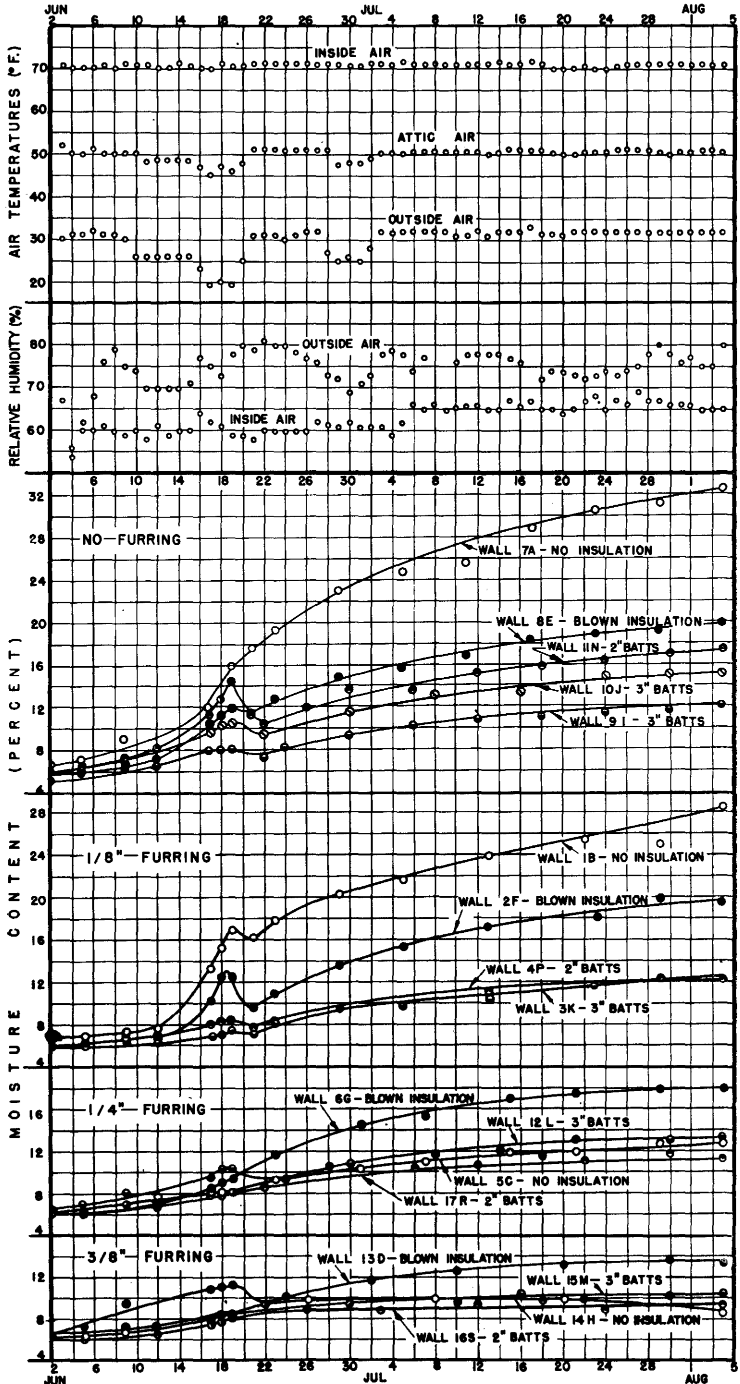


Figure 9. Summary Chart Showing the Average Moisture Content of the Siding Boards Throughout Test—Walls Grouped According to Thickness of Furring Strips Used Between Siding and Sheathing

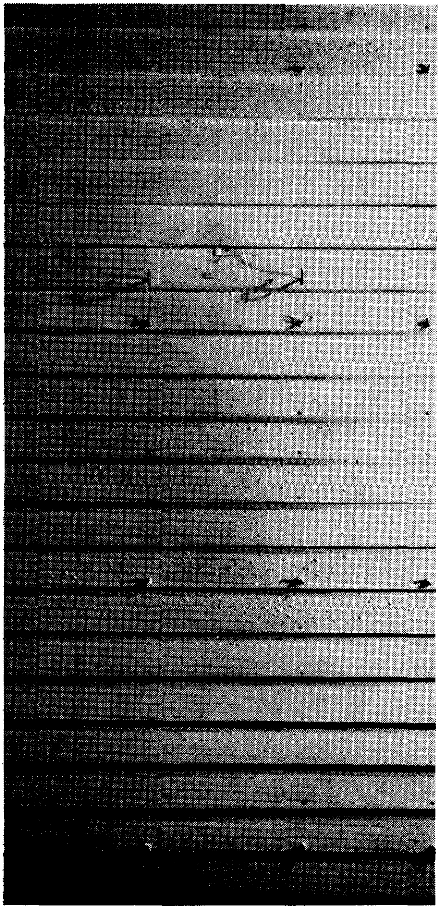


Figure 10. Extent of Blistering on Wall 1B (No Insulation, ⅛-Inch Furring) after Test

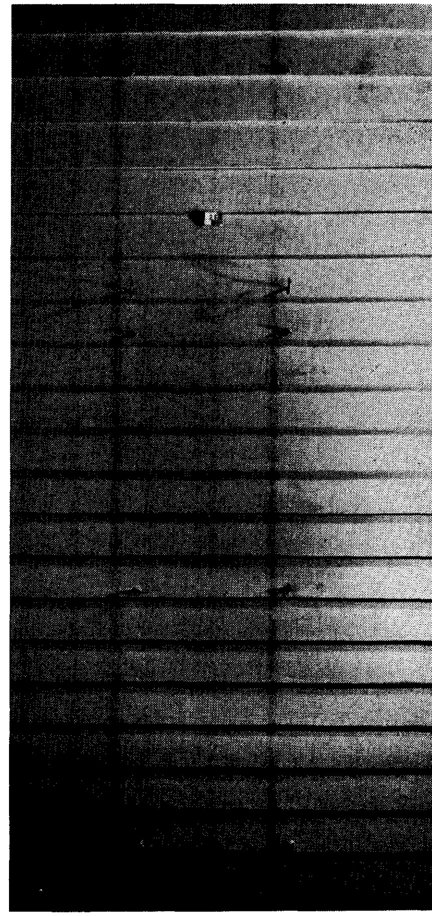


Figure 11. Extent of Blistering on Wall 2F (Blown Insulation, ⅛-Inch Furring) after Test

floor test walls when they were taken apart after the test was finished.

Analysis of Curves—Figures 8 and 9

The curves of Figures 8 and 9 show the general moisture condition of the siding in the test walls throughout the test period. In each case, the percentage of moisture indicated for a particular period is the average of nine readings as taken with the moisture meter for the exposed boards on the exterior of the wall. These moisture readings were taken at the points indicated in Figure 6.

Referring to Figure 8, the upper set of curves for the walls with no insulation shows very conclusively the effect of furring between the sheathing and siding. For instance, on wall 7A with no furring, the average moisture content at the end of the test was above 32 per cent, while, for wall 14H with ⅜-inch furring,

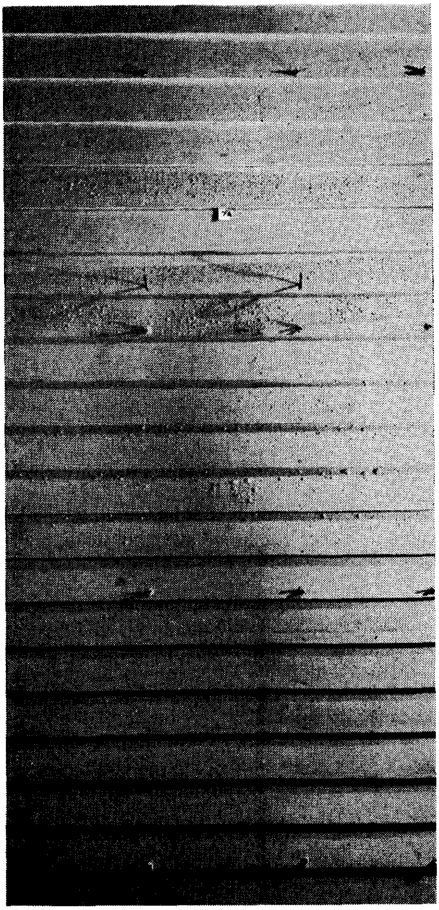


Figure 12. Extent of Blistering on Wall 7A (No Insulation, No Furring) after Test

Figure 13. Extent of Blistering on Wall 8E (Blown Insulation, No Furring) after Test

it was slightly over 8 per cent. After the first 16 days of test, the moisture content in the siding showed an inverse relationship to the thickness of the furring used.

In the set of curves for walls having blown insulation, the spread between the wall without furring and that with ⅜-inch furring was not as great nor were the extreme limits of moisture content as high as they were for the walls with no insulation. While furring did show some advantage, it was not as pronounced as for the noninsulated walls.

The advantage of furring strips is somewhat apparent in the set of curves for the walls having 2-inch mineral wool batts, but it is rather confusing in the set of curves for the walls having 3-inch mineral wool batts. In the walls represented by these curves, there were other differences besides the furring strips. For instance, some of the batts were on the warm side while

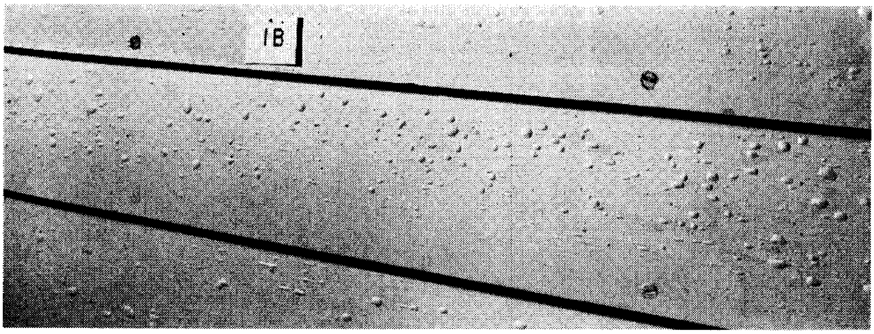


Figure 14. Close-Up View of Twelfth Board from Top of Wall 1B
(No Insulation, 1/8-Inch Furring) after Test

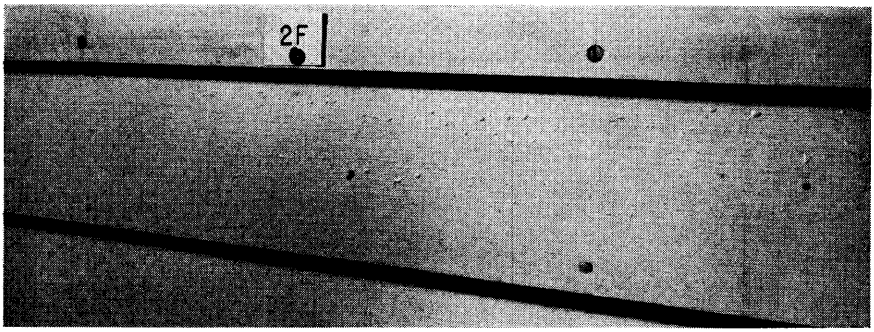


Figure 15. Close-Up View of Fourth Board from Top of Wall 2F
(Blown Insulation, 1/8-Inch Furring) after Test

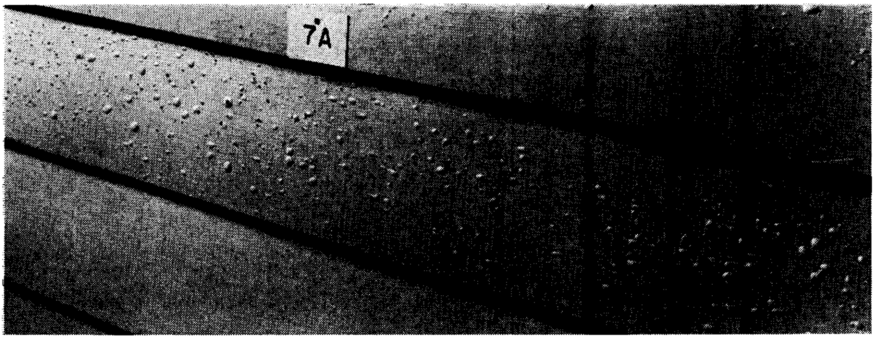


Figure 16. Close-Up View of Fifth Board from Top of Wall 7A
(No Insulation, No Furring) after Test

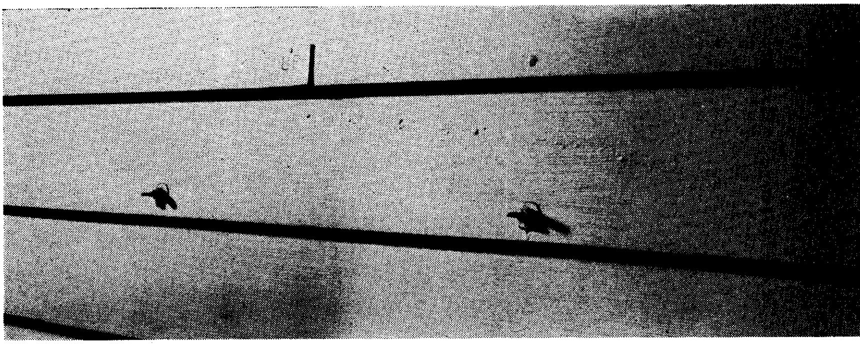


Figure 17. Close-Up View of Fourteenth Board from Top of Wall 8E
(Blown Insulation, No Furring) after Test

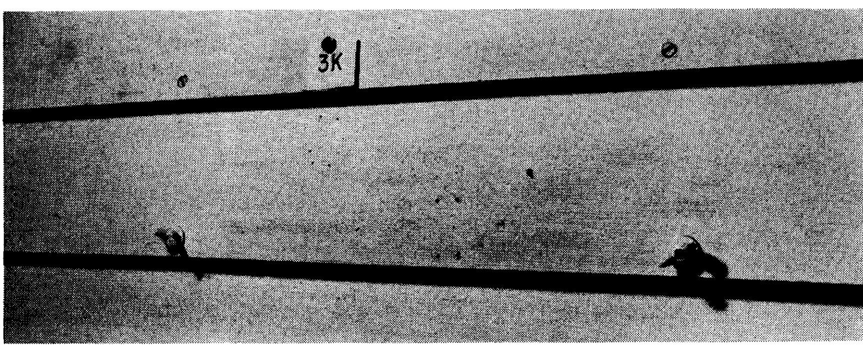


Figure 18. Close-Up View of Second Board from Top of Wall 3K
(3-Inch Batt Insulation, ⅛-Inch Furring) after Test

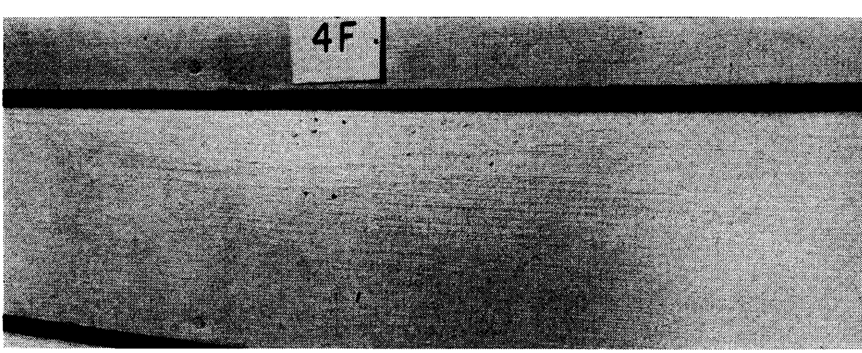


Figure 19. Close-Up View of Fifth Board from Top of Wall 4F
(2-Inch Batt Insulation, No Furring) after Test

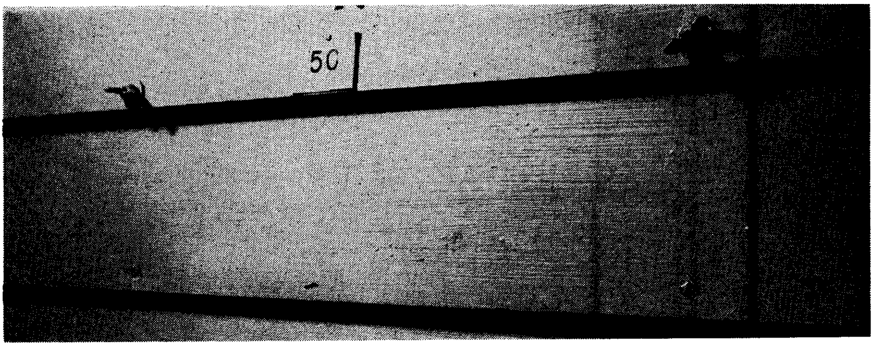


Figure 20. Close-up View of Third Board from Top of Wall 5C
(No Insulation, ¼-Inch Furring) after Test

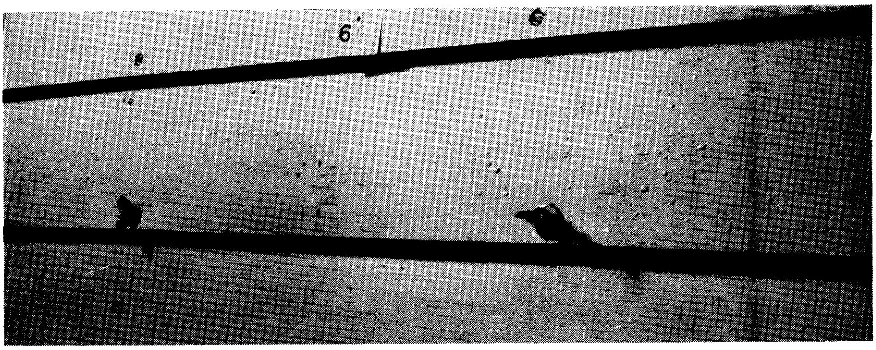


Figure 21. Close-Up View of Second Board from Top of Wall 6G
(Blown Insulation, ¼-Inch Furring) after Test

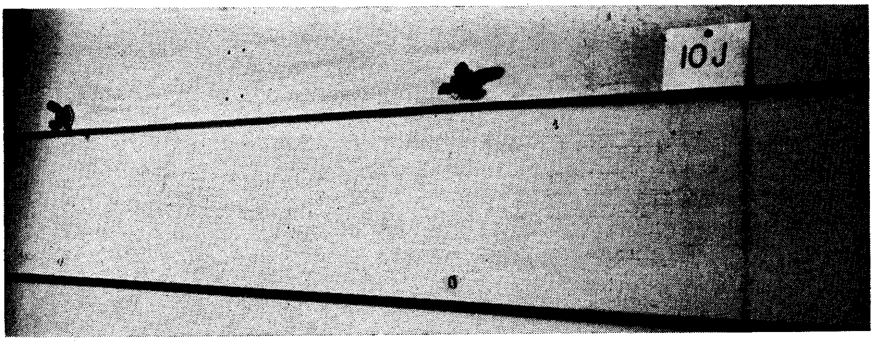


Figure 22. Close-Up View of Third Board from Top of Wall 10J
(3-Inch Batt Insulation, No Furring) after Test

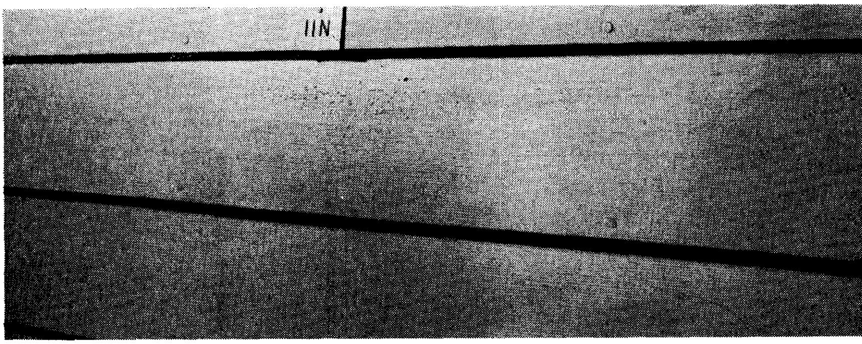


Figure 23. Close-Up View of Fifth Board from Top of Wall 11N (2-Inch Batt Insulation, No Furring) after Test

others were on the cold side. Furthermore, in each case, .the vapor barrier in the center stud space of the test panel was punctured, and this may have allowed vapor to escape and to distribute under the siding or between the siding and the sheathing. Thus, the moisture contents taken of the siding boards may not have been clear-cut indications of results that might have been obtained had all other conditions excepting the furring strips been equal in the two sets of walls.

The upper set of curves in Figure 9 shows the relative conditions found in the siding throughout the test for walls with different types of insulation and no furring strips. Wall 7A without insulation showed a more rapid gain in moisture content throughout the test with an average final content of slightly above 32 per cent. The best results were shown by the 3-inch batts, and the 2-inch batts showed somewhat better than the blown insulation. It should be pointed out, however, that the blown insulation did not have any vapor barrier on the wall, whereas all of the batts had a barrier. From this set of curves, wall 9I with a 3-inch batt next to the sheathing gave better results than did wall 10J with a 3-inch batt next to the inside sheet rock. There is not sufficient other evidence in these tests to draw any conclusions as to whether the batt should be placed next to the inner surface or next to the outer surface. It is possible that for wall 10J the vapor which passed through the center stud space where the barrier was punctured may have had a free chance to distribute between the insulation and the sheathing, whereas for wall 9I any vapor passing through the center stud space would not distribute over the sheathing. Therefore, the average moisture absorption of the siding for wall 9I would be less.

Analysis of Photographs of Wall Surfaces

The photograph, Figure 10, shows the surface of wall 1B without insulation after the test; the photograph, Figure 11, shows the surface of wall 2F with blown insulation after the test. In each case, ⅛-inch furring strips were used between the siding and sheathing. The blistering of the paint is observed to be more severe in wall 1B without insulation than in wall 2F with insulation.

The photograph, Figure 12, shows wall 7A without insulation, and the photograph, Figure 13, shows wall 8E with insulation after the test. There was no furring in either wall. Wall 7A without insulation in Figure 12 shows more blistering than does wall 8E with insulation in Figure 13.

Figure 14 shows a close-up view of the twelfth board from the top of wall 1B as shown in Figure 10. This close-up view is typical of many of the siding boards of this wall. Figure 15 shows a close-up view of the fourth board from the top of wall 2F with blown insulation.

Figure 16 shows a close-up view of the fifth board from the top on wall 7A with no insulation, and Figure 17 shows the blistering which occurred on the fourteenth board from the top of wall 8E with insulation. There were no furring strips in either case, and these photographs are typical of the conditions of the two walls after the test.

Figures 18 through 23 show the blisterings which occurred on board No. 2 of wall 3K, board No. 5 of wall 4F, board No. 3 of wall 5C, board No. 2 of wall 6G, board No. 3 of wall 10J, and board No. 5 of 11N in that order. In each case, these photographs represent the worst blistering which occurred on the respective walls, and these blisterings are considered to be light as compared with those which occurred on some of the other uninsulated walls.

Analysis of Material in Tables I to VII Inclusive

Table I shows the number of days from the start of test until blistering was first observed on the different walls and the percentage of moisture measured in the siding board at the time blistering occurred and at the end of the test. From this table, it will be noted that the first paint peeling occurred after 19 days in wall 7A which had no insulation and no furring strips. The second was observed in wall 1B at 21 days. This wall had no insulation but had ⅛-inch furring strip. The next wall to show paint peeling was 2F with blown insulation and ⅛-inch furring strip. The peeling on wall 2F showed up at the end of 38 days or after twice as long a period as for wall 7A with no insulation and no furring strips. The remainder of the walls where peeling was evident at all showed blistering in from 40 to 60 days.

In general, it was observed that the paint did not show blistering or peeling in any case until the moisture content of the siding had reached 25 per cent. However, the paint did not neces-

Table I. Summary of Blistering of Siding Boards in the Various Walls

Wall	No. of Days from Start of Test at Which Blistering First Occurred	Location*	Per Cent Moisture by Weight	
			At time of blistering	At end of test
1B	21	L-2	28	72
2F	38	L-4	26	42
3K	57	C-2	29	30
4F	54	C-5	34	42
5C	54	L, C-1	26	42
6G	39	R-2	29	45
7A	19	R-20	27	69
8E	42	C-2	33	45
9I	......	....	......	......
10J	61	R-3	34	34
11N	45	C-1	25	45
12L	......	....	......	......
13D	......	....	......	......
14H	......	....	......	......
15M	......	....	......	......
16S	......	....	......	......
17R	......	....	......	......

* The letters refer to the stud section, i.e., L = left, C = center, and R = right; the numerals refer to the siding board as numbered from the top. For example, L-2 indicates the second board from the top in the left stud section.

Table II. Summary of Moisture Content of Siding Boards in the Various Walls at End of Test

Wall	Furring	Moisture Content				
		Maximum		Minimum		Average
		Per cent by wt	Location*	Per cent by wt	Location*	Per cent by wt
		No Insulation				
7A	None	36.5	5	19.0	7	32.8
1B	1/8"	45.5	1	12.1	9	28.8
5C	1/4"	16.4	1	9.0	4	12.6
14H	3/8"	10.7	4, 6	9.0	1, 3, 7	8.3
		Blown Insulation				
8E	None	27.7	6	12.1	1	20.0
2F	1/8"	24.7	4	10.7	7	19.5
6G	1/4"	24.7	2	10.7	7	18.0
13D	3/8"	16.4	1	10.7	7	13.4
		3" Batts, Air Space Toward Inside				
9I	None	17.7	5	9.0	7	12.1
3K	1/8"	19.0	2	9.0	7	14.0
12L	1/4"	15.0	1, 4, 5, 6	10.7	3	13.1
15M	3/8"	12.7	2	10.1	7, 8, 9	10.5
		2" Batts, Air Space Toward Sheathing				
11N	None	23.6	2	10.1	7	17.5
4F	1/8"	16.4	2	10.1	8	12.3
17R	1/4"	15.7	3	9.0	9	11.7
16S	3/8"	10.7	1	9.0	3, 6, 7, 8, 9	9.6
		3" Batts, Air Space Toward Sheathing				
10J	None	21.4	5	9.0	7	15.3

* The numerals refer to the points indicated on the location chart of Figure 6.

sarily peel when the moisture had reached this percentage, and there were many cases where moisture reached as high as 40 per cent with no signs of peeling or blistering.

Table II gives a summary of the moisture content of the siding boards in the various walls at the end of the test. As will be noted, there is a great variation in the moisture content of the boards for the different walls. While there is no consistency, it may in general be said that the boards at the top of the walls showed greater moisture content than did those lower down in the wall. The uninsulated walls showed the highest per cent of moisture, with the blown-insulated walls second, the 2-inch batts third, and the 3-inch batts last. As previously pointed out, those walls of blown insulation did not have any barriers while those with batt insulation did have barriers, although these barriers had been punctured in the central stud section. These results are very similar to those shown on the curves of Figures 8 and 9.

Table III shows a summary of moisture content for sheathing boards in the various walls at the end of the test. In general, the moisture content was not high in the sheathing boards for any of

Table III. Summary of Moisture Content of Sheathing in the Various Walls at End of Test

Wall	Furring	Moisture Content				
		Maximum		Minimum		Average
		Per cent by wt	Location*	Per cent by wt	Location*	Per cent by wt
			No Insulation			
7A	None	2.4	7	1.5	3	0.5
1B	⅛″	2.4	4	0.8	5	1.7
5C	¼″	0.9	2	0.3	3, 6	0.6
14H	⅜″	0.8	7	0.5	1, 3, 4, 6	0.6
			Blown Insulation			
8E	None	4.2	9	2.3	3, 8	2.7
2F	⅛″	1.9	3	0.0	8	1.2
6G	¼″	2.6	6	1.3	2	2.0
13D	⅜″	2.7	1	0.2	8	1.6
			3″ Batts, Air Space Toward Inside			
9I	None	3.2	1	0.4	2, 7	1.0
3K	⅛″	2.6	5	0.0	8	1.0
12L	¼″	2.0	1	0.6	4, 5, 6	0.9
15M	⅜″	0.8	2	0.3	7	0.5
			2″ Batts, Air Space Toward Sheathing			
11N	None	2.3	2	0.5	7	1.3
4F	⅛″	2.6	2	0.3	1	0.8
17R	¼″	1.0	3	0.4	7	0.6
16S	⅜″	0.7	4	0.4	3, 6, 7, 8	0.5
			3″ Batts, Air Space Toward Sheathing			
10J	None	2.5	3	0.4	1	1.0

* The numerals refer to the points indicated on the location chart of Figure 6.

Table IV. Summary of Moisture Content of Insulation in the Various Walls at End of Test

Wall	Furring	Moisture Content: Maximum Per cent by wt	Maximum Location*	Minimum Per cent by wt	Minimum Location*	Average Per cent by wt
Blown Insulation						
8E	None	28.3	4	0.1	2, 6, 9	9.5
2F	⅛″	37.8	7	0.0	6, 9	12.5
6G	¼″	51.4	9	0.1	7	12.8
13D	⅜″	16.8	5	0.0	9	2.7
3″ Batts, Air Space Toward Inside						
9I	None	0.2	4, 5	0.0	1, 2, 6, 7, 8, 9	0.05
3K	⅛″	6.3	1	0.0	1, 3, 6, 7, 8, 9	0.8
12L	¼″	2.7	1	0.0	3, 4, 5, 6, 7, 8, 9	0.4
15M	⅜″	0.2	3	0.0	1, 2, 4, 6, 7, 8, 9	0.02
2″ Batts, Air Space Toward Sheathing						
11N	None	1.1	5	0.0	1, 3, 4, 6, 7, 8, 9	0.1
4F	⅛″	1.1	8	0.0	1, 2, 5, 6, 7, 9	0.2
17R	¼″	0.1	9	0.0	1, 3, 5, 6, 7	0.01
16S	⅜″	0.1	2, 6, 8	0.0	1, 3, 4, 5, 7, 9	0.03
3″ Batts, Air Space Toward Sheathing						
10J	None	0.9	3	0.0	4, 6, 7	0.2

* The numerals refer to the points indicated on the location chart of Figure 6.

the walls; however, the blown insulation without furring strips showed slightly more moisture than did any of the others.

Table IV shows a summary of moisture conditions found in the insulation of the various walls after the test. The group of walls with the blown insulation and without vapor barriers showed considerably more moisture than did those walls which had batts with barriers.

Table V shows the moisture content of the wood framing members of the wall panels taken after the tests. As will be noted, the maximum moisture content is rather high for several of the walls, the highest being for wall 13D with blown insulation and ⅜-inch furring strip. The letters and numerals in the location column of the table refer to those indicated on Figure 7.

Tables VI, VII, and VIII show the moisture gradient through the insulation for the walls with blown insulation, 2-inch batt insulation, and 3-inch batt insulation respectively. Samples were taken at the mid-height of the wall where a thin layer was peeled from the cold side, the mid-point, and the warm side of the insulation in each of the three stud spaces. There was no significant moisture accumulation on the warm side of the insulation in any of the walls, and there was no appreciable moisture accumulation at the mid-point of the insulation except for walls 2F, 8E, and 13D. However, on the cold side of the insulation, there was considerable moisture accumulation for walls 2F, 6G, 8E, and 13D. For these four walls, there was considerable moisture accumulation in the rock wool as shown in the table. It should, however, be pointed out again that there were no vapor barriers on these walls.

Table V. Summary of Moisture Content of Wood Framing in the Various Walls at End of Test

Wall	Furring	Moisture Content: Maximum Per cent by wt	Maximum Location*	Minimum Per cent by wt	Minimum Location*	Average Per cent by wt
No Insulation						
7A	None	27.0	E	15.3	4, 6	18.6
1B	1/8"	50.0	9	8.1	4	17.3
5C	1/4"	19.4	E	8.1	1, 4, 6, 9	11.1
14H	3/8"	15.3	C	5.5	6	9.5
Blown Insulation						
8E	None	42.5	F	8.1	7	16.6
2F	1/8"	54.0	F	8.1	4, 6, 7, 9	15.5
6G	1/4"	26.0	5	8.1	7	14.7
13D	3/8"	77.0	F	7.5	1, 4	15.5
3" Batts, Air Space Toward Inside						
9I	None	9.2	5	7.0	1, 4	7.8
3K	1/8"	18.8	B	7.0	4, E, D	9.7
12L	1/4"	21.0	A	7.0	8	11.1
15M	3/8"	10.5	B	7.0	4, 6, 7, 9	8.2
2" Batts, Air Space Toward Sheathing						
11N	None	50.0	E	6.5	C	17.9
4F	1/8"	15.3	B	7.0	7	8.7
17R	1/4"	17.8	C	7.0	1	9.1
16S	3/8"	15.3	A	7.0	1, 3, 6, 9, C	8.5
3" Batts, Air Space Toward Sheathing						
10J	None	16.5	C	6.0	2, 9	8.2

* The letters and numerals refer to the points indicated on the location chart of Figure 7.

Table VI. Moisture Gradient through Insulation at End of Test at Mid-Height of Walls with Blown Insulation*

Wall	Furring	Moisture Content, Per Cent by Weight — Cold side of insulation			Mid-point of insulation			Warm side of insulation		
		Low density mineral wool	High density mineral wool	Medium density mineral wool	Low density mineral wool	High density mineral wool	Medium density mineral wool	Low density mineral wool	High density mineral wool	Medium density mineral wool
8E	None	0.0	....	48.4	0.0	0.0	30.0	0.0	0.0	2.7
2F	1/8"	0.0	56.6	52.0	0.0	2.7	15.8	0.9	0.0	0.1
6G	1/4"	3.2	18.4	107.0	0.0	2.8	0.8	0.0	0.0	0.0
13D	3/8"	0.7	47.5	87.5	0.2	13.7	1.8	0.0	0.9	0.3

* Medium density mineral wool was blown to approximately 4.5 lb/cu ft; high density mineral wool to approximately 7 lb/cu ft; and low density mineral wool to approximately 3.5 lb/ cu ft.

Table VII. Moisture Gradient through Insulation at End of Test at Mid-Height of Walls with 2-Inch Batt Insulation*

Wall	Furring	Moisture Content, Per Cent by Weight — Cold side of insulation			Mid-point of insulation			Warm side of insulation		
		Right stud space	Center stud space	Left stud space	Right stud space	Center stud space	Left stud space	Right stud space	Center stud space	Left stud space
11N	None	0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0
4F	1/8"	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.2
17R	1/4"	0.0	......	0.0	0.0	.....	0.0	0.1	......	0.1
16S	3/8"	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1

* Air space toward sheathing. Stud spaces are designated as right, center, or left as observed from outside of test bungalow.

Table VIII. Moisture Gradient through Insulation at End of Test at Mid-Height of Walls with 3-Inch Batt Insulation*

Wall	Furring	Moisture Content, Per Cent by Weight								
		Cold side of insulation			Mid-point of insulation			Warm side of insulation		
		Right stud space	Center stud space	Left stud space	Right stud space	Center stud space	Left stud space	Right stud space	Center stud space	Left stud space
Air Space Toward Sheathing										
10J	None	0.0	0.2	0.1	0.1	0.2	0.0	0.0	1.2	0.0
Air Space Toward Inside										
9I	None	0.0	0.0	0.1	0.1	0.2	0.0	0.1	0.0	0.0
3K	⅛"	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12L	¼"	0.8	0.0	0.0	0.0	2.2	0.0	0.1	0.0	0.0
15M	⅜"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* Stud spaces are indicated as right, center, or left as observed from outside of test bungalow.

Discussion of Tables IX, X, and XI

Tables IX, X, and XI are summaries of observation notes taken upon removal of the exterior test panels at the end of test for walls with no insulation, blown insulation, and batt insulation respectively.

For the uninsulated walls 7A and 1B, it was found that the warm side of the siding was wet and that there was a rather heavy blistering of the surface paint. For similar walls with blown insulation, 8E and 2F, the back side of the siding boards was dry and the surface blistering was much lighter than that observed on the uninsulated walls. The uninsulated walls, 7A with no furring and 1B with ⅛-inch furring, showed a medium heavy concentration of moisture globules on the warm side of the sheathing and slight mold growth on the sheathing. The similar walls with blown insulation, 8E and 2F, showed a somewhat heavier concentration of moisture on the sheathing, but slight mold growth was found only in the wall 8E without furring. Blown-insulated walls 6G with ¼-inch furring and 13D with ⅜-inch furring both showed medium to heavy concentration of moisture globules on the warm side of the sheathing in all stud spaces. Neither showed any mold on the sheathing. Uninsulated walls 7A and 1B showed free moisture on the framing members. Wall 7A with no furring had free moisture over the entire bottom plate, while wall 1B with ⅛-inch furring had free moisture on the right stud and right bottom plate only. Wall 8E which had blown insulation and no furring had free moisture on the bottom plate and on the right and center studs, and wall 2F with ⅛-inch furring had free moisture on the bottom plate at right.

Table IX. Summary of Observation Notes Taken upon Removal of Exterior Test Panels at End of Test for Walls with No Insulation

Wall No.	Siding*	Sheathing	Framing	Insulation
7A (No furring)	Heavy to medium blistering on all boards Back side wet	Medium heavy concentration of moisture globules on warm side Slight mold growth at label on sheathing	Free moisture over entire bottom plate	No insulation
1B (1/8" furring)	Heavy to medium blistering on all boards Back side wet	Medium heavy concentration of moisture globules on warm side Slight mold growth at label on sheathing	Free moisture on right bottom plate and right stud	No insulation
5C (1/4" furring)	Light blistering on boards 1 and 3 Back side dry	Medium concentration of moisture globules on warm side in center stud space	No free moisture	No insulation
14H (3/8" furring)	No blistering Back side dry	No free moisture	No free moisture	No insulation

*Siding boards are numbered from 1 to 21, starting at the top.

Table X. Summary of Observation Notes Taken upon Removal of Exterior Test Panels at End of Test for Walls with Blown Insulation

Wall No.	Siding*	Sheathing	Framing	Insulation
8E (No furring)	Light to medium blistering on boards 2, 3, 5, 7, 8, 11, 14, 15, 16, 17, 18, and 20 Back side dry	Heavy to medium concentration of moisture globules on warm side in all stud spaces Slight mold growth at label on sheathing	Free moisture on bottom plate Free moisture on right and center studs	Irregular patches adhere to sheathing in all stud spaces Mineral wool (low density) feels slightly moist. Shows light concentration of comparatively large moisture globules on cold side Mineral wool (high density) feels very wet. Shows heavy concentration of comparatively small moisture globules on cold side Mineral wool (medium density) feels medium wet. Shows medium concentration of comparatively small moisture globules on cold side
2F (1/8" furring)	Light to medium blistering on boards 2, 4, 5, 6, 8, 11, 12, 13, 14, 15, 16, 17, and 18 Back side dry	Heavy to medium concentration of moisture globules on warm side in all stud spaces	Free moisture on bottom plate at right	Irregular patches adhere to sheathing in all stud spaces Mineral wool (low density) feels slightly moist. Shows light concentration of comparatively large moisture globules on cold side Mineral wool (high density) feels very wet. Shows heavy concentration of comparatively small moisture globules on cold side Mineral wool (medium density) feels medium wet. Shows medium concentration of comparatively small moisture globules on cold side

* Siding boards are numbered from 1 to 21, starting at the top.

Table X. Summary of Observation Notes Taken upon Removal of Exterior Test Panels at End of Test for Walls with Blown Insulation—(Continued)

Wall No.	Siding*	Sheathing	Framing	Insulation
6G (1/4" furring)	Light to medium blistering on boards 2, 3, 6, and 8 Back side dry	Heavy to medium concentration of moisture globules on warm side in all stud spaces	No free moisture	Irregular patches adhere to sheathing in all stud spaces Mineral wool (low density) feels slightly moist. Shows light concentration of comparatively large moisture globules on cold side Mineral wool (high density) feels very wet. Shows heavy concentration of comparatively small moisture globules on cold side Mineral wool (medium density) feels medium wet. Shows medium concentration of comparatively small moisture globules on cold side
13D (3/8" furring)	No blistering Back side dry	Heavy to medium concentration of moisture globules on warm side in all stud spaces	Free moisture on bottom plate at right	Irregular patches adhere to sheathing in all stud spaces Mineral wool (low density) feels slightly moist. Shows light concentration of comparatively large moisture globules on cold side Mineral wool (high density) feels very wet. Shows heavy concentration of comparatively small moisture globules on cold side Mineral wool (medium density) feels medium wet. Shows medium concentration of comparatively small moisture globules on cold side

* Siding boards are numbered from 1 to 21, starting at the top.

Table XI. Summary of Observation Notes Taken upon Removal of Exterior Test Panels at End of Test for Walls with Batt Insulation

Wall No.	Siding*	Sheathing	Framing	Insulation
		3″ Mineral Wool Batts, Air Space Toward Inside		
9I (No furring)	No blistering Back side dry	Light concentration of moisture globules on warm side at mid-height of center stud space	No free moisture	Slight concentration of free moisture on cold side at top
3K (1/8″ furring)	Light blistering on board 2 Back side dry	Light concentration of moisture globules on warm side at top of all three stud spaces	No free moisture	Slight concentration of free moisture on cold side at top
12L (1/4″ furring)	No blistering Back side dry	Light concentration of moisture globules on warm side at top of all three stud spaces	No free moisture	Slight concentration of free moisture on cold side at top
15M (3/8″ furring)	No blistering Back side dry	No free moisture	No free moisture	No free moisture
		3″ Mineral Wool Batts, Air Space Toward Sheathing		
10J (No furring)	Light blistering on board 3 Back side dry	Light concentration of moisture globules on warm side at top of right and center stud spaces	No free moisture	No free moisture

* Siding boards are numbered from 1 to 21, starting at the top.

Table XI. Summary of Observation Notes Taken upon Removal of Exterior Test Panels at End of Test for Walls with Batt Insulation—(Continued)

Wall No.	Siding*	Sheathing	Framing	Insulation
		2″ Mineral Wool Batts, Air Space Toward Sheathing		
11N (No furring)	Light to medium blistering on boards 1, 2, 4, 5, 6, 7, 8, and 12 Back side dry	Medium concentration of moisture globules on warm side in right stud space at top and in center stud space at bottom Left stud space dry	Free moisture at center of bottom plate	No free moisture
4F (1/8″ furring)	Light blistering on boards 2, 3, 5, and 6 Back side dry	Light concentration of moisture globules on warm side at top center	No free moisture	No free moisture
17R (1/4″ furring)	No blistering Back side dry	Light concentration of moisture globules on warm side at top right	Free moisture on top of center stud	No free moisture
16S (3/8″ furring)	No blistering Back side dry	No free moisture	No free moisture	No free moisture

* Siding boards are numbered from 1 to 21, starting at the top.

In general, for those walls with blown insulation, the higher density insulation appeared to show more moisture than did the lighter density insulation. The actual moisture content for the insulation as measured at the mid-height of the wall is shown in Table VI. The low density mineral wool insulation showed the least amount of total moisture absorbed. In all of the blown-insulated walls, there was a considerable amount of moisture entrapped in that portion of the insulation next to the sheathing, and there were irregular patches of insulation which stuck to the sheathing due to the moisture.

For those walls using batt insulation with barriers, there was no free moisture found in the insulation except for a slight concentration on the cold side at the very top (away from the section at which moisture readings of the insulation were taken) in walls 9I, 3K, and 12L which had 3-inch mineral wool batts with the air space toward the inside. No free moisture was found on the framing members, except for wall 11N which had free moisture at the center of the bottom plate and wall 17R which had free moisture on top of the center stud. Both walls had 2-inch mineral wool batts with the air space toward the sheathing. The back side of the siding was dry in all of the batt-insulated walls.

CONCLUSIONS

1. The blistering or peeling of paint may be caused by accumulation of moisture in the wood under the paint. In this series of tests, no blistering occurred until the moisture content reached 25 per cent by weight. However, there were cases where the moisture content reached as high as 40 per cent without the occurrence of blistering.
2. The amount of moisture which may collect in the siding boards of a house and cause paint to peel is governed by a number of factors. Among these are type of construction, temperature and humidity of the air within the house, and temperature of the air outside the house.
3. Contrary to general opinion, insulation may, under some operating conditions, reduce the possibility of paint peeling from a wall even though the wall is so constructed that the vapor freely enters the inner surface.
4. If furring strips are used between the sheathing and the siding, the tendency is to reduce the possibility of paint peeling. These strips are not particularly effective unless they are ¼-inch or more in thickness.

5. Sufficient test data are not available to draw conclusions as to whether the air space should be on the warm or the cold side of the insulating batt when the batt is not the full stud space in thickness.
6. It is apparent from these tests that the peeling of paint is affected by many factors. The comparative effect of insulation on paint peeling for walls without vapor barriers may be reversed by different conditions of operation.
7. A vapor barrier on the warm side of either an uninsulated or an insulated wall is desirable and should be applied in new construction located in any area where condensation problems can possibly occur.

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Bulletins

*1. The Use of Marl in Road Construction, by Charles H. Dow. viii + 67 pages, 10 plates, 61 illustrations. 1923.

*2. The Manufacture of Portland Cement from Marl, by Raymond E. Kirk. viii + 52 pages, 1 plate, 9 illustrations. 1923.

*3. Transmission of Heat through Building Materials, by Frank B. Rowley. viii + 74 pages, 46 illustrations. 1923. (See Bulletin No. 12.)

*4. The Manufacture of Portland Cement from Marl, by Raymond E. Kirk. Revised edition. x + 98 pages, 3 plates, 24 illustrations. 1926.

*5. Turns and Phases in Squirrel Cage Windings, by George F. Corcoran and Henry R. Reed. iv + 45 pages, 15 illustrations, 9 oscillograms. 1927.

6. Integral Waterproofing Compounds for Concrete, by M. B. Lagaard. vi + 25 pages, 12 illustrations. 1927.

*7. Manifold Phenomena in Internal Combustion Engines, by Kalman J. DeJuhasz. vi + 35 pages, 15 plates, 10 illustrations. 1931.

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*9. Influence Lines for Arches, with Tables, by Walter J. Grabner and Joseph A. Wise. iv + 30 pages, 5 plates, 12 diagrams. 1933.

*10. An Investigation of Motor Oils, by Burton J. Robertson. vi + 47 pages, 4 illustrations. 1935.

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12. Thermal Conductivity of Building Materials, by Frank B. Rowley and Axel B. Algren. x + 134 pages, 109 illustrations. 1937. $1.50. (Purchased through University Press.)

*13. An Investigation of Motor Gasolines, by Burton J. Robertson. vi + 45 pages, 5 plates, 5 illustrations. 1939.

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*22. Vapor Transmission Analysis of Structural Insulating Board, by F. B. Rowley and C. E. Lund. vi + 71 pages, 24 illustrations, 16 tables. October, 1944.

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24. Factors Affecting Heat Transmission through Insulated Walls, by F. B. Rowley and C. E. Lund. iv + 25 pages, 8 illustrations, 8 tables. April, 1946.

25. Vapor Resistant Coatings for Structural Insulating Board, by F. B. Rowley, M. H. LaJoy, and E. T. Erickson. vi + 31 pages, 9 illustrations, 10 tables September, 1946.

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27. Water Permeability of Structural Clay Tile Facing Walls, by J. A. Wise. iv + 32 pages, 26 illustrations, 4 tables. August, 1948.

28. Thermal Properties of Soils, by Miles S. Kersten. xiv + 227 pages, 138 figures, 15 tables, 5 plates. June, 1949.

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* Out of Print.

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*1. Condensation within Walls, by F. B. Rowley, A. B. Algren, and C. E. Lund. 12 pages. January, 1938.
*2. The Variation in the High-Frequency Resistance and Permeability of Ferromagnetic Materials Due to a Superimposed Magnetic Field, by James S. Webb. 9 pages. April, 1938.
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