Blistering of exterior house paints on wood siding has been a troublesome problem in recent years. In order to study its cause and prevention on a laboratory scale, the authors have designed a small apparatus in which a miniature wall section can be subjected to various conditions of heat and moisture. Several aspects of the blistering problem have been investigated with the aid of this apparatus including wood species and thickness of wood; effect of back-priming and vapor barriers; use of special primers and moisture-permeable paints; value of air vents; behaviour of varnish coatings. The mechanism of blistering is discussed.

Experimental Study Of
Blistering Of Paints On Wood

C. Y. HOPKINS and B. C. SMART, National Research Council, Ottawa.

BLISTERING of exterior house paint, followed by peeling, has become a serious problem in recent years. It is not a new problem, for it was studied at the U.S. Forest Products Laboratory as early as 1927 and by many other investigators up to the present time. The subject was reviewed by Browne in 1933 [1]. The most recent knowledge is summarized in the report of a conference on condensation control held in 1952[2].

The present paper deals only with blistering caused by moisture. There may be other causes but they are believed to be of relatively minor importance. The mechanism of moisture blistering is not yet fully understood. The forces involved in the passage of liquid water and water vapor through wood are apparently quite complex [3,4,5]. These forces are large enough to overcome the powerful adhesion of paint to wood. However, there is not sufficient information available to provide a clear explanation of the physical process by which mechanical energy accumulates at the wood-paint interface and ruptures the bond.

Early studies of the phenomenon were based on cases of blistering on existing wood buildings [6]. It was soon found that moisture blistering could be produced at will on small test huts by maintaining certain conditions of moisture concentration and temperature [7,8,9]. The huts were usually placed outdoors, hence the exterior temperature was not controllable. More recently, a large test house was built at the University of Minnesota [10] which was completely enclosed by a refrigerated chamber so as to maintain the desired external temperatures. Other work on moisture migration is referred to in the bibliography at the end of this paper.

The present authors wished to reduce experiments of this type to a laboratory scale, and in so doing, to make it easier to control the external temperature. It was expected also that results could be secured more quickly on the small scale. These objectives were realized to a satisfactory degree.

Preliminary Experiments

Test panels of white pine ⅝ inch thick were painted on one face with three coats of ordinary linseed oil house paint and the opposite face (or back) was left unpainted. In order to simulate the adverse conditions that affect ordinary house siding, the experiments were begun by trying various means of applying moisture to the back of these painted panels. Absorbent cotton was placed against the back of several panels and moistened with water frequently so that it was always saturated. The paint film was apparently unaffected and the test was discontinued after 18 days without any evidence of blistering.

A panel was fastened to the open side of a container and the con-

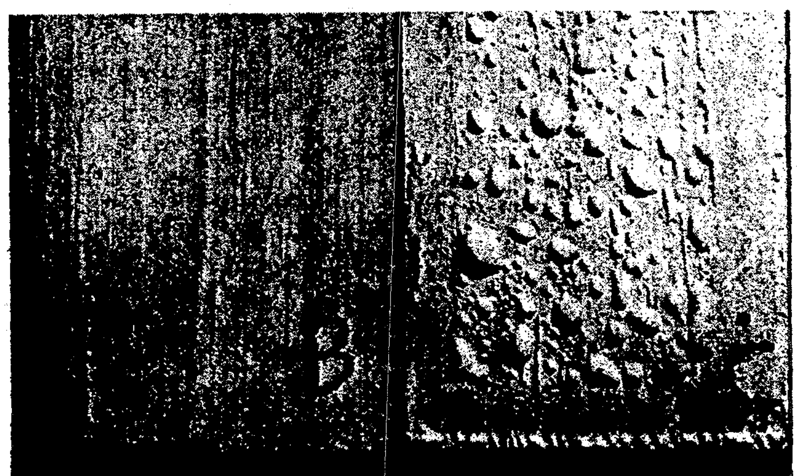

FIGURE 1—Both panels were in contact with liquid water at the back. Panel B (water not heated) shows no effect; Panel C (water heated slightly) is badly blistered.

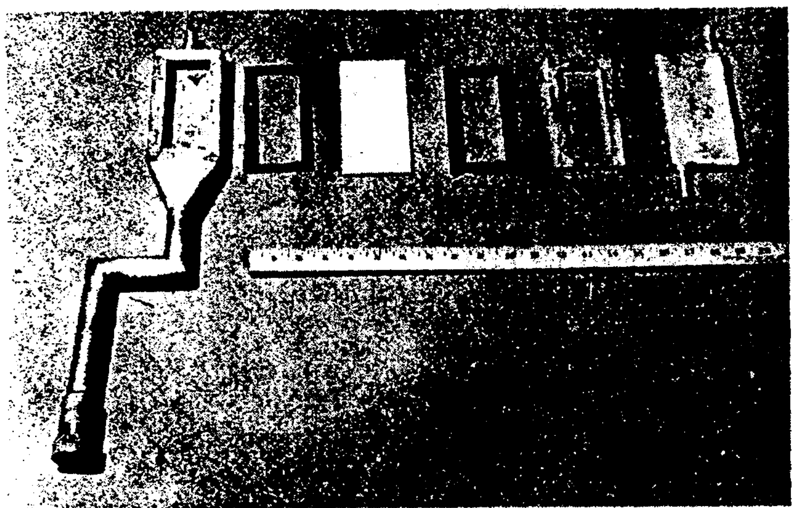

FIGURE 2—Blistering apparatus, showing (left to right): water vapor box, gasket, painted test panel, gasket, frameplate, hollow cooling block.

tainer was filled with water so that the unpainted back of the panel was in continuous contact with water under a slight head. There was no sign of blistering during a period of 13 days (Figure 1).

These simple experiments show that blistering does not take place readily because of moisture alone. Evidently a temperature differential is necessary as well. Methods of maintaining a difference in temperature between the back and the face of the test panel were examined.

Test panels were placed in a carbon-arc water-spray weathering machine with the back towards the arc. Blistering occurred in two or three days.

Payne cups [17] were used in another procedure and the test panels were made from single ply birch veneer 0.01 inch thick, painted on one side. A little water was placed in the cup, the painted wood specimen was clamped on with the painted side out and the cup was placed on a heat source at about 60°C. Blistering took place quickly, usually in one or two hours.

Closer control of the temperature was desired. This was achieved by using glass jars instead of the Payne cup. The test panel was fastened over the mouth of the jar and the jar was immersed to the neck in a water bath at controlled temperature. The bath was maintained at a few degrees above room temperature. Blistering was produced in 8 hours at a temperature differential as low as 3°C., using the thin veneer panels. It was more rapid at greater temperature differences.

Finally an all-metal apparatus was designed, with which temperatures on both sides of the test panel could be controlled.

Apparatus

The apparatus consists essentially of a metal box, open on one side, and connected by a tapered section to a metal tube, closed at the bottom end (Figure 2). There is an opening at the top of the box for a thermometer. The lower portion of the tube is offset so that it can be conveniently placed in a heating bath. The outside surfaces of the box are coated with asbestos-cement insulation before use.

The tube is filled with water up to the tapered section and immersed in a thermostated bath. The test panel is mounted against the open side of the box with a rubber gasket and a metal frame-plate. It is not necessary that the joint be air-tight.

The bath temperature is regulated so that the temperature in the box remains at the desired level. Evaporation of the warm water in the tube raises the moisture vapor content of the air in the box. The conditions are therefore similar to those existing in the wall space of a building when excessive moisture is present.

When it is desired to control the temperature at the outside (painted) face of the test panel, a hollow metal cooling block is mounted over a gasket in front of the panel so as to leave a ⅛-inch air space. Water is circulated through the cooling block at the desired temperature from a second thermostated bath (Figure 3).

Other modifications of the apparatus are described in the experimental part.

Procedure

Test panels of white pine 2¾" x 5¾" x ⅝" were used in most of the experiments. Their moisture content was in the range 8-10%. Paints were applied by brushing, allowing 24 hours' drying between coats and 7 days' ageing before exposure. Film thickness was in conformity with ordinary painting practice.

The painted panels were attached to the blistering apparatus as described above with the back of the panel (usually unpainted) towards the interior of the box. Temperatures at the back and the face of the test panel were recorded. The time of initial blistering and increase in number and size of blisters was noted.

Room temperature was fairly constant at 25°C. and the temperature in the box was regulated as desired up to 60°C.

In some experiments it was desired to maintain temperatures corresponding to winter conditions. Accordingly, the whole apparatus was placed in a constant-temperature refrigerated room (5°C.) and the temperature in the box was held at 25°C.

Experimental Results

Rapidity and extent of blistering was found to depend on several factors including the temperature differential between the back and the face of the panel. In many experiments blistering commenced within 24 hours and was profuse after 48 hours. The newly-formed blisters always contained water. Systems

TABLE I

Rate of Blistering of Paint on Panels of Various Thicknesses

Temp. Diff. 25° - 5° = 20°C.

Thickness of panel	Extent of Blistering 8 hrs.	24 hrs.	48 hrs.	72 hrs.
⅛"	none	slight	marked	marked
¼"	none	trace	slight	marked
½"	none	none	trace	marked
1"	none	none	none	trace

TABLE II

Effect of Back-priming

Coating on Back of Panel	Extent of Blistering 2 days	7 days
Uncoated	marked	very marked
Aluminum-varnish, one coat	none	none
Aluminum-varnish, two coats	none	none
White lead primer, one coat	slight	marked
White lead primer, two coats	none	none

that did not blister in 14 days were found to be practically immune to blistering even on much longer exposure.

The following ratings were employed to describe extent of blistering: none, trace, slight, marked, very marked.

A. Reproducibility.—Test panels prepared and exposed in triplicate showed good agreement in rapidity and extent of blistering.

B. Nature of test panel.—White pine panels of varying thickness were painted with three coats of linseed oil house paint (white lead 70, zinc oxide 20, asbestine 10) and attached to the blistering apparatus. Blistering was rapid on the thin panels and slower on thick panels but otherwise no difference in results was apparent (Table I).

Panels of white pine, basswood, birch sapwood and birch heartwood, ⅛"-thick, were painted identically and exposed at a temperature difference of 40°-25°=15°C. All blistered within 48 hours to approximately the same extent.

C. Type of paint coating.—Oil paints, enamels and varnishes were applied in three coats to white pine panels ¼" thick and exposed at a temperature difference of 20°C. The linseed oil house paints blistered most readily, usually in 24-48 hours. If allowed to age for one month or more, blistering was retarded.

Enamels were less susceptible to blistering. Some commercial architectural enamels showed no blistering in 14 days. However, when the 7-day ageing period was omitted and the panels were exposed after 24 hours' drying, two enamels out of three developed marked blistering.

Three commercial exterior varnishes were exposed. Two showed no blistering in 14 days while the third developed one blister with no further damage. The temperature difference was 20°C.

D. Influence of primers.—Two coats of linseed oil house paint (white lead 70, zinc oxide 20, asbestine 10) were applied over three different primers on ⅛" birch panels. After 7 days' ageing, the panels were exposed at 20°C. temperature difference, with the following results (Figure 4):

Self-primed—blistered in 2 days.
White lead primer (zinc-free)—blistered in 5 days.
Aluminum-varnish primer — no blistering in 7 days, slight blistering in 10 days.

Several commercial primers for exterior use on wood were tested in combination with the same lead-zinc topcoat. There was some variation in resistance to blistering but all permitted some blistering of the system.

E. Effect of back-priming. — The effect of painting the back of the wood was determined, using ⅛" birch panels.

Three coats of lead-zinc oil paint were applied to the face of the panels. The backs were coated as shown in Table II. After ageing, the panels were exposed in the blistering apparatus for 7 days at 20°C. temperature difference.

In a further experiment, a panel was painted as before and back-primed with aluminum-varnish but leaving a one-inch wide uncoated strip across the back. Upon exposure, blistering took place rapidly opposite the uncoated strip but not elsewhere on the panel (Figure 5).

F. Special paints. — The effect of formula changes on resistance to blistering was examined.

(a) Paints containing diatomaceous earth.

Three paints were made up having white lead and zinc oxide as the prime pigments with a diatomaceous earth as extender. A comparison paint was made with asbestine extender. The pigment proportions by weight are given in Table III.

TABLE III

Pigment Mixtures

White lead	60	55	55	60
Zinc oxide	30	20	15	30
Asbestine	—	—	—	10
Diatomaceous earth	10	25	30	—

The ratio of pigment to linseed oil was 68:32 by weight in each paint.

White pine panels, ¼-inch thick, were given three coats of each paint on successive days and allowed to age for 7 days.

Upon exposure in the blistering apparatus at a temperature difference of 20°C., all four paints showed slight blistering in 24 hrs. and marked blistering in 3 days. There were no appreciable differences among the paints.

(b) Highly pigmented paints.

The effect of increasing the ratio of pigment to oil in linseed oil paints was examined. A pigment mixture of white lead 60, zinc oxide 30, asbestine 10 (by weight) was ground in linseed oil in varying proportions.

When tested as in (a) above, the results shown in Table IV were obtained.

TABLE IV

Blistering Test; Lead-zinc Paints

Pigment: oil ratio by wt.	Extent of Blistering 1 day	2 days	4 days	7 days
68:32	trace	slight	marked	marked
73:27	trace	slight	marked	marked
78:22	none	none	slight	slight
83:17	none	none	none	trace

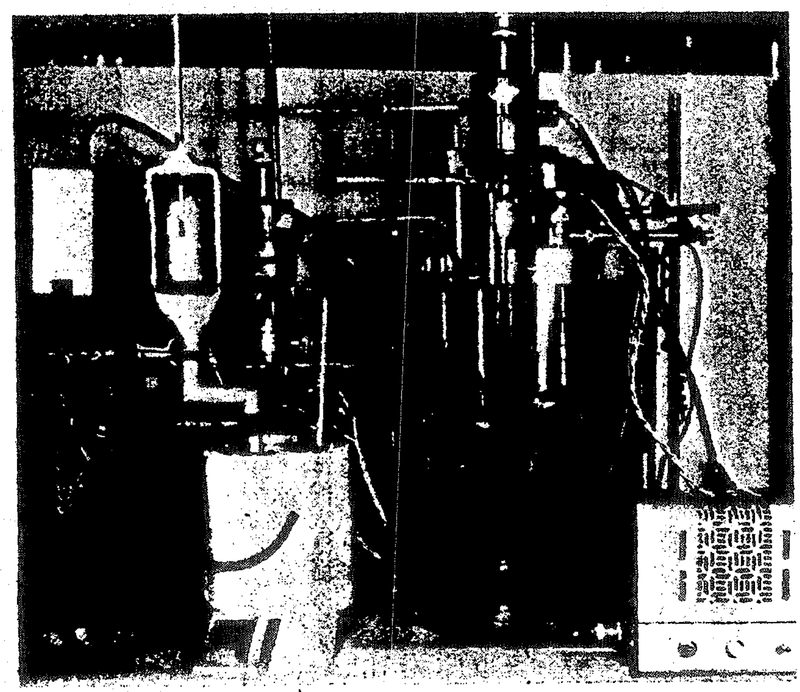

FIGURE 3—Blistering assembly (test panel removed) showing cooling block, water vapor box and heating bath, and large cold water bath with circulating pump.

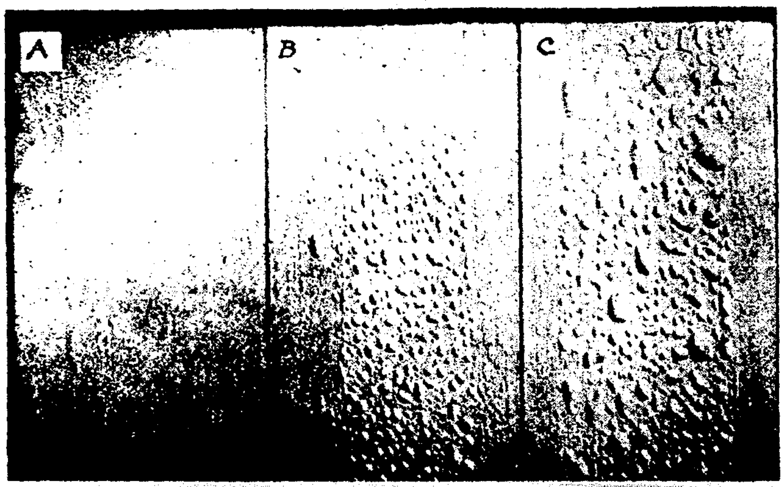

FIGURE 4—Influence of primers. A, aluminum-varnish. B, white lead. C, self-primed. Lead-zinc-inert top coat on all.

TABLE V

Composition of Clear and Pigmented Coatings
(Parts by Weight)

Paint No.	1	2	3	4	5	6
Glyptal G2466, solids	49	49			70	
Glyptal G2466, solvent	21	21				
Bakelite VF1249 (a)			100	100		100
Raw linseed oil	12	12			12	
Mineral spirits	15	15			15	
Driers	3	3			3	
White lead	50			50		
Zinc oxide	35			35		
Titanox RC		100	100			
Asbestine	15			15		

TABLE VI

Extent of Blistering, 3-day Test
Clear and Pigmented Coatings

		Drying Time of Coating			
	Paint No.	4 days	7 days	15 days	47 days
1	Pigmented	very marked	marked	marked	slight
2	Pigmented	marked	marked	none	none
3	Pigmented	none (7-day test)			
4	Pigmented	none "			
5	Clear	none "			
6	Clear	none "			

A lead-titanium pigment mixture was formulated as follows (parts by weight): titanium-calcium pigment (type RCHT) 50, white lead 35, asbestine 15. This pigment was ground with oil and thinner: pigment 67, raw linseed oil 10, bodied linseed oil 6, mineral spirits 17, drier. The paint was tested as in (a) above except that panels were made up with one and two coats respectively. There was no blistering on any of the panels in a 12-day test. The pigment: oil ratio in this paint is 81:19 by weight.

(c) Clear and pigmented coatings.

A group of finishes was prepared to compare the blister resistance of two different vehicles (a) unpigmented, and (b) pigmented. The first was a mixture of alkyd resin with raw linseed oil. The second was a phenolic varnish. The composition of the clear and pigmented coatings is shown in Table V.

(a) Composition of this vehicle is given as phenolic resin 16 parts, linseed oil 32 parts, mineral spirits and driers 52 parts.

The paints were applied in 3 coats to the usual white pine panels. Duplicate sets of panels were allowed to dry for various periods of time. They were subjected to the blistering test at a 20° temperature difference. The results are shown in Table VI.

Although the clear alkyd-linseed oil coating is blister-resistant, it appears to lose this property when pigmented. The enamels (3 and 4) had good resistance to blistering, in spite of the heavy pigmentation.

G. Effect of a vapor barrier.—Some experiments were carried out with a miniature hollow wall section as the test piece in order to study the effect of vapor barriers (Figure 6). Both the inner and outer panels were of ⅝" white pine.

When the inner panel was unpainted and the outer panel painted with ordinary linseed oil paint, blistering occurred quickly under the usual test conditions. Upon opening up the test piece, liquid water was found in the wall space.

The inside surface of the inner panel was then painted with two coats of linseed oil paint as a water vapor barrier. Under the same test conditions, there was no blistering in 7 days and no visible moisture accumulation in the wall space.

A thin sheet of waxed paper was not effective as a vapor barrier. It proved to be quite permeable to water vapor and early blistering of the paint ensued. A heavy waxed membrane prevented blistering over a period of 7 days. It was found that a small break in the paper resulted in total loss of effectiveness.

H. Effect of ventilating the wall space. — Miniature wall sections were employed for tests in which the wall space was vented by holes drilled through the outer panel. The inner panel was unpainted in these tests.

A single hole of ¼" diameter in the outer panel had no apparent effect on the incidence of blistering. Under the usual test conditions (20° temperature difference) blisters appeared in 72 hours on the test panel and on an unvented control. Similarly, two ¼" holes, one near the top and one near the bottom of the outer panel, did not prevent blistering (Figure 7).

J. Effects of condensible vapors other than water. — Several organic liquids were tried in place of water in the blistering apparatus. The usual test procedure was followed, using a white pine panel coated with linseed oil paint and a 20°C. temperature difference, for a 7-day period.

Methanol as the test liquid produced slight blistering in 5 days. A control test with water gave very marked blistering in the same time.

Ethanol, hexane, ether, ethylene chlorohydrin, turpentine and mineral spirits did not produce any blistering in 7 days under the same conditions.

K. Other experiments. — A transparent rubber membrane was stretched over the face of a wood panel so as to act as a coating in place of a paint film. When attached to the blistering apparatus, liquid water accumulated progressively between the membrane and the panel, having passed through the wood.

Painted test panels were weighed before and at intervals during the blistering test to determine the amount of water absorbed by the wood. An air-dry painted panel (moisture content about 7%) weighing 18.5 gm. increased in weight to 37.3 gm. in 7 days. Thus its final moisture was over 100% of the original bone-dry panel weight.

By weighing the test panel at intervals it was observed that blistering of linseed oil paint always occurred when the moisture content of the wood exceeded 30%. However, there was blistering at lower moisture percentages in some cases and it was not possible to establish a threshold value.

Discussion of Results

Sufficient testing has been done to show that the simple blistering apparatus produces rapid blistering of ordinary oil paints on wood. The results are reproducible although the variability of the wood itself has some effect.

Blistering did not occur in these tests unless there was a higher temperature at the back of the test panel than at the painted face, even when the wood was saturated with water.

Blistering occurred more rapidly on thin panels than on thick ones and the rate increased with the temperature difference between the back and front of the panel. A few trials were made with different species of wood but no relation was observed between species and rate of blistering.

Linseed oil house paints had much greater tendency to blister than did enamels or varnishes. The resistance of enamels to blistering has been observed by Vannoy [11]. Certain enamels and varnishes did not blister at all under the conditions of our test but it is not yet certain that the conditions are as severe as those encounered in practice or that a period of weathering might not increase the susceptibility of the coating to blistering. The same reservation applies to the favorable results obtained with aluminum primer (varnish pigmented with aluminum). This primer was more resistant than the conventional linseed oil white-pigmented primers.

Painting the back of the test panel (back-priming) was effective in retarding blistering. Two coats of aluminum-varnish on the back of the panel prevented blistering for the duration of the tests.

Oil paints containing up to 30% of diatomaceous earth in the pigment mixture did not resist blistering. Increasing the pigment:oil ratio of a lead-zinc formula reduced its blistering tendency. A matt coating containing white lead and titanium dioxide with a pigment:oil ratio of 81:19 by weight did not blister in these tests.

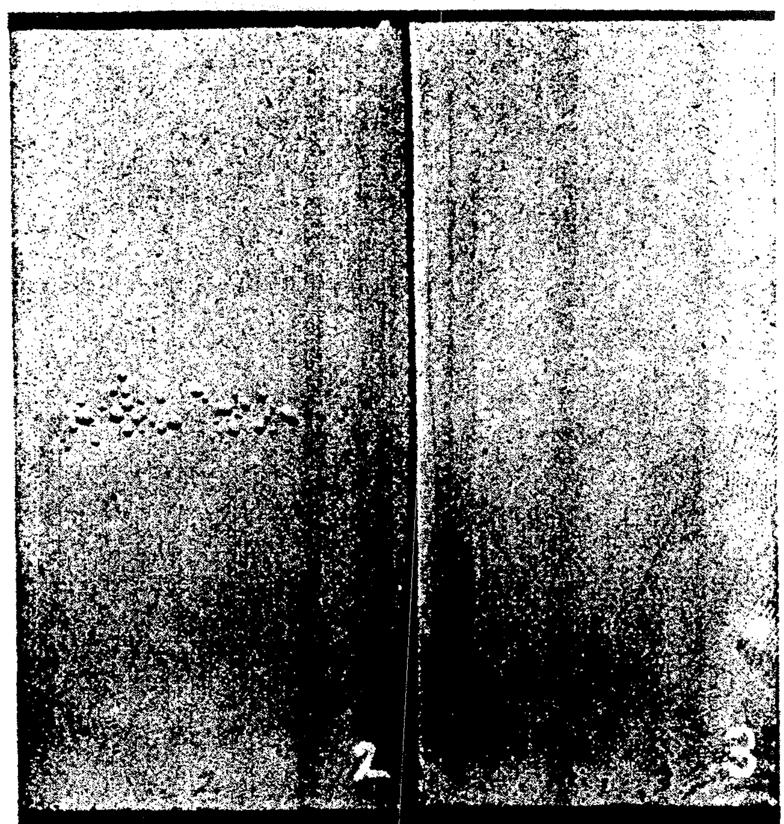

FIGURE 5—Panel 3, back-primed with aluminum-varnish. Panel 2 treated similarly but a 1-inch strip at the middle not back-primed.

The value of a vapor barrier on the warm side was readily shown using a miniature wall section. Two coats of linseed oil paint on the inner face of the wall prevented blistering of the exterior paint during the test.

Ventilating the wall space by means of holes drilled through the outer panel did not prevent blistering under the test conditions. (Figure 7). Apparently much of the water vapor must have condensed on the back of the exterior panel before it could escape through the vents.

Mechanism of Blistering

The experimental results do not as yet give a full understanding of the mechanism of blistering. They do indicate the following points: (a) No matter how wet the back of the siding, blistering does not occur unless there is a temperature differential. This suggests that the mechanism is not simple osmosis but rather a movement of vapor as well as liquid. (b) Blistering is not observed unless there is liquid water on the back of the test panel.

At least two theories have been advanced to explain blistering. According to one theory, the liquid water that has condensed on the back of the siding travels through the wood capillaries by osmosis. Upon reaching the outer face it exerts strong pressure against the paint and raises blisters.

According to the second theory, which we favor, the partial pressure of water vapor is higher on the interior of the wall than on the exterior because of the temperature difference; as a result, water vapor travels through the wood toward the outside. Upon reaching the outside surface of the wood, it condenses because the temperature is low and the paint coating is rela tively impermeable. Thus there i liquid water trapped between th wood and the paint. As it increase in volume it raises the paint i blisters. This theory is supporte by the apparent dependence on temperature difference and by th observation that newly-formed bli ters always contain liquid water.

There are several features th are not clear, however. If the mec anism depends merely on water v pour movement, why does blisteri occur only when the wood is ve wet throughout? Presumably this because the moisture vapor tra mission rate increases with the m sture content of the wood.

Experiments with liquids ot

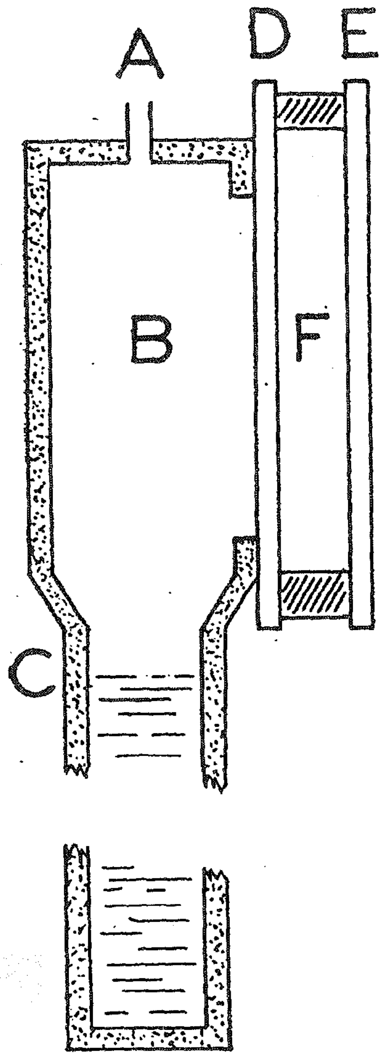

FIGURE 6 — Schematic cross-section of blistering apparatus with miniature wall section on test. A, opening for thermometer. B, water vapor box. C, water level. D, inner wood panel (warm side), E, outer wood panel (cold side). F, wall space.

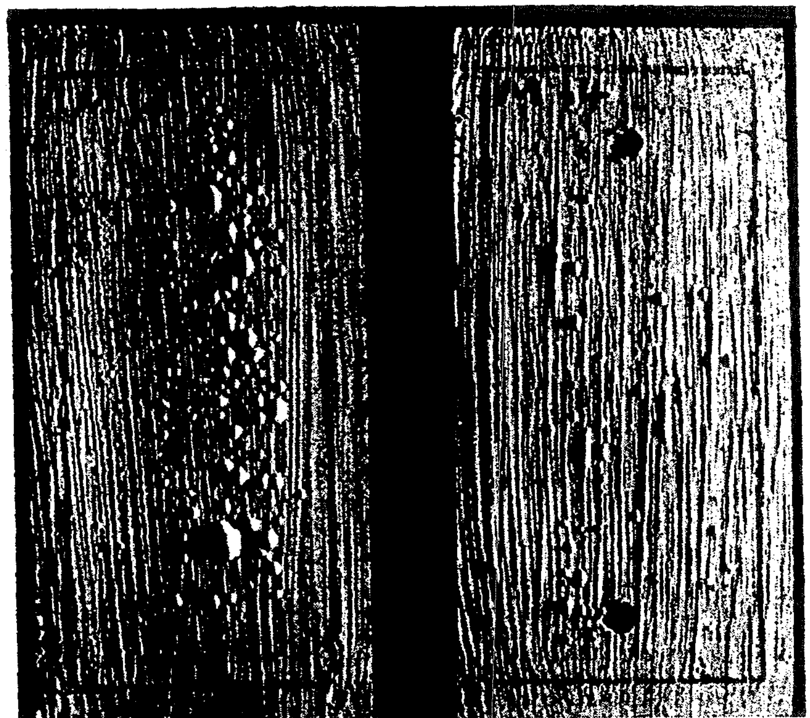

FIGURE 7—Venting wall space by two openings reduced but did not prevent blistering.

than water did not produce blistering, except to a small extent with methanol. Accordingly, there may be some effect related to the absorption and swelling of wood by water that influences the result.

Conclusions

The tendency of a paint coating on wood to blister under any given circumstances can be determined readily by means of the laboratory apparatus described in this paper.

It has been demonstated that there is little or no tendency to blistering unless a temperature difference exists between the inner face and the outer face of the painted wood.

The experiments did not reveal any simple way to prevent blistering of paint on buildings. The tendency to blistering was reduced by back-priming, by use of aluminum-varnish primer under exterior paint, by heavily pigmented paints, and by use of enamel or varnish instead of oil paint. However, these procedures are attended by certain disadvantages and it is not suggested that they will prevent blistering entirely.

It is judged that every possible effort in building construction and maintenance should be directed towards preventing the entrance and accumulation of moisture in the sidewalls.

Acknowledgement

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