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INTERNAL AIR SPACES
AND
THEIR EFFECT ON MOISTURE AND HEAT TRANSFER

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INTRODUCTION

The article shown in Figure 1 became the initial impetus for this study on internal air spaces and their effect on moisture and heat transfer. This article first appeared in the August 1985 issue of the magazine, Energy Design Update and is now reproduced in a publication by this organization entitled, "Moisture in Houses". The article, "Moisture Mysteries No. 1" reported on the formation of condensation and subsequent dripping from the ceilings in a number of school classrooms. The mystery was that the condition occurred in only 18 out of 20 classrooms. Since construction was identical, why had most of the cathedral ceilings developed condensation problems while two had not?

It turned out that the only notable difference in the classrooms was the amount of insulation used in the ceiling cavities. Where the cavity was completely filled with insulation no problem occurred, but where the cavities contained a combination of insulation and an air space, then severe moisture condensation and resultant dripping did occur. Quoting from the article, "The culprit was found to be air convection". The schematic in this article, enlarged as Figure 2, shows the convective air currents as dark black arrows. Note that the air currents appear to travel upward along the warm side of the cavity. As moisture permeates thru the ceiling it is picked up by the air current, carried to the top of the cavity where the air current transports the moisture around and down the cold side. Here the air temperature drops and the moisture laden air soon reaches dew point and the moisture is released up at the top of the cavity.

The authors of this study have seen a similar occurrence in a fairly steep roof in a metal building is Kansas City. Again, it was a case where the insulation cavities were not completely filled allowing convective air currents to operate within the cavity. And again, condensation was found to be forming on the cold surface in the upper portion of the cavity.

QUESTIONS

Since air spaces appear to be of a deleterious nature in several sloped roof installations, are they also active in wall cavities? And if so, to what extent? Do they affect heat transfer as well as moisture transfer? And what is the best way to break up these air currents?

EQUIPMENT

A testing program was initiated at the Manville Research Facility shown in Figure 3. This facility is located in Denver, Colorado. Two pieces of equipment were selected for the study, a large Water Vapor Transmission (WVT) Box used to measure moisture accumulation in building sections shown in Figure 4, and a large Calibrated Hot Box to measure heat transfer through similar building sections shown in Figure 5. As mentioned earlier, the interest was primarily in wall sections so these boxes were positioned in the vertical configuration. Both pieces of equipment were of sufficient size; 8 by 10 ft. test area for the Hot Box and 5 by 10 ft. test area for the WVT Box, so that make actual wall installations could be made complete with the kind of air spaces or cavities which might be expected in actual service. Because of the primary concern with air spaces in metal building, this type of construction was employed in both boxes.

This next series of figures show the actual assembly in the boxes. Photos of the installation in the Calibrated Hot Box are used here, however, the installation in the WVT Box was exactly the same. First, as shown in Figure 6, the exterior metal sheathing and structural members were positioned in the box and caulked in place. The structural members, see Figure 7, are called girts and were positioned seven feet apart as is typical in a metal building sidewall. This seven foot section is also fairly representative of the cavity height to be found in other methods of construction including the home. Next, as shown in Figure 8, fiber glass insulation at a density of 0.5 pcf was installed to completely fill the eight inch deep cavity formed between the metal girts. Finally, Figure 9 shows the internal insulation system which was installed flat against the inside flange of the girt. The system was composed of a 1.5 pcf fiber glass board with a vapor retarder facing adhered to one side. Suitable hardware was used to hold the whole assembly in place. The completed assembly for either box looked like that shown in Figure 10, complete with thermocouple wires used for the test.

TEST CONDITIONS

Environmental conditions in the boxes were set to simulate winter conditions. The Calibrated Hot Box was set at 70°F on the hot side and 20°F on the cold side giving us a 50 degree delta-T. Conditions in the WVT Box were similar but with a higher delta-T to accelerate moisture accumulation in the test section. Conditions on the hot side were 75°F and 50% RH with 0°F on the cold side. The lower cold side temperature was also used to insure that moisture accumulating in the test section would remain frozen once it had formed as condensation.

A total of 28 environmental tests were conducted for this evaluation, 7 in the WVT Box and 21 in the Hot Box. In most situations, identical tests were run in both boxes to examine the interaction between moisture and heat flow. The reason for the inbalance in the number of tests in each piece of equipment is because the WVT Test requires much longer to run; something like 8 to 10 days versus 24 hours in the Hot Box. As a result, a test condition was first looked at in the Hot box and when the test results appeared significant, then a similar test was run in the WVT Box.

Nine tests have been selected to illustrate the five test conditions covered by this report. These tests do serve to confirm the theory that convection air currents may be active within insulation systems containing air spaces.

TEST RESULTS

In order to draw a true comparison, this study will be examining various configurations as compared to the fully insulated cavity. Figure 11 illustrates the fully insulated or control condition. This illustration shows a cross section of the test wall section starting with the exterior metal skin, steel structural members which are called girts, fiber glass batt insulation between the girts and finally a faced fiber glass board which is held against the inside surface of the girt by a system very similar to that used in suspended ceiling panel systems. For the test condition shown in Figure 11, an R-value of 19.2 hr. sq. ft. °F/BTU was measured. The calculated value for this same condition was 19.3. The measured R-value is, of course, the test on the actual wall section as installed in the calibrated hot box. The calculated R-value was determined by the Zone Method as outlined in the ASHRAE Handbook of Fundamentals. Considering the complicated heat transfer path, it is worthy of notice that the measured value came out so close to the calculated value.

The first test represents an optimum installation where even the flutes in the corrugated metal skin were filled with insulation. In an actual installation, of course, these flutes would not be individually filled but would be considered insignificant when looking at the amount of insulation used in the system. Figure 12 illustrates the actual installation with the flutes uninsulated. The calculated R-value for this configuration is 19.0, only three tenths of an R less than when the flutes were filled. On the other hand the measured R-value was 17.9 showing a 5.8% lower value than the 19.0 anticipated. The first indication, small as it is, that convection currents were operating to short circuit some of the insulating value of the wall system. For the first time, the test configuration was also installed in the WVT Box and developed a WVT rate of 1.13 grains of moisture per sq. ft. per hour for this test configuration. Since the WVT box was testing 50 square foot of wall, we were accumulating about 0.19 pounds of water in that section every 24 hours.

In the third test configuration, a portion of the fiber glass batt was removed to develop a 3-1/2" internal air space within the wall, see Figure 13. This means that the amount of batt insulation was reduced from eight inches down to 4-1/2 inches. This figure shows the insulation positioned against the exterior wall however, in the actual tests, and we assume in real-life installations, the fiber glass batt sagged away from the exterior wall as shown in Figure 14. This allowed the convective air currents to go up one side of the batt and down the other. These currents not only reduced the insulating effect of the 4.5 inch batt, but also created an ideal transport path to move the moisture from the rear face of the fiber glass panel up and over the batt and then deposit the moisture on the upper third of the cold exterior wall. After depositing a good portion of its moisture, the air current, now dryer, completes the circuit by moving back up along the fiber glass panel.

Since the return air is now drier, a greater vapor pressure differential is created through and around the vapor retarder facing. This condition causes a subsequent increase in the rate of moisture transfer past the facing thereby increasing the amount of moisture accumulating within the cavity. Comparing the WVT test results with the prior test, it should be noted that a doubling of the WVT rate was observed, from 1.13 to 2.27 grains/sq. ft./hr. This condition would help to clarify the "Moisture Mystery" posed earlier. As to heat transfer, this third configuration by calculation, should have developed an R value of 13.5. In actuality the measured R value was only 8.2, a significant reduction of 39.3 percent over what was anticipated. Left unchecked, it appears that convective air currents can almost destroy the insulating properties of an internal fiber glass batt.

In this study then, steps were taken to reduce or restrict the movement of internal air currents. Several methods were looked at to hold the insulation against one side of the internal cavity, thereby restricting multiple-space cavities as well as convection bridges between spaces. Internal spacer blocks, strapping and adhesives were all used to position the batt against one surface. The use of an adhesive was found to be the most secure method for these tests and for the balance of this study the batts were adhered to the exterior meter skin thereby resembling the configuration shown in Figure 13.

To further restrict the effect of the convective air currents, the use of internal air barrier membranes were investigated. These membranes were adhered to the exposed surfaces of the batts to isolate them from the convective air currents. See Figure 15 for the placement of these membranes. Two membranes were tested, a spun bonded polyolefin air barrier material commercially available and a pin-perforated foil-scrim-kraft laminate. Using the spun bonded material, a measured R value of 13.7 was achieved which was slightly better than the calculated value of 13.5. Referring to the previous test, where the measured R value was 8.2, it can be seen that careful placement of the batts plus the use of internal air barrier materials can vastly improve the overall resistance of an insulation wall section. In addition, the WVT value measured for this test configuration was 1.73, a 24 percent improvement over the former rate of 2.27 grains/sq. ft./hr. This is still not as good as the 1.13 WVT rate established for the fully insulated control.

The final test in this study used the foil-scrim-kraft membrane adhered in like manner to the spun bonded membrane used in the previous test. The measured R value here was 14.9, a further improvement over the previous test value of 13.7, but not as good as anticipated. Using the ASHRAE calculation method as it relates to spaces with one low-emittance surface, the calculated R value should have been 15.9. Several reasons for the difference are possible. One, the difference of 6.3 percent could be just experimental error but this equipment has consistently produced values with less than five percent experimental error. Secondly, the reflective facing was perforated and this may have affected the emissivity of the surface. And thirdly, although convective air currents were effectively cut off from the insulation, they were probably more active in the 3-1/2 inch air space than anticipated. This last reason is supported by the WVT value reported for this last test. The WVT rate was reduced to 1.49 grains/Sq. ft. hr. indicating that it had been slowed down in this test configuration, however, the fact that it did not get back down to the 1.13 WVT rate established in the control, would seem to reinforce the theory that air convection currents were still active in this final configuration.

CONCLUSION

From the results of the above tests, shown in summary form in Figure 16, it is concluded that internal air spaces tend to create convection air currents within an insulation system particularly if that system is positioned vertically. In systems using unprotected fibrous insulations, among others, in conjunction with internal air spaces it is concluded that air currents may adversly affect the efficiency of a system in its attempt to retard heat and moisture flow. Of interest is the fact that in these tests, no air barrier material, even if reflective, was able to be an effective substitute for the fiber glass insulation which was removed to create the internal air space. Although measuring different properties in this study, the two test boxes did develop data which reinforced the premise that internal air spaces may actually work to reduce the effectiveness of an insulated section. Additional work needs to be done to measure the relative effect of the location of the air space within an insulated section as well as its position, be it in flat roofs, sloped roofs or in walls.

Moisture Mysteries:

Mystery 1

Here's a moisture mystery to challenge even the most experienced building science sleuths. It was solved by Harold Orr of the National Research Council of Canada.

The Situation

A public school with twenty classrooms. All twenty rooms were identically constructed. The ceilings are cathedral type, constructed with 2x10-inch rafters insulated with R-30 fiberglass batts. There is no ventilation above the insulation and a poorly installed polyethylene vapor barrier installed just under the ceiling gypsum board.

Of the twenty classrooms, eighteen developed severe moisture condensation problems -- water was dripping down through the gypsum board. But two of the classroom ceilings had no problem. Since they were all identical, why was the problem not occurring in all the classrooms?

When the ceilings were opened up for inspection, one minor construction variation was noticed: the eighteen classrooms with moisture condensation problems were insulated with pink insulation; the two classrooms with no problems were insulated with yellow insulation. With that as the only clue, what was causing the condensation problem?

Fortunately, no one at NRC risked their reputation by suggesting that pink is more conducive to moisture condensation than yellow. Furthermore, they knew quite well that the material properties of the two products are basically the same. So why the problem only with the pink insulation?

The Solution

The culprit was found to be air convection. Here's what evidently happened:

The pink batts used in the eighteen problem classrooms were thinner than the yellow batts used in the other two classrooms. When installed they didn't quite fill the rafter cavities, leaving a small unvented space above the insulation (see Figure 1). That space allowed air to circulate relatively freely around the batts. Since the vapor barrier was poorly installed, some interior water vapor leaked up into the rafter cavities. As air circulated around the batts, some of the water vapor condensed on the underside of the cold roof sheathing. Eventually the condensed water saturated the insulation and dripped down through the drywall.

In the rafter cavities insulated with the thicker yellow insulation, no problem occurred because the batts filled the entire cavity, thus inhibiting air convection.

NOTE: Both types of fiberglass batts were R-30. Fiberglass insulation manufacturers produce R-30 batts in several thicknesses. For example, Manville produces unfaced R-30 batts in both 9-1/4" and 10-1/2" thicknesses.

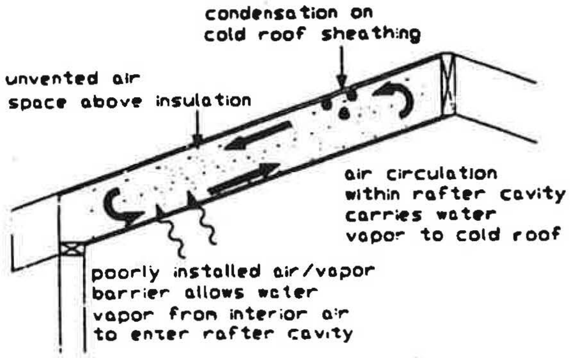
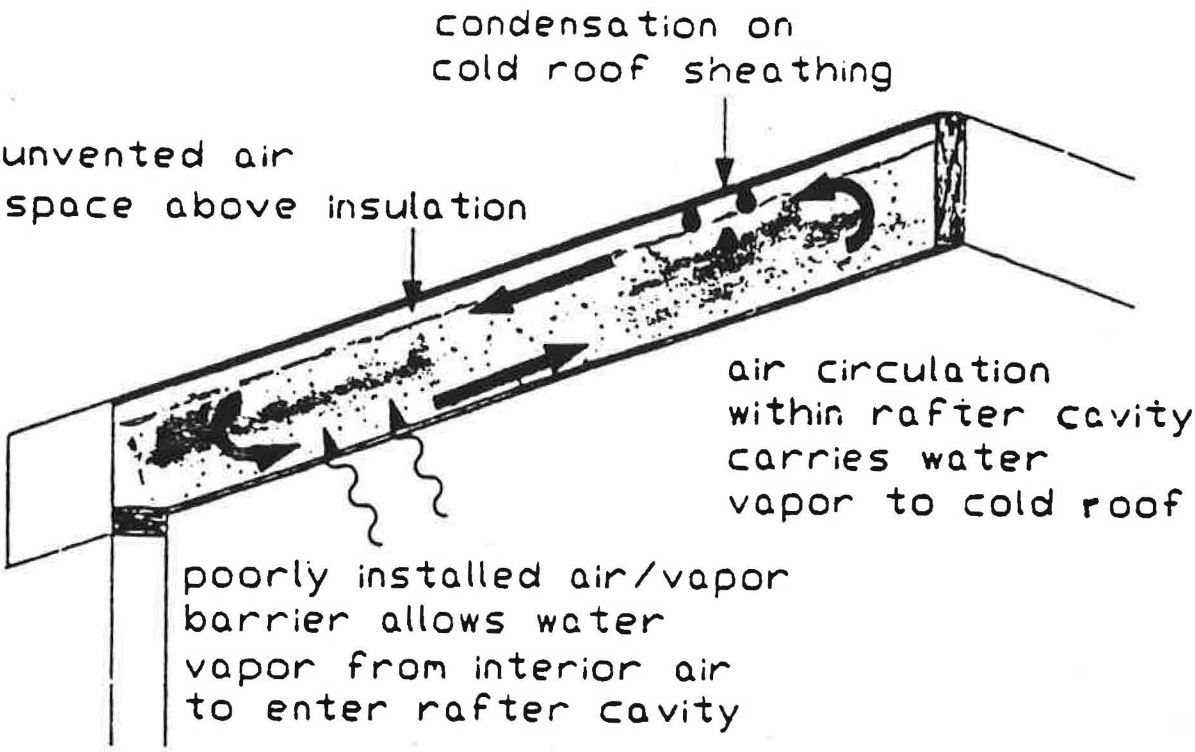


FIGURE 1.



Cathedral ceiling with severe condensation problems

FIGURE 2.

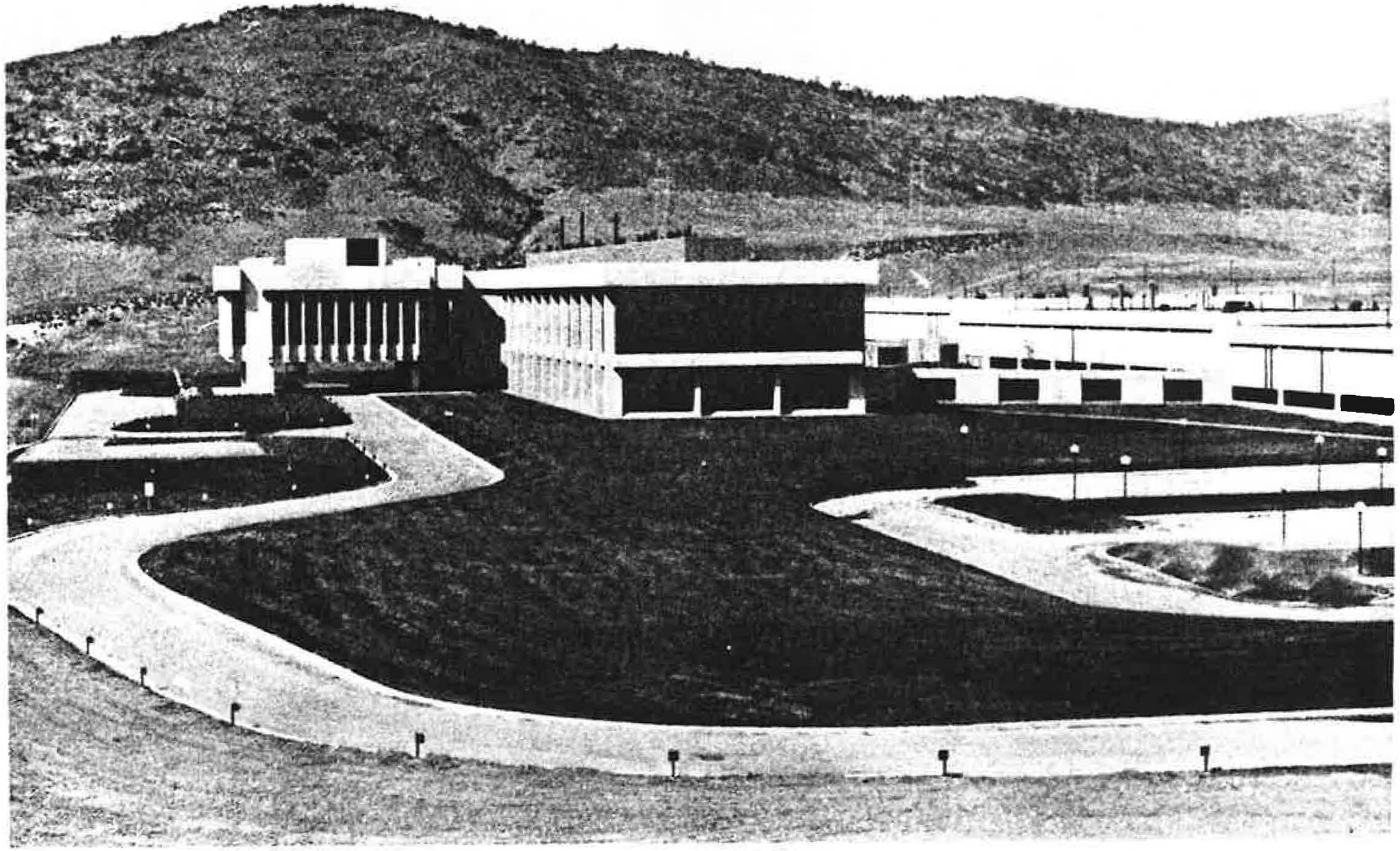


FIGURE 3.

FIGURE 4.

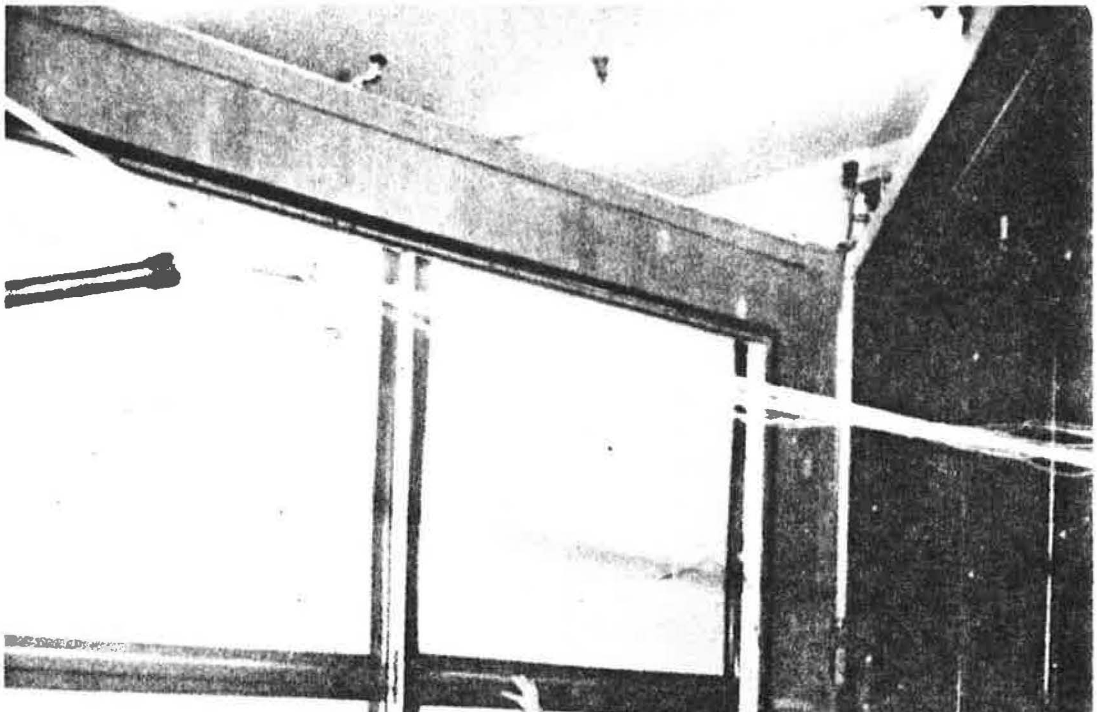


FIGURE 5.

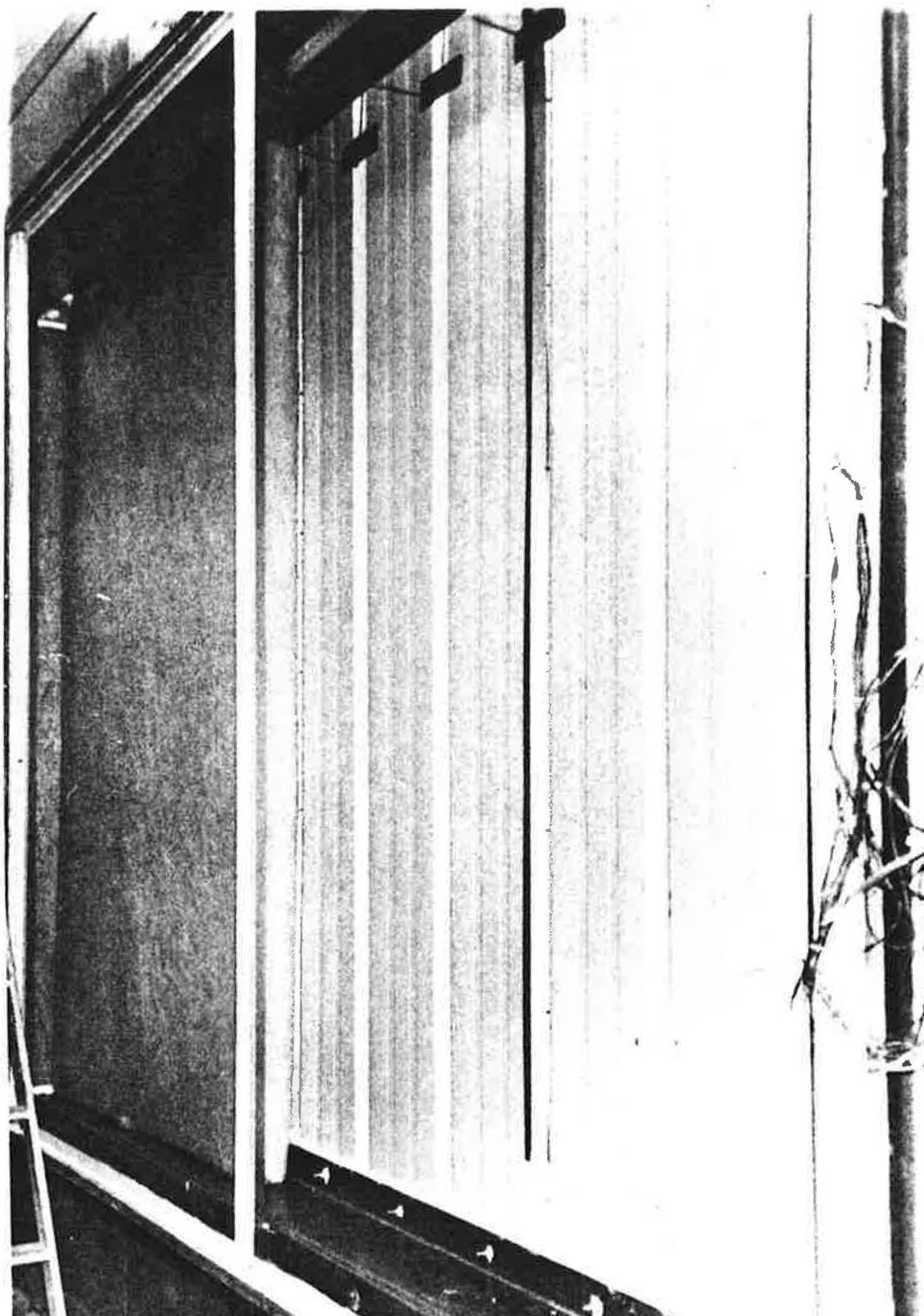


FIGURE 6.

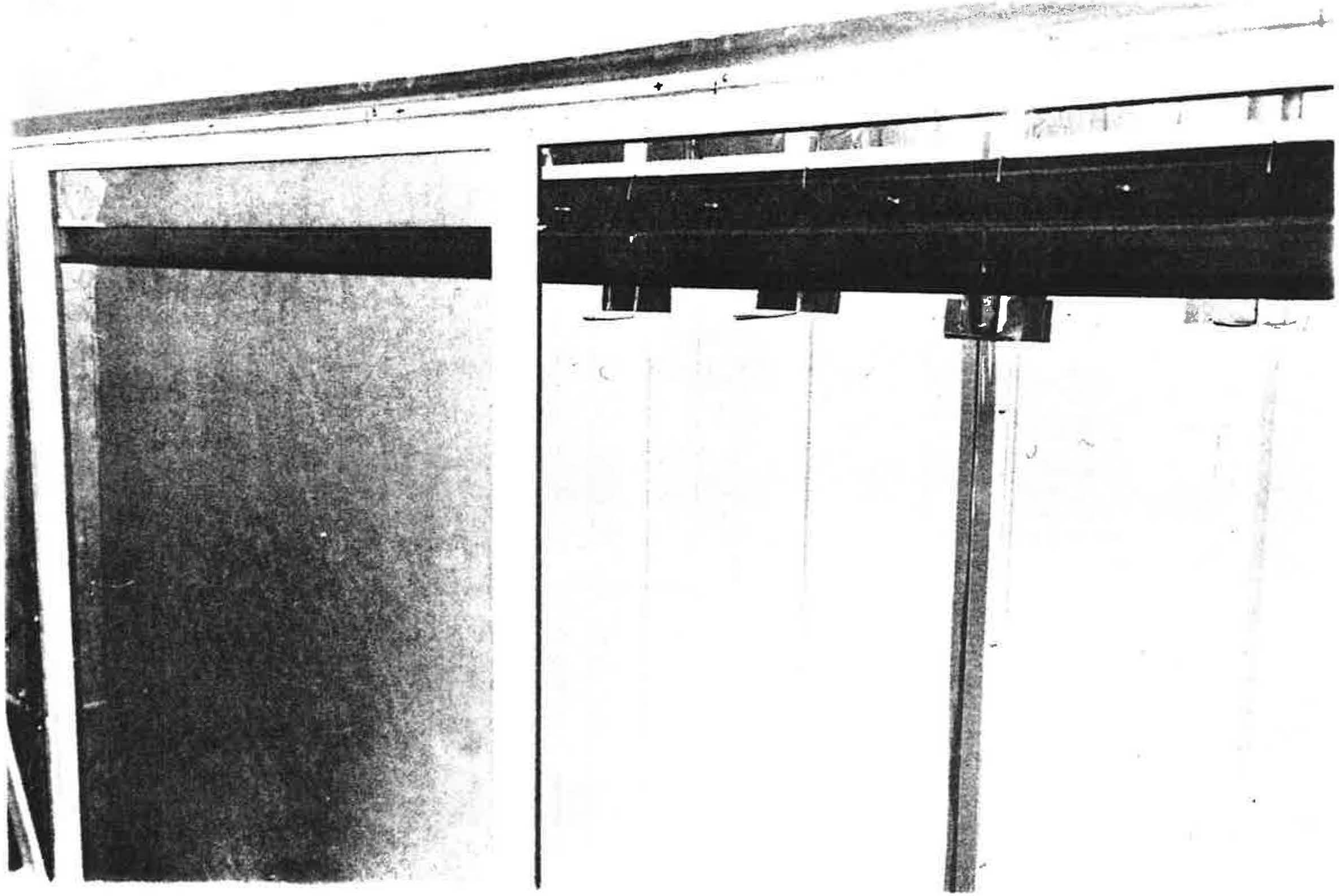


FIGURE 7.

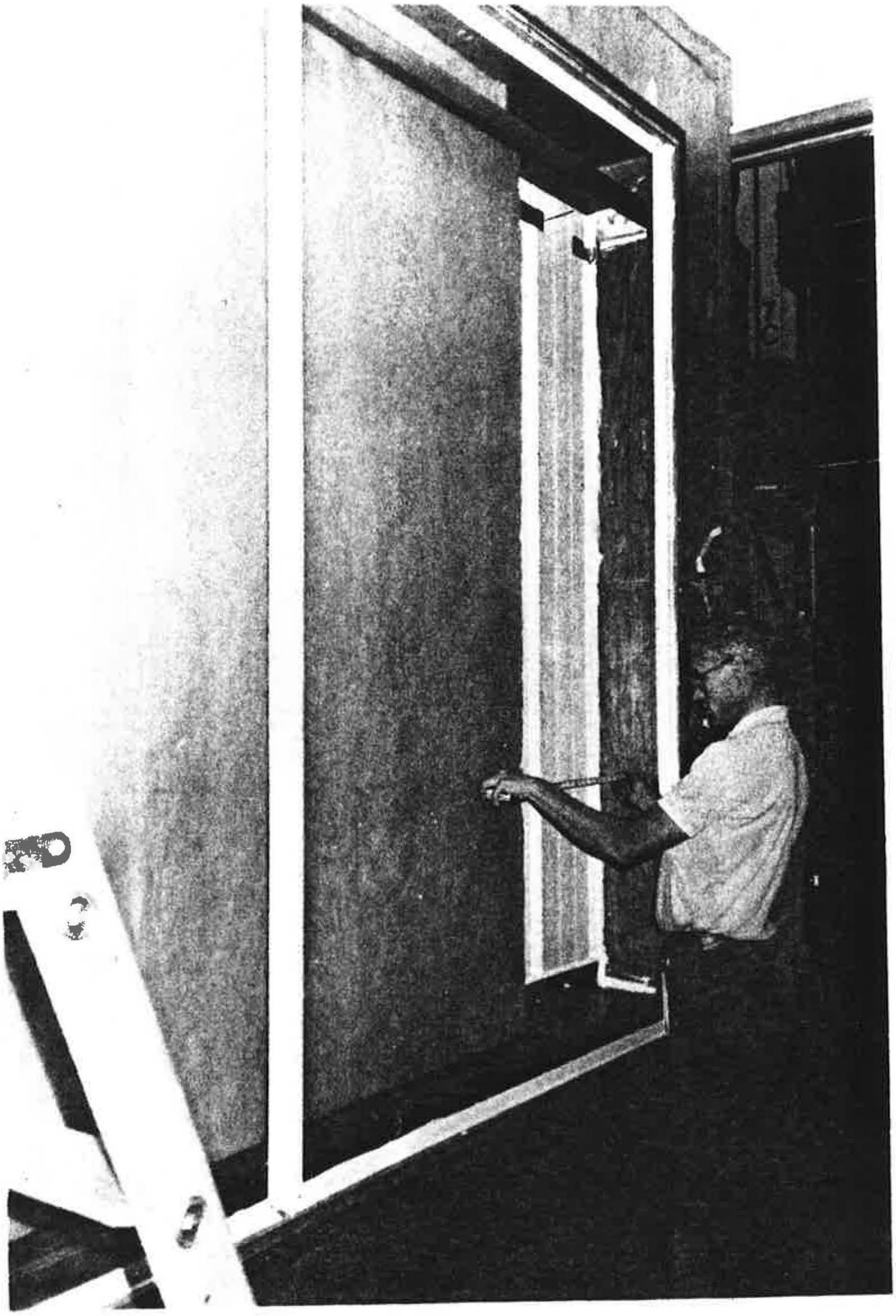


FIGURE 8.

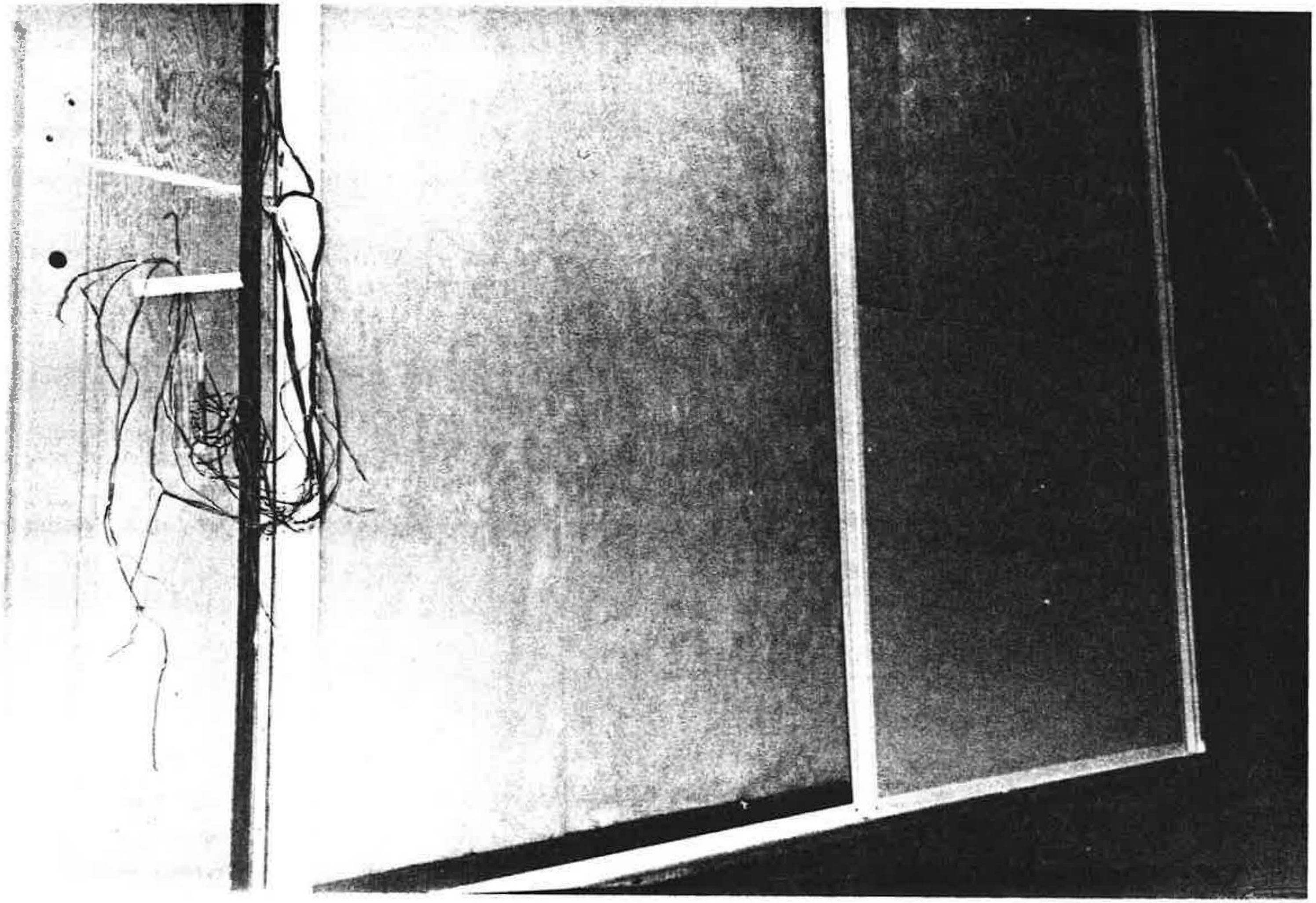


FIGURE 9.

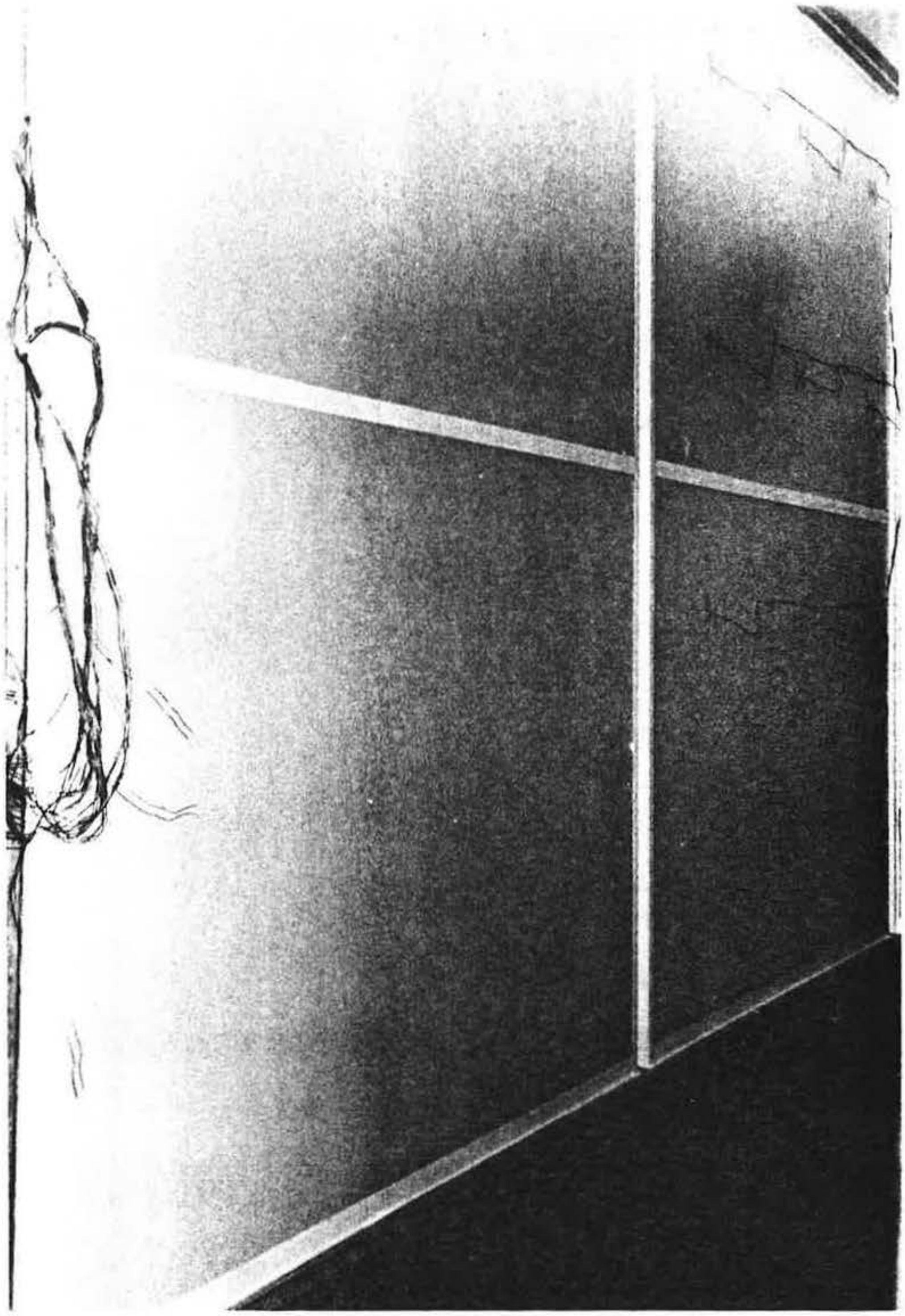
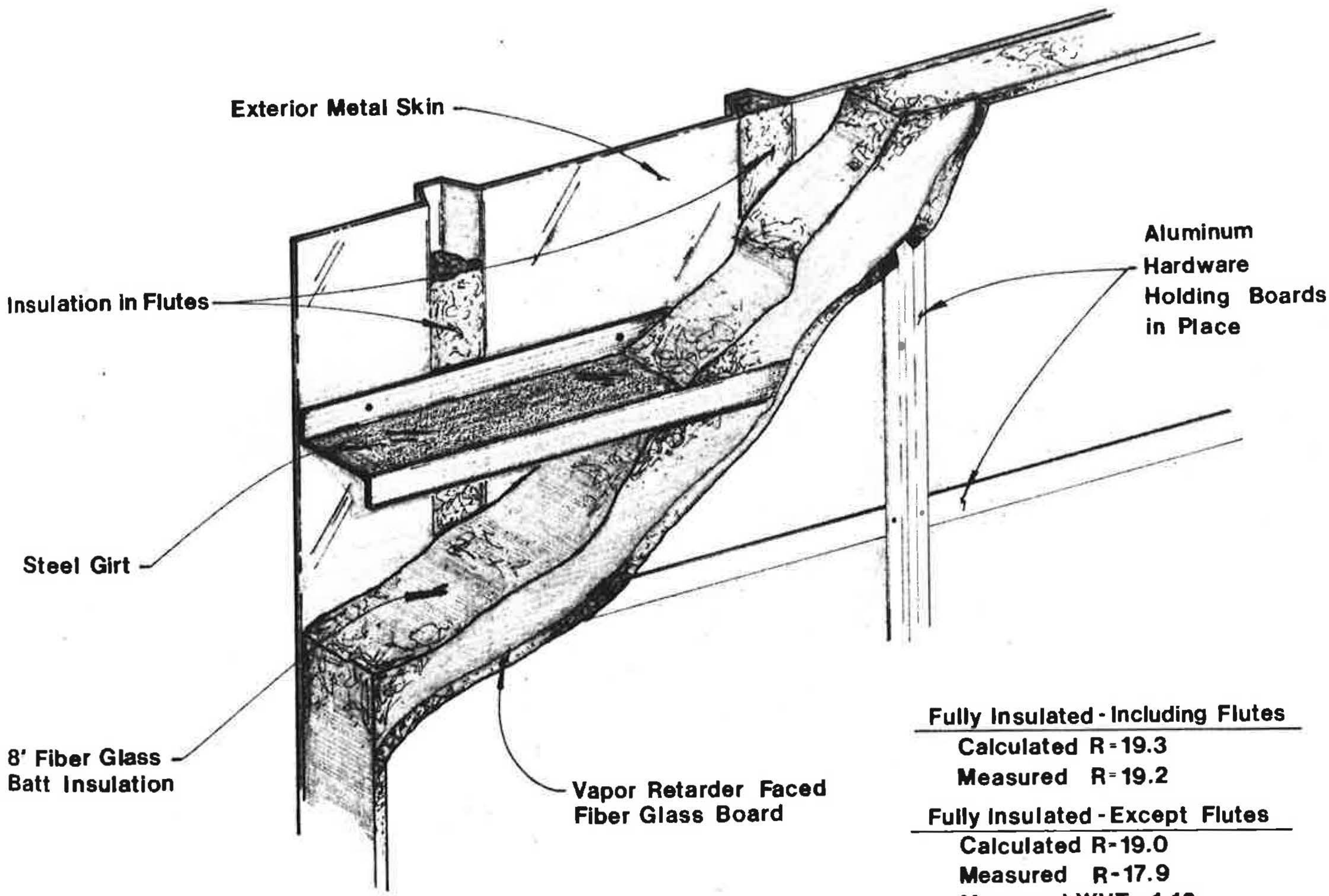


FIGURE 10.



Fully Insulated - Including Flutes

Calculated R = 19.3

Measured R = 19.2

Fully Insulated - Except Flutes

Calculated R - 19.0

Measured R - 17.9

Measured WVT - 1.13

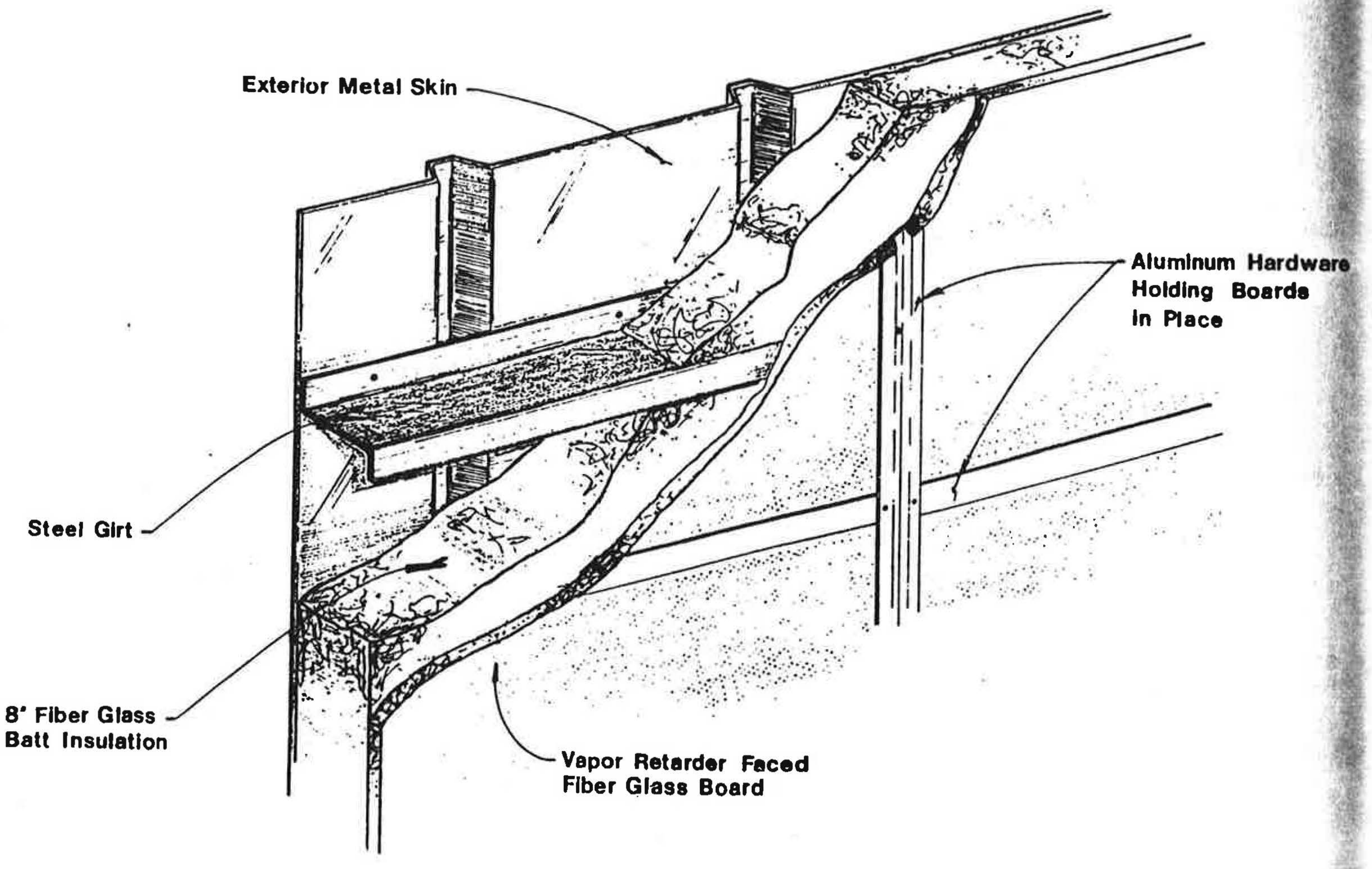

Exterior Metal Skin
Aluminum Hardware
Holding Boards
In Place
Steel Girt
8' Fiber Glass
Batt Insulation
Vapor Retarder Faced
Fiber Glass Board

FIGURE 12

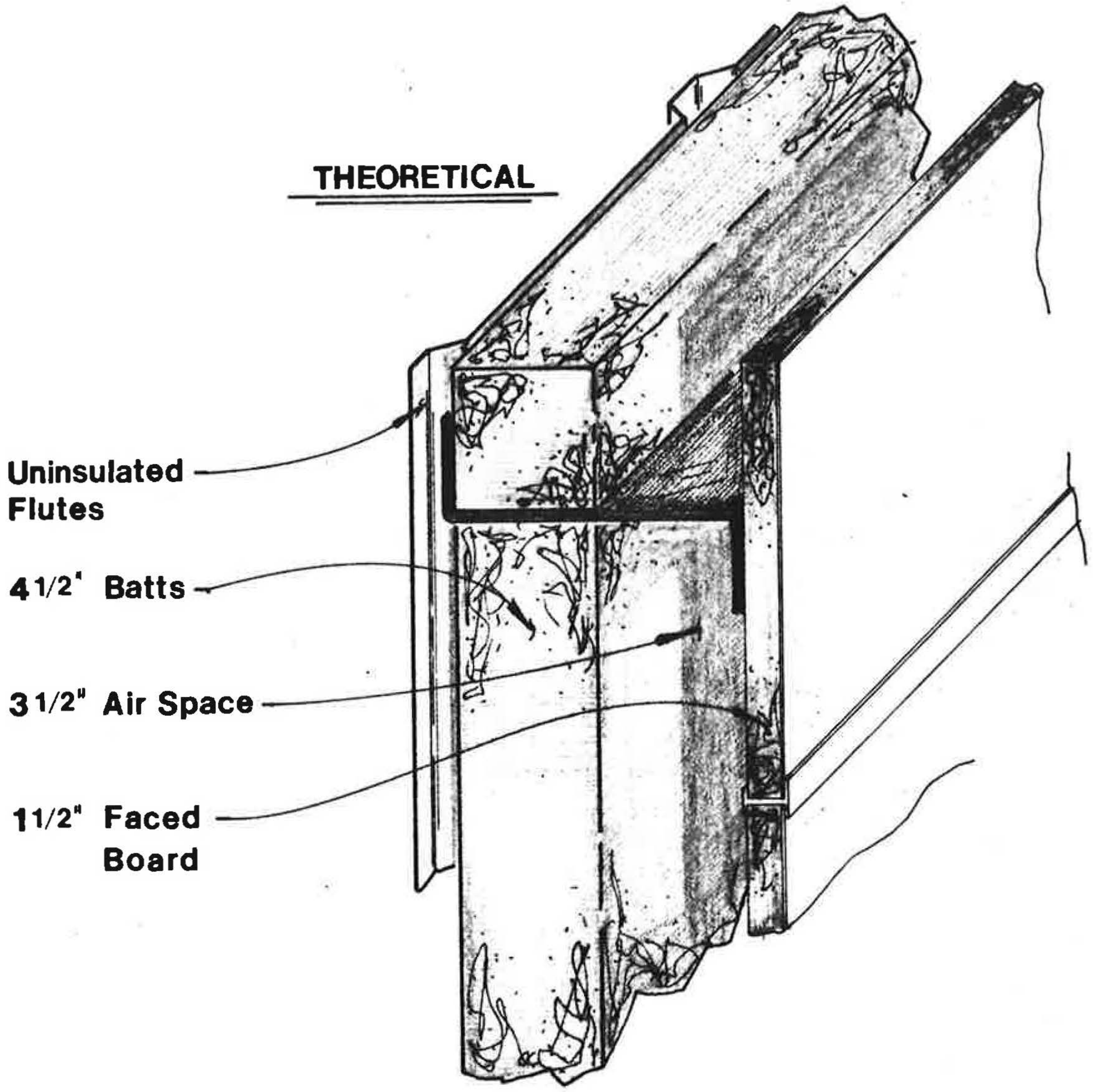

THEORETICAL
Uninsulated Flutes
4 1/2' Batts
3 1/2" Air Space
1 1/2" Faced Board

FIGURE 13

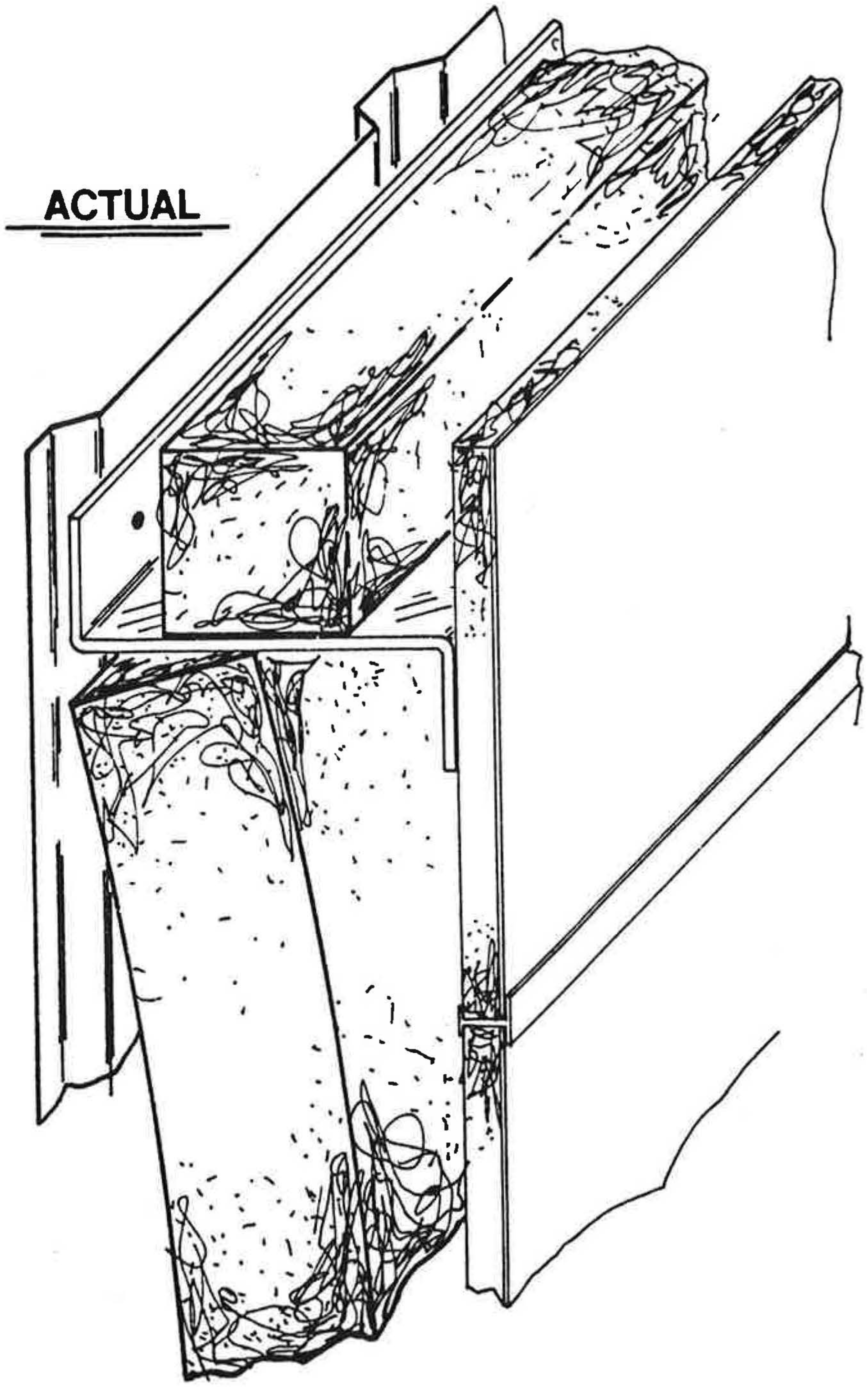


FIGURE 14.

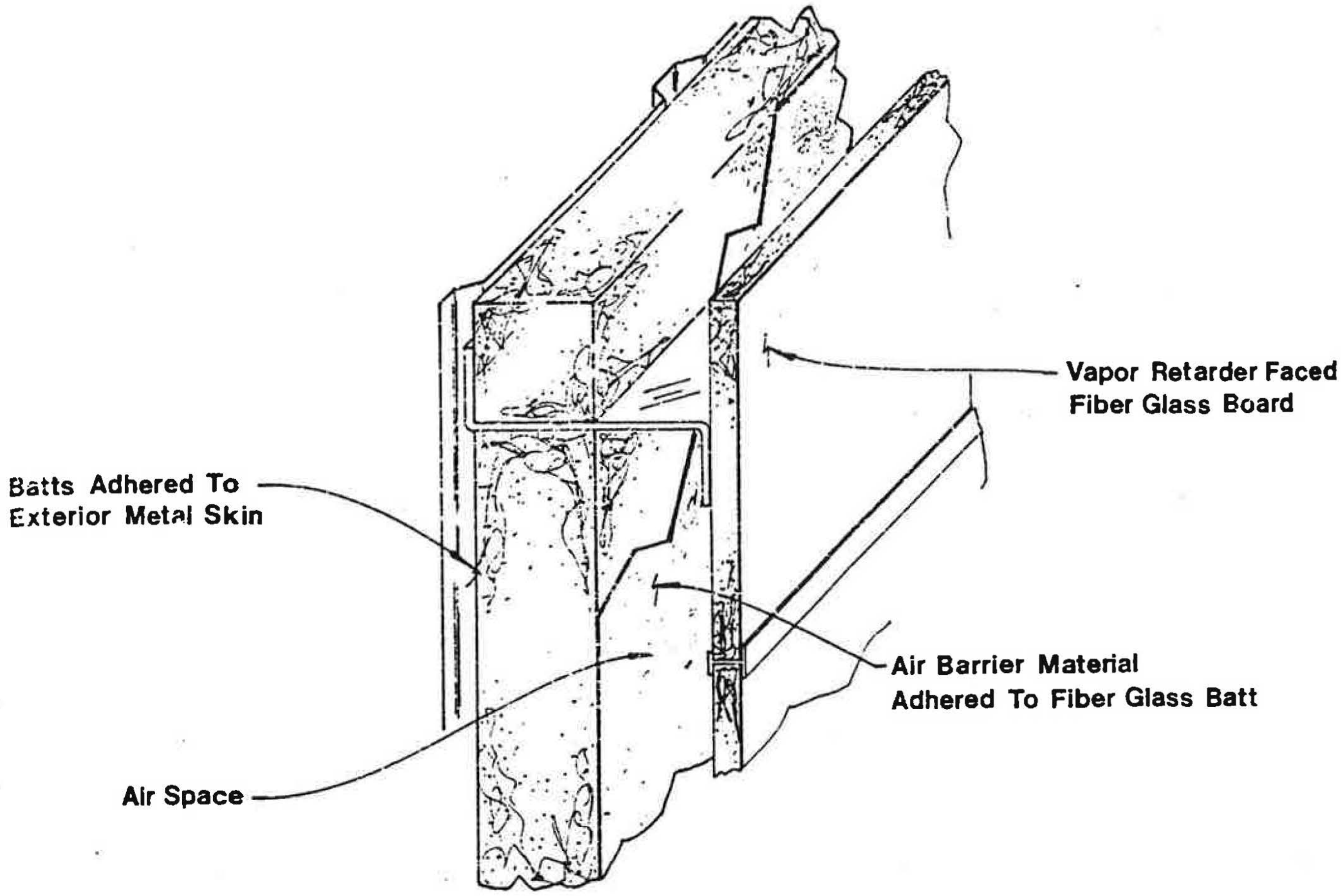

Vapor Retarder Faced
Fiber Glass Board
Batts Adhered To
Exterior Metal Skin
Air Barrier Material
Adhered To Fiber Glass Batt
Air Space

FIGURE 15.

TEST RESULTS SUMMARY

	WVT	R	Cal.R
Fully Insulated	–	19.2	19.3
Insulated, None in Flute	1.13	17.9	19.0
3.5" Air Space + Insul.	2.27	8.2	13.5
3.5" Air Sp.,Tyvek,Insul.	1.73	13.7	13.5
3.5" Air Sp.,FSK, Insul.	1.49	14.9	15.9

FIGURE 16.