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Effect of an Exterior Air-Infiltration Barrier on Moisture Condensation and Accumulation within Insulated Frame Wall Cavities

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ABSTRACT

Increased airtightness of buildings has been promoted for energy savings. One method for achieving greater airtightness is the installation of an air-infiltration barrier on the exterior of building sheathing. Although most barrier materials promoted for this application have a high water vapor permeance, it has been a concern that such installations could lead to moisture problems.

To evaluate the potential for such problems, a series of laboratory tests were conducted. One such series involved the condition where warm and moist indoor air circulates through wall cavities. To simulate this condition, three wall segments were installed in an environmental chamber, warm moist air was circulated by fan through three stud spaces, the wall segments were subjected to temperature differentials, and the moisture content of the sheathing and insulation was measured before and after each test. The tests were conducted first on the wall segments without the air-infiltration barrier and were then repeated with a barrier installed.

The results indicate that the air-infiltration barrier installed between the sheathing and the siding causes a more even moisture distribution by decreasing the accumulation of condensation in building materials in areas of high moisture content and by increasing it in areas of low moisture content. It was also observed that the highest moisture content in the sheathing occurred under moderately cold conditions, while the highest moisture accumulation in the fiberglass occurred under more severely cold conditions.

INTRODUCTION

Two field studies conducted recently have shown that the installation of an air infiltration barrier on the exterior of a stud wall can reduce air infiltration and energy use of the houses used for the tests by seven to twenty percent (Davidson and Eyre 1983; Luebs and Weimar 1984). In laboratory tests conducted on a wall segment, the installation of an air infiltration barrier over a sheathing with known air leaks reduced the thermal transmittance by approximately 10 percent at 12 ft/s (4 m/s) wind and 40 percent at 42 ft/s (14 m/s) wind (Henning 1983). To prevent moisture being trapped behind an exterior applied air barrier, it is commonly accepted that the material of exterior barriers should have a high vapor permeance (ASHRAE 1981; ASTM 1984; U.S. Department of Housing and Urban Development 1980). Accordingly, most or all materials used or suggested for exterior air barriers have a high water vapor permeance.

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However, moisture moves through cavity wall constructions primarily through convection (or mass transfer) with air (ASHRAE 1981). Thus when the flow of air is reduced, so, it would appear, water vapor flow is also reduced (Davidson and Eyre 1983). But conditions could occur where warm moist air recirculates from the indoors through the wall cavity, such as where cracks, electrical outlets, or plumbing penetrations exist on the interior of a wall in a studspace both low and high in a wall, or where warm and moist air flows from the house interior into the wall cavity and out at the top into the attic space or at the bottom into a basement or crawlspace, as could happen whenever electrical services drop from the attic (or rise from a basement or crawlspace) to a switch or outlet in the wall. Then the air barrier, by reducing the available cold and drier outside air for mixing with the warm moist air, could actually increase the potential for condensation within the cavity. It was the purpose of the work reported below to investigate the effect, if any, of the installation of an exterior air barrier on moisture condensation within insulated frame wall cavities under conditions of such recirculating warm and humid air.

APPROACH

The concept of the study was to install in an environmental chamber a test wall consisting of three panels with differing openness of the sheathing and two different exterior sidings, subjecting the wall to temperature differentials, while circulating warm moist air through the center stud space of each panel. The tests were conducted first on a wall without the installation of an air-infiltration barrier and then again on the same wall but with an air-infiltration barrier installed on the cold side (exterior) of the wall between the sheathing and the siding. In each configuration two tests were conducted. In the first series on the specimen without the air-infiltration barrier, the cold-side (exterior) temperature was different for the two tests. In the second series on the specimen with the air-infiltration barrier, the relative humidity of the air circulating through the panels was different for the two tests.

CONSTRUCTION OF TEST PANELS

The wall specimen was installed in an environmental chamber at York, PA. The chamber measures approximately 14 feet (4.3 metres) wide, 9 feet (2.7 metres) deep, and 8.5 feet (2.6 metres) high. The chamber has three access doors and a cold air supply along one of the long sides. The chamber is lined with galvanized steel but is not airtight.

Three four-foot-wide (1.2 meter-wide) panels were installed in a row approximately in the middle of the chamber. The air supply loops (one per panel) for the stud spaces under test, including the heaters and humidifiers for their conditioning, are located in the "warm" side of the chamber. Figure 1 shows the chamber and wall panels.

All panels measured 4 feet by 8 feet (1.2 metres by 2.4 metres). The interior (warm) side consisted of 1/2-inch (13 milimetres) thick marine-grade plywood, painted with aluminum paint and sealed, to form an essentially air and vapor tight back. Each panel contained three 16-inch (0.4 metre) stud spaces. The studs were painted with aluminum paint to reduce the absorption of moisture. The 16-inch (0.4 metre) (nominal) cavities were filled with 3 1/2-inch (89 milimetre) R-11 unbacked fiberglass insulation batts. The exterior of the stud spaces was covered with 1/2-inch (13 milimetre) clear soft wood pine sheathing with tongue and groove joints sealed by masking tape. The joints between the studs and the sheathing and interior back panels were sealed to prevent air movement between stud spaces. At the middle stud space of each panel, two air ports with nipples for connecting to the air loops were provided at top and bottom. The holes and nipples had a clear opening of 1/2-inch (13 milimetre) diameter, located as shown in Figures 2 and 3. The rationale for the selection of the opening dimensions was based on R-values of test wall, estimated typical opaque wall air leakage area, stack effect, and calculated resulting airflow rates within the wall cavity. In addition to the openings for supply air, the middle stud space of each panel had sampling ports with removable plugs on the warm side for removing samples of sheathing and insulation. The sample ports measured 12 inches by 9 inches (0.3 metres by 0.23 metres), allowing the removal of fiberglass sample specimens of 10 inches by 7 inches by 3 1/2 inches (0.25 metres by 0.18 metres by 0.09 metres), and siding samples of 8 inches by 5 inches by 1/2 inch (0.20

metres by 0.13 metres by 13 millimetres). The sample specimens were pre-cut and pre-drilled. Figure 3 shows the panels in elevation, giving the location of air ports, sample ports, thermocouples, and moisture probes. Figure 4 shows a photograph of Panel A with air loop installed.

For identification purposes, the panels in each series are labeled A, B, and C, and the test series are numbered 1 and 2. Thus, panel A1 denotes panel design A tested in the first series, and panel design C2 denotes panel design C tested in the second series. The tests themselves were numbered consecutively from 1 to 4.

In Panel A the sheathing was perforated with 3/32-inch (2.4 mm) diameter holes at 5-inch (0.13 metre) horizontal and 6-inch (0.15 metre) vertical spacings to simulate a wall with a "tight" exterior wall. These perforations give a leakage area of approximately 0.3 in^2 (190 mm^2), or slightly more than one-third of the area of the air ports on the warm side of the wall.

In Panels B and C, the siding was perforated with 3/32-inch (2.4 mm) diameter holes at 2-inch (50 milimetre) spacings, vertically and horizontally, simulating a "loose" exterior wall. These perforations give a leakage area of approximately 2.3 in^2 (1480 mm^2) or not quite three times that of the air ports. Thus, Panels B and C had approximately eight times the leakage area of Panel A.

Panels A and B had an exterior (cold side) finish of aluminum siding, panel C, an exterior of wood clapboard siding painted. Figure 5 shows schematic sections through the two types of siding and the location of thermocouples and moisture gages.

In Tests 1 and 2 (Panels A1, B1, and C1), the panels are as described above. In Tests 3 and 4 (Panels A2, B2, and C2) an air-infiltration barrier was installed between sheathing and siding.

Table 1 gives the specifications for the panels: perforations, air barriers (yes/no water vapor permenace), type of siding installed on the warm side, and other wall construction materials.

The center stud space of each panel was connected to a closed air loop at top and bottom. Each air loop contained a pump capable of maintaining an airflow of approximately 1 cfm (4.7×10^{-4} m^3/s). Between the pump and the upper connection to the panel, each loop also contained a flowmeter and a heater and humidifier to condition the air. Each loop also had a rubber stopped port for inserting and sampling tracer gas. During the test, the air in the loop was pumped upward and then downward through the wall stud space.

In addition to the instrumentation required for the air loops, surface and air temperatures were measured, and the pressure differences across the test specimen and between top and bottom of the stud spaces were monitored. (The test plan did not call for a pressure difference across the specimen, and the monitoring of the difference was performed only to verify this condition.)

Air temperatures were measured in the cold and warm rooms. The temperatures were also measured in the center of the insulation at the top, mid-high, and bottom of the center stud space and at the top of one adjacent stud space in each panel. Surface temperatures were measured on the exterior (cold side) of the siding, on the exterior (cold side) and interior (warm side) of the sheathing, and on the exterior and interior of the interior plywood panel, as shown in Figures 3 and 5.

The moisture contents of the sheathing were monitored by 12 moisture probes located as shown in Figures 3 and 5. The results of these measurements were intended primarily to observe trends in moisture levels and to determine the relative moisture levels at different locations. Sheathing samples and samples of insulation were tested for moisture content by weighing and drying. In evaluating the test results, moisture content as determined by weight was used primarily.

The air change rate in the wall cavities and air loops was measured by injecting tracer-gas into the air loops and determining the decay rate for each panel. The actual instrumentation used is listed in the acknowledgement section.

TEST CONDITIONS

Table 2 gives the nominal conditions for the four tests selected to represent moderate and cold climates prevailing over extended periods. Tests No. 1 and No. 4 are directly comparable, having the same test conditions but differing only in that in Test No. 4 an air barrier was installed, whereas in Test No. 1 no such barrier was installed. Test No. 2 showed the effect of a lower cold room temperature, with all other parameters kept the same as in Test No. 1. Test No. 3 indicates the effect of reduced relative humidity of the recirculating air in the loop, with all other parameters kept the same as in Test No. 4. The airflow rate through the loop and test stud space was based on calculations of flow rates that might occur due to stack effect in an uninsulated (empty) stud space.

TEST PROCEDURE

The test procedure consisted of the following steps:

1. Prior to start of tests, weigh fiberglass and sheathing inserts, dry the inserts (samples), weigh again, store at room temperature, and weigh again before installation into the test wall. To dry samples, place in drying oven (without container) at 200 to 220 F, and weigh after one, two, and, if necessary, three days, or until weight remains essentially unchanged.
2. Adjust temperatures and relative humidities in the cold and warm rooms and the airflow rate temperature and relative humidity in the air loops to the values given in Table 3 for "warm climate" conditions. Maintain these conditions for five days or until moisture in siding has ceased to increase. (Test No. 3 was conducted over two five-day periods).
3. Determine decay rate of tracer gas injected into air loops immediately after flow rates and temperatures are adjusted and compute the air change rate in the loop.
4. Record temperatures at all measuring points at one-quarter-hour intervals and determine average readings over each six-hour period and for the last three 24-hour periods. Measure pressure difference across test wall once per day.
5. Record moisture content of siding as measured by moisture probes no less than two times per day.
6. Remove samples of siding and insulation and weigh as described in item 1.
7. Dry out wall by pumping warm air into the wall cavities. For this step, the return air loop was not connected to the pump. With the access doors open, cold and warm rooms were at ambient temperature. Adjust airflow rate to a value of approximately 1 cfm per panel. Maintain airflow for two days or until the moisture content of the sheathing has essentially returned to the initial reading.
8. Weigh siding and insulation samples.
9. Adjust air in air loops to "cold climate" conditions for Test 2 in Table 3 and maintain for five days.
10. Determine decay rate of tracer gas as in step 3 after air and temperatures are adjusted to "cold climate" conditions.
11. Record temperatures, pressure difference, and moisture content as indicated in steps 4 and 5.
12. Remove samples of siding and insulation and test for moisture content as shown in step 1.
13. Remove siding and install air-infiltration barrier over exterior of sheathing. Reinstall all thermocouples and sidings.
14. Repeat procedure from steps 1 through 12 for sample with an air barrier, adjusting temperatures and relative humidities to the values for Tests 3 and 4 given in Table 3.

TEST RESULTS

Tables 3 and 4 give a summary of the test results. Both tables show on the left for each panel and each test the air change rate within the center stud space, the pressure difference between the top and bottom of the stud space, and the relative humidity of the air within the stud space and loop, averaged over the last three days of the test period. These parts of Tables 4 and 5 are identical. The tables show then on the right for each test the values relating to the moisture content of the sheathing and the insulation (by weight). In Table 3, the moisture content is given in percent as determined at the end of the five-day test period (two five-day test periods in Test 3). Table 4 provides the increase of moisture content over the test period.

Table 5 gives the temperatures averaged over the last three days of the test for the cold room exterior surface of the sheathing (Station 1), interior surface of sheathing (Station 2), mid-insulation (Station 3), exterior surface of interior plywood panel facing stud space (Station 4), interior surface of interior plywood panel facing warm room (Station 5), and warm room temperatures. The cold room temperature is given for mid-height; temperatures on and in panels are shown for the center stud space of each panel at top and bottom. The warm room temperature is provided for both top and bottom. A typical temperature profile through the wall is shown on Figure 6.

DISCUSSION

The primary purpose of the tests was to determine the effect of the installation of an air-infiltration barrier on the moisture content in the sheathing and insulation of conventional frame walls. A direct comparison is possible for Tests 1 and 4.

When comparing the final moisture content of the sheathing and the insulation at the conclusion of Tests 1 and 4, it can be seen from Table 3 that, for all sample locations, those in Test 4 (with an air-infiltration barrier) were lower than those in Test 1 (without an air-infiltration barrier). When comparing the increase of moisture content over the duration of the tests, this relationship holds only partially true. The most significant difference is that, while the previously established pattern (that is, a reduction of moisture content with the installation of an air-infiltration barrier) holds true as a general rule (with the marginal exception of Panel C) for locations high in the wall, the opposite pattern (that is, an increase of moisture content with the installation of an air-infiltration barrier) was observed for locations low in the wall. Thus, the installation of an air-infiltration barrier seems to result in a trade-off in moisture condensation and accumulation within the sheathing between locations low and high in the wall. Since the high locations showed significantly higher moisture content than the lower locations (by a factor of approximately two), this trade-off results in lowering the maximum moisture content and, therefore, should lead to a reduction of potential problems such as fungus growth and paint peeling.

Another exception, noted above, was Panel C, which showed a slight reverse in the pattern in that, even in the top location, it showed a marginal growth in the increase of moisture content. The reason for this is not apparent. Finally, it appears from Table 4 that the increase of moisture content in the insulation did not follow any pattern. (The increase for Test No. 2 is not available, since the insulation samples were not measured prior to the test.) However, except under the severe conditions of Test No. 2, both the final moisture content and its increase over the duration of the tests do not appear to be of significant magnitude to warrant concern.

The reasons for the observed differences in moisture condensation and accumulation between panels with and without an air-infiltration barrier are not clear. However, the following mechanisms may contribute to the observed patterns. Without the air-infiltration barrier, some of the warm humid air pumped into the stud space at the top moved through the insulation and through openings in the sheathing, depositing a major part of its moisture through condensation as the air passed through the openings in the cold sheathing. Conversely, this air had to be made up by colder, drier air moving into the stud space at the bottom (since the air loop had to have the same intake at the bottom as the supply at the top), mixing with the remaining warm moist air, and reducing its relative humidity. When the air-infiltration barrier was added, the moist air supplied at the top of the stud space could not move through the sheathing into the cold room, but was deflected downward through the insulation, and thus did not fully get in contact with the cold sheathing in the upper part of the wall, leading to less condensation and accumulation in that location. On the lower end of the stud space, this warm air retained much of its moisture and was not diluted with cool dry air infiltrating through the sheathing. Thus, more moisture could condense and accumulate in the sheathing at the bottom of the panels with an air-infiltration barrier than in panels without such a barrier.

Comparing Tests No. 3 and No. 4, which differed only by the relative humidity of the air circulated through the loop and the stud spaces, it appears from Table 3 that the level of relative humidity in the air loop affects the moisture content in the fiberglass insulation and in the sheathing inversely; that is, the lesser relative humidity in the loop appeared to cause a higher moisture content in the wall. In investigating this apparent inconsistency, it was found that Test No. 3 was started after a prolonged shutdown of the apparatus, during which the ambient relative humidity of the laboratory air (not conditioned) was very high and the moisture content of the wood siding therefore also was high. However, if instead of comparing the final moisture content directly, the increase of moisture content over the test period is observed, then it will be seen on Table 4 that Test No. 3 indeed resulted in a lesser increase in moisture content for both sheathing and insulation.

Finally, it is also interesting to compare Tests No. 1 and No. 2. These tests differed only insofar as the cold room temperature was lower in Test No. 2 than in Test No. 1. It was expected that both siding and fiberglass insulation would show a higher moisture content for Test No. 2. However, as can be seen from Table 3, the moisture content of the fiberglass insulation was indeed much higher, but the moisture content of the siding was lower at the end of Test No. 2 ("cold" test) than it was at the end of Test No. 1 with the warmer cold room temperature.

The air change rates within the three test stud spaces, the rates for panels with and without the air-infiltration barrier, and the pressures required to achieve a uniform airflow of 50 cubic feet per hour (4 x 10^{-4} cubic metre per second) appear inconsistent. Particularly, this applies to the small differences in leakage rates between Panel A (total leakage areas to the cold room of 0.3 sin (190 mm^2)) and Panels B and C (total leakage areas of 2.3 sin (58 mm^2)) and the somewhat larger, but still small, difference between the leakage rates of panels with and without the air-infiltration barriers (Tests 3 and 4 on one hand and Tests 1 and 2 on the other). To investigate the reasons for these apparent inconsistencies, smoke and tracer-gas tests were conducted to determine the air leakage from the test stud spaces and the loop into the warm room. It was found that this leakage accounted for virtually all the residual leakage of the panels with the air-infiltration barrier. This large leakage into the warm room also masked the difference in air change rates between Panel A and Panels B and C. The smoke tests indicated that the air leakage into the warm room occurred primarily at locations where multiple wires penetrated the interior plywood panels and the conditioning boxes in the air loop.

CONCLUSIONS

Based on the results of the tests in which warm and humid air was circulated within wall cavities, it appears that the installation of an exterior air barrier between the sheathing and siding of an insulated frame wall reduces the potential for problems from moisture condensation under typical long-term cold weather conditions by decreasing the moisture accumulation in high moisture areas, while increasing the moisture accumulation in low moisture areas.

Also based on the test results, it appears that high moisture condensation and accumulation in the sheathing without an air-infiltration barrier is more pronounced under moderately cold climate conditions than under colder conditions. However, condensation and accumulation (and freezing) of moisture within the thermal insulation was shown to be greater under the colder conditions. Thus, moisture accumulation within the insulation appears to be more likely to degrade the thermal insulation value in colder climates than in more moderate climates, but paint peeling and fungus growth in sheathing (and probably siding as well) is more likely to occur in moderately cold climates. The latter conclusion is consistent with a recent Canadian study (Marshall Macklin Monaghan Limited 1983), which found that moisture problems in walls were more numerous in the maritime (and relatively moderate) climate of Newfoundland than in the colder and dryer climate of the Canadian Middle West. That study also documented the problems in the Newfoundland houses to be primarily related to sidings.

REFERENCES

ASHRAE Handbook of Fundamentals, Chapter 21.

ASTM C 755-73, (Reapproved 1984). Standard Practice for Selection of Vapor Retarders for Thermal Insulations, ASTM Book of Standards, Vol. 04.05, Philadelphia, PA, 1984.

Davidson, R., and Eyre, D. 1983. "An evaluation of TYVEK as an exterior retrofit air seal" Saskatchewan Research Council, Saskatoon, Saskatchewan, Canada, December.

Henning, G. N. 1983. "Energy Conservation with Air Infiltration Barriers," Thermal Insulation, Materials, and Systems for Energy Conservation in the '80's. ASTM STP 789, F. A. Govan, D. M. Greason, and J. D. McAllister, Eds, American Society for Testing and Materials, 1983, pp. 551-558.

Luebs, D. F. and Weimar, R. D. 1984. "Field Performance of an Air-infiltration Barrier," presented at ASTM Symposium on Measured Air Leakage Performance of Buildings, April 3, 1984 (Proceedings in Preparation).

Marshall Macklin Monaghan Limited 1983. "Moisture Induced Problems in NHA Housing, Part 1, Analysis of Field Survey Results and Projections of Future Problems," Prepared for the Canada Mortgage and Housing Corporation, Cat. No. NH20-1/2-1983-1E, ISBN o-662-12662-9, Toronto, Canada, 1983.

U.S. Department of Housing and Urban Development 1980. "Minimum Property Standards for One- and Two-Family Dwellings," Washington, D.C., 1980.

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Test Equipment and Instrumentation

Hewlett Packard 86 Computer/Controller

Hewlett Packard 3497A Data Acquisition and System Controller

Hewlett Packard 7470-A Plotter

Hewlett Packard 82905B Printer

Setra Systems, Inc. Pressure Transducers

Rotron Blowers

Teledyne Hastings Raydist Mass Flow Meter

Vaisala HMI Humidity and Temperature Indicator and HMP 32 UT Probe

Hygrodynamics Humidity Transducer

Copper Constantan Type T Thermocouple Wire

R502 Single Stage Direct Expansion Refrigeration Systems

Electric Resistance Type Heaters

Delmhorst Wood Moisture Detectors

Bally Walk in Test Chamber 14' x 9' x 8.5' (4.3 m x 2.7 m x 2.6 m)

Laboratory Tracer Gas Monitor Model 215BGD, S-Cubed

TABLE 1

Panel Specifications

Panel	Sheathing Perforations	Effective Leakage Area per Stud Space	Air Infiltration Barrier	Siding
A1	3/32 in holes, 5 and 6 in o.c.	0.3 in^2	None	Aluminum
B1	3/32 in holes, 2 in o.c.	2.3 in^2	None	Aluminum
C1	3/32 in holes, 2 in o.c.	2.3 in^2	None	Wood
A2	3/32 in holes, 5 and 6 in o.c.	NA	Yes	Aluminum
B2	3/32 in holes, 2 in o.c.	NA	Yes	Aluminum
C2	3/32 in holes, 2 in o.c.	NA	Yes	Wood

All panels framed with painted 2" x 4" studs, 16 inch on center, 2" x 4" sill plate and header, warm side (interior) face of 1/2-inch painted Marine grade plywood, 1/2-inch unpainted softwood sheathing, tongue and groove jointed. Wood siding pre-painted, lap joints not caulked or otherwise sealed. All siding fasteners at studs only. Between tests 1 and 2, the siding was removed, an air-infiltration barrier installed over all three panels, and the siding reinstalled.

The air-infiltration barrier used in the tests was a sheet of ultra-fine fibers made from high density polyethelene with a thickness of 0.006 inch and a water vapor permeance of 94 perms.

TABLE 2

Nominal* Test Conditions

	Without Air Barrier		With Air Barrier	
	Test #1	Test #2	Test #3	Test #4
Warm Room Air				
Temperature	70°F	70°F	70°F	70°F
Relative Humidity	30%	30%	30%	30%
Air Loop Air				
Temperature	70°F	70°F	70°F	70°F
Relative Humidity	50%	50%	30%	50%
Air Flow	50 cfh	50 cfh	50 cfh	50 cfh
Cold Room Air				
Temperature	30°F	10°F	30°F	30°F
Relative Humidity	70%	40%	70%	70%

* Actual conditions varied somewhat. See Table 3 for actual conditions.

Multiply in by 25.4 to obtain mm
Multiply in^2 by 645 to obtain mm^2

Multiply 0.5555 by (°F-32) to obtain °C
Multiply cfh by 7.8×10^{-6} to obtain m^3/s

TABLE 3

Relative Humidity in Air Loops and Stud Spaces, and Actual Moisture Content of Siding and Fiberglass after Tests

						Moisture Content of Sheathing (Percent)		Moisture Content of Insulation (Percent)	
Panel	Air Infiltration Barrier	Test No.	ACH	P in H_2O	RH in Loop*	Top	Bottom	Top	Bottom
A	None	1	6	0.04	44.8	13.9	6.8	4.8	1.4
	None	2	7	NA	46.7	10.6	5.0	11.6	2.6
	Yes	3	4	0.01	34.3	12.6	9.3	2.4	1.6
	Yes	4	3	0.03	47.4	8.8	4.9	1.8	1.3
B	None	1	6	0.03	45.9	15.1	6.6	6.1	2.1
	None	2	9	NA	54.4	11.4	3.7	16.2	2.1
	Yes	3	4	0.01	39.1	13.4	9.0	2.7	1.9
	Yes	4	2	0.02	49.1	9.9	5.3	1.7	1.0
C	None	1	9	0.04	39.2	10.8	6.8	1.7	2.1
	None	2	13	NA	47.3	9.1	4.8	15.8	2.4
	Yes	3	6	0.003	38.6	10.4	9.9	1.9	2.3
	Yes	4	5	0.03	48.5	8.9	4.9	1.5	1.5

Note: The relative humidity of the air in the loops are averaged over the entire test periods. In Test No. 1, one data point each was excluded from the average as being outside the normal range. The cause of this is not known, but it could be that the data point was collected at a moment when the loop was opened to check the moisture supply equipment. No abnormal data points were encountered in tests other than No. 1.

Multiply in H_2O by 249 to obtain Pa

TABLE 4

Increase of Moisture Content of Sheathing and Insulation During Tests

Panel	Air Infiltration Barrier	Test No.	ACH	P in H_2O	RH in Loop*	Increase in Moisture Content of Sheathing (Percent)		Increase in Moisture Content of Insulation (Percent)	
						Top	Bottom	Top	Bottom
A	None	1	6	0.04	44.8	9.8	1.4	2.6	0.1
Tight Alum.	None	2	7	NA	46.7	7.3	1.2	NA	NA
	Yes	3	4	0.01	34.3	3.8	1.5	0.0	0.5
	Yes	4	3	0.03	47.4	6.7	3.1	1.3	0.1
B	None	1	6	0.03	45.9	10.7	1.7	3.7	0.5
Loose Alum.	None	2	9	NA	54.4	7.7	0.8	NA	NA
	Yes	3	4	0.01	39.1	5.2	1.4	0.5	0.0
	Yes	4	2	0.02	49.1	7.9	3.5	0.4	0.1
C	None	1	9	0.04	39.2	5.9	1.2	0.4	0.3
	None	2	13	NA	47.3	5.9	0.7	NA	NA
	Yes	3	6	0.003	38.6	1.7	2.2	0.2	0.3
	Yes	4	5	0.03	48.5	6.9	3.2	0.7	0.4

Note: The relative humidity of the air in the loops are averaged over the entire test periods. In Test No. 1, one data point each was excluded from the average as being outside the normal range. The cause of this is not known, but it could be that the data point was collected at a moment when the loop was opened to check the moisture supply equipment. No abnormal data points were encountered in tests other than No. 1.

Multiply in H_2O by 249 to obtain Pa

TABLE 5

Average Temperatures in F for Last 3 Days of Tests
(Top and Bottom of Panels Only)

	PANEL	LOCATION	CR *1	Stations *2					
				1	2	3	4	5	WR
Test 1	A	TOP	29.0	38.5	41.2	55.4	69.2	70.0	70.6
		BOT	29.0	32.8	34.9	37.7	61.4	63.7	68.0
	B	TOP	29.0	38.8	41.8	59.5	68.6	69.4	70.6
		BOT	29.0	32.2	NA	39.8	62.6	63.7	68.0
	C	TOP	29.0	37.0	41.3	58.1	67.1	68.5	70.6
		BOT	29.0	37.8 *3	39.8	51.0	65.6	67.3	68.0
Average			29.1	35.6 *4	39.8 *5	50.2	65.8	67.1	69.3
Test 2	A	TOP	4.2	22.2	28.0	51.0	68.2	69.1	70.4
		BOT	4.2	11.9	15.9	20.7	58.1	61.3	65.7
	B	TOP	4.2	18.1	22.5	52.9	67.1	67.8	70.4
		BOT	4.2	8.7	NA	20.8	57.2	59.6	65.7
	C	TOP	4.2	16.8	21.8	50.7	64.2	67.2	70.4
		BOT	4.2	17.2 *3	20.1	38.5	61.4	63.8	65.7
Average			4.2	15.2 *4	21.4 *5	39.1	62.7	64.8	68.0
Test 3	A	TOP	32.8	40.5	42.6	52.9	66.9	68.0	70.7
		BOT	32.8	36.9	38.7	52.8	62.8	65.3	66.3
	B	TOP	32.8	40.3	41.8	58.3	66.9	67.9	70.7
		BOT	32.8	36.8	39.9	52.2	64.8	66.4	66.3
	C	TOP	32.8	40.5	43.2	58.1	66.5	68.2	70.7
		BOT	32.8	40.2 *3	41.1	51.4	64.6	67.1	66.3
Average			32.8	38.6 *4	41.2	59.3	65.4	67.2	68.5
Test 4	A	TOP	30.7	41.1	43.3	54.0	66.7	67.8	70.4
		BOT	30.7	37.5	39.2	41.0	63.2	65.0	68.1
	B	TOP	30.7	41.4	43.1	58.7	67.0	68.0	70.4
		BOT	30.7	37.2	39.4	48.4	64.6	65.3	68.1
	C	TOP	30.7	40.7	43.4	57.9	66.3	67.7	70.4
		BOT	30.7	40.2 *3	41.4	51.5	64.7	67.3	68.1
Average			30.7	39.3 *4	41.6	51.9	65.4	66.8	69.25

*1 Cold Room Temperature available only at mid-height.
*2 See Figure 4 for location of stations.
*3 Data appears inconsistent.
*4 Averages of Panels A and B only.
*5 Averages of Panels A and C only.

WR = Warm Room Temperature
CR = Cold Room Temperature
TOP = Top of Panel
BOT = Bottom of Panel
NA = Not Available

Multiply 0.5555 by (^{o}F-32) to obtain ^{o}C

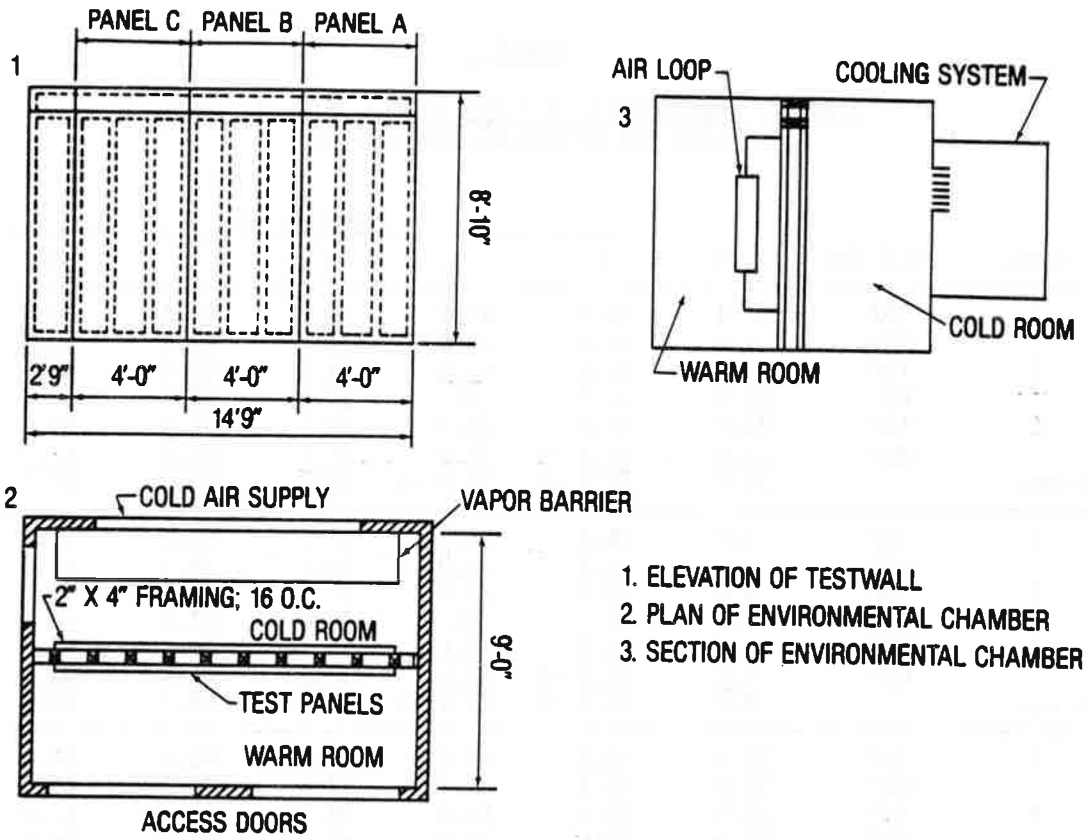

Figure 1. Environmental chamber and test wall

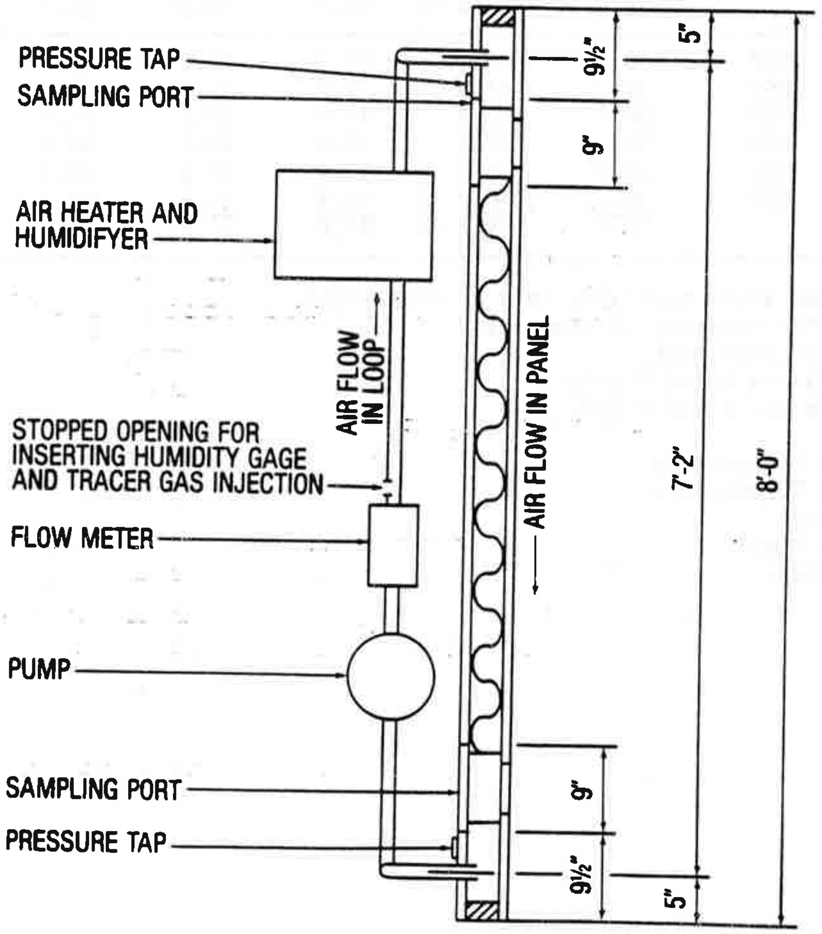

Figure 2. Section of panel with schematic of air loop

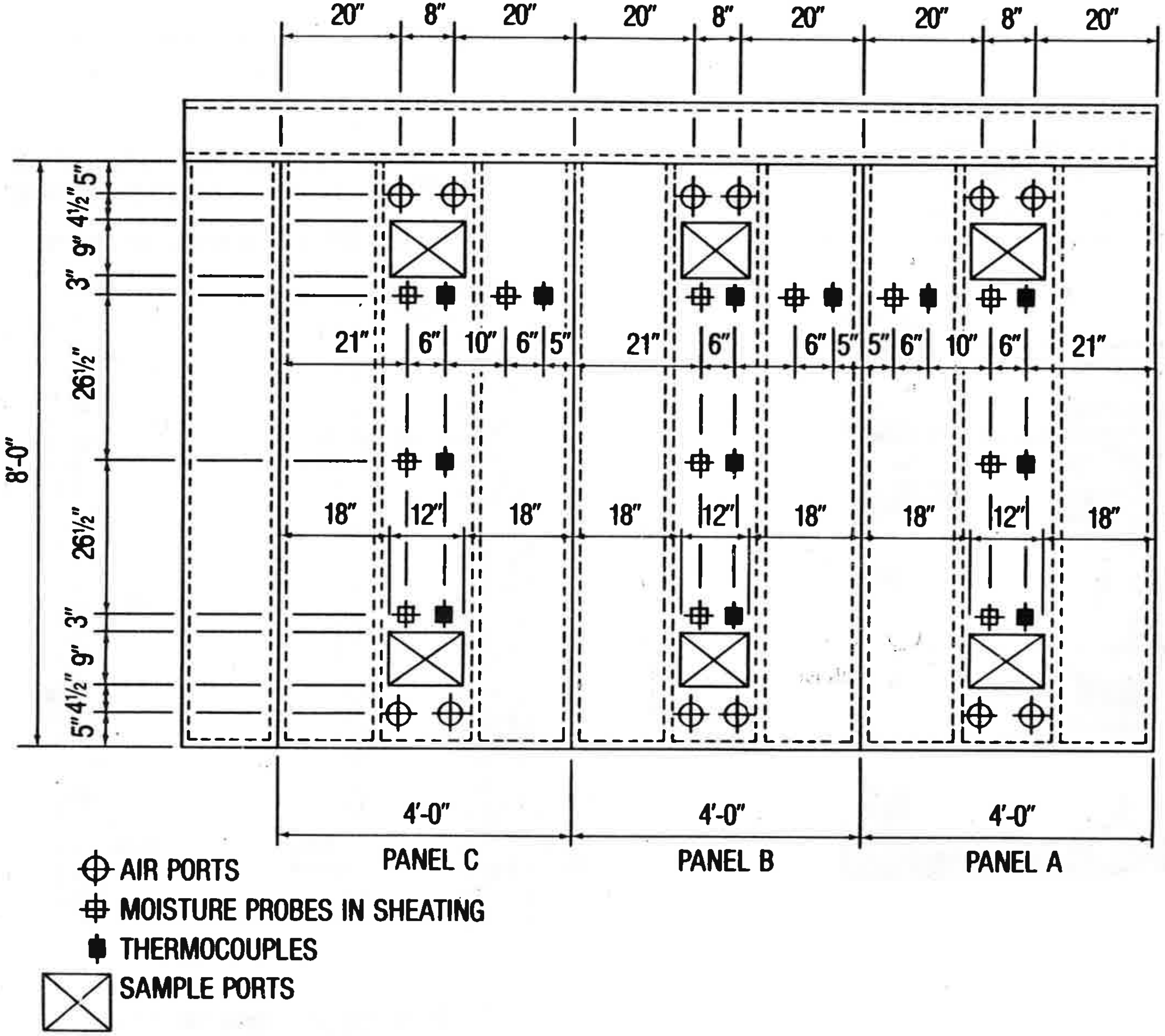

Figure 3. Elevation of test wall-location of ports and gage locations-viewed from warm room legend

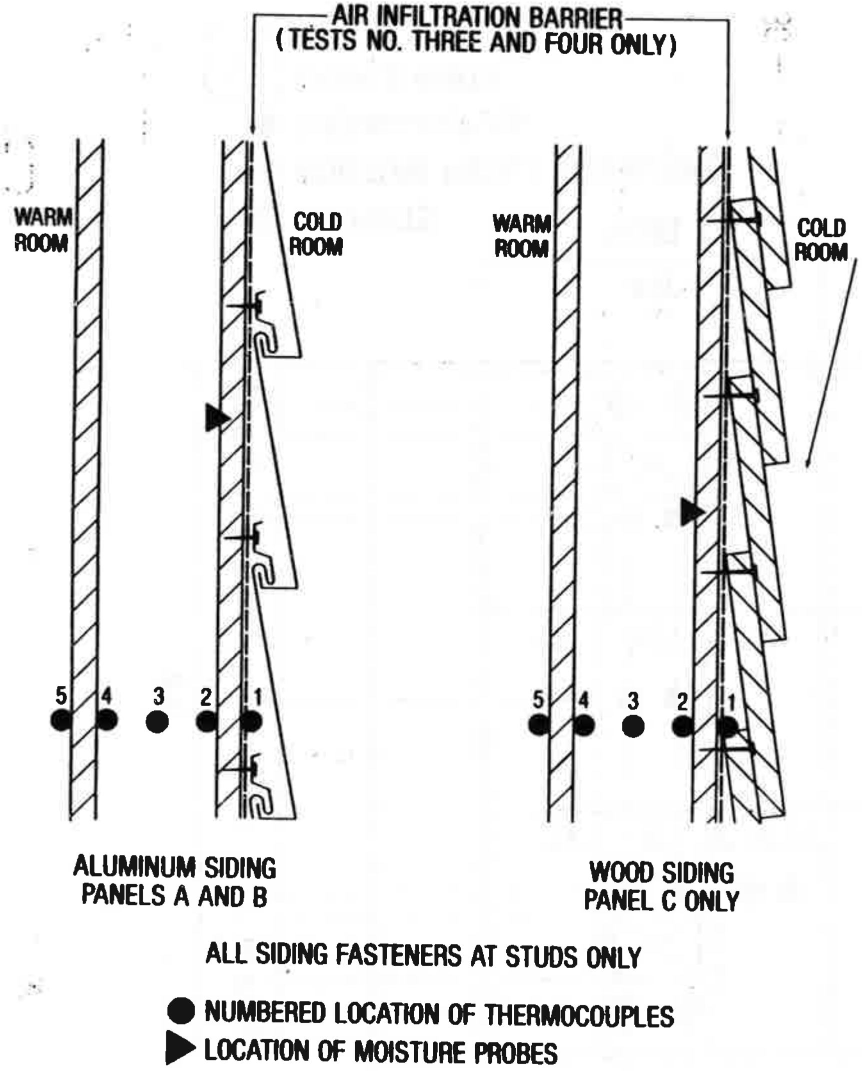

Figure 4. Schematic of sidings showing location of moisture probes and thermo couples

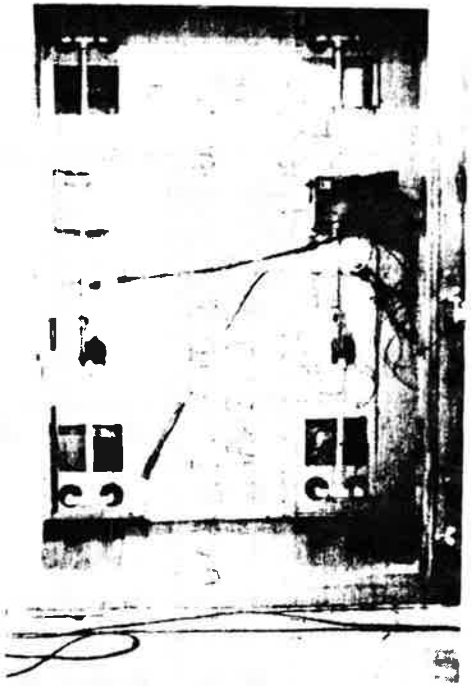

Figure 5. Air loop of panel A with moisture sensor installed (conditioning chamber open. Lower sample port also open)

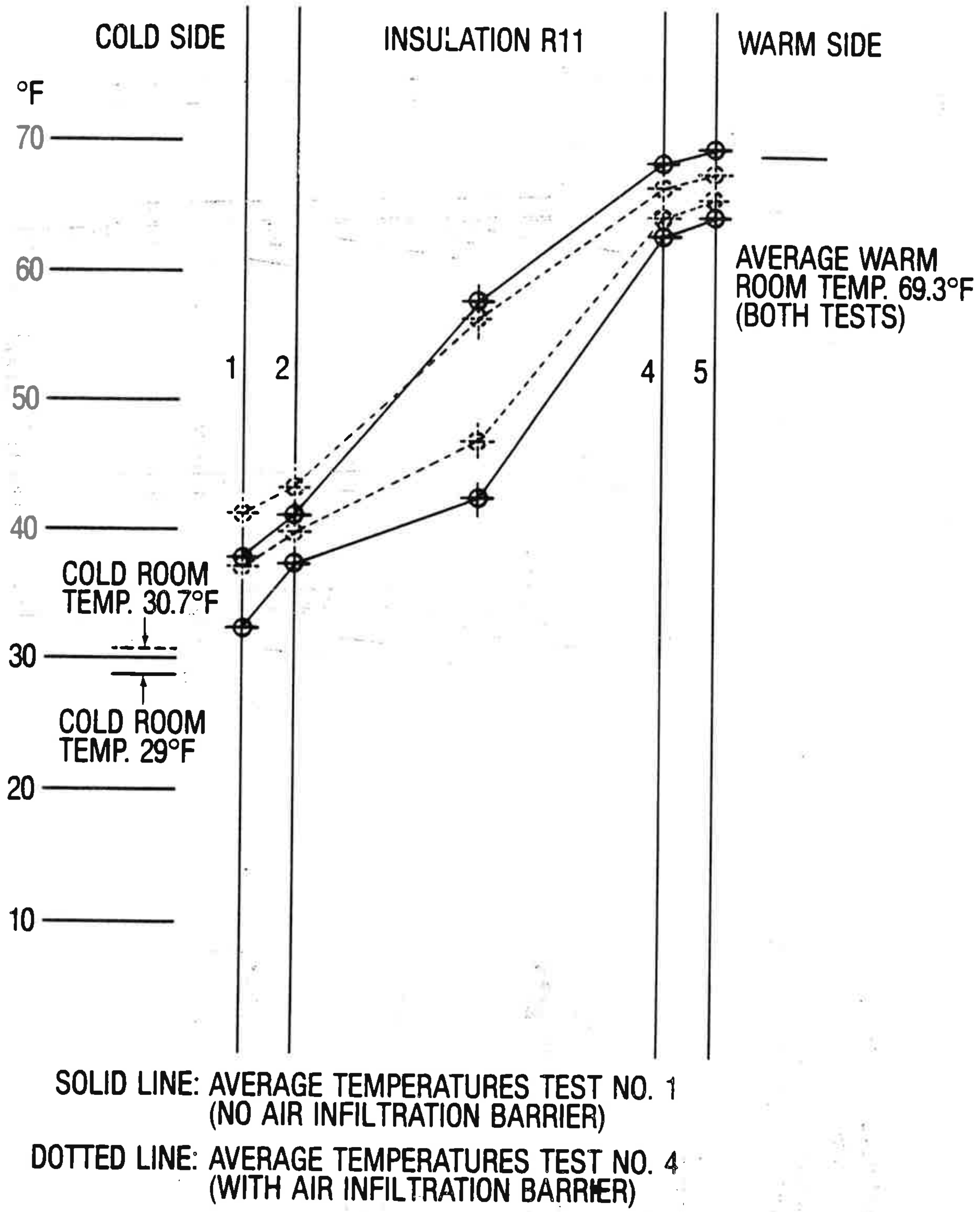

Figure 6. Typical temperature profile

[illegible]

[illegible]