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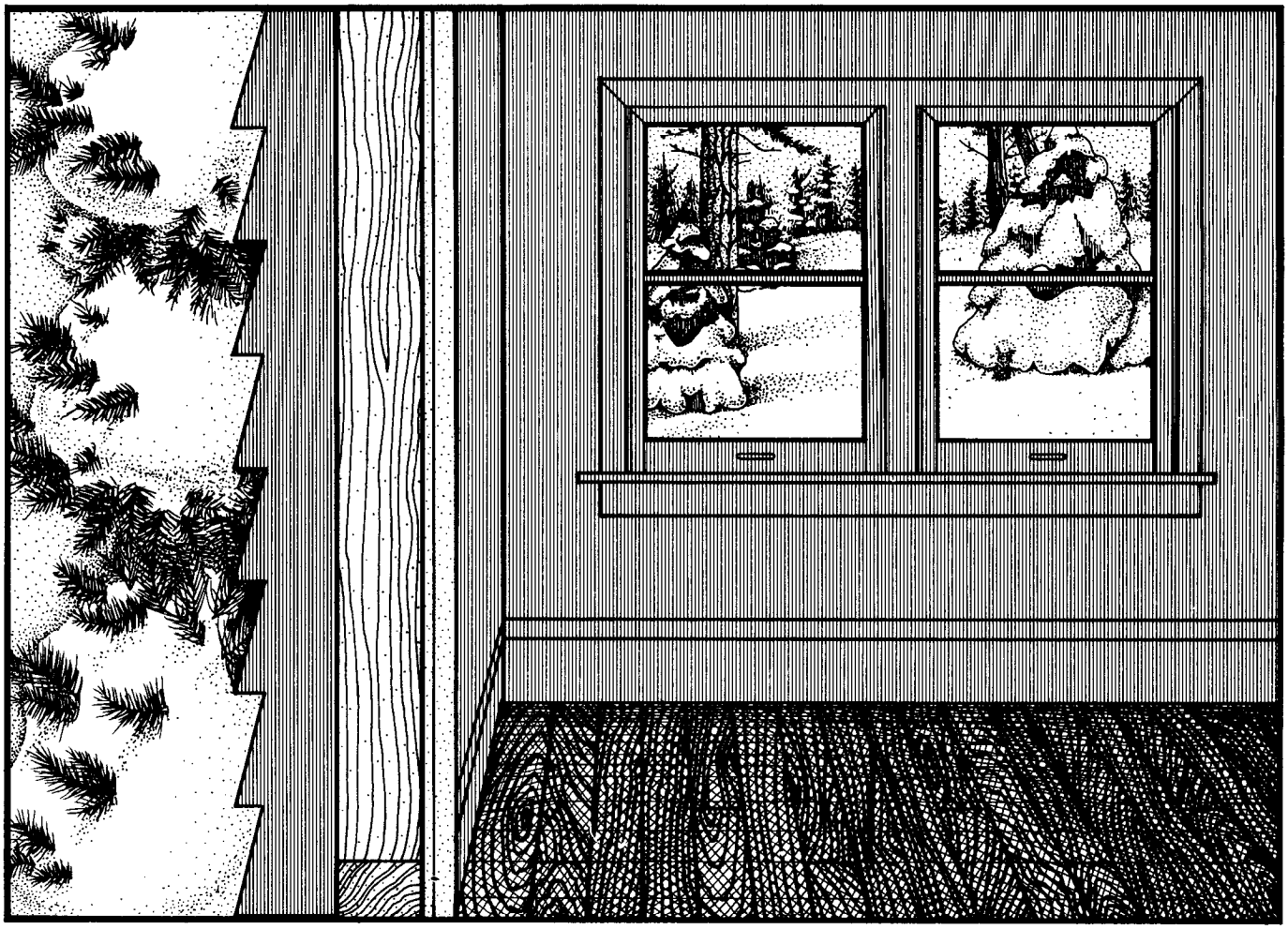
Condensation Potential in High Thermal Performance Walls – Cold Winter Climate

by G. E. Sherwood



Abstract

As a result of steadily rising energy costs, construction practice for light-frame wood structures has changed over the past few years. The use of 6-inch-thick walls and application of high-“R”-value, low-permeance sheathings to 4-inch walls has caused concern for the changing moisture patterns that may occur in walls. To observe actual moisture patterns and the potential for condensation, a test structure was constructed near Madison, Wis., for exposure of eight types of insulated wall panels at controlled indoor conditions and typical outdoor weather conditions. Panels were instrumented with moisture sensors and tested without (Phase 1) and with (Phase 2) penetrations (electrical outlets) in the indoor surface.

Continuous vapor retarders effectively prevented condensation; asphalted paper stapled between studs was inadequate. The installation of an electrical outlet changed the moisture profile and resulted in some condensation in most panels. Moisture levels on the back of siding in most Phase 2 panels have been known to produce buckling in long sections of hardboard siding. Although streaking occurred on the siding of two types of Phase 1 panels and three Phase 2 types, and some condensation occurred in all types of Phase 2 panels, there was no long-term accumulation of free water in the structure. The moisture content of framing remained below 12 percent throughout the P-year study. There was no apparent increase in condensation potential with the addition of low-permeance foam sheathing in this study with controlled indoor conditions.

This paper should be useful to building designers, builders, and building code officials.

KEYWORDS: Condensation, Moisture control, Vapor retarder, Air leakage, Wood-frame walls, Foam sheathing.

Acknowledgments

The author acknowledges Doug Wheeler’s valuable contributions in instrumenting the test structure and providing electronics expertise throughout the P-year study. Thanks also go to Terry Niedziela for his creative solutions to problems during the constructon, instrumentation, and installation of test panels.

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Condensation Potential in High Thermal Performance Walls—Cold Winter Climate[2]

BY
G. E. SHERWOOD, Engineer

Introduction

The escalation of energy costs in recent years plus a concern for reducing dependence on foreign oil has resulted in the development of highly efficient thermal insulation systems for wood-frame residential construction. These systems include rigid foam wall sheathing, foil-backed foam wall sheathing, or nominal 6-inch wall studs with 6-inch insulation batts. Theoretically all of these systems should result in within-wall moisture patterns different from those of conventional walls with nominal 4-inch studs and wood or wood-base sheathing materials.

Excessive moisture in wall cavities can have several detrimental effects. It may decrease the effectiveness of the cavity insulation (7)[3]. If the cavity remains wet for extended periods coincident with warm temperatures in the wall, wood structural components may decay. As the moisture moves to the outer face of the wall it may cause buckling or warping of siding or paint peeling (7). The potential for these detrimental effects can be assessed based on measurements of moisture levels at various locations in walls exposed on one side to a complete annual cycle of outdoor weather conditions while having the opposite side exposed to indoor conditions with controlled temperature and humidity. A better understanding of the moisture patterns in these highly thermal efficient walls is needed.

This paper presents the results of a study of moisture patterns in a variety of wall construction types exposed to weather conditions in a cold winter climate-i.e., Madison, Wis. This study is part of an ongoing program of thermal/moisture research at the Forest Products Laboratory (FPL). Because all variables could not be considered in a single study, additional studies are planned in both controlled laboratory tests and field observations of complete houses. Similar studies in a hot, humid summer climate will be reported in a subsequent report.

Background

The results of previous research at FPL on moisture condensation in walls have been summarized (7). General recommended practice in cold climates has been to provide a vapor retarder on the inside face of the wall with a perm rating of no more than one-fifth the rating of the outside covering material. Where closed-cell foam sheathing is used, this ratio can usually be achieved by applying a polyethylene film vapor retarder on the warm side of the wall. However, the addition of unperforated foil backing to rigid foam results in a near-zero permeance, so the 5-to-1 ratio of cold-side to warm-side permeance is not achieved.

The fact that moisture reduces the thermal resistance of insulating materials was established by Joy (7) in the 1950's. A more recent study by Burch (3) showed that for certain conditions, condensation occurred as a thin film on the surface of sheathing and had minimal effect on rate of heat transfer because it did not wet the insulation. However, wet insulation has been found in walls after prolonged periods of condensation. In some cases the condensation runs to the bottom of the wall cavity, saturating the sole plate as well as the lower few inches of insulation.

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[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]This research was conducted in cooperation with the American Hardboard Association, Dow Chemical, U.S.A., Jim Walter Research Corporation, and the U.S. Department of Housing and Urban Development

[3]Italicized numbers in parentheses refer to literature cited at end of report.

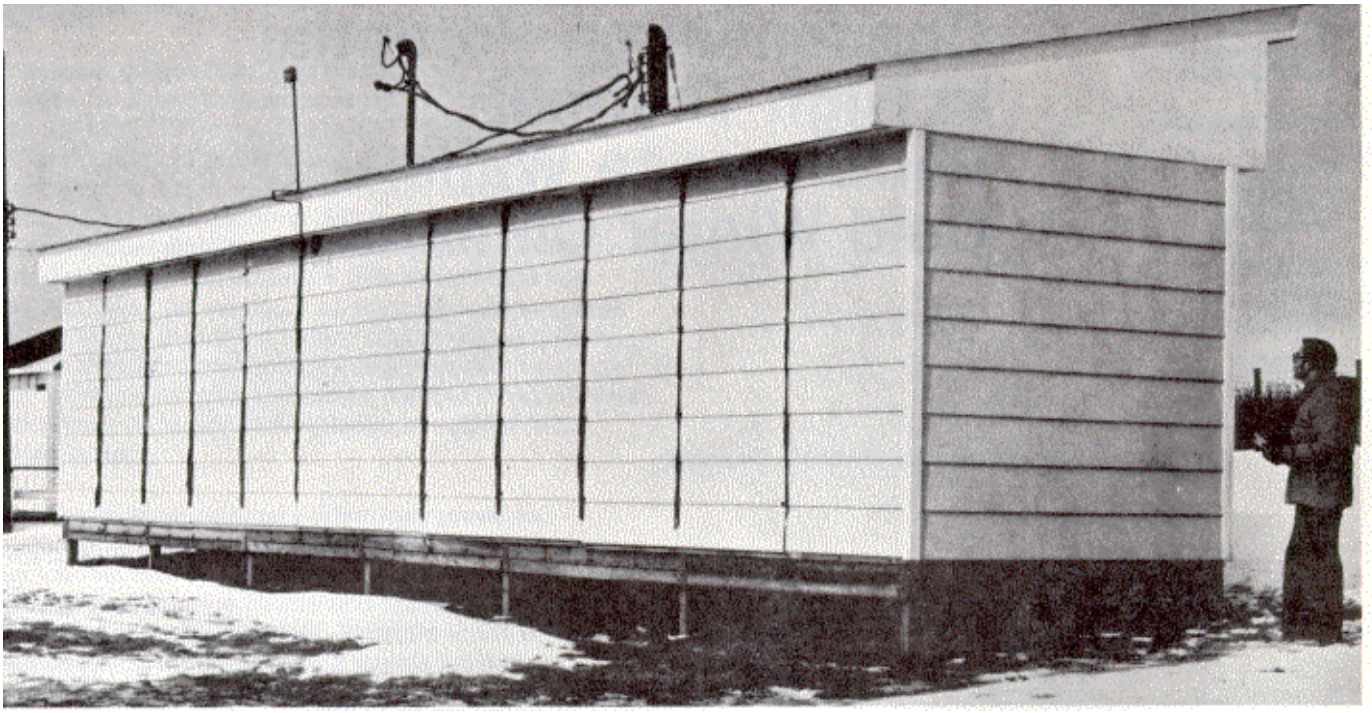

Figure 1.–Experimental condensation-study structure at Valley View test site near Madison, Wis. (M 147 763-11)

Moisture also reduces the thermal resistance of wood and wood products. A method for estimating that reduction is presented in the Wood Handbook (70). More serious effects of moisture on wood are dimensional changes and the potential for decay, though this author is not aware of documented reports of extensive decay in wood-frame walls due to condensation. Such decay is not probable because decay fungi do not grow at temperatures below 40° F, and the wall can dry out at higher temperatures (70). The most visible problems are paint peeling or blistering; expansion of the siding with increased moisture content may cause paint peeling, and moisture migration through the siding may blister the paint.

Previous studies (8, 9) have shown the increased potential for condensation with high indoor humidities when outdoor winter temperatures are low. As more airtight houses result in higher indoor humidities, an even greater potential for condensation may be expected. Although laboratory tests have included condensation studies, the actual moisture patterns through the cross section of a variety of walls exposed to outdoor conditions are needed to evaluate the effect of construction changes. This can best be accomplished by testing exposure structures in more than one climate to include the effect of climate on moisture patterns.

Materials and Methods

Exposure Structures

Two structures were built for the purpose of exposing test walls to outdoor weather conditions on one side while exposing the opposite side to typical indoor conditions. One structure was erected near Madison, Wis.; the other structure was erected near Gulfport, Miss. The two locations were planned to provide data on moisture patterns in a cold winter climate and in a hot, humid climate. This paper is limited to tests at Madison. Results from the Gulfport building will be discussed in a later report.

The buildings are long and narrow, 8 feet wide by 48 feet long, with the long axis east-west for maximum exposure of north and south walls (fig. 1). The center 8 feet is an instrument room. The remaining length of the building is partitioned every 4 feet resulting in ten 4- by 8-foot rooms (fig. 2) connected by doors in partitions. The only exterior door is in the instrument room. Support for the roof and ceiling is provided by partitions (fig. 3), so exterior wall panels can be removed and replaced while the building remains intact.

Four- by eight-foot wall panels were completely instrumented during fabrication and then installed by lag bolting them to partitions. Identical panels were installed on north and south walls for extremes of exposure. Both the ceiling and floor were insulated with R-38[4] glass fiber batts to limit heat transfer so the walls would be the major element of heat loss from each room.

Rooms are individually heated by a resistance-type electric heater, and individually cooled by a

[4]"R" is a measure of insulating value or resistance to heat flow. It is the reciprocal of conductance, which is the amount of heat in Btu's that will flow in 1 hour through 1 square foot of homogeneous material per 1 ° F temperature difference between surface of materials.

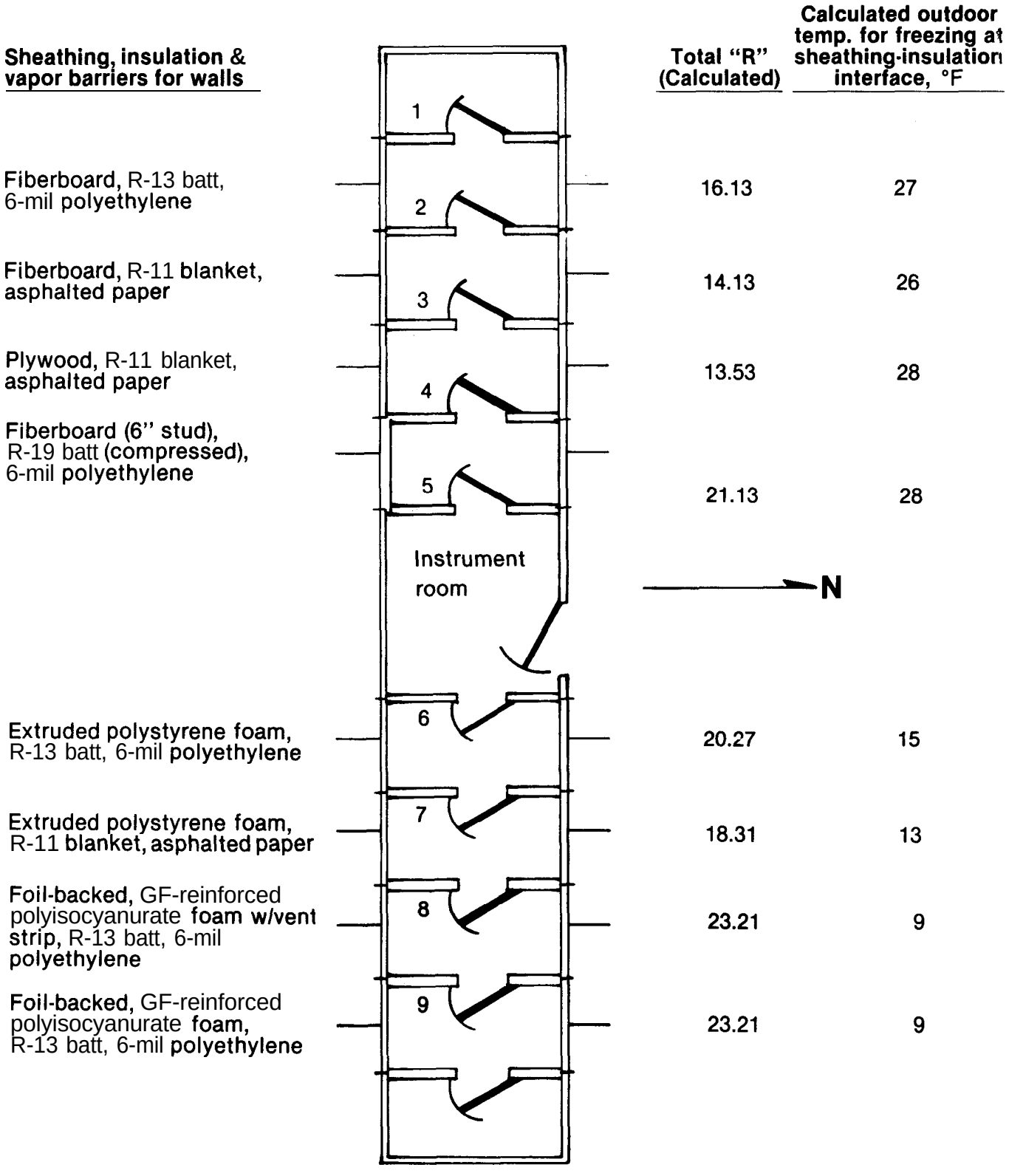

Figure 2.–Plan of experimental structure showing variables of construction of each wall panel. Note that both "R" values and interface temperature are based on calculation methods shown in the ASHRAE Handbook of Fundamentals (2). (ML83 5060)

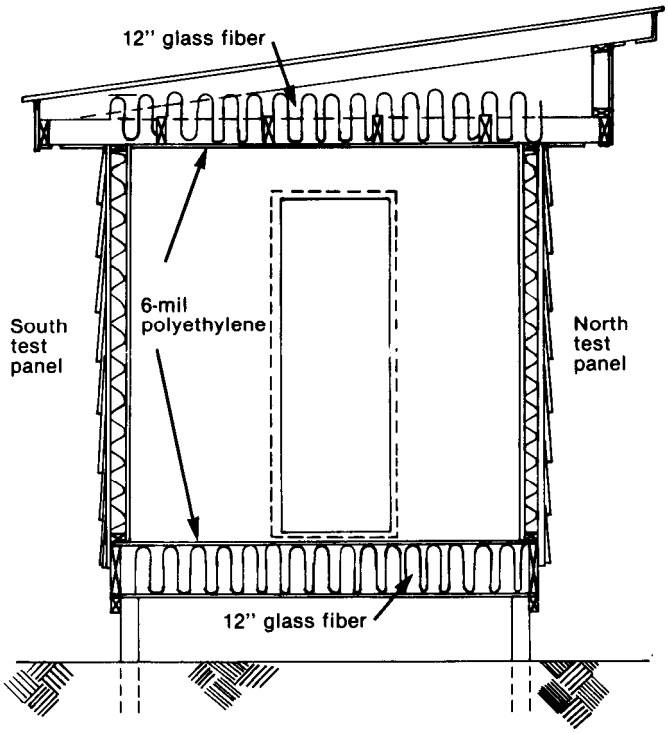

Figure 3.–Cross section of experimental structure showing construction details, (M83 5061)

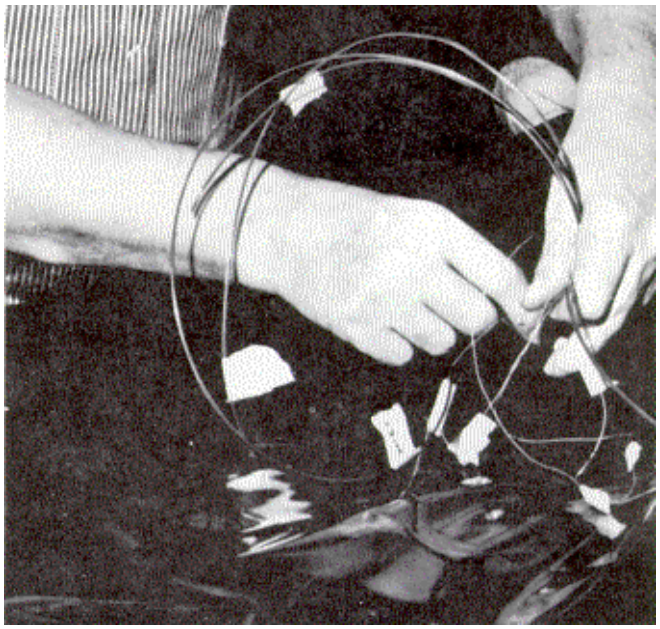

Figure 4.–Six-mil polyethylene film being applied as a continous vapor retarder on an experimental panel. Lead wires to moisture sensors and thermocouples are brought through a small slit thoroughly caulked to preserve the integrity of the vapor retarder. (M 147 188-11)

window-type air-conditioner mounted in the floor. Humidification is provided by a vaporizing-type humidifier in each room during the heating season. Humidity is not controlled during the air-conditioning season. Heaters are controlled by wall thermostats to maintain a temperature between 67° and 70° F. Air-conditioners are set to cycle on at 79° F and off at 76° F. Heating season relative humidity is maintained at 40 ± 5 percent, as compared to 35 percent for previous studies of retrofit insulation (8, 9). High humidity was desirable for this study to reveal any potential for moisture problems. While 40 percent humidity is higher than generally recommended, a limited survey of homes built in Madison since the energy crisis began showed it to be realistic. The current trend toward airtight houses may produce more widespread occurrence of high indoor humidity.

End rooms are considered buffers rather than test rooms as they have an 8-by 8-foot end wall exposed to the exterior and would not have heat loss, heat gain, or water-vapor loss comparable to other rooms with only a north and south wall exposed. This leaves eight identical rooms in each building for test and comparison purposes. Test panels of the same construction are inserted on north and south exposures of a room, so there is only one type of wall construction for each room.

Test Panels

For this study, test panels all have 1/2-inch gypsum board on the inside and 7/16-by 12-inch primed hardboard lap siding on the outside. Hardboard was painted after panels were fabricated. Full thickness glass fiber insulation was placed in each wall cavity. One type of panel was framed with 2 by 6 studs at 24-inch spacing. The remaining panels were all framed with 2 by 4 studs at 16-inch spacing. The primary variables are the sheathing material and the vapor retarder (fig. 2). Polystyrene sheathing was in 2-by 4-foot sections, while all other sheathings were 4-by 8-foot sections. Sheathing materials included: 1/2-inch fiberboard, 1/2-inch plywood, 1-inch extruded polystyrene foam, and 1-inch foil-backed glass-fiber reinforced polyisocyanurate foam. Only two types of vapor retarders were used: 6-mil polyethylene film continuous over the face of the framing (fig. 4), or asphalted kraft paper backing on blanket insulation stapled between studs (fig. 5). Although the asphalted kraft paper could be installed by the recommended method of lapping all joints over studs, in field practice it is often stapled between studs with no laps (fig. 5). That method was followed to simulate typical field conditions.

Each test panel was instrumented with moisture sensors at 11 locations in the wall (fig. 6). A thermocouple was also placed at each moisture sensor location. At heights of 1 foot and 7 feet above the floor, moisture measurements were made at the siding-sheathing interface, at the sheathing-insulation interface, at the center of the cavity insulation, and in the adjacent stud. Sensors were also located in the top plate, the sole plate, and between siding and sheathing at the midheight of the wall. Lead wires from all these data points were brought into the room through the vapor retarder and gypsum board at two points (1 foot and 7 feet above the floor). The punctures in the vapor

Figure 5.–Asphalted kraft paper vapor retarder stapled to sides of studs. (M 147 191-11)

retarders were caulked around each wire individually (fig. 4).

All test panels were without open punctures in the gypsum board or vapor retarder for Phase I-the first year-of the study.

In the second year of testing-Phase 2–a standard duplex electrical outlet was installed in each wall panel to observe the effect of air leakage into the wall cavity. As moisture-laden indoor air moves through and around the outlet bypassing the vapor retarder, it creates a potential for cold weather condensation. In conventional construction, joints around windows or at baseboards and other discontinuities in the vapor retarder may result in additional leakage. For this study the electrical outlet was selected as uniform penetration to provide air leakage for comparison purposes.

After installation of test panels, all joints with floor, ceiling, and partitions were caulked. On the outside, vertical joints between panels were caulked and the joint between floor framing and the bottom edge of the wall panel was caulked. Six-mil polyethylene taped to each face of the partitions extends out between adjoining panels to prevent transfer of moisture between panels (fig. 1).

Data Acquisition

Moisture Content

Moisture conditions were measured at 189 locations (fig. 6) using small wood sensors. The moisture content (MC) of the wood sensor was converted to MC of the members in which they were imbedded, based on the relative humidity of the air in the immediate vicinity. Relative humidity in the rooms, outdoors, and at interfaces between two materials was also recorded.

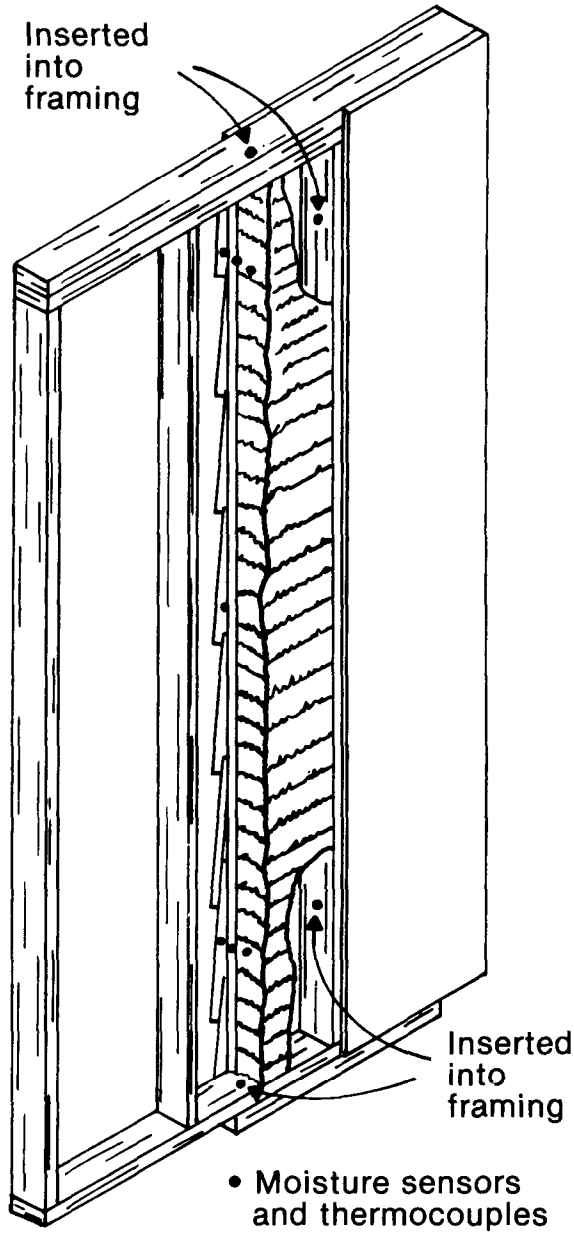

Figure 6.–Moisture sensor locations in each test panel. Four sensors are in framing; two are in the center of insulation; two are at the insulation-sheathing interface; and three are at the sheathing-siding interface. (ML83 5062)

The sensors were calibrated wood elements in which electrical resistance changed with MC of the wood (construction and details of operation of this sensor are given by Duff (4)). The sensors were calibrated in humidity rooms to an accuracy of ± 2 percent MC over a relative humidity range of 35 to 90 percent, which corresponds to an MC in the wood sensor of 7.0 to 20.0 percent. Determination of MC beyond these limits was less accurate because of difficulties in measuring extreme ranges of resistance and because of beads of condensed water often present on surfaces at sensor readings of 20 percent or higher.

To effectively measure the very high resistance inherent in the sensor and to accurately transmit data

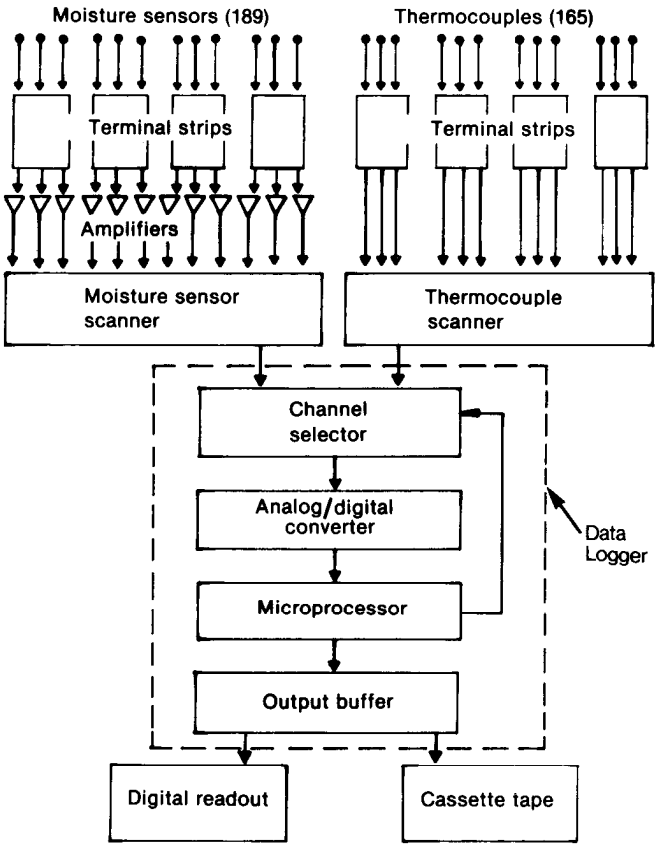

Figure 7.–Flow chart of instrumentation and data recording system. (ML83 5063)

Figure 8–Instrumentation room showing data logger and electric meters for individual rooms. (M 147 451-11)

to the logger, amplifiers were located as close to the test wall, as close to each sensor as practical; their output was connected to the data logger and calibrated (fig. 7).

The resistance readings are first converted to MC for the sensor species and corrected for temperature effects. Further conversions were then made to provide the MC of the species in structural members or to provide the relative humidity of ambient air conditions.

Temperature

Temperature measurements were made at each wood sensor with a type T (copper-constantan) thermocouple, and used for the temperature corrections.

Power and Water Usage

Power and water usage were measured weekly. Because a corresponding monthly record could not be obtained, a 3-week period in February of both 1980 and 1981 was selected to compare consumption for walls with and without electrical outlets.

The original purpose of recording power input was to evaluate the effect of moisture in insulation on rate of heat transfer. Because there was no evidence of moisture accumulation in the insulation, that effect could not be observed. Pressurization of individual rooms showed significant air leakage around doors between rooms; these leaks could not have been sealed without major redesign and construction. Without pressurization, heat and moisture leakage should have been minimal because temperature and humidity conditions were the same in all rooms. A heat balance could not be calculated because of the air leakage at doors.

Data Recording

All of the moisture and temperature data were digitized and recorded on cassette tape using a multichannel, programmable data logger (fig. 8). Because of equipment malfunctions often caused by local storms, hand readings were required much of the time. Data were collected three times a week.

Results

Phase 1–No Penetrations

During the summer of 1979, MC's of probes in all parts of most walls not penetrated by electrical outlets remained constant between 8 and 12 percent. Probe MC below 12 percent was considered low; 12 to 16 percent was moderate; 16 to 20 percent was high; above 20 percent caused condensation. For brief time periods the moisture level in several panels at a specific data point rose for 1 to 3 days and returned to normal; these were usually one-time occurrences for which no explanation could be found. In certain cases there was a repetitive pattern in slight moisture changes. This appeared to be caused by day-night cycling with the cooling of the siding at night. Moisture

content at the siding interface dropped to very dry readings on warm, dry days, especially where siding was exposed to the sun (6). If MC's above or below 12 percent sustained for less than 3 days are considered insignificant, all of the walls remained essentially dry throughout the summer.

The first high moisture levels occurred in December when temperatures dropped to consistently below freezing levels; the most severe month was February (figs. 9-16). A plot of daily low temperatures during January, February, and March is shown in figure 17. In all cases the northern exposure resulted in higher measured moisture levels than did the southern exposure, so discussion will be primarily directed to the north-wall panels. Three panels (2N, 3N, and 5N) had fiberboard sheathing.

Three factors affected moisture patterns: 1) type of vapor retarder, 2) permeability of sheathing material, and 3) temperature of sheathing material. Panel 2N (polyethylene, R-13 glass fiber, fiberboard)[5] remained quite dry, with MC at the sheathing rising slightly but not until February (fig. 9). Panel 3N (asphalted paper, R-11 glass fiber, fiberboard), with similar construction but with side-stapled asphalted kraft paper rather than polyethylene vapor retarder, showed high MC's by December (fig. 10). Condensation occurred at the sheathing-siding interface and later at the insulation-sheathing interface. Brown streaking on the siding (figs. 18 and 19) when warm weather followed a period of extreme cold gave visual verification that significant condensation did occur on the back of the siding. Moisture levels also increased somewhat in panel 5N (polyethylene, R-19 glass fiber, fiberboard) (fig. 12) which was similar in construction to 2N except that it had 2 by 6 studs and thicker batt insulation. The thicker insulation resulted in lower sheathing temperature and consequently higher MC as more moisture condensed on the colder surface. However, panel 5N did not exhibit any streaking because the polyethylene vapor retarder limited the amount of moisture entering its wall cavity.

The remaining wall cavities had sheathings resistant to water vapor movement. Panel 4N with plywood sheathing (asphalted paper, R-11 glass fiber, plywood) (fig. 11) had increased MC at the insulation-sheathing interface, but probes did not indicate condensation. The plywood-sheathed panel dried more quickly than did the polystyrene-sheathed panel 7N (fig. 14) when outdoor temperatures increased, possibly because it was able to absorb and redistribute the moisture present. Panel 4N, however, had no brown streaking on its siding as wall cavity moisture could not readily move through the plywood sheathing to the siding. Panel 7N (asphalted paper, R-11 glass fiber, polystyrene) had condensation on the sheathing from mid-February through March and had very slight streaking of the siding, probably because sufficient moisture could leak through to the siding at horizontal joints in the 2-by 4-foot polystyrene sheathing. In early April the panel was opened to check on the probe that was reading saturated; the wall was found to be completely dry. The probe had malfunctioned due to fungal growth on the surface, an indication that an RH of at least 85 percent had existed for some period of time.

Wall cavities with both polyethylene vapor retarder and low-permeance foam sheathing had no indication of condensation. Moisture content at the insulation-sheathing interface in the wall with polystyrene sheathing (6N) (fig. 13) did rise significantly by December and remained high until March. Both walls with foil-backed foam (8N, 9N) had increases in MC at the insulation-sheathing interface only during periods of extreme cold in January and February (figs. 15 and 16).

Moisture content levels during the three winter months at the insulation-sheathing interface and at the sheathing-siding interface are presented in table 1. The moderate range may be high enough to cause problems in certain cases, and the high range is definitely high enough to cause expansion and potential buckling of thin materials.

The overall results from the Phase 1 walls, with no penetrations, are summarized as follows:

1. No condensation was detected in walls having a continuous 6-mil polyethylene vapor retarder, whereas walls with fiberboard or polystyrene sheathing and a vapor retarder of asphalted paper stapled between studs with no overlap showed visual evidence of condensation.
2. Plywood-sheathed panels had no indication of condensation even though a vapor retarder of asphalted paper stapled between studs was used.
3. Moisture levels at the insulation-sheathing interface in the wall cavity were highest in walls with the lowest sheathing temperature-i.e., walls with the lowest "R" value for sheathing.
4. Where large amounts of water vapor entered wall cavities, it passed through permeable sheathing and condensed on the siding, resulting in streaking. However, sheathings with low perm ratings and an effective vapor retarder generally resulted in small amounts of water vapor that entered and remained in the cavity.
5. In no case did MC gains remain in liquid form for more than about 6 weeks, and MC of framing never exceeded 12 percent.

Phase 2–Outlet Penetrations

Based on the experience of the first summer when all moisture readings were constantly between 8 and 12 percent, the test building was not conditioned and no data were taken during the second (Phase 2) summer. Conditioning of the rooms was resumed with the 1980-1981 (Phase 2) heating season.

[5]Vapor retarder, insulation, and sheathing, respectively.

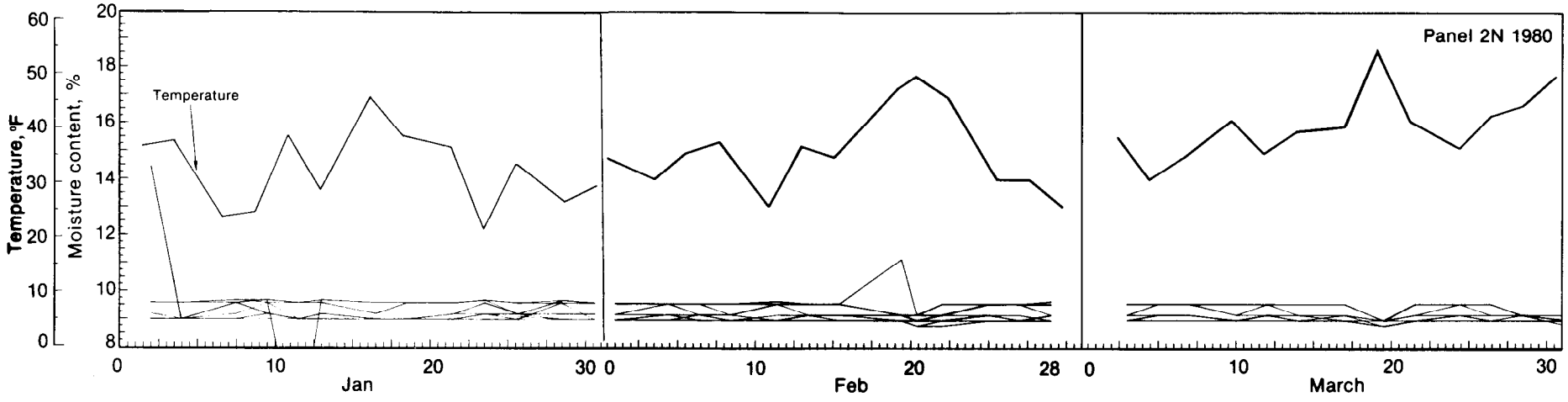

Figure 9.–Moisture content of wood probes in panel 2N (polyethylene, R-13 glass fiber, fiberboard) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5064)

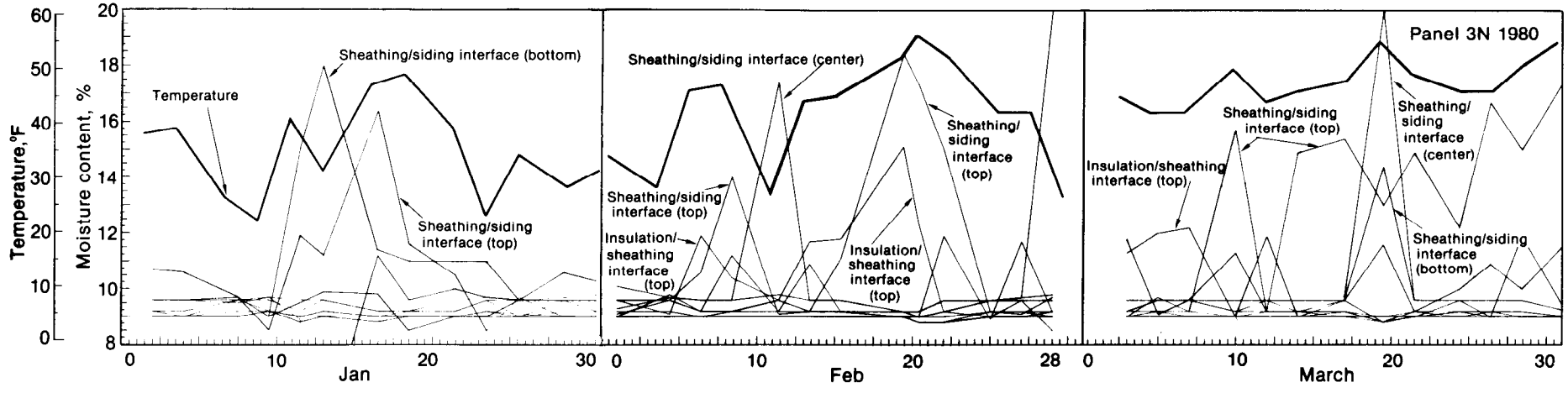

Figure 10.–Moisture content of wood in panel 3N (asphalted paper, R-11 glass fiber, fiberboard) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5065)

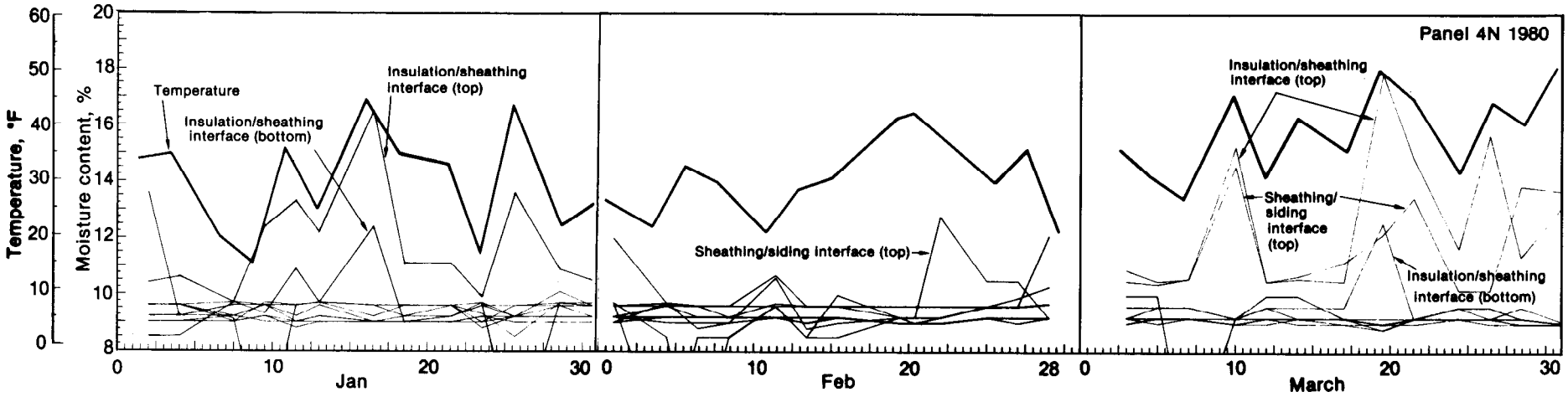

Figure 11.–Moisture content of wood in panel 4N (asphalted paper, R-11 glass fiber, plywood) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5066)

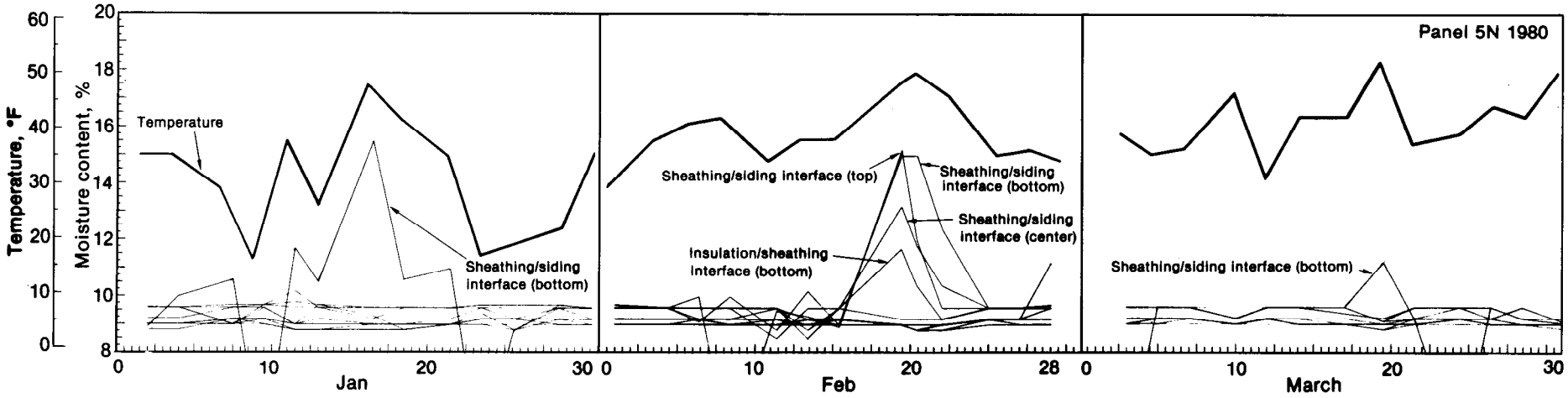

Figure 12.–Moisture content of wood probes in panel 5N (polyethylene, R-19 glass fiber, fiberboard) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5067)

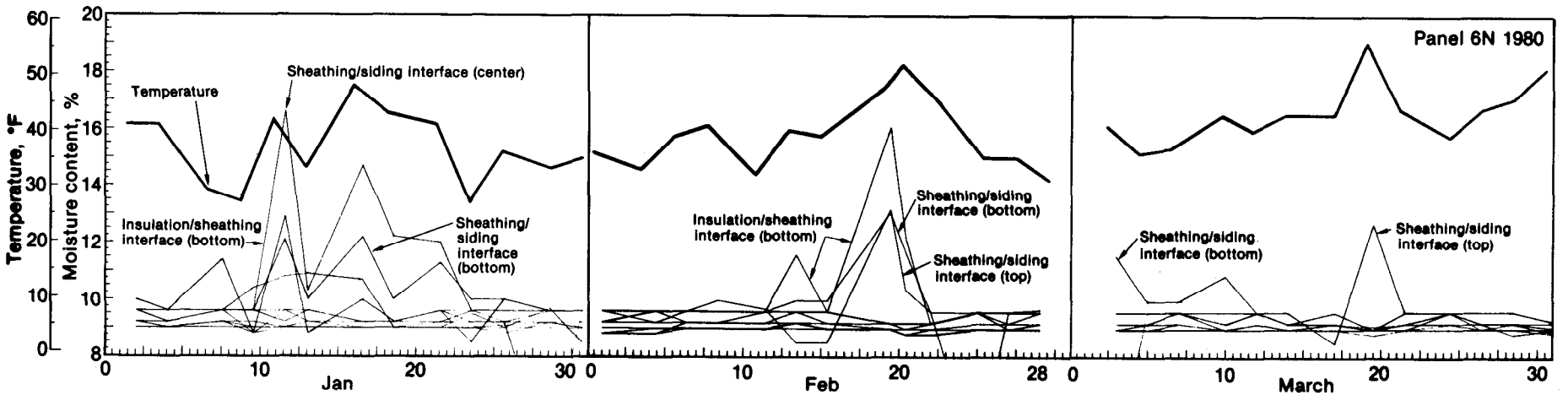

Figure 13.–Moisture content of wood probes in panel 6N (polyethylene, R-13 glass fiber, polystyrene) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5068)

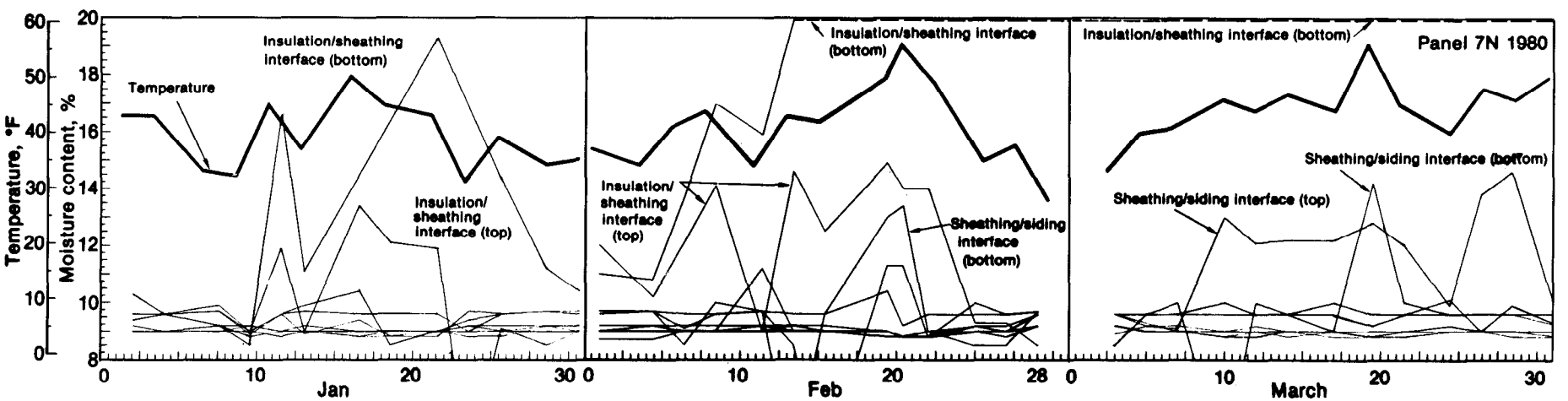

Figure 14.–Moisture content of wood probes in panel 7N (asphalted paper, R-11 glass fiber, polystyrene) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5069)

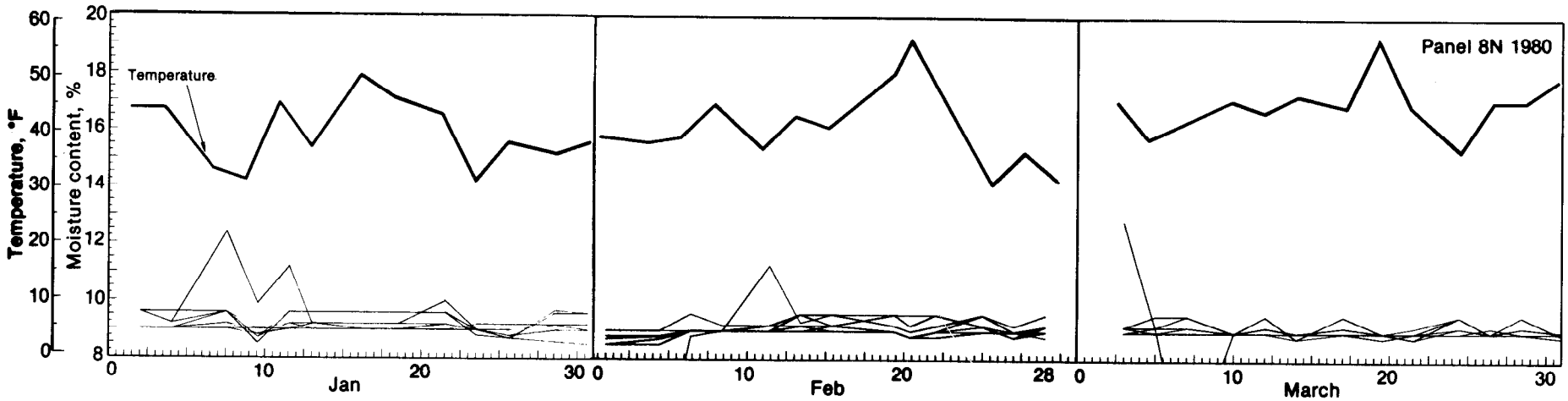

Figure 15.–Moisture content of wood probes in panel 8N (polyethylene, R-13 glass fiber, vented foil-backed isocyanurate) and corresponding temperature on the warm face of sheathing, January through March 1980. The only probe showing MC exceeding 10 percent was at the insulation-sheathing interface (top). (ML83 5070)

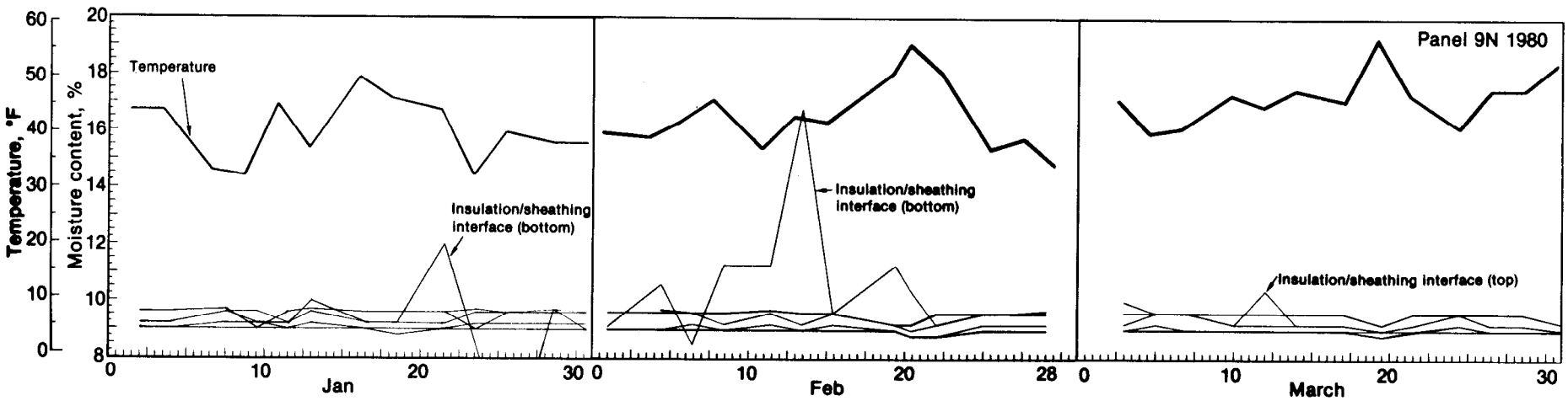

Figure 16.–Moisture content of wood probes in panel 9N (polyethylene, R-13 glass fiber, foil-backed isocyanurate) and corresponding temperature on the warm face of sheathing, January through March 1980. (ML83 5071)

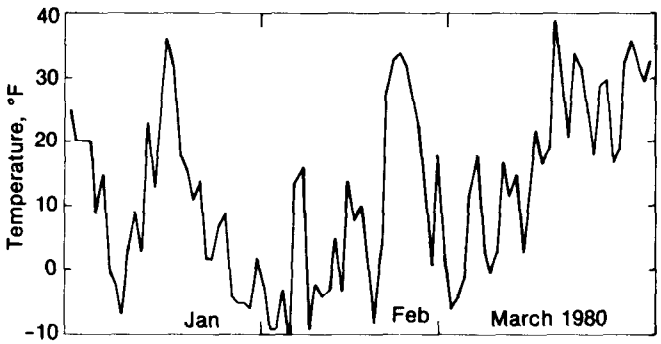

Figure 17.–Daily low temperatures for January through March 1980. (ML83 5072)

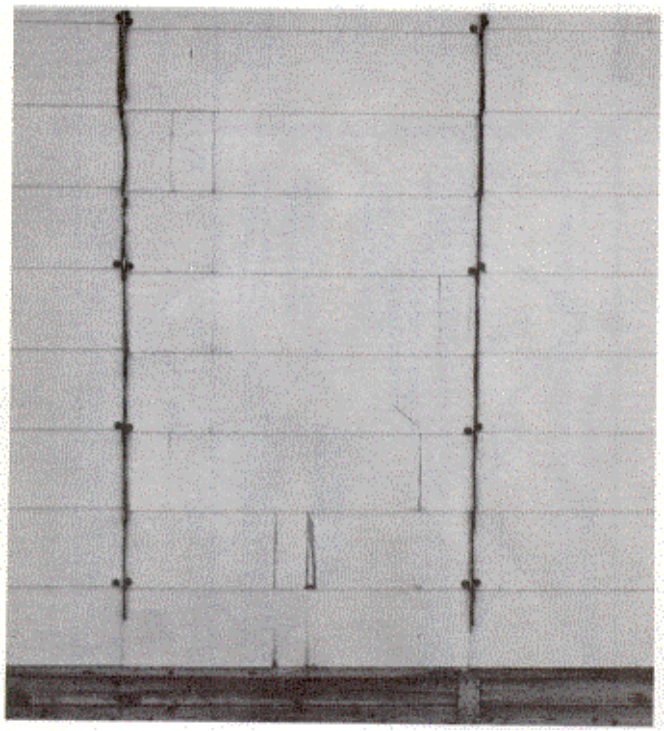

Figure 18.–Severe staining on panel 3N (north side) due to condensation on the back of siding. **(M 147 763-2)**

Moisture in all north panels during January, February, and March 1981 is plotted in figures 20 through 27. Temperatures at the insulation-sheathing interface are also shown for each panel. Daily low temperature during January, February, and March is plotted in figure 28.

By January condensation had occurred in some of the panels on the sheathing directly behind the electrical outlet and remained there through the coldest part of the winter. The three walls with R-11 insulation were exceptions in that there was no condensation behind outlets. One explanation may be that the less-dense glass fiber insulation allowed greater convection air circulation within the wall cavity, which permitted water vapor to distribute over more wall area rather than to condense locally behind the electrical outlet. Streaking occurred only on the fiberboard-sheathed panels 2N, 3N, and 5N.

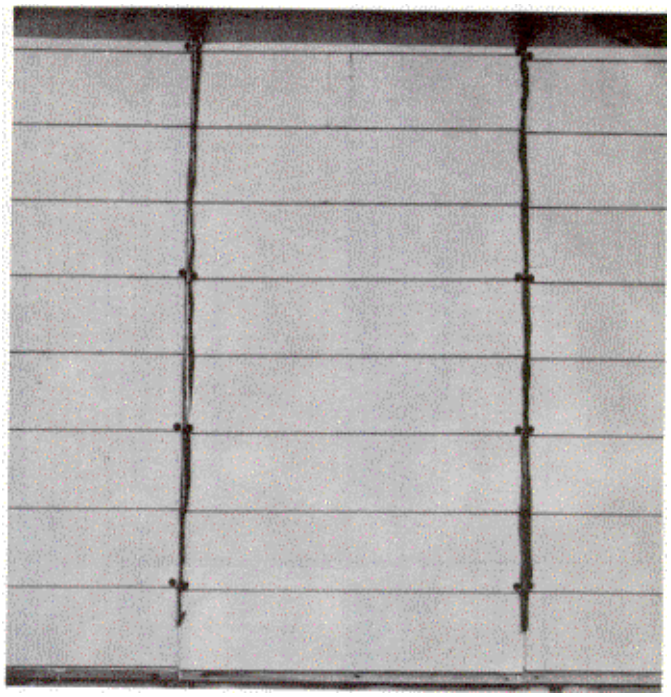

Figure 19.–Slight staining on panel 3S (south side). (M 147 763-9)

Panel 9N (polyethylene, R-13 glass fiber, foil-backed foam) (fig. 27) had condensation behind the outlet for only about 2 weeks. It dried out in early February. The remaining four north wall panels had condensation remaining long enough that fungus on the surface caused some moisture sensors to malfunction and appear to be saturated. in early April those sensors were removed and all walls were observed to be completely dry. There was also no staining or other visual evidence of previous excessive moisture in the cavity. Panels 8N (fig. 26) and 9N (fig. 27) had R-8 sheathing, which resulted in the highest sheathing temperature of all north-facing panels. Panel 8N was vented at the top plate. Under north wind conditions, the north wall sheathing temperature was observed to be colder in the top vented wall with penetrated vapor retarder. Greater air movement from the room through the cavity is likely with a vented top plate. This possibility is supported by the fact that Test Room 8 did require more water input than Test Room 9 to maintain 40 percent relative humidity.

Panels 4N (asphalted paper, R-11 glass fiber, plywood) and 5N (polyethylene, R-19 glass fiber, fiberboard) (figs. 22 and 23) also had extended periods when condensation was apparently present on the sheathing near the top of the wall. Because these two types of walls indicate the lowest sheathing temperatures, condensation could occur at lower cavity humidity conditions than in any other wall tested. The warmest and coldest sheathing temperatures for January, February, and March 1981 (fig. 29) illustrated a range of up to 20° F temperature difference at this critical interface for the various types of construction.

Condensation occurred on the back of the siding in all panels with fiberboard sheathing. It remained through

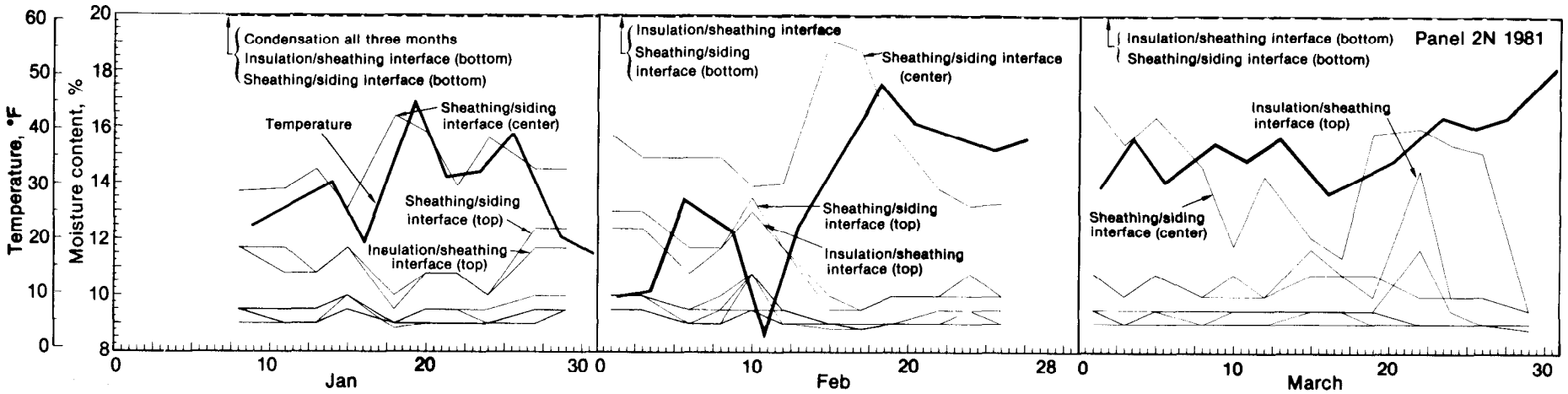

Figure 20.–Moisture content *of wood probes in panel* 2N (polyethylene, R-13 glass *fiber,* fiberboard) and corresponding *temperature on the warm face of sheathing, January through March 1981.* (ML83 5073)

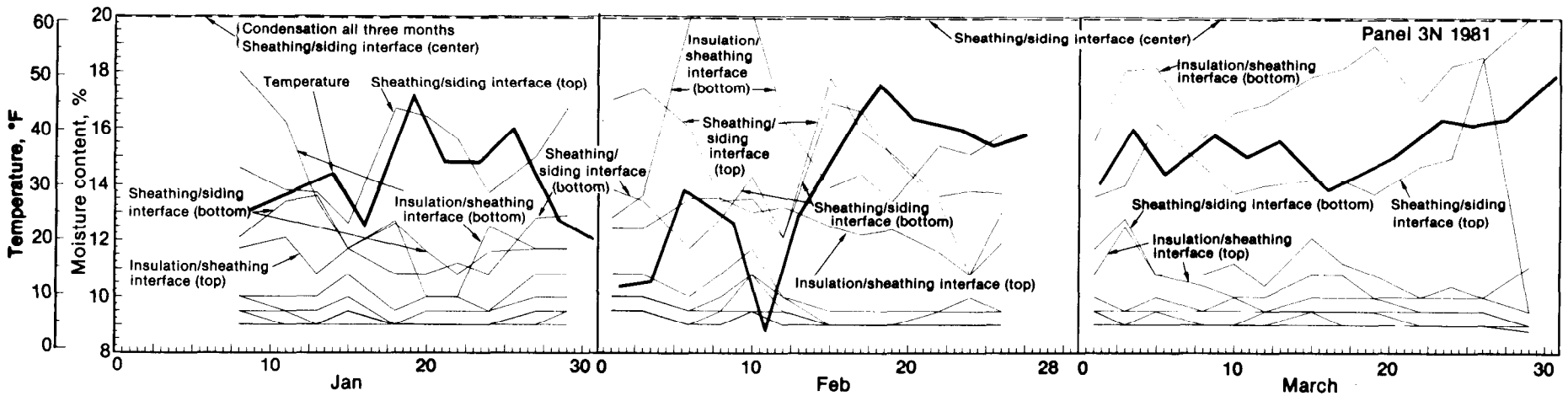

Figure 21.–Moisture content of wood probes in panel 3N (asphalted paper, R-11 glass fiber, fiberboard) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5074)

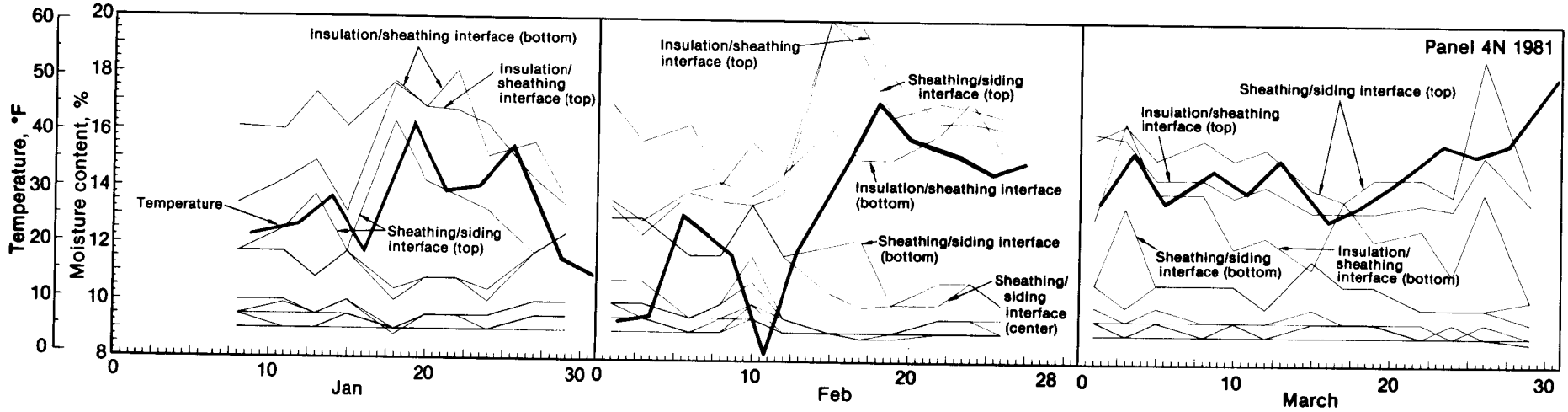

Figure 22. —Moisture content of wood probes in panel 4N (asphalted paper, R-11 glass fiber, plywood) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5075)

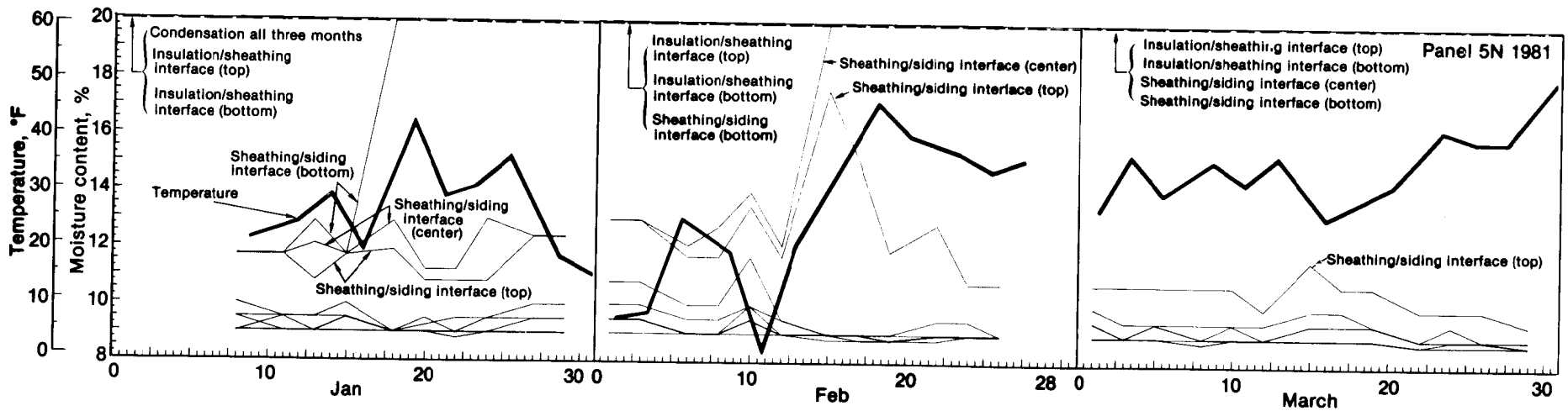

Figure 23. —Moisture content of wood probes in panel 5N (polyethylene, R-19 glass fiber, fiberboard) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5076)

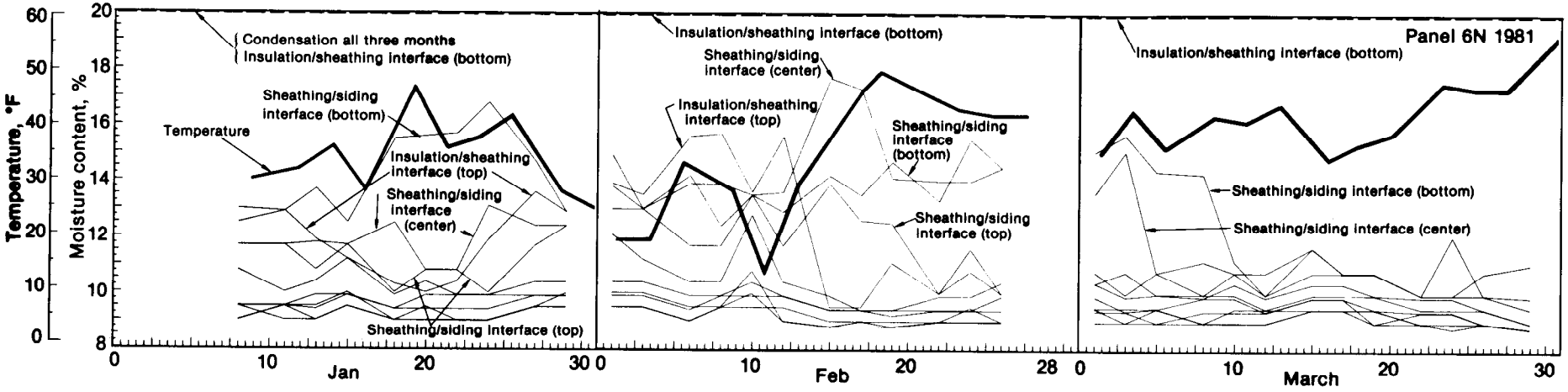

Figure 24.–Moisture content of wood probes in panel 6N (polyethylene, R-13 glass fiber, polystyrene) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5077)

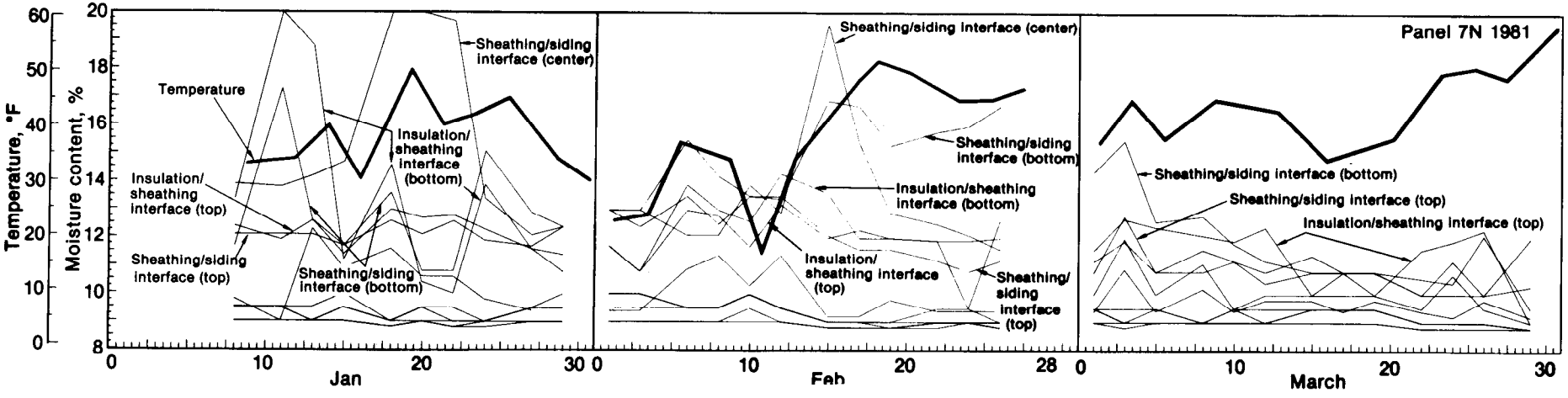

Figure 25.–Moisture content of probes in panel 7N (asphalted paper, R-11 glass fiber, polystyrene) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5078)

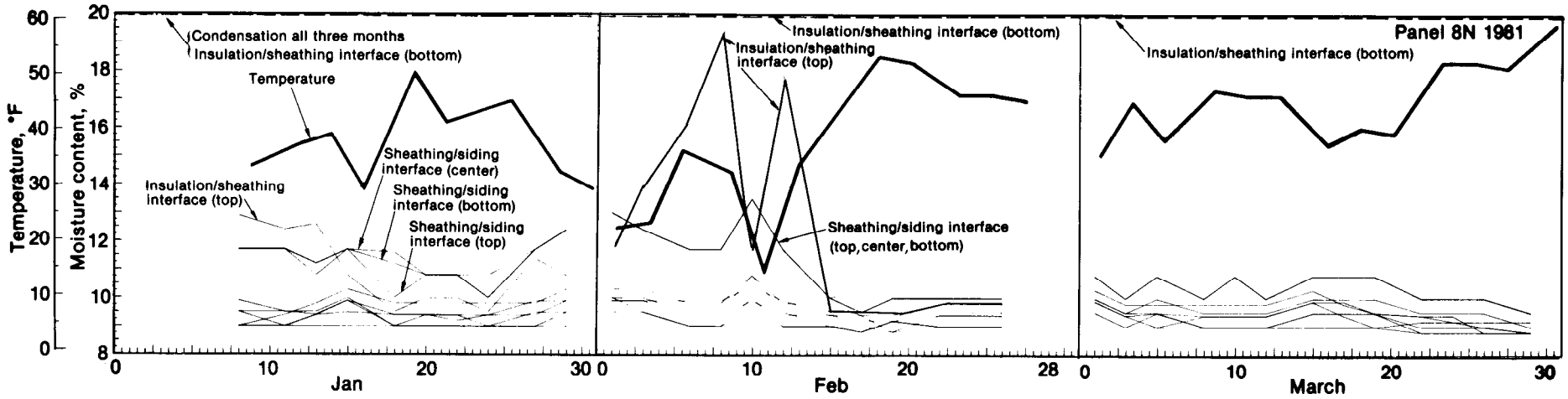

Figure 26.–Moisture content of wood probes in panel 8N (polyethylene, R-13 glass fiber, vented foil-backed isocyanurate) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5079)

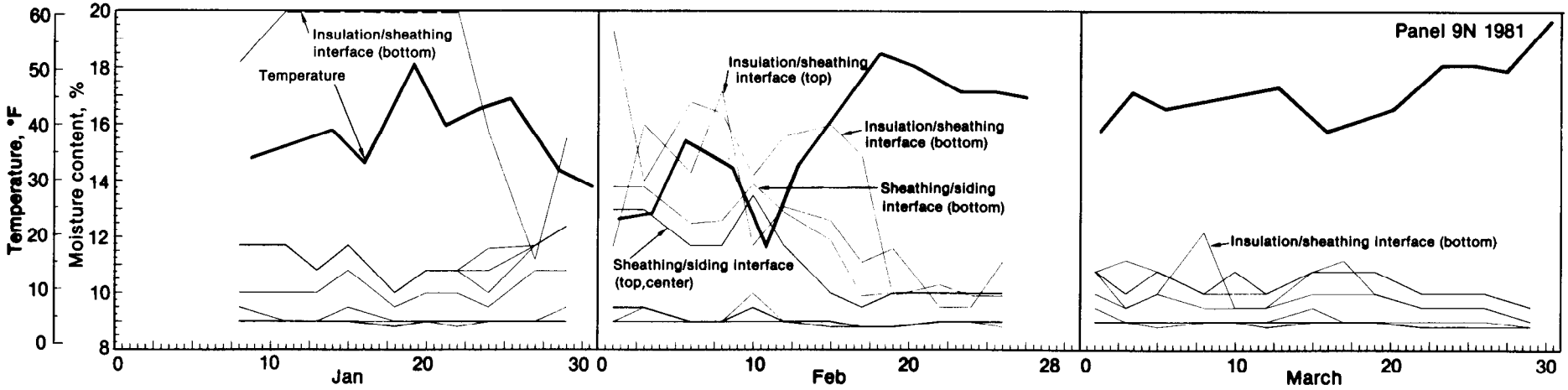

Figure 27.–Moisture content of wood probes in panel 9N (polyethylene, R-13 glass fiber, foil-backed isocyanurate) and corresponding temperature on the warm face of sheathing, January through March 1981. (ML83 5080)

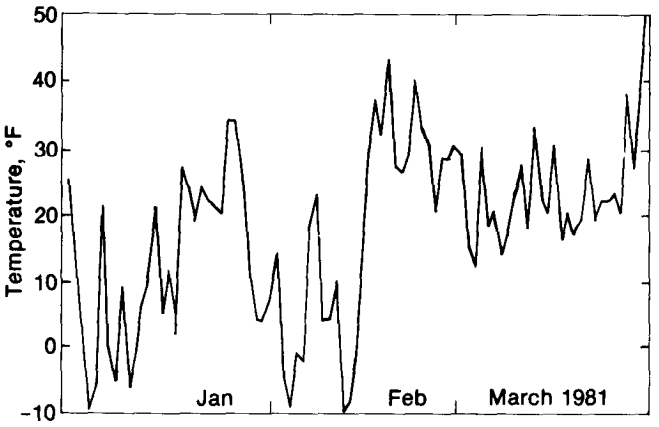

Figure 28.–Daily low temperatures for *January through March 1981.* (ML83 5081)

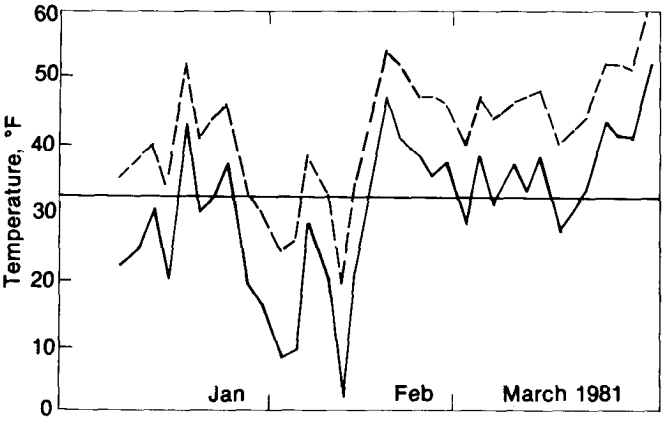

Figure 29.–Warmest and coldest north-side sheathing temperatures (panels 5N and 9N) for January *through March 1981.* (ML83 5082)

the end of the winter in most cases. There was slight streaking of siding on panels 2N, 3N, and 5N, the panels with fiberboard sheathing. For short periods of time there was condensation on the back of siding in panels 7S (asphalted paper, R-11 glass fiber, polystyrene) and 7N. These panels had polystyrene foam sheathing with horizontal joints at 2-foot spacing, which permitted some moisture to pass through to the siding.

The MC of wood probes at the insulation-sheathing interface and the sheathing-siding interface is summarized in table 2. All constructions showed high enough MC's near the siding to create a potential for buckling of long strips of hardboard siding.

The overall results from walls with an electrical outlet penetrating the vapor retarder are summarized as follows:

1. All north walls with R-13 and R-19 batt insulation had localized condensation on the sheathing surface behind the electrical outlet in January. This condensation appeared to remain in all but one panel through February and March.
2. No localized condensation occurred behind electrical outlets in walls with low-density R-11 blanket insulation, presumably because of internal air circulation by convection.
3. Condensation on sheathing at higher locations in the walls was observed only in walls with very low sheathing temperature.
4. Condensation occurred for long periods on the back of the siding of all north walls with fiberboard sheathing and briefly on two walls with polystyrene sheathing having horizontal joints at 2-foot spacing. No siding condensation was observed on north walls sheathed with foil-backed foam.
5. All panels had high-enough moisture levels on the back of the siding to produce buckling in long strips of hardboard siding.
6. All data points showed MC below 11 percent by early April and no rise in MC of framing at any time.

Power and Water Usage

Because power and water usage was measured weekly and a record corresponding exactly to a month could not be obtained, a 3-week period in February was selected from both 1980 and 1981 to compare consumption for walls without and with an electrical outlet (table 3). Both power and water consumption were higher in 1981 even though heating degree-days were much less for both the period shown and the entire winter (table 4). Although data are not available to quantify the effects of solar gain and wind on power consumption, the change in kilowatt-hours per degree-day is a good indication of increased power consumption due to two electrical outlets in a wall section 8 feet wide (two 4-foot sections). Based on kilowatt-hours per degree-day, the power requirement was 35 to 54 percent (average 41 pct) higher with the electrical outlets. Rooms with the lowest R-value walls showed the greatest increase in power consumption. Water usage for humidification for the same time period increased by 10 to 72 percent (average 42 pct). This additional water escaped primarily by indoor air movement through the electrical outlet and wall cavity. This air movement also contributed to heat loss, by loss of both the heated air and latent heat in the water vapor.

Findings

The following findings apply to the climate of Madison, Wis. (7,800 heating degree-days per year), at controlled indoor conditions of 67°-70° F and 40 ± 5 percent relative humidity. The test building was electrically heated so there were no pressure changes due to combustion air requirements or blower operation.

1. No condensation occurred in walls with a continuous polyethylene vapor retarder, regardless of type of sheathing.
2. North walls with fiberboard or polystyrene sheathing and only asphalted paper backing on glass fiber insulation (no punctures) stapled between studs had condensation on the sheathing for a limited time (no more than 6 weeks).

Table 1. — Moisture content[1] of wood probes at critical points in north-facing panels in 1980

Panel number	Insulation-sheathing interface			Sheathing-siding interface		
	January	February	March	January	February	March
2N	Low	Low	Low	Low	Low	Low
3N	Low	Moderate	Low	High	Condensation	Condensation
4N	High	Low	High	Low	Moderate	Moderate
5N	Low	Low	Low	Moderate	Moderate	Low
6N	Moderate	High	Low	High	Moderate	Moderate
7N	High	Condensation	Condensation	Low	Moderate	Moderate
8N	Moderate	Low	Moderate	Low	Low	Low
9N	Low	High	Low	Low	Low	Low

[1]Low = <12 percent MC; moderate = 12 to 16 percent; high = 16 to 20 percent; condensation = >20 percent.

Table 2. — Moisture content[1] of wood probes at critical points in north-facing panels in 1981

Panel number	Insulation-sheathing interface			Sheathing-siding interface		
	January	February	March	January	February	March
2N	Condensation	Condensation	Condensation	Condensation	Condensation	Condensation
3N	High	Condensation	High	Condensation	Condensation	Condensation
4N	High	Condensation	High	High	Condensation	High
5N	Condensation	Condensation	Condensation	Condensation	Condensation	Condensation
6N	Condensation	Condensation	Condensation	High	High	Moderate
7N	Condensation	Moderate	Moderate	Condensation	High	Moderate
8N	Condensation	Condensation	Condensation	Low	Moderate	Low
9N	Condensation	High	Moderate	Low	High	Low

[1]Low = <12 percent MC; moderate = 12 to 16 percent; high = 16 to 20 percent; condensation = >20 percent.

3. Where condensation occurred in walls with fiberboard sheathing it initially formed on the back of siding and later on the sheathing. Some moisture also passed through horizontal joints in polystyrene sheathing and condensed on siding.
4. A cold-side vapor retarder, such as the glue joint in plywood sheathing, reduced the hazard of condensation at the sheathing-siding interface without unduly increasing the cavity MC.
5. Condensation formed on the sheathing behind electrical outlets in all north-facing walls with batt insulation of R-13 and R-19. No localized condensation formed behind outlets in walls with R-11 blanket insulation.
6. Condensation formed on sheathing near the top of walls with electrical outlets only where sheathing temperatures were quite low.
7. After electrical outlets were added all panels had high enough moisture levels on the back of the siding to create a potential for buckling of long strips of hardboard siding.
8. For both years and all construction, all data points showed MC to be below 11 percent by early April.
9. MC of framing did not increase significantly at any time during the 2-year study.
10. The addition of two electrical outlets in each room resulted in an average increase of about 40 percent in both heating energy and water consumption for comparable time periods.

Conclusions

The findings of this study are limited to specific indoor and outdoor conditions; they should, however, be applicable to much of the upper midwest and northeast of the United States. The winter condensation potential would be less in warmer climates, but greater where winters are more severe than those in Madison, Wis., were during 1980 and 1981.

Asphalted paper backing on insulation stapled between studs does not provide adequate vapor retarder protection to prevent condensation in the wall cavity or streaking of the siding where a permeable sheathing is used. A continuous 6-mil polyethylene vapor retarder can control condensation in insulated walls even where low-permeance sheathing is used. Puncturing the vapor retarder, as with an electrical outlet, can completely change moisture patterns in the wall and result in condensation on the sheathing behind the electrical outlet. Punctured polyethylene performed no better than asphalt-coated paper.

In all of the types of construction observed both with and without outlets, condensation in the wall cavity forms on the back of siding or on the back surface of the sheathing and does not wet the bulk of the cavity insulation. There is no rise in MC of any framing materials. All wood in walls remains below 12 percent MC when temperatures are high enough for fungi to grow, from April to December. Low-permeance foam sheathings present no greater cold-weather condensation hazard than the other types of sheathing studied. Vent strips at the top of walls with high-"R", low-permeance sheathing result in greater air leakage with no apparent benefit in moisture control.

While conditions that would promote decay in wood framing do not appear to be a danger, moisture levels can be high enough in all panels to produce significant dimensional changes in thin panel products or long strips of siding.

Table 3. — Power and water consumption for test rooms

Room number	Power		Water consumption
	kWh	kWh/degree-day	L
	FEBRUARY 4-25, 1980; 949 DEGREE-DAYS		
2	91	0.096	10.4
3	87	.092	10.8
4	86	.091	8.0
5	77	.081	11.8
6	81	.085	12.9
7	73	.077	7.9
8	70	.074	7.5
9	74	.078	7.6
	FEBRUARY 2-23, 1981; 807 DEGREE-DAYS		
2	112	.139	15.1
3	100	.124	11.9
4	113	.140	13.8
5	91	.113	15.4
6	90	.112	16.5
7	89	.110	13.3
8	81	.100	11.1
9	82	.102	9.5

Table 4. — Summary of heating degree-days for the 2 years of the study

Phase 1		Phase 2	
Month	Degree-days	Month	Degree-days
November 1979	890	November 1980	881
December 1979	1,112	December 1980	1,303
January 1980	1,471	January 1981	1,373
February 1980	1,424	February 1981	1,107
March 1980	1,138	March 1981	864
April 1980	586	April 1981	482
Total	6,621	Total	6,010

Fungal growth and consequent malfunction of some moisture sensors indicate water was present for some period of time when temperatures were high enough to promote fungal growth. If this water could not escape from the wall, a definite decay hazard would exist. However, as observed in this study, in the conventional site-built wood frame wall, moisture does escape without adversely affecting wood framing.

These conclusions apply only to conventional construction and indoor conditions of 70° F, 40 percent relative humidity. Higher humidities may occur due to construction moisture, extremely tight construction, or major indoor moisture sources such as numerous house plants, unvented clothes driers, etc. Also, some manufactured houses may be constructed in a manner that greatly limits air movement through the wall cavity, and thus moisture patterns may be different.

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20 p. (USDA For. Serv. Research Paper FPL 433).

Increased use of high “R”-value, low-permeance sheathings and other changes in construction practices have caused concern over moisture patterns in walls. To observe actual moisture patterns and the potential for condensation, a test structure was constructed near Madison, Wis., for exposure of eight types of insulated wall panels at controlled indoor conditions and typical outdoor weather conditions, for 2 years. Continuous vapor retarders effectively prevented condensation; asphalted paper stapled between studs was inadequate. Installation of an electrical outlet changed the moisture profile and resulted in some condensation in most panels. The moisture content of the framing remained under 12 percent throughout the study and there was no long-term accumulation of free water in the structure.

Keywords: Condensation, moisture control, vapor retarder, air leakage, wood-frame walls, foam sheathing.

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