Condensation in flat roofs, II

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CONDENSATION IN FLAT ROOFS, II

by

G.H. Kuester

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OTTAWA

March 1971

PREFACE

The problem of condensation in frame roofs is well recognized in Canada and construction practices have been developed to minimize the resultant difficulties in most systems. The problems with flat wood-frame roofs have not been adequately solved through the application of traditional methods.

Ventilation of the roof space with outside air is more restricted in flat roofs and the degree of leakage of moist air from within the house into the roof space becomes a more critical factor. The study described in this report was designed to evaluate the degree of ceiling tightness necessary to minimize condensation with different ventilation arrangements.

This progress report covers the second, and concluding winter of observations on a small test building in Ottawa, undertaken as a cooperative project of the Building Services and Design sections. The instrumentation, operation and many of the observations of the building were carried out by Mr. J. J. M. Lavoie to whom the author is particularly grateful.

N. B. Hutcheon
Director

Ottawa
March 1971

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by

G. H. Kuester

REPORT OF TEST HUT, 1969-1970

(A) INTRODUCTION

The mechanism of condensation in spaces of flat wood structural roofs was studied during the winter of 1968-1969 in a test building on the DBR premises. Based on those observations,* it was felt that more information, particularly with respect to the thermal and moisture conditions inside roof spaces, with different insulation and ventilation arrangements, was needed so that the final results of this study could be more accurately reported. It was necessary to completely eliminate air leakage into some joist spaces for comparison. An economical readily available material was chosen as an air barrier, recognizing the practical aspects of the housing industry. The study was continued through the winter of 1969-1970, beginning on 21 November 1969 and ending on 12 June 1970.

(B) THE BUILDING

(1) Description of Test Building

The size of the wood frame test building was 20 ft by 20 ft with a ceiling height of 8 ft. The building was set on concrete block foundation posts with an underfloor clearance of approximately 1 ft.

Floor Construction:

- 2 in. by 8 in. joists at 16 in. o.c.
- masonite sheets on the bottom of the joists
- 3-in. fibreglass insulation between joists
- $\frac{3}{4}$-in. plywood sub-floor, 6-mil polyethylene sheets lapped 18 in. and taped at joints, masonite floor finish.

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* Reported in "Condensation in Flat Roofs," DBR internal report No. 377.

Wall Construction:

- $\frac{1}{2}$-in. exterior plywood sheathing, painted
- 2 in. by 4 in. studs at 2 ft o. c.
- 2-in. friction fit type fibreglass insulation
- 6-mil polyethylene film with joints taped and held tightly against studs with wood battens.

Roof Construction:

- asphalt and gravel roof
- $\frac{3}{4}$-in. plywood
- 2 in. by 8 in. joists at 16 in. o. c.
- Insulation, air barrier and polyethylene sheets were installed to suit test requirements (see Section C).

The joists were arranged in north and south directions to face into the prevailing wind. A 12-in. roof overhang was provided to allow for soffit ventilation where required. Before the installation of the plywood roof deck, a continuous caulking bead was applied to the top of all joists to minimize air leakage between joist spaces. Even with this precaution, air leakage between individual joist spaces took place during the winter of 1968-1969. Therefore, additional caulking was applied to the corner at the roof deck and joists on both faces of the joists. In addition to this caulking, joists, separating two entirely different test arrangements, were faced with a 6-mil polyethylene film up to the roof deck. This proved to be very satisfactory with no indication of any cross leakage or vapour migration.

Two observation holes at both the north and south end, approximately 2 in. square, were cut into the fascia board of joist spaces 4 to 12 and were covered with removable aluminum plates. A larger access opening was cut into the fascia board of joist space 11, panel D, on the south side for the purpose of taking photographs. This opening was covered with a hinged plywood door.

An exterior platform was built on the north and south sides for easier accessibility to the observation holes.

(2) The Inside Environment

The building has no windows. Major air infiltration was obtained through two 4 in. by 12 in. holes in the floor near the centre of the building and below the heater. A plywood sheet on 4-in. -high corner legs covered the holes to provide good distribution of the incoming air. With this arrangement it was estimated that a pressure difference across the ceiling of 0.01 in. W.G. would be realized at an inside to outside temperature difference of 100°F.

The relative humidity was maintained at between 30 and 40 per cent by vapourizing about 5 gallons of water each 72 hr in an ordinary household humidifier.

On March 31, 1970, mechanical humidification was shut off so that the length of time required to dry sections of the roof deck that had absorbed moisture could be recorded.

(3) Method of Moisture and Temperature Recording

Before the insulation was placed between the joists, thermo-couples and moisture meter pins were installed in the joist spaces. The moisture meter pins were made from $\frac{3}{4}$-in. copper nails and placed in five locations in the instrumented joist space of each test. The pins were placed in the centre between joists and to a depth of 5/8 in. into the roof deck. The distance between each set of moisture meter pins was 1 1/8 in. A 25-ft copper lead was soldered to each pin. The total lengths of wire for each set of pins was 50 ft with a measured resistance of 1.15 ohms total. The moisture content readings were read on a Delmhorst Model RC-1 moisture meter. One moisture meter pin was continually recorded on an L and N type G resistance measuring recorder (single point).

Thermo-couples were installed on the inside surface of the roof deck and in the joist space centred between the roof deck and the top of the insulation. Thermo-couples were located near the moisture meter pins. Test panel A had roof deck thermo-couples only.

The temperatures were read on an L and N type G temperature indicator (-80°F to 160°F). Fifteen thermo-couples were recorded on a continuous basis on a L and N type G 16-point temperature recorder (-80°F to + 160°F). The sixteenth point was used to record the outside air temperature.

(4) General

Spot readings and observations were taken at 8:30 and 11:30 in the morning, and 3:30 in the afternoon during five days each week. No spot readings or observations were taken on holidays or week-ends.

Wind direction was recorded by observation of a flag projecting above the roof of the test building. Snow and ice covering on top of the roof were recorded, as well as the sunshine hours.

Before the test recordings began, the roof deck was checked for its moisture content on 8 October 1969. All panels showed a moisture content of between 11 and 15 per cent on this date.

The recording of the gain in moisture content of the roof deck, as shown in Figures 6 to 9, does not represent the actual moisture percentage indicated by the moisture meter pins for this particular period of time. However, it does attempt to show the moisture pick-up based on the highest value shown on the recorder sometime during this period. The moisture content recorded by the moisture meter pins for a particular period of time is shown on Figures 6a and 8a.

It was taken into consideration that local conditions at the moisture meter pins were not necessarily representative of the actual moisture content of the roof deck. Frost on the surface of the roof deck always produced a low moisture content reading; so did low roof deck temperatures. Water or wetness on the surface of the roof deck produced high moisture content readings. It is likely that these readings were affected by surface moisture as frost or water and could have been influenced by temperature. A close approximation of the moisture content of the roof deck is given by Figures 6, 7, 8 and 9.

The data used for plotting these curves were selected from the continuous record and from spot readings taken at times when surface moisture was not apparent and temperature conditions were more suitable or were interpolated from more reliable preceding and succeeding observations.

The moisture content readings of the roof deck during the cold part of the winter are therefore not to be regarded as accurate.

It is the drying curves in the spring which are significant, the data here being more reliable because of decreased likelihood of surface moisture and more suitable temperatures.

(C) THE TESTS - ARRANGEMENTS AND OBSERVATIONS

The ceiling was divided into five test panels, with three joist spaces each, as shown in Figure 1. Instrumentation was located in the centre joist space of each group of three. The test arrangements and the observations obtained are described in the following section.

(1) Panel A, Spaces 1, 2 and 3

Insulation against Underside of Roof Deck, Not Vented

Three and one-half in. fibreglass R-10 insulation with vapour barrier paper was pushed against the underside of the roof deck, stapled and taped against the side of the joists and taped at joints between the insulation batts. Then a wire was spanned lengthwise in the centre between joists to prevent sagging of the insulation. "Windows" were cut into the vapour barrier paper and covered with a polyethylene film so that possible accumulation of melting condensate could be observed. These joist spaces were not ventilated to the outside.

Five thermo-couples were installed on the surface of the roof deck at points referred to as R17, R18, R19, R20 and R21. The corresponding moisture pins inside the roof deck were given the denomination Z1, Z2, Z3, Z4 and Z5 (Figure 2). The instrumented space was space No. 2.

The roof deck showed an increase in moisture content during the first week of the test. The moisture content increased gradually, except at the location of pins Z3 which seemed to have reached its maximum moisture content between December 19 and January 6. Pins Z1 recorded maximum moisture content between March 18 and April 2, pins Z2 and Z4 between February 4 and February 17 and pins Z5 between April 3 and April 16 (Figure 6). When mechanical humidification was discontinued, the moisture content decreased gradually at pins Z1, Z2 and Z4, rapidly at pins Z5 and very slowly at Z3 above the centre ceiling beam (Figure 6). Moisture pins at Z1 (north) recorded the lowest, pins at Z5 (south) the highest moisture content. This might indicate a pressure difference inside the space from north to south, that is from the windward toward the leeward side. Moisture pins at Z3 located above the centre ceiling beam also showed a relatively high moisture content. Pins at Z2 and at Z4 recorded similar values somewhere between Z3 and Z1. The tests were discontinued on June 12, 1970. Even on this date some moisture was still present in this system and could be observed as mist on top of the polyethylene "windows" on days when the roof deck temperature was recorded to be between 110°F and 125°F (Figure 16).

The roof deck temperature at the location of all five thermo-couples appeared to be about the same, but R17 (north) was slightly colder, while

R19 (centre) was slightly warmer than the average temperature of the three other thermo-couples (Figure 10). The roof deck temperature was considerably higher than the outside air temperature when snow covered the roof deck (Figure 3). The greatest difference in these temperatures occurred on February 13, 1970, a sunny day with outside air temperature below 0°, and 8 in. of snow cover. The roof deck temperature on this day measured at thermo-couple R19 in the centre of the building was 36°.

Between February 11 and March 9, a period of 27 days, the roof was covered with a blanket of snow. The thickness of snow was from 8 in. on February 11 to 3 in. on March 9. During this time the roof deck temperature as recorded by thermo-couples R19 and R20 remained constant at 36° independent of changes in the outside air temperature. During the same time the corresponding moisture meter pins at Z3 and Z4 recorded a constant maximum or near maximum moisture content.

One small water puddle (Figure 14) was observed on a "window" of space No. 2 while stains on the vapour barrier paper of the insulation of spaces 1 and 3 indicated that water had accumulated at some time during the test. The quantity of water collected on the paper was relatively small. Nevertheless the existence of water and the increase in the moisture content of the roof deck proves that moisture from within the building had migrated into the space above the vapour barrier paper on the insulation and had condensed inside the insulation or on the roof deck of panel A. All joints between the insulation batts and ceiling joists were carefully sealed with tape. Air leakage, therefore, would have to be ruled out as a force in moving vapour into the space. It is suggested that vapour diffusion through the paper backing and through and from the wood joists would account for this moisture.

The temperature at four locations on the face of the ceiling joists of space 3 were recorded with thermo-couple Y13, Y14, Y15 and Y16, as shown in Figure 5. The location was 4 ft south of the centre ceiling beam. On many days the temperature at thermo-couple Y16 was well below the dew-point temperature of the inside air vapour mixture (40 per cent at 70°F), which resulted in the formation of heavy water droplets along the edge of the vapour barrier paper of the insulation. Although the temperature at Y13 was always above the dew-point temperature of the inside air vapour mixture at this particular location, water drops were noticed along the edge of the paper in other locations (Figure 15). The temperature at Y14 was, as an average, 8 degrees warmer than at Y13, and 2 degrees colder than at Y15.

(2) Panel D, Spaces 10, 11 and 12

Air Leakage Permitted - Vented

Three and one-half in. of fibreglass R-10 insulation with the vapour barrier paper removed was installed flush with the bottom of the joists. A 6-mil polyethylene film was then taped to the bottom of the joists in place of a conventional ceiling, so that any melting condensate collecting on this surface could easily be observed. Air was permitted to leak into these joist spaces through orifices cut into two 2 in. by 12 in. by 26 in. plenums which were attached to the bottom of the joists, each side of the centre ceiling beam. The free opening above the plenum below the insulation was 12 in. by 26 in. Air leakage into the space was provided by five holes of 1 in. diameter each.

Space No. 10 was ventilated through 1 in. by 14 in. soffit vents with fly screen on both ends of the space. This conforms to the NBC requirement of 1/300 free area of the ceiling area. Space No. 11 had a 1 in. by 14 in. soffit vent with fly screen on the south side, a 3 in.-diameter soffit vent with fly screen on the north side. Space No. 12 was provided with a 1 in. by 14 in. soffit vent, no fly screen, on both ends of the space. This amounted to 1/150 of the ceiling area.

Roof space temperatures were recorded with thermo-couples W12, W14, W16, W18, W20, W22 and W24. Roof deck temperatures were recorded with thermo-couples W11, W13, W15, W17, W19, W21 and W23. Moisture content readings of the roof deck were recorded by pins X6, X7, X8, X9 and X10 (Figure 2). The instrumented space was space No. 11.

Heavy condensation was observed from November 1969 to the middle of February 1970, both on the roof deck and on the top layers of the insulation (Figures 17 and 18). The insulation was never dry during this period. Large water puddles were observed on top of the polyethylene vapour barrier in all three spaces of panel D (Figures 19, 20). The water was drained from space No. 10 twice during the test period. The amount on December 9, 1969 was 1,250 ml and on January 27, 1970 almost the same quantity was drained. No measurement of the water retained in the insulation after drainage was possible.

The indicated moisture content of the roof deck at the location of all moisture meter pins increased very rapidly during the first week of operation and reached its maximum at pins X7 and X9 between

5 December and 18 December, at pins X10 between 7 January and 20 January, at pins X8 between 19 December and 6 January and at pins X6 between 18 February and 3 March. Readings at pins X8, which were located above the centre ceiling beam indicated that the roof deck in this location began to dry after January 6. All other pins showed that the roof deck maintained its high level of moisture for many months. Pins X6 (north) showed a slightly lower moisture content in that location (Figure 8). The moisture content decreased rapidly after April 16, when roof deck temperatures near the 100° mark were recorded. The roof deck dried faster near the exterior walls than towards the centre, resulting in a moisture content lower than at the centre of the roof deck, although the centre of the roof deck had begun to dry after January 6, 1970. Moisture content recordings were discontinued on May 29, 1970 when the average indicated moisture content in this panel reached 30 per cent. It was assumed that the drying process would continue to a level close to the initial moisture content of 13 per cent, measured on October 8, 1969.

The roof deck and roof space temperatures inside panel D varied greatly, depending on their location and the difference between outside and indoor temperature. The roof deck temperature near the exterior wall on the north end of the building, as recorded by thermo-couple W11, was colder than at any other location and on the average remained below freezing from November 21 to March 17. The highest temperature occurred in the centre or near the centre (W15, W17, W19) of the panel. These locations recorded below freezing temperatures from January 7 to January 20 only. As a rule, average roof space and roof deck temperatures in this panel appear to be 25° or 30° above outside temperatures (see Figures 12 and 12a). The temperature difference was greatest when the outside air temperature was lowest indicating an increased pressure difference and air leakage at the ceiling level. As in Panels B and C, the roof deck temperature remained well above the roof space temperature during the night when 4 to 8 in. of snow covered the roof deck, but fell below the roof space temperature at night when the roof was bare. Figure 4 indicates the 24-hr cycle of roof deck and roof space temperature when snow covered the roof.

A 1-sq-in. sample of the roof deck was examined for its actual moisture content. The sample was taken from the south end of the panel near moisture meter pins X10 on April 1, 1970. The roof deck was cut as deeply as possible without damaging the roofing membrane. The result, after 8 days drying, showed a moisture content of 46.7

per cent. When the sample was cut, the surface of the roof deck appeared to be dry to the eye. But, the moisture meter pins recorded 85 per cent.

Fungi or mold was observed near the south end of the test panel (Figure 22) and subsequently analyzed to be of a kind known not to deteriorate wood (coadostorium species).

(3) Air Barrier - No Intentional Air Leakage

Panel B, Spaces 4, 5 and 6

(a) Polyethylene Air Barrier - Vented

Three and one-half in. fibreglass R-10 insulation with the vapour barrier paper removed was installed flush with the bottom of the joists. The insulation and joists were then covered with a 6-mil polyethylene air barrier. Special care was taken to tape the air barrier against the face of the joists in an attempt to completely eliminate air leakage. Soffit vents 1 in. by 14 in. (1/300 of ceiling area, NBC standard) on both the north and south eaves provided ventilation through the spaces.

Roof deck temperatures were recorded with thermo-couples R7, R9, R11, R13 and R15. Roof space temperatures were recorded with thermo-couples R8, R10, R12, R14 and R16. Moisture content readings of the roof deck were recorded by pins Y6, Y7, Y8, Y9 and Y10 (see Figure 2). The instrumented space was space No. 5.

Panel C, Spaces 7, 8 and 9

(b) Plywood Air Barrier - Vented

Three and one-half in. fibreglass R-10 insulation with the vapour barrier paper removed was installed flush with the bottom of the joists. A $\frac{1}{4}$-in. B.C. fir plywood air barrier was screwed to the bottom of the joists. All joints were carefully taped to eliminate all air leakage. Soffit vents 1 in. by 4 in. (1/300 of ceiling area, NBC standard) on both the north and south eaves provided ventilation through the spaces.

Roof deck temperatures were recorded with thermo-couples W25, W27, R1, R3 and R5. Roof space temperatures were recorded with thermo-couples W26, W28, R2, R4 and R6. Moisture content readings of the roof deck were recorded by pins Y1, Y2, Y3, Y4 and Y5 (see Figure 2). The instrumented space was space No. 8.

The test arrangements in these two panels were the same with the exception of the material used as air barrier; Panel B having a

6-mil polyethylene film, panel C $\frac{1}{4}$-in. plywood sheet. Throughout the test period it was observed that no condensation in the form of frost or water occurred inside these panels (Figure 21). The moisture content as measured at the moisture meter pins remained constant at 11 to 12.5 per cent (Figure 7). The pins near the exterior walls had a slightly higher reading ($\frac{1}{2}$ per cent) than the pins in the centre and near the centre of the building.

Both roof space and roof deck temperatures remained near the outside temperature during the day, independent of the snow condition on top of the deck. However the roof deck temperature was generally higher than the roof space temperature during the night, when the roof was covered with 4 in. to 8 in. of snow (Figure 3). Average roof deck and roof space temperatures are shown on Figures 11 and 11a. The tests in both panels were discontinued on 31 March 1970.

Panel E, Spaces 13, 14 and 15

(c) Plywood Air Barrier - Not Vented

Three and one-half in. fibreglass R-10 insulation with the vapour barrier paper removed was installed flush with the bottom of the joists. A $\frac{1}{4}$-in. B.C. Fir plywood air barrier was screwed to the bottom of the joists. All joints were carefully taped in an attempt to eliminate all air leakage. The spaces were not ventilated to the outside.

Roof deck temperatures were recorded with thermo-couples W1, W3, W5, W7 and W9. Roof space temperatures were recorded with thermo-couples W2, W4, W6, W8 and W10. Moisture content readings of the roof deck were recorded by pins X1, X2, X3, X4 and X5 (Figure 2). The instrumented space was space No. 14.

Eighty per cent of the roof deck increased its moisture content above the initial recording by only 1 per cent throughout the test period. Twenty per cent of the roof deck near the exterior wall on the south side increased its moisture content by 13 per cent, as was recorded by moisture meter pins X5 (Figure 9). This would indicate a pressure difference inside this panel with moisture deposited in the leeward (south) end. It is assumed that this small amount of moisture was deposited by vapour diffusion or air leakage from within the wall panel.

The roof deck temperature was, most of the time, 1° to 3° below the temperature of the roof space, independent of the condition on top of the roof. Both these temperatures were close to the outside air temperature when the roof was bare but considerably higher than the outside air temperature when the roof was covered with snow (Figure 3). As in panel A, the roof deck temperature, under snow conditions, did not increase above 36°.

The roof deck temperature on the north end of the panel was recorded as being lower than the roof deck temperature in the centre and near the south end of the panel. Average roof space and roof deck temperatures are shown on Figures 13a and 13.

The test in this panel was discontinued on 31 March 1970.

(D) SUMMARY AND CONCLUSIONS

Relative to the thermal and moisture conditions of the roof deck, a common characteristic appears to have developed in all test panels. The lowest moisture content was recorded where the roof deck temperature was either very cold or very warm (Figures 6 to 13). Peculiar to panels A and E, both not ventilated with outside air, was the thermal condition on the face of the roof deck when snow covered the top of the roof. The temperature of the roof deck in panel A, as recorded by thermo-couples R19 and R20, remained at 36° as long as the snow covered the roof. This occurred for a period of 27 consecutive days. The fluctuation in the outside air temperature from -10° to 35° did not appear to be of any influence.

At no time did the roof deck temperature in both panels increase above 36° with snow on the roof.

During the same period a constant high moisture reading was obtained in panel A. This was probably an indication of free water on the surface of the roof deck or saturation of the roof deck material. It appeared that the moisture content did not decrease during the 27 days, remaining constant at the maximum level at the location of each pair of moisture meter pins.

It appears that in the geographic location of Ottawa, most severe condensation can take place between the end of November and the middle of February. Before and after this date condensation, if it occurs, is light and can readily be evaporated if the roof space is ventilated.

It is unlikely that condensation inside the roof spaces of the test hut occurred due to outside conditions alone. Space No. 11 of panel D into which air leakage was permitted to take place recorded, throughout the winter, roof deck temperature higher than the dew-point temperature of the outside air measured at 9:00 a.m. and 4:00 p.m. on the DBR premises. Test panels B and C which were separated from the interior environment by a positive air barrier, should have given a clear indication of condensation due to outside conditions, if this had been a factor. At no time, however, was frost observed or recorded on the roof deck of these panels. The mean dew-point temperature of the outside air was 30° for the month of November, 11° for December, -5° for January, 5.5° for February and 16.5° for March. The mean roof deck temperature at panel C during this time was:

Nov.	21	-	Dec.	4	=	24°
Dec.	5	-	Dec.	18	=	27°
Dec.	19	-	Jan.	6	=	14°
Jan.	7	-	Jan.	20	=	6°
Jan.	21	-	Feb.	3	=	17°
Feb.	4	-	Feb.	17	=	18°
Feb.	18	-	Mar.	3	=	19°
Mar.	4	-	Mar.	17	=	27°

The tests have shown that the thermal and moisture conditions inside of flat wood structural roofs are controllable only when a positive air barrier is incorporated into the system on the warm side of the insulation. It must be recognized, however, that other mechanisms can deposit moisture in cold sections of the roof even if openings for air leakage are not present. This was demonstrated on test panel A.

This panel has shown that moisture, once accumulated, can remain inside the panel for a long period of time. The system may perhaps return to its original moisture content and thus might not result in rotting of the structure or the roof deck. The condensation that occurs may, however, result in objectionable staining of the ceiling depending on the quantity involved.

Space 11 of panel D has demonstrated that a significant quantity of frost or water can be deposited in the roof space by condensation of water vapour if air leakage is permitted to take place. The amount of water that collected on top of the polyethylene ceiling (Figures 19, 20) could have caused considerable damage to a conventional ceiling had the water been able to find its way through joints, nail holes and other openings in the vapour barrier above. The tests demonstrated once again that openings from a heated room into roof spaces also permit the escape of heat. The amount of heat can be large enough to keep the roof deck over or in the vicinity of these openings above freezing temperature, but not necessarily above the dew-point temperature of the resulting air vapour mixture, throughout most of the winter (Figure 12).

It seems impossible to predict or calculate the thermal and moisture condition that may exist inside of roof spaces as a result of the mixing of outside air and air leaking from within the building, for the rates of air flow both from the interior and from the exterior vary greatly with temperatures and wind conditions; and these are constantly changing.

The tests have conclusively demonstrated that a positive air barrier, when installed as shown in panels B, C and E, is the only guarantee to control moisture and heat flow into the roof space. At no time during the test period was condensation in any form observed nor did the moisture inside the deck increase above the initial moisture content, as was recorded by moisture meter pins in these panels.

The slight increase in the moisture content of the roof deck at the south section, panel E, might be due to vapour diffusion or air leakage from within the adjoining wall panel. It underlines the importance of ventilating a roof space of this particular construction with outside air.

The different sizes of ventilation provided for panel D, spaces 10, 11 and 12, did not appear to have any effect on temperature or moisture content. It seems to be important, however, to provide some ventilation for this type of roof construction so that moisture that might accumulate can be removed to the outside. The flow of humid indoor air into the roof space can cause a decrease in the free area of the ventilation opening when condensation occurs on the fly screen, as is shown in Figure 24. On several occasions the fly screen was observed to be completely blocked with frost, greatly reducing or eliminating ventilation. This is likely to result in more condensation.

This has been the second of two reports on roof condensation tests made in a test building on the DBR premises during the winters of 1968-1969 and 1969-1970. It is hoped that the reports will contribute to better understanding of the mechanisms of condensation so that the problem of condensation in roof spaces can be eliminated in the future.

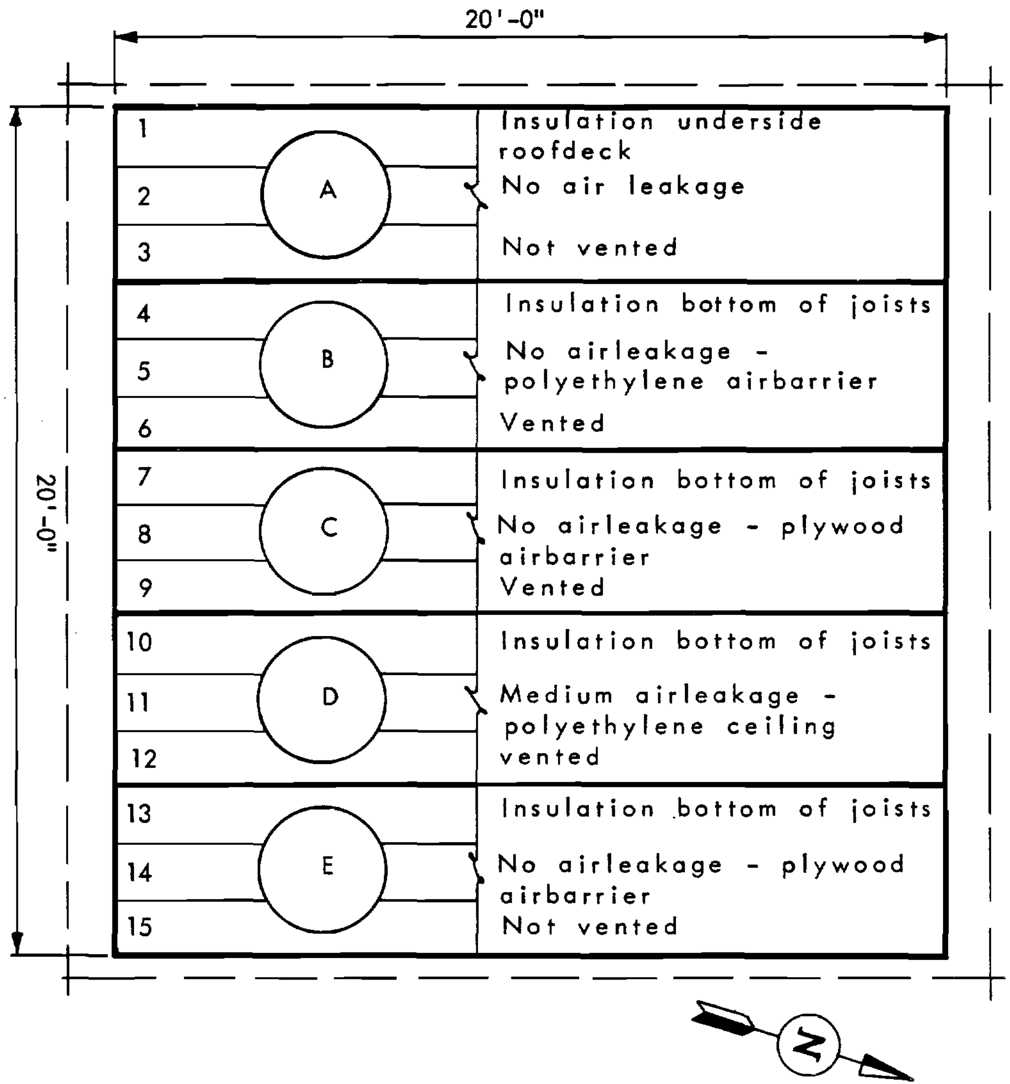


FIGURE : 1 ARRANGEMENT OF TEST PANELS

BR 4590-1

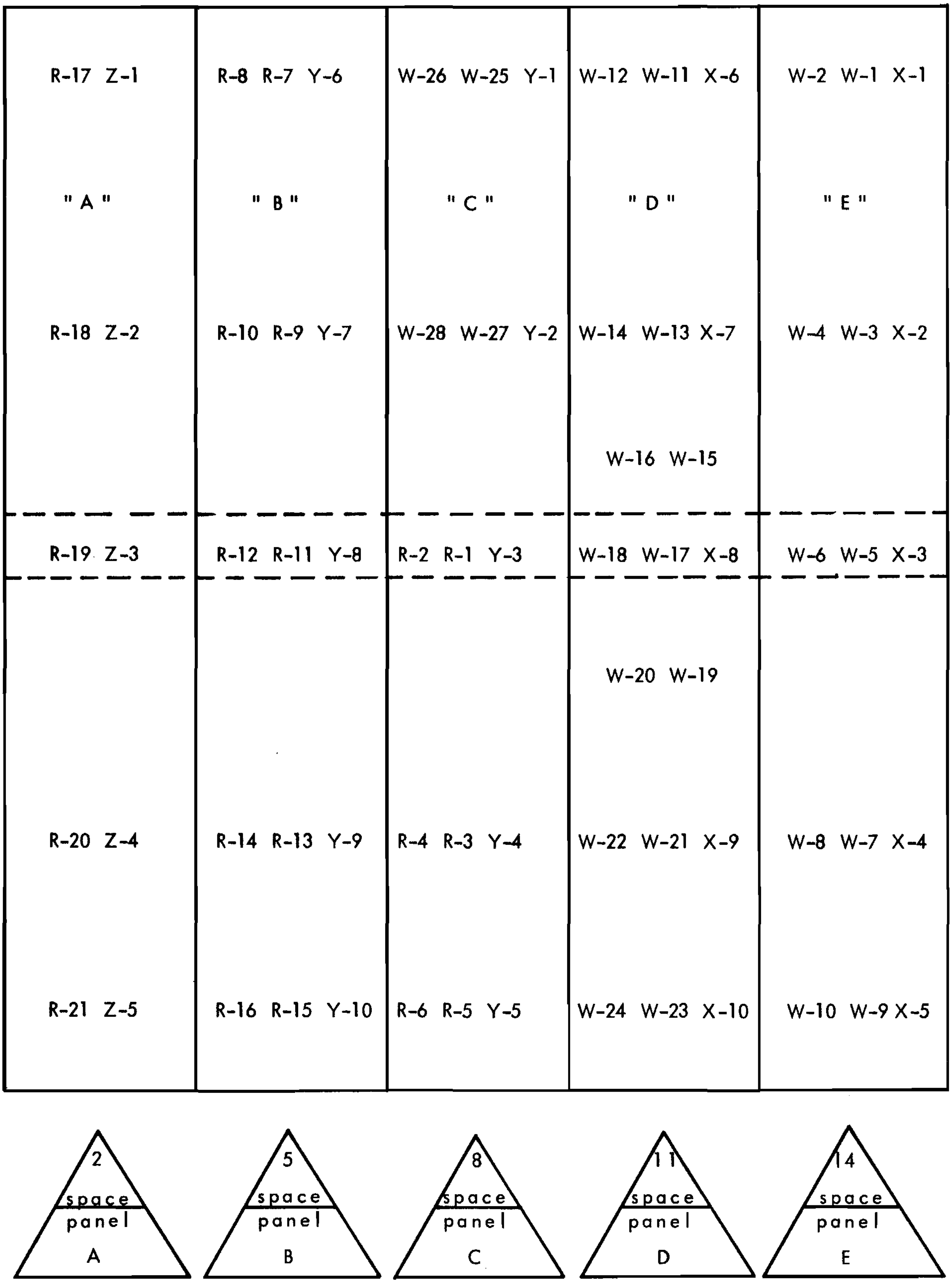


FIGURE : 2 LOCATION OF THERMOCOUPLES AND MOISTURE PINS

BR 4590-4

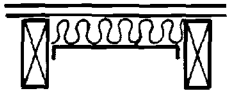
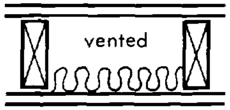
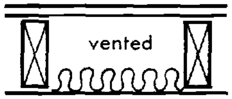
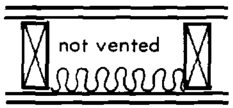
PANEL	DESIGN	LOCATION OF THERMOCOUPLE	NORTH		CENTRE		SOUTH	
			2" to 8" Snow	Bare	2" to 8" Snow	Bare	2" to 8" Snow	Bare
A		R.D.T.	15° to 35° Above O.T.	5° to 10° Above O.T.	20° to 45° Above O.T.	5° to 15° Above O.T.	15° to 40° Above O.T.	5° to 15° Above O.T.
		REMARK			R.D.T. constant between Feb. 11 Mar. 9			
B & C	 AIR BARRIER	R.D.T.	2° to 5° Below O.T.	2° to 5° Below O.T.	5° to 10° Above O.T.	2° to 5° Above O.T.	5° to 10° Above O.T.	2° to 7° Above O.T.
		R.S.T.	2° to 5° below O.T.	2° to 5° Below O.T.	3° to 5° Above O.T.	2° to 5° Above O.T.	3° to 5° Above O.T.	2° to 5° Above O.T.
		REMARK	R.D.T. was slightly warmer than R.S.T. except in north, where R.D.T. colder than R.S.T.					
D	 AIR-LEAKAGE	R.D.T.	No attempt was made to relate the roofspace and roofdeck temperature in this panel to the outside air temperature because of indeterminable thermal **conditions inside** this panel.					
		R.S.T.						
		REMARK						
E	 AIR BARRIER	R.D.T.	5° to 15° Above O.T.	2° to 5° Above O.T.	5° to 40° Above O.T.	2° to 10° Above O.T.	5° to 30° Above O.T.	2° to 7° Above O.T.
		R.S.T.	7° to 18° Above O.T.	3° to 6° Above O.T.	7° to 42° Above O.T.	4° to 12° Above O.T.	7° to 32° Above O.T.	5° to 10° Above O.T.
		REMARK	R.S.T. was always slightly warmer than R.D.T.					

FIGURE : 3

ROOFSPACE AND ROOFDECK TEMPERATURE RELATIVE TO OUTSIDE AIR TEMPERATURE

LEGEND : R.D.T. = roofdeck temp.
R.S.T. = roofspace temp.
O.T. = outside air temp.

BR 4590-5

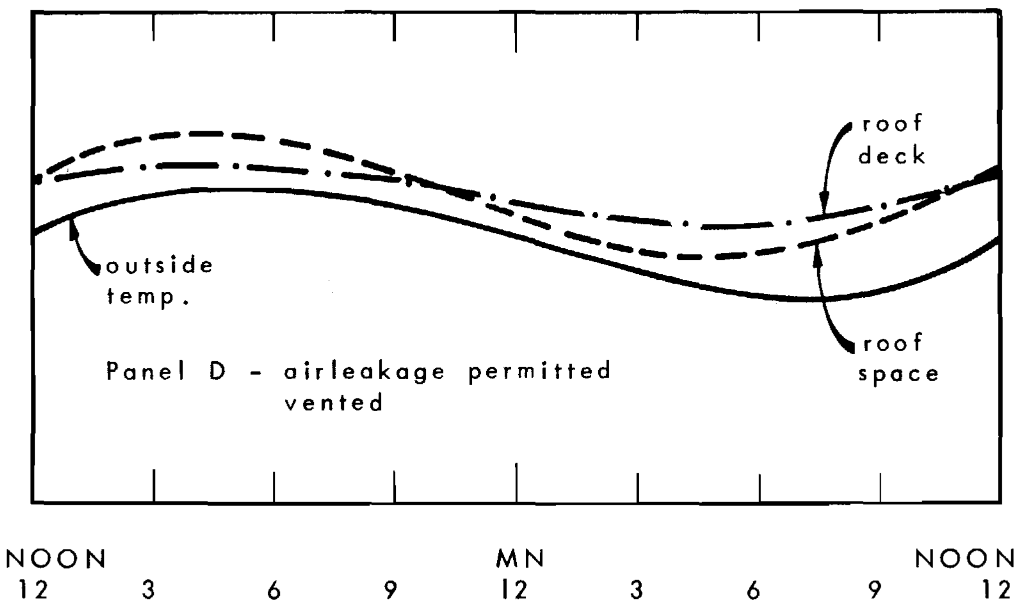


FIGURE: 4

24 HRS. CYCLE OF ROOF DECK AND ROOFSPACE TEMPS. WITH SNOW COVER ON ROOF DECK.

BR 4590-3

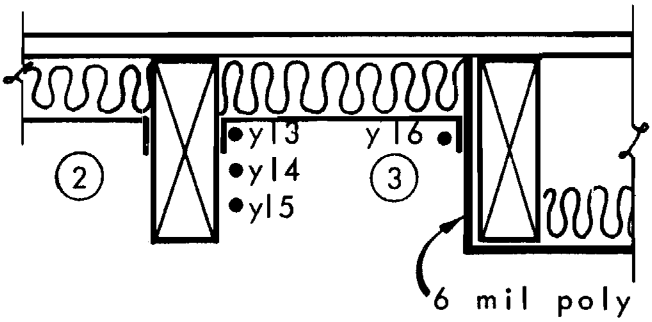


FIGURE : 5 LOCATION OF THERMOCOUPLES ON CEILING JOISTS PANEL "A"

BR 4590-2

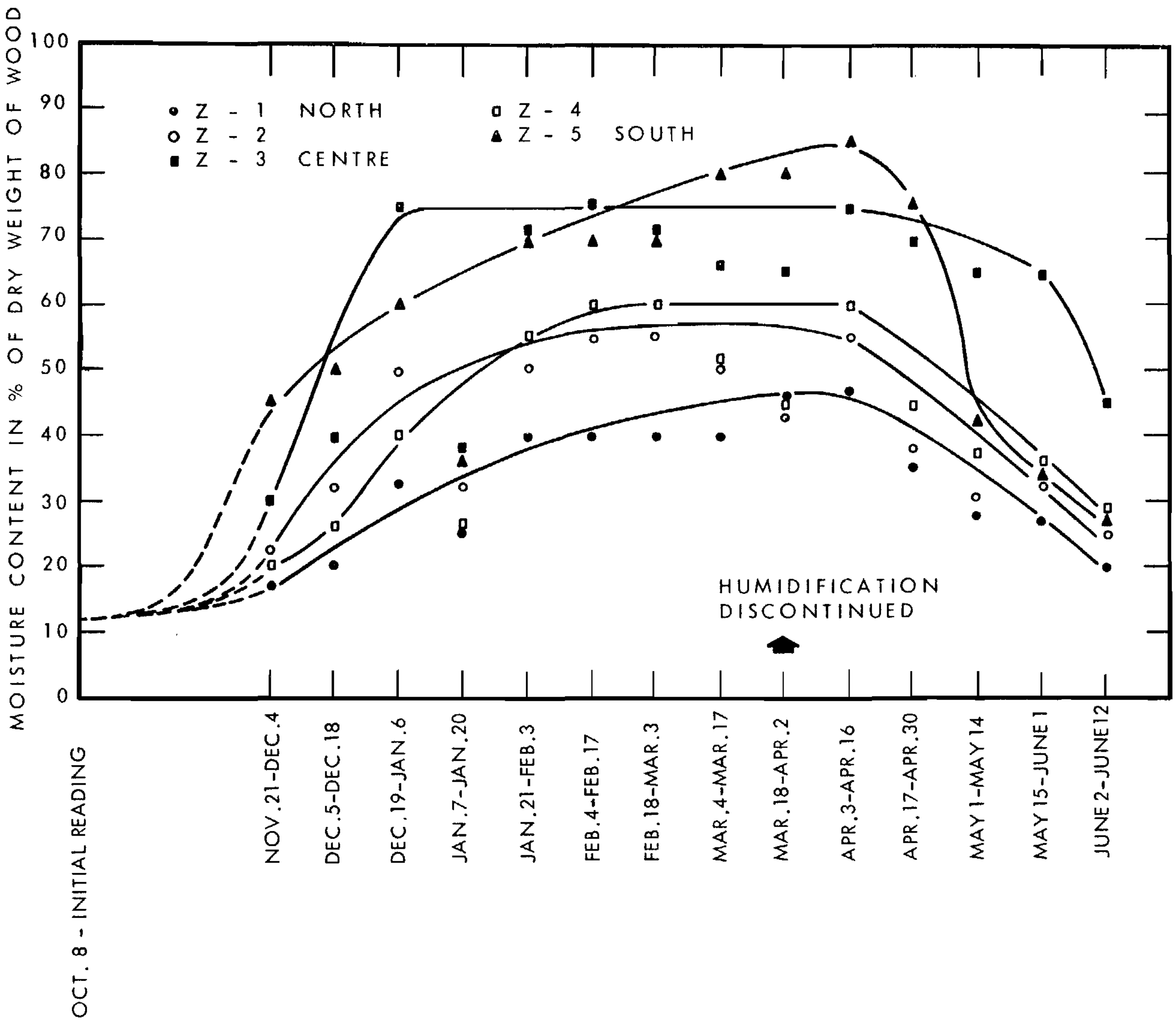


FIGURE 6 MAXIMUM MOISTURE METER READING FOR ROOF DECK - PANEL 'A'

BR 4590-6

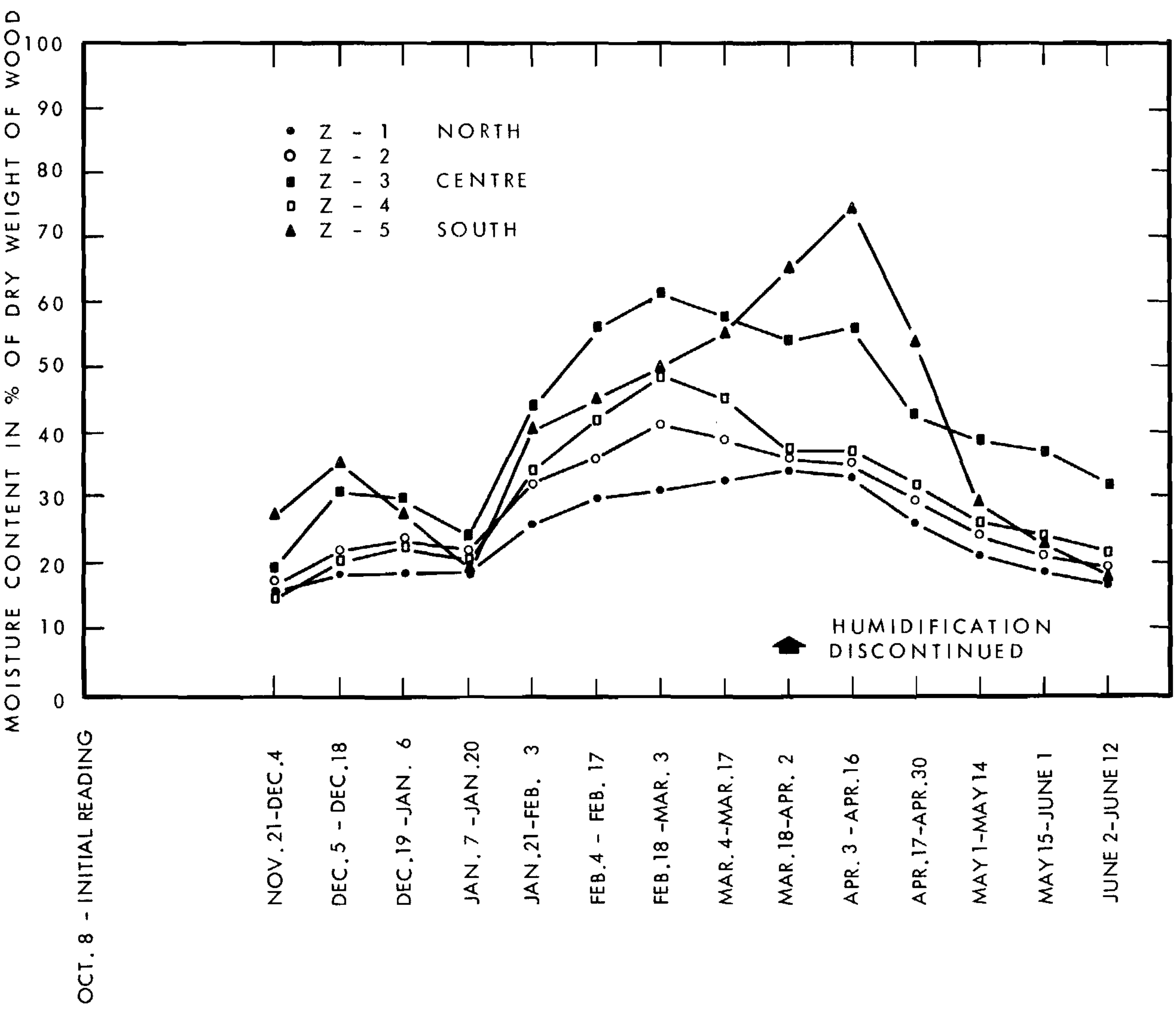


FIGURE 6a

WEEKLY AVERAGE MOISTURE METER READING FOR ROOF DECK - PANEL ' A '

BR 4590-7

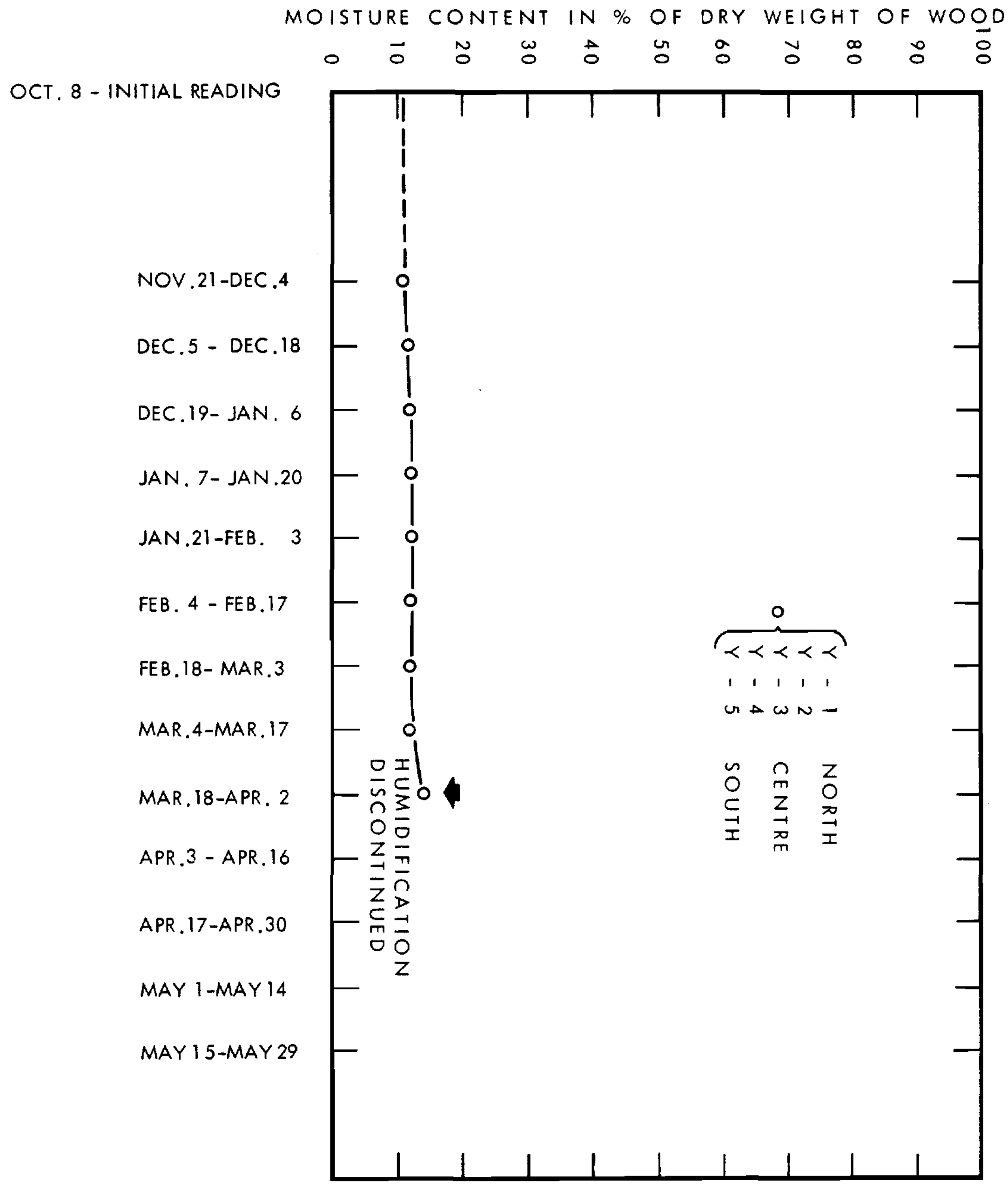


FIGURE 7 MAXIMUM MOISTURE METER READING FOR ROOF DECK - PANEL 'C'

BR 4590-8

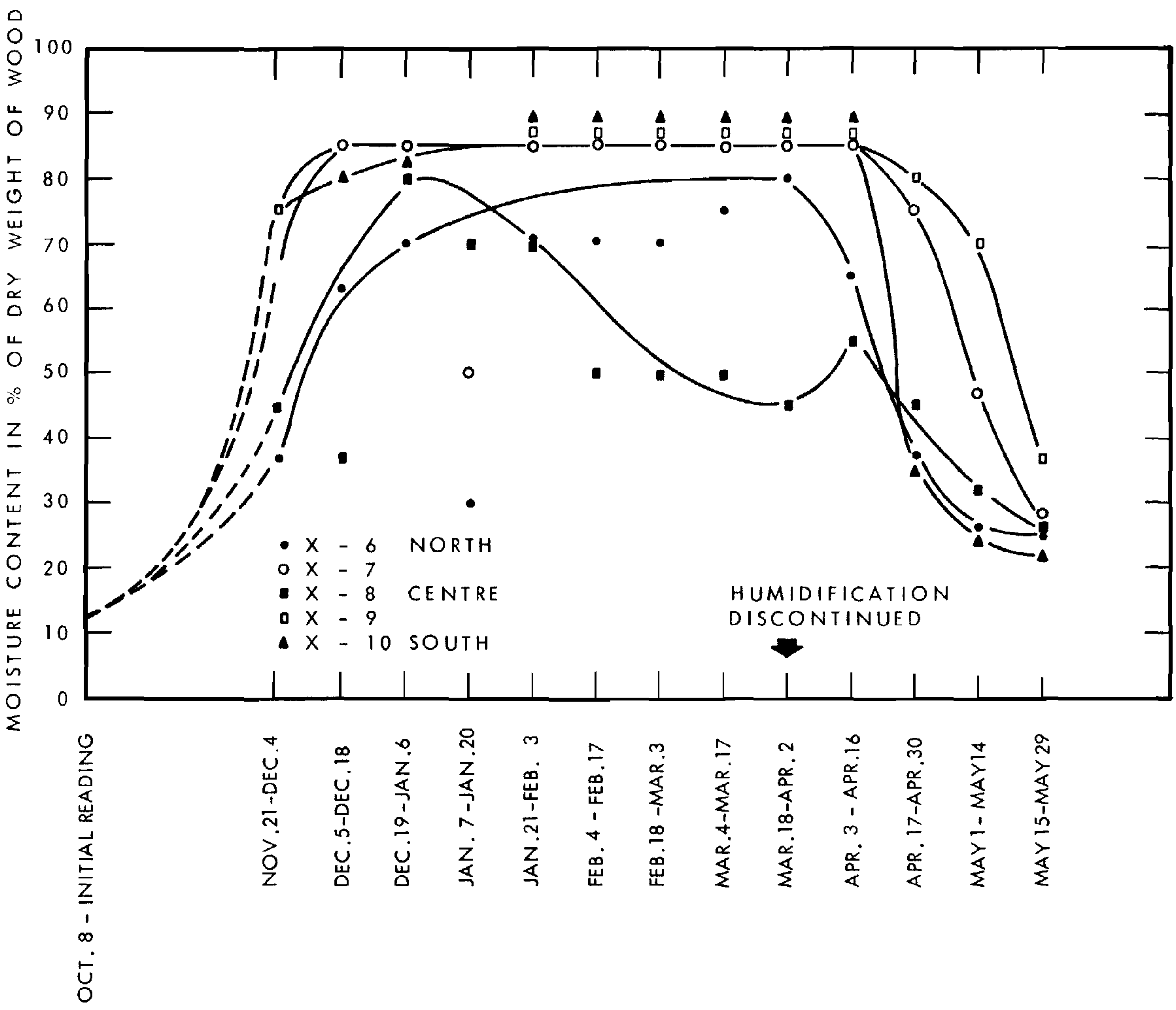


FIGURE 8 MAXIMUM MOISTURE METER READING FOR ROOF DECK - PANEL ' D '

BR 4590-9

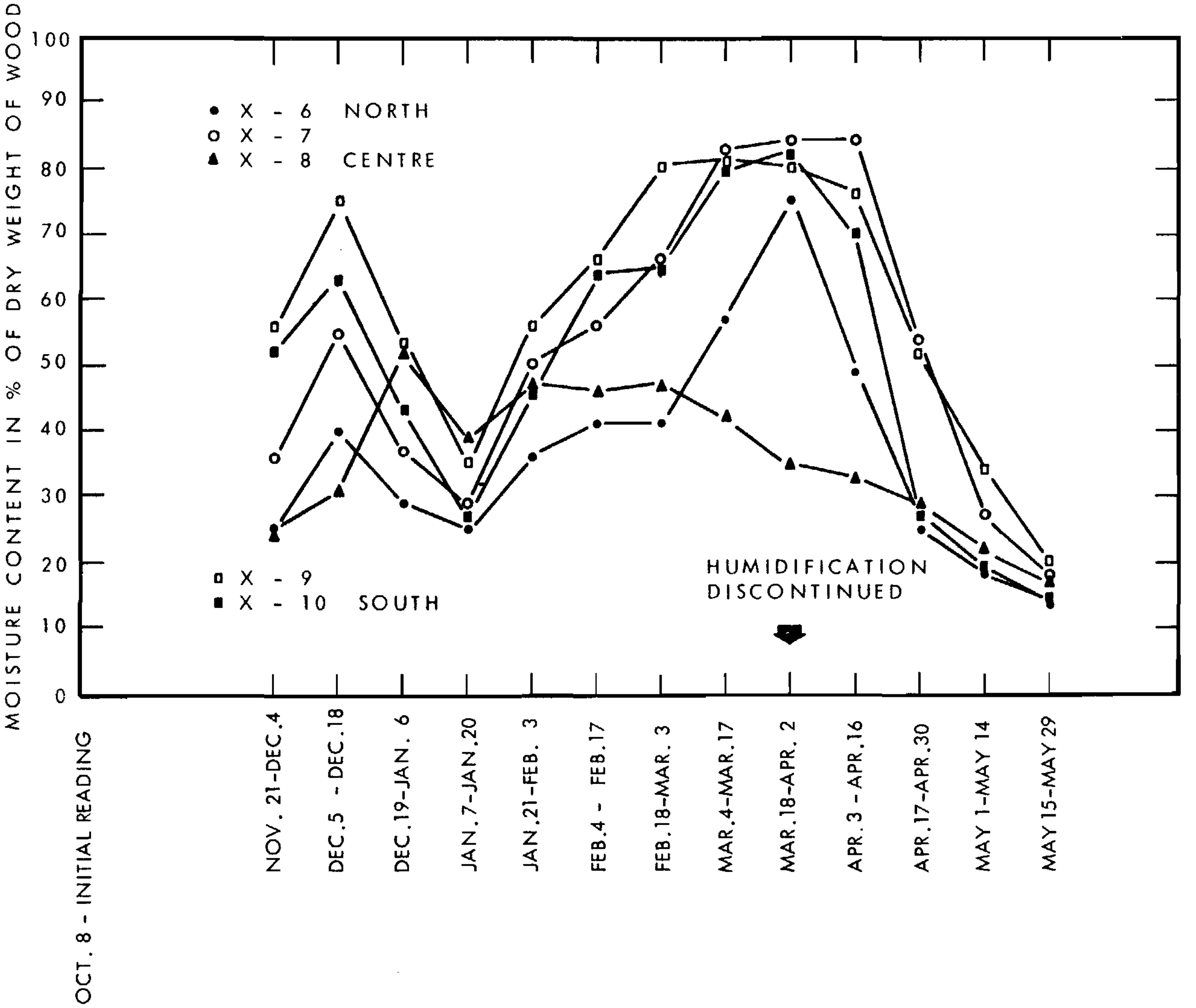


FIGURE 8a

WEEKLY AVERAGE MOISTURE METER READING FOR ROOF DECK - PANEL ' D '

BR 4590 -10

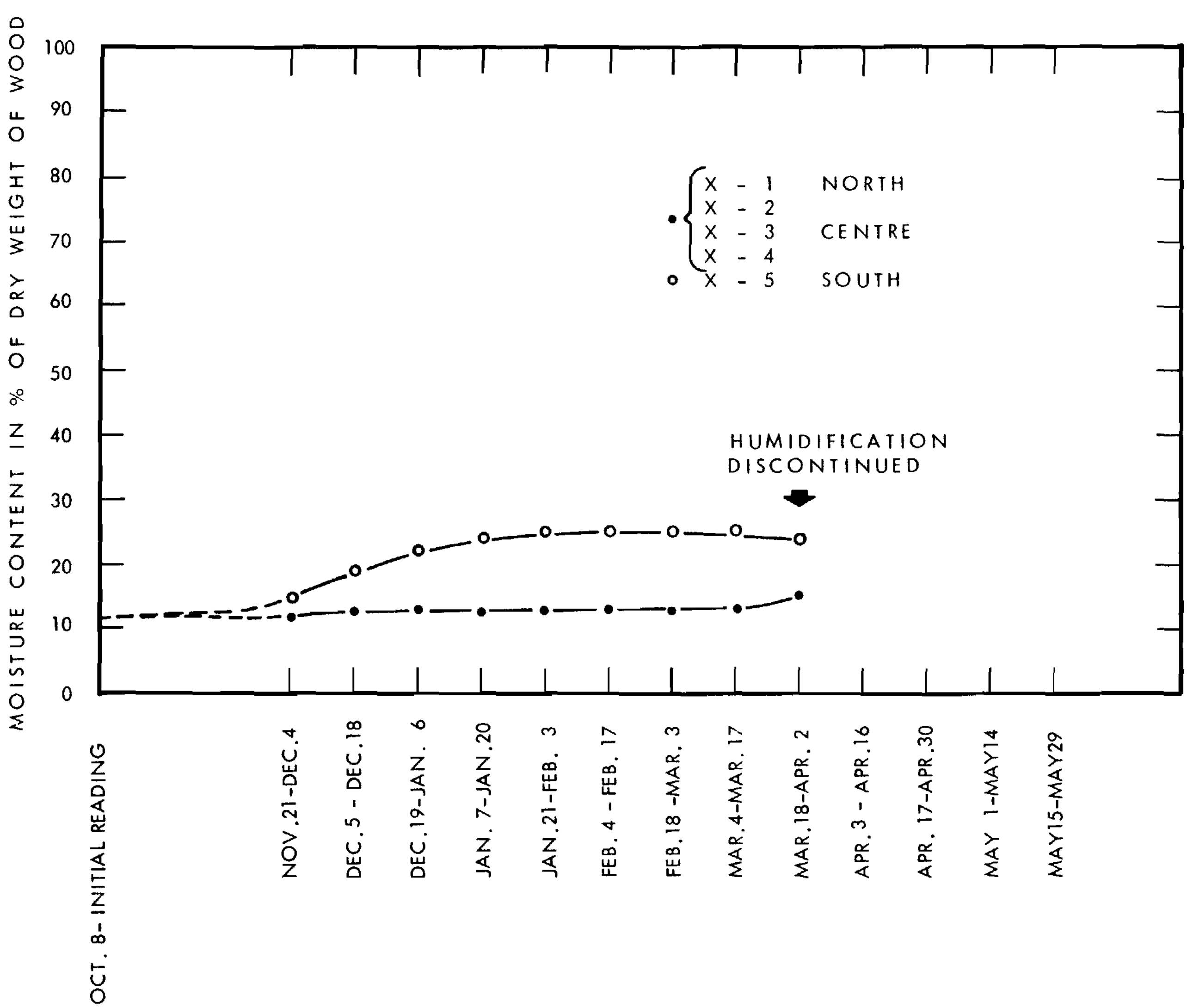


FIGURE 9 MAXIMUM MOISTURE METER READING FOR ROOF DECK - PANEL ' E '

BR 4590-11

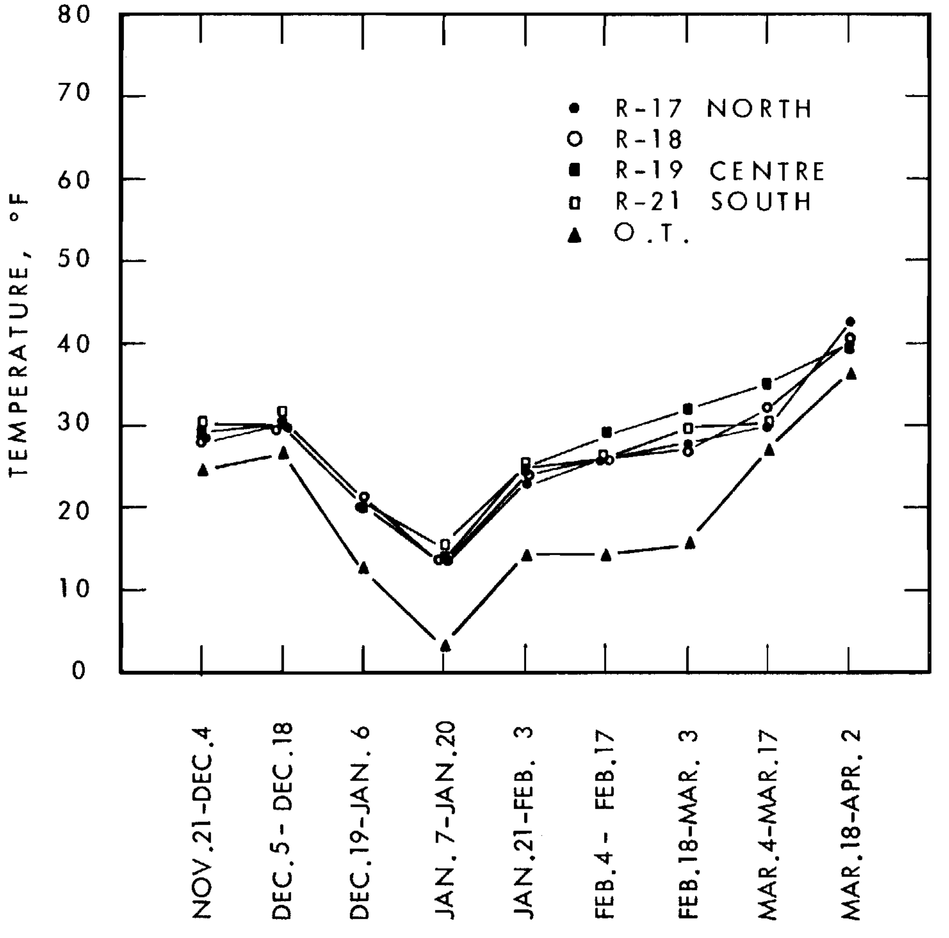


FIGURE 10
PANEL 'A' INSULATION UP
AVERAGE ROOF DECK TEMPERATURE

BR 4590-12

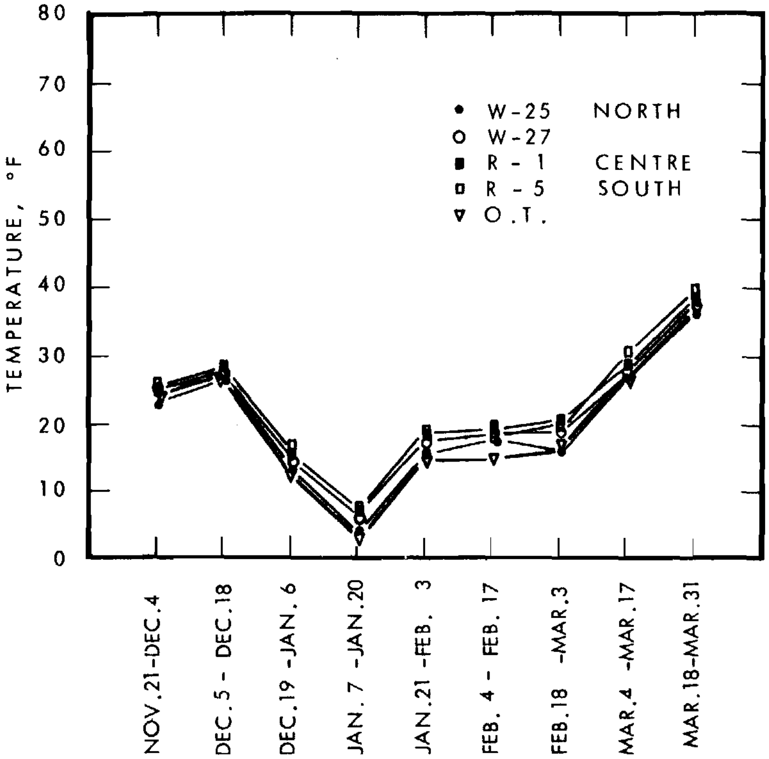


FIGURE 11
PANEL 'C' PLYWOOD AIRBARRIER - VENTED -
AVERAGE ROOF DECK TEMPERATURE

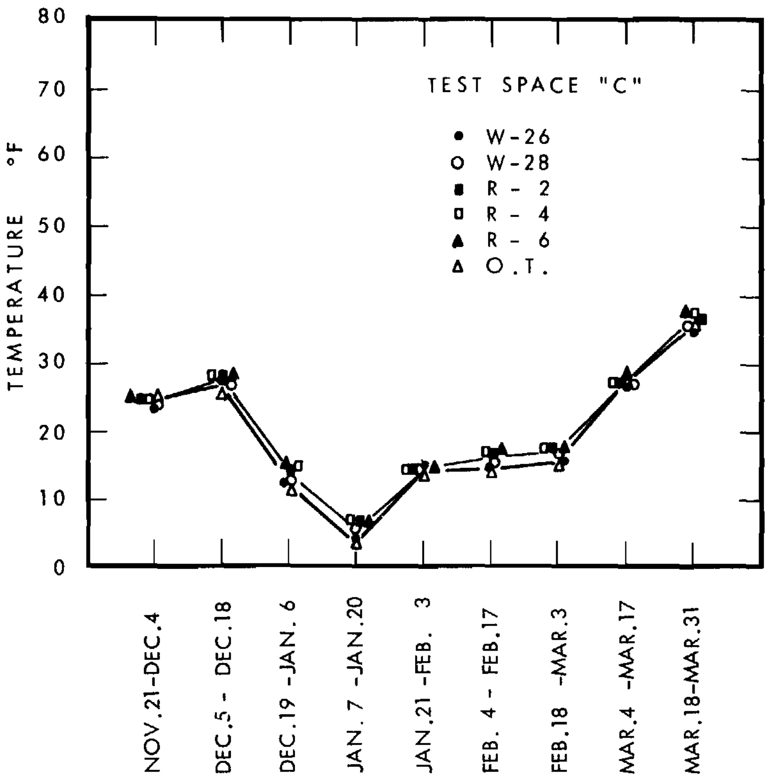


FIGURE 11a
PANEL 'C' PLYWOOD AIRBARRIER - VENTED -
AVERAGE JOIST SPACE TEMPERATURE

BR 4590-13

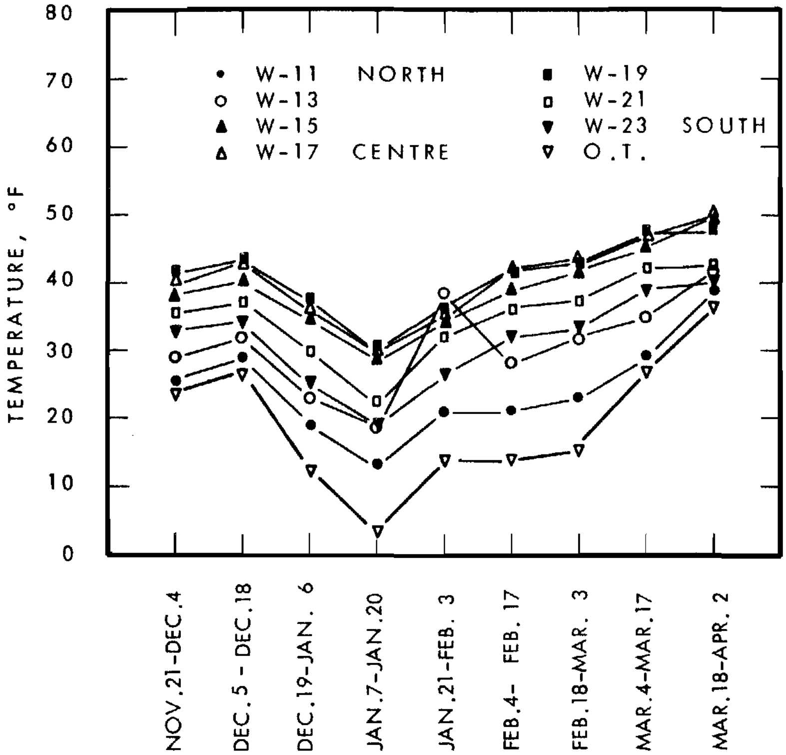


FIGURE 12
PANEL 'D' AIRLEAKAGE PERMITTED, VENTED
AVERAGE ROOF DECK TEMPERATURE

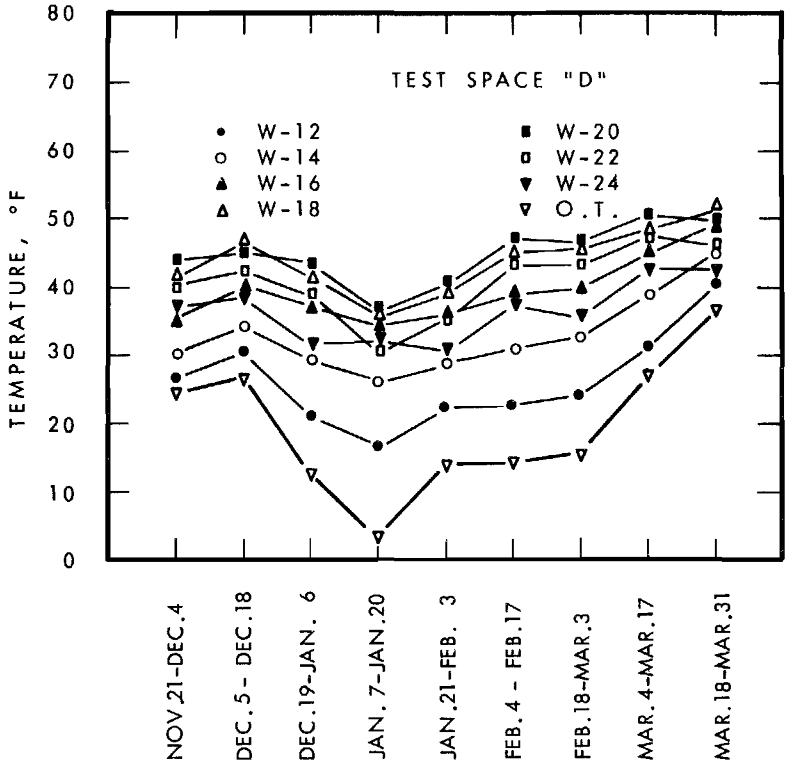


FIGURE 12a
PANEL 'D' AIRLEAKAGE PERMITTED, VENTED
AVERAGE JOIST SPACE TEMPERATURE

BR 4590-14

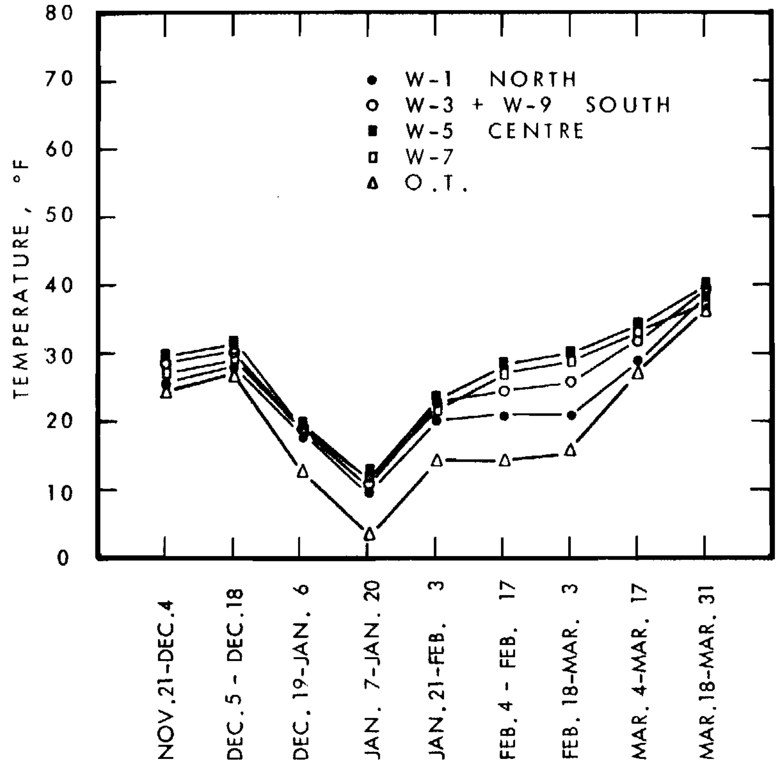


FIGURE 13
PANEL 'E' PLYWOOD AIRBARRIER, NOT VENTED
AVERAGE ROOF DECK TEMPERATURE

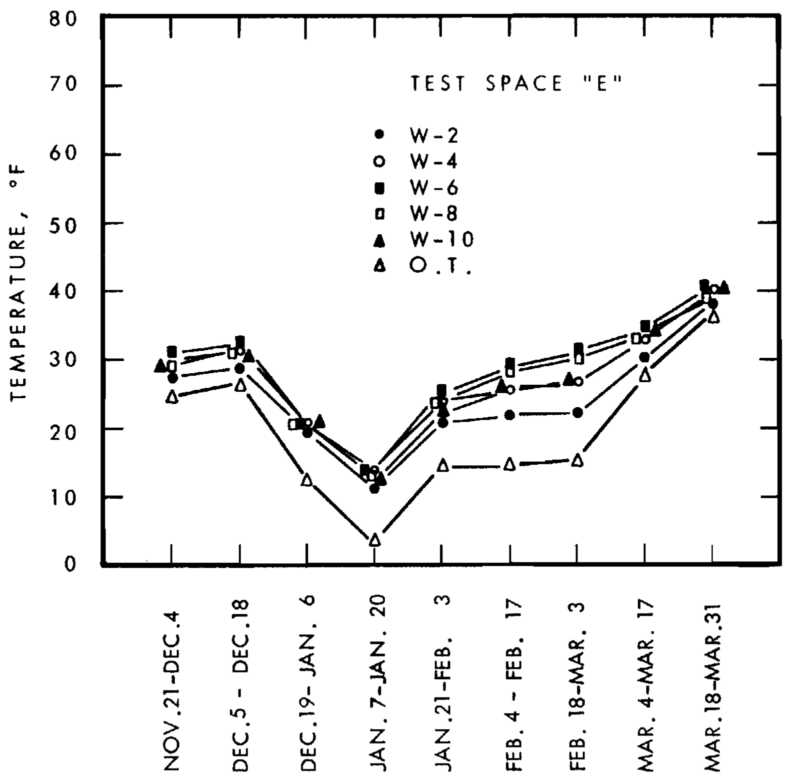


FIGURE 13a

PANEL 'E' PLYWOOD AIRBARRIER, NOT VENTED
AVERAGE JOIST SPACE TEMPERATURE

BR4590-15

Figure 14

Panel A, space 2.Small water puddle on "window" indicates that condensation on roof deck had occurred.

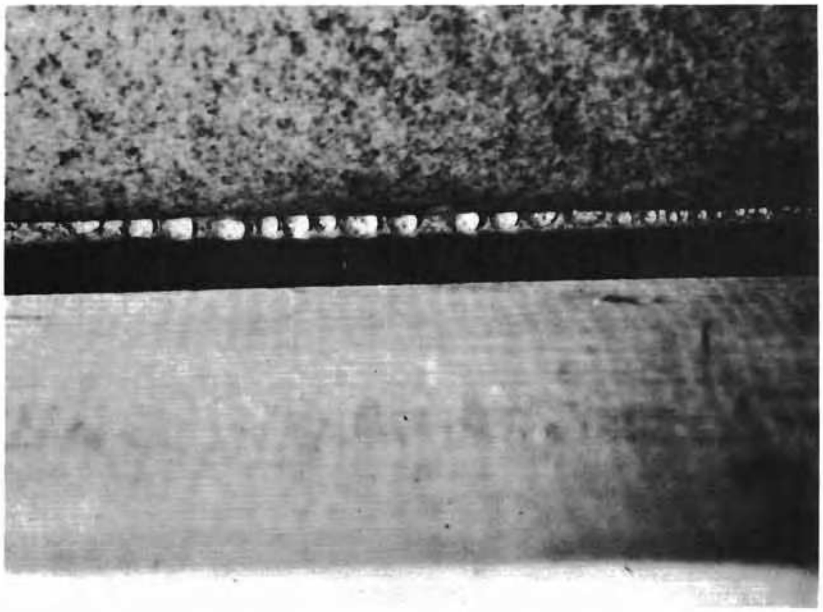


Figure 15

Panel A, space 3. Water droplets on paper backing of insulation where insulation taped to ceiling joists.

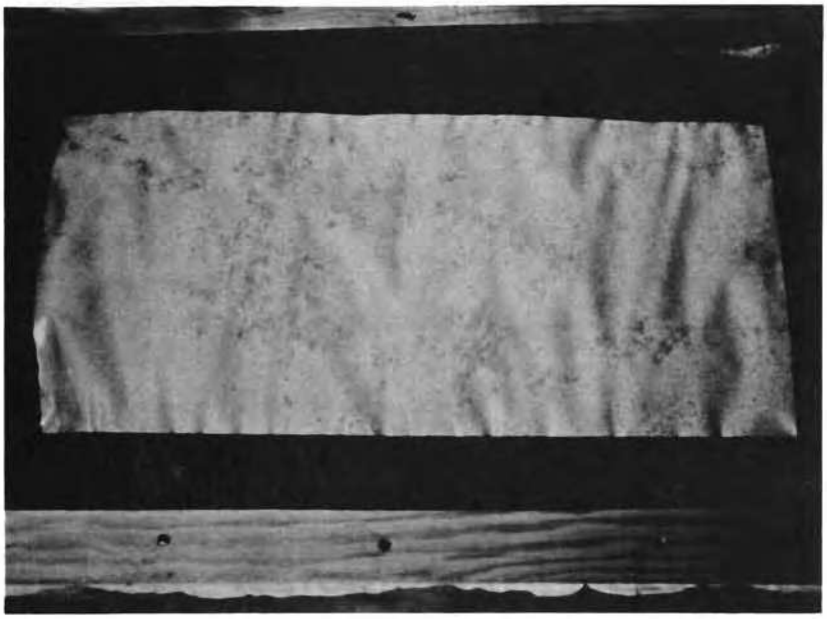


Figure 16

Panel A, space 2. Water droplets on top of "window" in June 1970, roof deck temperature 125°F.

Figure 17

Panel D, space 11. Condensation on roof deck and top of insulation.

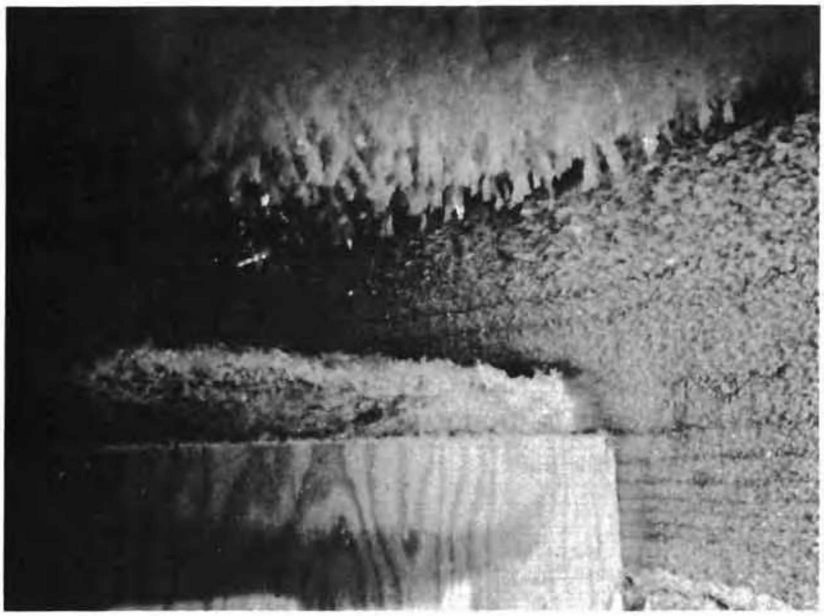


Figure 18

Panel D, space 11. Condensation on roof deck ceiling joists and top of insulation.

Figure 19

Panel D, spaces 10, 11, 12. Water from condensing surfaces accumulates on top of polyethylene.

Figure 20

Panel D. Close-up of Figure 19.

Figure 21

Panel C. Airtight ceiling, no condensation throughout winter.

Figure 22

Panel D, space 11. Fungus on wet roof deck.

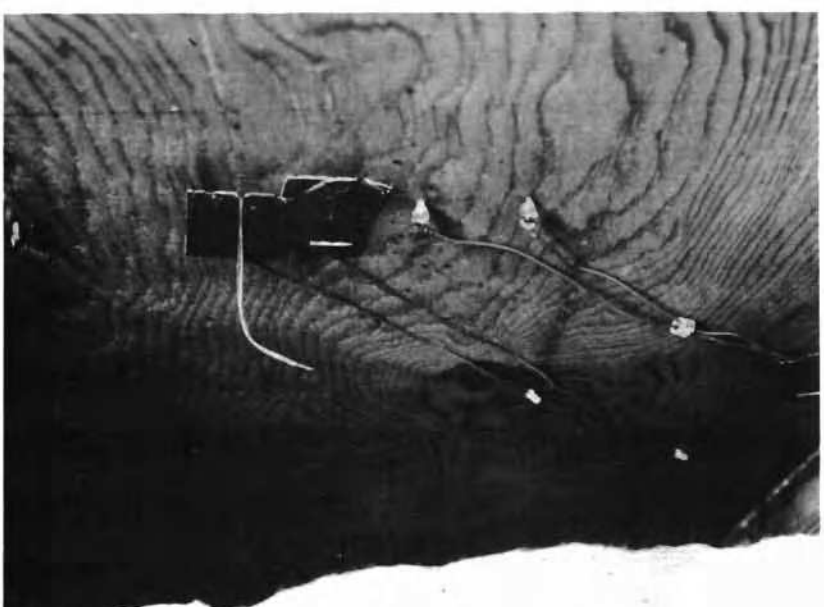


Figure 23

Arrangements of thermo-couples and moisture pins.

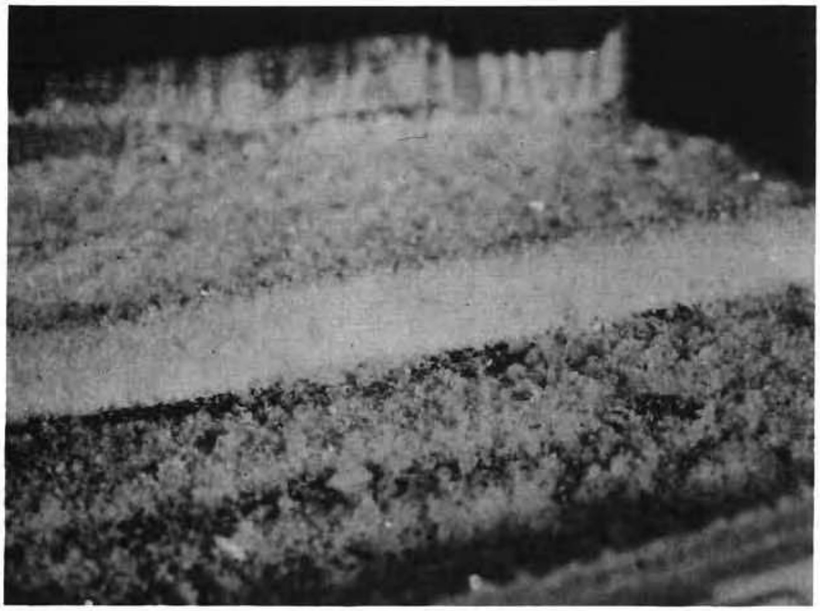


Figure 24

Panel D, space 11. Frost on fly screen of soffit ventilation.

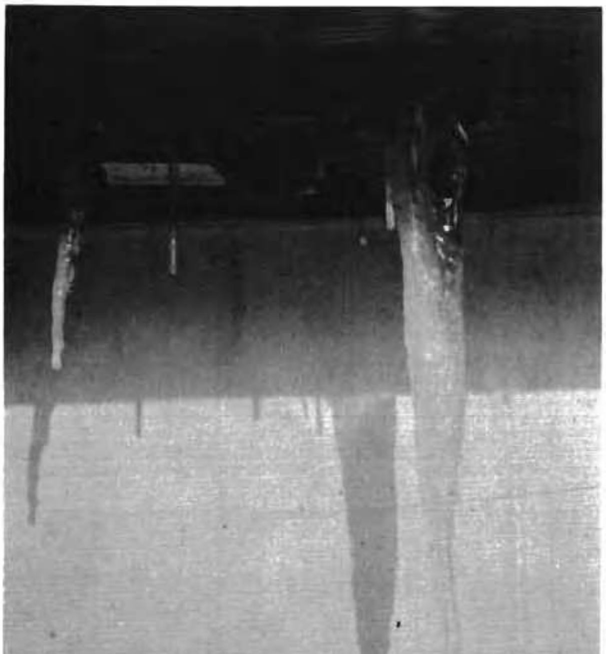


Figure 25

Panel D, space 12. Icicles, indication of air leakage into roof space.