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Moisture Measurements in Single-Family Houses with Attics Containing Radiant Barriers

W. P. Levins
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MOISTURE MEASUREMENTS IN SINGLE-FAMILY HOUSES WITH ATTICS CONTAINING RADIANT BARRIERS

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ABSTRACT

Tests were conducted by Oak Ridge National Laboratory researchers at three unoccupied research houses in Karns, Tennessee, to determine the effects of moisture condensation on the underside of perforated horizontal radiant barriers during the winter of 1987-88. An experimental plan called for the houses to be operated at high indoor relative humidities (45 and 55% at 70°F), with data concerning the attic moisture conditions collected by both visual and instrument measurements.

The testing showed that moisture went through a diurnal cycle at the Karns research houses. Moisture could condense on the bottom surface of a horizontal barrier in cold (below 35°F) weather, but it could also dissipate to the attic air during a normal Tennessee winter afternoon, leaving the barrier dry. In long periods of subfreezing weather, all the condensation did not vaporize, as some remained on the surface through the day. However, the testing did show that the moisture cycle occurring on a perforated horizontal radiant barrier during a typical Tennessee winter did not appear to pose any structural, wet insulation, or stained ceiling problems to the Karns research houses, even though they were operated at higher than normal indoor relative humidities.

Care should be taken in extrapolating the observations of this experimental work to areas with prolonged periods of subfreezing weather. The diurnal moisture cycle under a barrier may be different in colder climates. Further testing of horizontal barriers in colder climates is recommended.

EXECUTIVE SUMMARY

Previous work at the three unoccupied Karns research houses was devoted to measuring the energy related effects of radiant barriers (RBs) in both heating and cooling seasons. This testing had shown that horizontal radiant barriers (HRB) were more effective than truss radiant barriers (TRB) at reducing house heating and cooling loads. However, moisture condensation under an HRB had been noted in previous winter testing, and a potential problem area was indicated. The work covered in this report was aimed at providing answers to the questions pertaining to moisture condensation under HRBs.

Data from the TVA Solar Homes for the Valley Program had shown that the median indoor relative humidity (RH) in test houses in the Tennessee Valley area in below freezing weather is about 35% (when the data are normalized to 70°F indoor dry bulb temperature). Previous winter testing with HRBs had been carried out at Karns with a 40% indoor RH. No structural or other moisture related damage was observed during this previous testing. A test plan was developed to determine the level of indoor RH (at 70°F indoor dry bulb temperature) at which moisture condensation on an HRB during the heating season would become a problem.

The plan called for indoor RHs of 45 and 55% to be maintained by humidifiers, while moisture levels in the attic of each house were monitored both visually and with data logging instrumentation. The affect of reduced attic ventilation area ratio (from 1/150 to 1/300 ft^2 of effective ventilation area per square feet of attic area) and that of a kraft paper vapor barrier attached to the under side of the R-19 fiberglass batt attic insulation were also tested.

A perforated RB that had a measured total hole area of 0.46% with an average hole diameter of 0.040 in. was used. Previous winter

testing (1986-87) had been done with unperforated barriers and with barriers having a measured total hole area of 0.05% and an average hole diameter of 0.013 in. Perforations in an HRB ostensibly make it easier for condensed moisture to escape into the free attic air space. We assumed that the manufacturer of the RB material had increased the hole size to allow moisture to escape more easily.

Section 2 reveals that a typical family of four in a house can add a latent load that is equivalent to about 25 lb water per/day. The amount of water added to the test houses during the course of our testing varied from about 5 to 50 lb/day to maintain the desired high indoor RHs. The highest water additions to the houses occurred during cold weather periods when the humidifiers were constantly running and producing their maximum output. Clearly an average household would have trouble maintaining 45% RH in below freezing temperatures.

Visual observations of the underside of horizontally installed RBs revealed that condensation formed when the outdoor dry bulb temperature approached freezing (32°F) during normal Tennessee winter temperature cycles. Condensation was heavier at 55% RH than at 45% RH. During the warmer afternoon hours, the moisture would usually evaporate from the barrier, leaving it dry. However, in prolonged periods of subfreezing temperatures, all the moisture did not vaporize (although some did) but appeared to maintain a wet surface on the underside of the HRB. Some moisture did drip off the barrier onto the insulation (especially at 55% RH) but never appeared to penetrate more than 1/8 in. into the fiberglass insulation.

Four sections of 12 x 12 in. blotting paper were placed in the centers of quadrants in each of the attics on the top surface of the insulation under the HRB. The blotting papers were removed weekly and weighed to obtain an estimate of the amount of moisture remaining under the HRB in the fiberglass insulation. A fifth section of blotter was fastened to a section of roof truss in the free attic air to act as a control. The blotter weights generally agreed with the visual observations; when heavy condensation was noted on the HRB, moisture appeared to have dripped onto the blotters. The control blotter also varied in weight over the course of the testing. All blotters weighed more in the morning than in the afternoon, clearly showing that moisture absorption and desorption in the attics were undergoing a diurnal cycle. At the conclusion of the testing in the middle of March, 1988, all blotters were very close to their original weights.

Measurements of moisture content of wood truss members located under HRBs showed an increase from about 7 wt% moisture in early December to about 11 wt% during January and February, with a general decline to about 8 wt% in March. These values are well under the wood fiber saturation level of 28 to 30 wt%. The moisture levels in attic truss members above the barrier were not significantly different from those of members below the barrier. Higher humidity conditions inside the test houses appeared to raise attic wood moisture levels slightly, although the levels of humidity in all houses were higher than normally would be found.

Instrument measurements showed that although conditions were favorable for moisture to condense on the under surface of an HRB at outdoor temperatures below about 35°F, all the moisture did not accumulate under the barrier. Since the partial pressure of water vapor under the HRB was usually higher than that in the free attic air, moisture could escape through any openings (perforations, edge areas, etc.) that existed between the HRB and the attic air. Even in extremely cold weather, moisture could escape. Although there appeared to be some moisture accumulation during these very cold periods. None was noticed in more normal Tennessee winter weather. Increased attic ventilation would be expected to improve moisture dissipation, but no great difference was noted when the effective attic ventilation area ratio was reduced from 1/150 to 1/300. A ratio of 1/300 is a recommended value for attics (such as those at the Karns houses) with either high/low ventilation combinations or vapor barriers under the insulation. There are also heat and mass transfer balances that must be maintained to dissipate moisture, and attics may contain some thermal limitations. Measured surface emissivities of the HRB material used in this work showed little or no degradation during the relatively short testing period.

The main conclusion arrived from this work at the Karns houses was that moisture appeared to go through a diurnal cycle. It could condense on the under surface of an HRB in cold (below 35°F) weather but could also dissipate during a normal Tennessee winter afternoon, leaving the barrier dry. If the weather was continually in the subfreezing range, all the condensation would not dissipate, as some remained throughout the day. However, our testing showed that the moisture cycle occurring on a perforated HRB during a typical Tennessee winter did not appear to pose any structural, wet insulation, or stained ceiling problems to the Karns test houses, even though the houses were operated at higher than normal indoor RHs.

Care should be taken in extrapolating the observations of this experimental work to areas with prolonged periods of subfreezing weather. The diurnal moisture cycle under an HRB could be quite different in colder climates. Further testing of HRBs in colder climates is recommended.

NOMENCLATURE

Note: The following abbreviations are used in the report body as well as in some of the plots.

Abbreviation	Meaning
A/C	Air conditioning
BSFH	Btu/ft^2/h
BTUSF	Btu/ft^2
BTUSFH	Btu/ft^2/h
Cr Sp	Crawl space
DB	Dry bulb temperature
DTemp	Temperature difference
Gr Rm, Gr Room	Great Room (combination dining and living)
HB and HRB	Horizontal radiant barrier
HP	Heat pump
HFM1, HFM2	Heat flux meter number 1, 2
Ht Flx	Heat flux
Hum	Humidifier
HVAC	Heating, ventilating, and air conditioning
IR	Resistance heat
Jan.-Dec.	Months
Lt	Light
OD air	Outdoor air
RH	Relative humidity
RB	Radiant barrier
R-11 or R11	The R-value of insulation
R11 + HRB	Combination of R-11 insulation and a horizontal radiant barrier
R-19 or R19	The R-value of insulation
R19 + HRB	Combination of R-19 insulation and a horizontal radiant barrier
R-30 or R30	The R-value of insulation
R30 + HRB	Combination of R-30 insulation and a horizontal radiant barrier
TB or TRB	Truss radiant barrier
WB	Wet bulb temperature
No. 1, No. 2, No. 3	Houses No. 1, No. 2, No. 3
TI	Top of insulation
TF	Top of foil (radiant barrier)
UHRBB	Under horizontal radiant barrier blotter
VB	Vapor barrier
Vlt	Very light

1. INTRODUCTION

The Department of Energy (DOE), the Tennessee Valley Authority (TVA), the Reflective Insulation Manufacturers Association (RIMA), and the Electric Power Research Institute (EPRI) have jointly sponsored these experiments to measure moisture conditions in houses with attics containing horizontally installed radiant barriers (RBs). A RB is a foil material with either one or both surfaces coated with a low-emissivity material (usually aluminum), which works as a system in conjunction with an air space. This barrier theoretically can block up to 95% of the far infrared radiant heat transfer.

The experiments were carried out in three unoccupied houses located in Karns, Tennessee, midway between Oak Ridge and Knoxville. These houses have been used for seasonal space conditioning experiments that measured the energy performance of RBs. The first RB experiment was a cooling test conducted in the summer of 1985.[1] The following winter, a heating experiment was conducted in the same houses.[2] In these experiments, RBs were installed in combination with R-19 fiberglass batt insulation. A second cooling season experiment was completed in the summer of 1986 when a RB was installed with both R-11 and R-30 fiberglass batt insulation.[3] The following winter, a similar heating experiment was conducted.[4] A review of these experiments is contained in Sect. 1.3. The moisture measurement experiments performed in the winter of 1987-88 are reported in the following.

1.1 OBJECTIVE OF THIS INVESTIGATION

The objective of this winter experiment was to determine if moisture condensation can cause problems when HRBs are used in attics of single-family houses given high and extremely high indoor relative humidities (RHs). Both the ORNL and TVA testing have shown that a RB located on top of attic insulation is the most energy-efficient method of installation. This method is also the easiest to install in retrofit situations, as well as the one requiring the minimum amount of RB material. The two potential problem areas with a horizontal installation are dust buildup and moisture accumulation. This investigation addresses only the questions regarding moisture.

1.2 DESCRIPTION OF KARNS RESEARCH HOUSES

The Karns Research Facility consists of three identical, unoccupied single-family, ranch-style houses. Each has a conditioned space of 1200 ft^2 (approximately 40 x 30 ft) located over a crawl space. The houses are situated on Wilnoty Drive in the Karns community, between Oak Ridge and Knoxville, Tennessee. They were built by the same contractor using standard construction methods. Each house has the same make and model two-ton, single-package residential heat pump. All duct work is located in the crawl space and is insulated to R-7.6. The houses have soffit and gable vents with unfaced R-19 fiberglass batt attic insulation. No vapor barrier is in the attic, although there are vapor barriers on the wall and floor insulations. The effective attic ventilation area ratio is 1 ft^2 net free area of attic ventilation per 150 ft^2 of attic floor. Appendix C contains more detailed construction information about the houses.

Each house is highly instrumented with its own microcomputer controlled data acquisition system. Approximately 50 data sensors are scanned at 30-second intervals. Appendix C also contains a listing of the data channels used in this work.

1.3 REVIEW OF PREVIOUS RADIANT BARRIER EXPERIMENTS AT THE KARNS HOUSE FACILITY

The objective of the previous heating and cooling experiments at the Karns facility was to quantify the energy performance of RBs when various levels of fiberglass batt attic insulation were used. The RB tests were done in combination with three levels of unfaced attic insulation (R-11, R-19, and R-30). Two different methods of installing

RBs were also tested. In one configuration, the RB was laid on top of the fiberglass insulation [horizontal radiant barrier (HRB)], and in the other, the RB was attached to the underside of the roof trusses [truss radiant barrier (TRB)]. Previously in combination with R-19 insulation RBs were tested in both the cooling mode (summer of 1985) and the heating mode (winter of 1985-86). RBs were also tested in combination with both R-11 and R-30 insulation in the cooling mode (summer of 1986) and the heating mode (winter of 1986-87).

The results of the energy performance testing are summarized in Fig. 1.1. The cooling results testing R-11 attic insulation show that a TRB reduced the house cooling load by 10%, while an HRB reduced the load by 16% compared with R-11/no RB. The cooling results with R-19 attic insulation show that a TRB reduced the cooling load by about 12%, while an HRB reduced the load by 21% compared to R-19/no RB. RBs had very little effect when used in combination with R-30 insulation. An HRB tested in the heating mode with R-11 decreased the heating load by an average of 9%, while a TRB showed a very slight increase in the load of 0.8% compared with R-11/no RB. An HRB with R-19 decreased the heating load by an average of 10%. R-30 with a RB showed a reduction of 3.5% for both HRBs and TRBs. The heating load reduction with R-30 and a TRB is inconsistent when comparing the trends obtained from R-11 and R-19 with TRBs, and no explanation is offered for this behavior. Note, however, that the absolute values of the R-30 load changes are relatively small compared with those of R-11 and R-19 loads.

The results of the heating season test of 1985-86 (for R-19) and 1986-87 (for R-11 and R-30) were integrated using the DOE 2.1 building simulation program. Figure 1.2 summarizes both the heating and cooling tests and shows the effect of an RB relative to R-11 attic insulation with no RB. The results show that R-19 with a HRB outperforms all the other options in the cooling mode, including R-30 with an HRB. An HRB in combination with R-19 ceiling insulation reduced the cooling load by 25% in comparison with R-11/no RB. This situation is not the same in the heating mode, where R-30 alone or with either type of RB

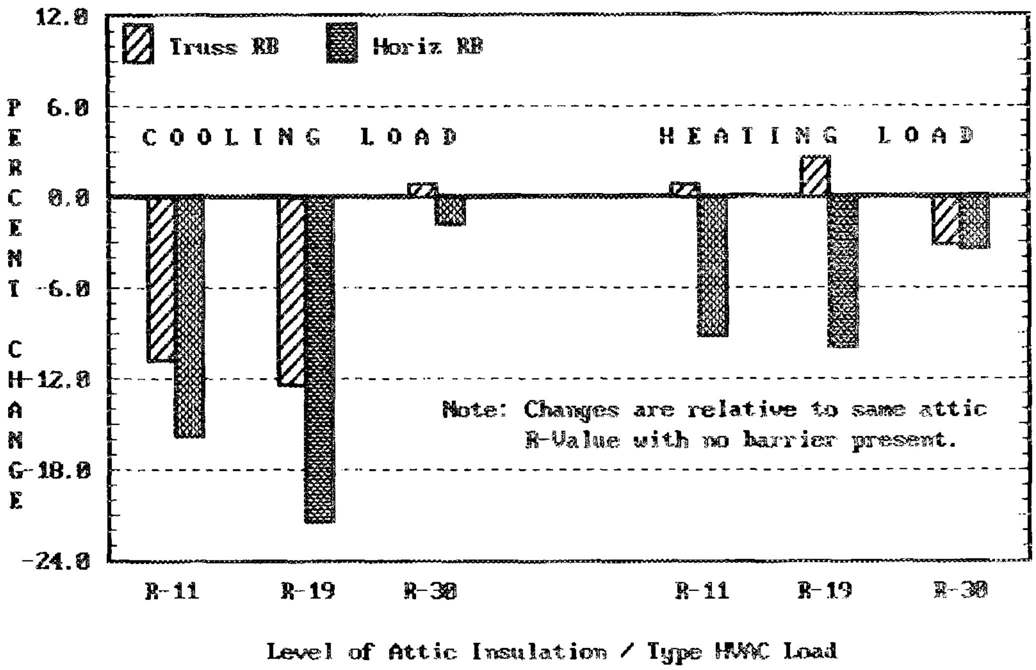


Fig. 1.1 Summary of radiant barrier effects on Karns house loads.

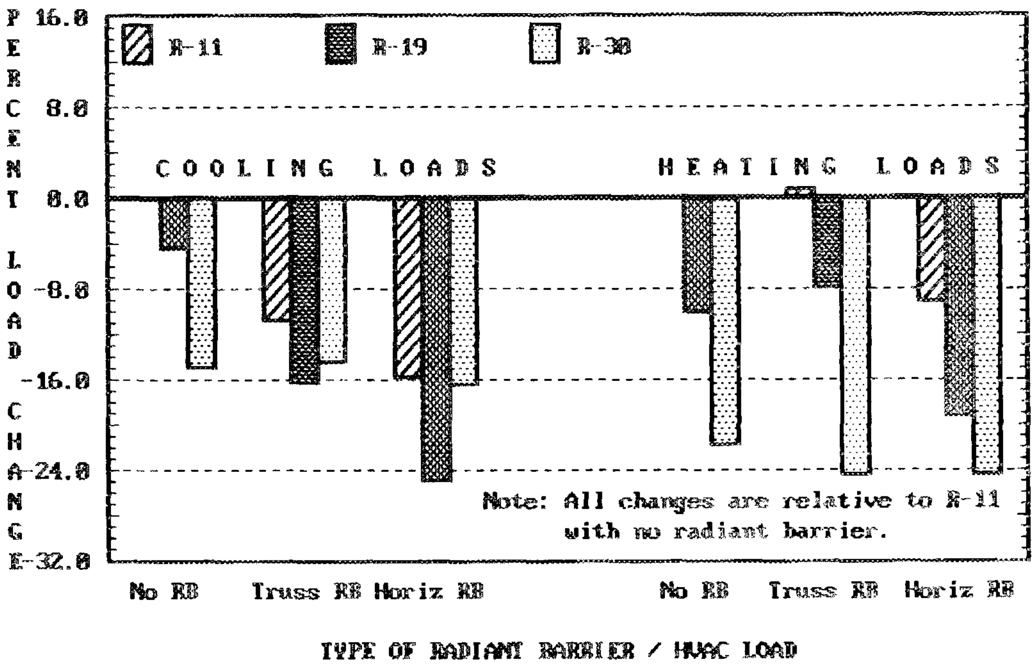


Fig. 1.2 Affect of radiant barrier/attic insulation on Karns HVAC loads.

outperforms R-19 with an HRB. We speculate that an HRB works more as a convective barrier in the heating mode than as a RB. However, we have no evidence to support this. We also believe that the size and quantity of perforations in an HRB had little affect on its energy performance, but, again, this is conjecture.

Observations were made during both heating season tests to detect the presence of moisture on a horizontally installed RB. Both measured and visual checks of the HRBs showed that moisture can form on the underside of the barrier during the winter. The houses were normally kept at 40% RH in the living area, and light condensation was detected on the HRB in the early morning hours during cold weather. However, the moisture vaporized in the warmer afternoon hours, and neither the insulation nor the RB showed any adverse effects for the six-week period when HRBs were present.

A three-day high humidity test was carried out in house No.3 when the RH was increased to 60%. The house felt uncomfortable at this humidity level, and condensed water was streaming down from the double-pane windows. Much moisture formed on the underside of the HRB and did not dissipate during the afternoon as it did in house No.2, where the inside humidity was 40%. When the humidity in house No.3 was reduced to 40%, the moisture on the barrier vaporized after a few days. These observations show that moisture can be a potential problem in cold weather with HRBs, especially in excessively humid houses. No high humidity tests were conducted in the control house, so high humidity affects there are unknown.

1.4 REVIEW OF OTHER RADIANT BARRIER INVESTIGATIONS

Other experimental investigations of RBs have been made by Joy[5] at the Pennsylvania State University in 1958, McQuiston[6] at Oklahoma State University; Rish and Roux[7] at the University of Mississippi; Fairey, Chandra, and Huston[8,9] at the Florida Solar Energy Center; Katipamula and O'Neal[10] at Texas A&M University; Hall[11,12] at the Tennessee Valley Authority, Chattanooga, Tennessee; and Lear, Barrup, and Davis[13] at the University of Florida. Joy's study was performed under laboratory conditions, while the others were performed under field conditions. A summary of most of these investigations is documented in a paper by Wilkes[14] of ORNL.

The ORNL work and the University of Florida work are the only documented experiments done in full-scale attics in real houses. The previous sections summarized the ORNL work; the remainder of this paragraph will summarize the results of the University of Florida investigation. Their experiments were performed using two side-by-side 1250-ft^2 houses on the University of Florida campus. Both houses had roof pitches of 5 in 12 and both attics were insulated to an R-22 level. One house, used as a control house, had soffit and gable vents. The other house was used to test RBs and had soffit, gable, and ridge vents. The vent system in the test house could be modified to be identical to that in the control house. Summer data were analyzed by integrating heat fluxes over the time period from 10 a.m. to 10 p.m. (when all heat fluxes in the test house were heat gains) and by calculating the ratio between the total heat flows for the test and control houses. With no RB in the test house, more efficient (ridge) venting reduced the ceiling heat flux by 40%. With an RB attached between the top cords of the roof trusses and the reflective surface facing downward, ceiling heat flow in the test house was 81% lower. The heat flow reduction with a RB evidently was due to the combination of more effective venting and the affect of the RB.

2. MOISTURE BACKGROUND INFORMATION

The purpose of this experiment at the Karns houses was to determine whether problems caused by moisture condensation occur during high and very high indoor RH winter conditions when a RB is placed on top of the attic insulation. It was very important that an investigation be made of what actually constitutes high and very high indoor RH during winter so that the proper indoor RHs could be tested. This section discusses some background information on RHs in homes and highlights the principal findings of the investigation of winter indoor RHs.

2.1 WINTER INDOOR MOISTURE BALANCE

Outdoor air is typically very dry during the winter, although RHs are usually moderate to high. This fact is misleading, however, since RHs are strongly temperature dependent. Psychrometric charts show that 30°F air at 100% RH contains less than half as much moisture per pound of dry air as does air at 70°F and 50% RH.

This dry winter air can lead to very low indoor RHs because the indoor/outdoor vapor pressure difference drives indoor moisture outdoors. For example, assuming no internal house moisture generation and indoor/outdoor moisture equilibrium (i.e., equal humidity ratios) and an outdoor temperature and RH at 30°F of 80%, the indoor RH at 70°F is 18%. Internal house moisture generation raises the RH in a house above this low level, but this example shows why indoor RHs tend to be low during cold winter conditions.

Following is a list of some internal moisture sources that can raise indoor moisture levels, along with estimates of the pounds of water added per day to house air from each source:

Source	Daily Estimate
People	3.5 lb/person(1)
Plants	1.8 lb/plant
Showers	0.5 lb/shower
Cooking	5.7 lb
Clothes washing and drying	7.7 lb
Floor mopping	3.0 lb per 100 ft^2
Kerosene heaters	Depends on usage
Humidifiers	Depends on usage

Some other factors affecting indoor humidity levels are:

House size relative to the number of occupants,
Presence of vapor barriers in crawl space, ceiling, walls, and floors,
"Tightness" of a house, and
Area and type of windows and doors.

When a large number of people are in a small house, the RH levels will generally be higher than levels in a larger house with the same number of people and their activities. Also, if a vapor barrier is not used over the ground in a crawl space, the ground can add as much moisture to a home as all other sources combined. Finally, a "tight" house (i.e., with good caulking, weatherstripping, etc.) can raise winter humidity levels by trapping indoor moisture that would normally escape to the dry outdoors.

Figure 2.1 shows the relationship between RH, dry bulb temperature, and the dew point temperature.

2.2 WINTER INDOOR RELATIVE HUMIDITIES

A literature search was conducted to locate actual RH data. Only one source of continuous monitoring of winter RHs in several occupied homes was found, data from TVA's Solar Homes for the Valley (SHFV) Program. However, many references to "proper" and "maximum allowable" indoor RHs were located. Also, one study was found that contained numerous single-point RH measurements (as opposed to continuous

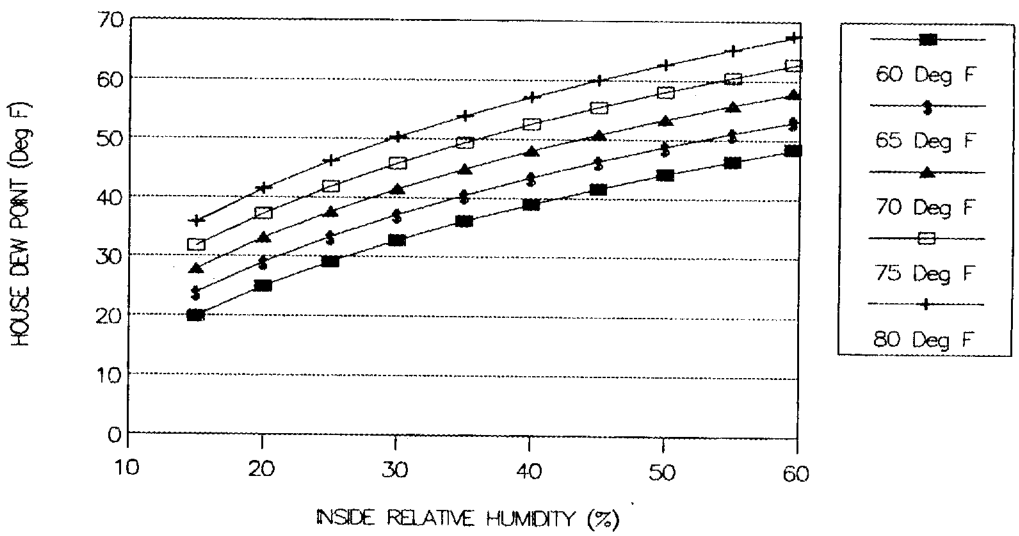


Fig. 2.1 House dew point vs relative humidity for various indoor temperatures.

monitoring). The single-point measurements and references to proper humidity levels will be briefly discussed, followed by a detailed discussion of the TVA SHFV data.

2.2.1 Literature References to Winter Relative Humidities

Several references to "proper" and "maximum allowable" winter humidities were found in the literature. These are described briefly in the following:

1. The publication "Moisture and Home Energy Conservation,"[2] prepared by the National Center for Appropriate Technology states that "Prolonged high indoor RH - above about 45% - can cause a wide variety of problems."

2. In "Moisture in Homes,"[3] it is stated that "Taking condensation control into account, optimum indoor RH is 40% in winter."

3. Product literature for a typical central home humidifier[4] shows the maximum safe recommended indoor RH as a function of temperature. For 10, 20, and 30°F outside temperatures, the maximum safe indoor humidities that are recommended are 30, 35, and 35%, respectively.

4. In a study described in "Residential Moisture Conditions Facts and Experience,"[5] single-point RH data were collected during one week in 16 homes located in Utah, Alabama, and Ohio. The results varied widely. The Ohio homes averaged 27% RH at an average outdoor temperature of 23°F. The Utah homes averaged 62% RH with an average outdoor temperature of 31°F. The Alabama homes averaged 66% RH, but the outdoor temperature was much warmer at 55°F.

5. "Residential Moisture Conditions and Perceived Health Status,"[6] describes single-point winter humidity measurements in 253

randomly selected houses. From a regression analysis of the data, the average indoor RH from this study was estimated to be 58%. However, the adjusted R^2 for the regression analysis was very low. More importantly, the single-point measurements likely were made during the day hours when outdoor temperatures are warmer, which will tend to cause higher indoor humidities. Outdoor temperatures, which would have strongly affected indoor humidities, were not measured.

2.2.2 TVA's Solar Homes for the Valley Data

One of the primary objectives of the RH literature search was to locate winter indoor RH data from occupied houses that were continuously monitored. Also, it would be highly desirable to have continuously monitored indoor and outdoor temperatures since these parameters critically affect the indoor RH.

The literature search located only one data set that met the above conditions. During the later 1970s and early 1980s, a number of homes were built in the TVA region as part of a TVA program called SHFV. These homes had many passive solar features and were well-insulated, energy-efficient houses. During this program, TVA monitored the environmental conditions and energy use of several of these homes to determine the effectiveness of the designs. Among the many parameters monitored continuously were indoor and outdoor temperatures and indoor RH.

The data from the SHFV that were applicable to our study were obtained from 12 homes that were monitored from December 1982 to March 1983. Data were recorded continuously at 15-minute intervals. However, only three of the sites had data for the entire four-month period. Six of the sites had data for one month, while three of the sites contained data for three of the four months.

Indoor RH is strongly dependent on indoor temperature. For example, indoor air at 75°F and 40% RH has the same amount of moisture (per lbm of dry air) as 65°F air at 56% RH. Accordingly, a "normalization" procedure was used to allow all the humidity data to be compared assuming the same indoor temperature (70°F).

This normalization procedure determined the humidity ratio for each indoor temperature and RH data point. Then, the proper RH at 70°F indoor temperature was selected that would give the same previously determined humidity ratio. For example, given indoor conditions of 75°F and 40%, the humidity ratio (0.0074 pounds of water per pound of air) would be determined. Then, the RH at 70°F (48%) would be estimated that would give the same (0.0074) humidity ratio. By using this normalization procedure, all the RHs can be compared fairly as they are all based on the same 70°F indoor temperature.

Table 2.1 and Fig. 2.2 summarize the results of the SHFV RH data. Table 2.1 gives the number and percentage of observations (i.e., 15-minute data points) that occur in each outdoor temperature range in each RH range. Fig. 2.2 graphically displays the information in Table 2.1.

The main conclusion drawn from Table 2.1 and Fig. 2.2 is that RHs above 45% are not common when ambient temperatures are less than 35°F (i.e., at outdoor temperatures when condensation may be a problem). The percentage of observations for the 45-50% humidity range was well below 10% for each temperature range less than 35°F.

The occurrence of RHs in the 50-55%, 55-60%, and above 60% ranges at outdoor temperatures below 35°F is even less. Except for one case (50-55%, 15-20°F), the percentage of observations are all well below 5%.

Table 2.1 TVA Solar Homes for the Valley humidity data

Temp Range	% Relative Humidity 0-35	35-40	40-45	45-50	50-55	55-60	>60	Obs in Temp Range Tot	%	Median % Rel Hum
0-15	0.0	0.0	33.3	0.0	66.7	0.0	0.0	3	0.01	44.5
15-20	66.0	7.4	11.1	8.6	6.2	0.6	0.0	162	0.33	30.5
20-25	67.9	12.9	12.8	5.2	1.1	0.2	0.0	1292	2.62	31.7
25-30	57.3	20.8	12.2	6.0	3.0	0.6	0.1	3585	7.27	32.8
30-35	52.6	24.5	10.9	6.6	3.3	1.2	0.9	9364	19.00	34.0
35-40	39.1	25.7	11.5	13.3	7.2	1.9	1.3	13125	26.63	36.5
40-45	31.6	23.6	13.6	13.3	10.5	4.1	3.2	11154	22.63	38.0
45-50	28.3	22.1	14.7	12.9	12.2	4.7	5.2	10596	21.50	38.8
Tot in %RH	19624	11570	6224	5503	3856	1343	1161	49281		
% in Range	39.8	23.5	12.6	11.2	7.8	2.7	2.4		100.0	

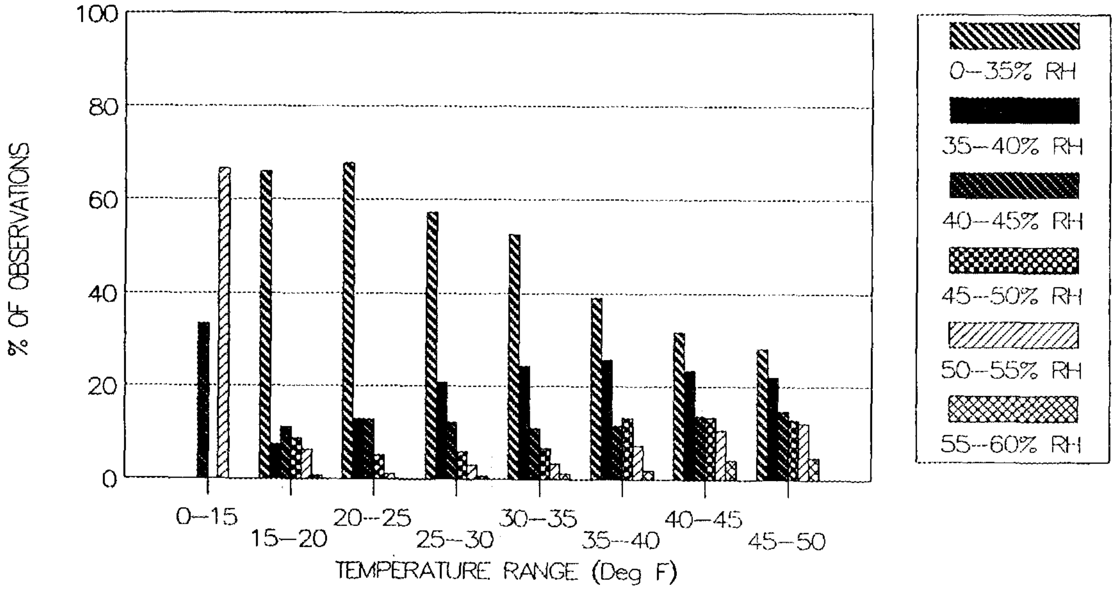


Fig. 2.2 TVA Solar Homes for the Valley relative humidity data.

It should be noted that the results for the 0^oF - 15^oF range should be viewed with caution since there were only three observations in this temperature range from a grand total of over 49,000 observations. As would be expected given the dryness of outdoor air during winter, most of the RHs in the SHFV data were in the 0-35% range. In the outdoor temperature ranges below 35^oF, the occurrence of RHs in the 0-35% range was greater than 50%. During the coldest temperature ranges, 15-20^oF and 20-25^oF, the occurrence of 0-35% RH observations was almost 70%. The three lowest RH ranges (i.e., 0-35, 35-40, and 40-45%) account for 84, 94, and 90 respectively, and 88% of all the observations in the below 35^oF temperature ranges.

When the outdoor temperature rises above 35^oF, the occurrence of higher RHs increases, because the capacity of outdoor air for holding moisture increases significantly as the temperature increases. For example, when outdoor temperatures were between 45 and 50^oF, the percentage of RH observations above 45% RH was 35% compared with 12% of the observation above 45% RH during 30-35^oF temperatures.

2.3 CONCLUSIONS FROM INVESTIGATION OF WINTER INDOOR RELATIVE HUMIDITIES

Based on the literature search and especially the SHFV data, the following conclusions concerning the experimental test conditions were made:

- 45% indoor RH during cold weather (below 35^oF) is moderately high (greater than 80% of RH observations from SHFV data were less).

- 50% indoor RH during cold weather (below 35^oF) is very high (less than 5% of SHFV observations were greater).

- 55% indoor RH during cold weather (below 35^oF) is extremely high (less than 1% of SHFV observations were greater).

2.4 POTENTIAL PROBLEMS OF CONDENSATION ON A HORIZONTAL RADIANT BARRIER

If significant amounts of condensation occurred on the underside of a HRB, three problems could occur:

a. The ceiling joists and/or ceiling could experience wood rot and decay.
b. The existing insulation could become wet.
c. Water spots could appear on ceilings.

Wood rot and decay are caused by fungi and can make wood permanently soft and weak. The growth of wood decay fungi is a function of two parameters: wood moisture content and temperatures. The wood moisture content threshold below which fungi will not grow (and therefore wood rot and decay will not occur, no matter what the temperature) is approximately 20%. Above 30%, given the proper temperatures, decay fungi will thrive.

Decay fungi can grow in temperatures from just above freezing to 100°F. These fungi thrive in the moderate temperature range of 50-75°F. Fungi growth is slower at temperatures below 50°F and above 90°F.

If significant amounts of condensation accumulate on the underside of a barrier, the existing insulation could get wet, which would decrease its R-value significantly. This problem may be more serious with blown-in insulations as opposed to batts. Blown-in insulation can become compressed if it becomes wet and would degrade the R-value even when the insulation dries.

The last potential problem is water spots if the condensation is excessive and drips to the ceiling. This problem is probably the least serious of the three, but if there is enough condensation to cause water spots on the ceiling, the previous two problems also may be occurring.

3. EXPERIMENTAL DESIGN

ORNL, DOE, TVA, EPRI, and RIMA formulated an experimental plan that was based on the results of the background literature search concerning moisture in houses. All three Karns houses initially were set up with R-19 unfaced fiberglass batt insulation and perforated HRBs in the attics.

The plan called for changes to be made if the results from one phase indicated that a given humidity condition was either too high, too low, or some happening in the testing pointed to new directions. The SHFV data had shown that 60% indoor RH at 70°F was an extremely high winter indoor humidity (this was also found to be true at Karns) and that a median indoor RH at outdoor temperatures below 35°F was below 35%. The previous winter testing at Karns was conducted at 40% indoor RH with no apparent problems, so we decided to start this testing at 45% RH in houses No. 2 and No. 3, and 55% RH in house No. 1. We also agreed to operate house No. 2 at 45% RH for most of the testing in order to obtain season-long data at constant humidity conditions.

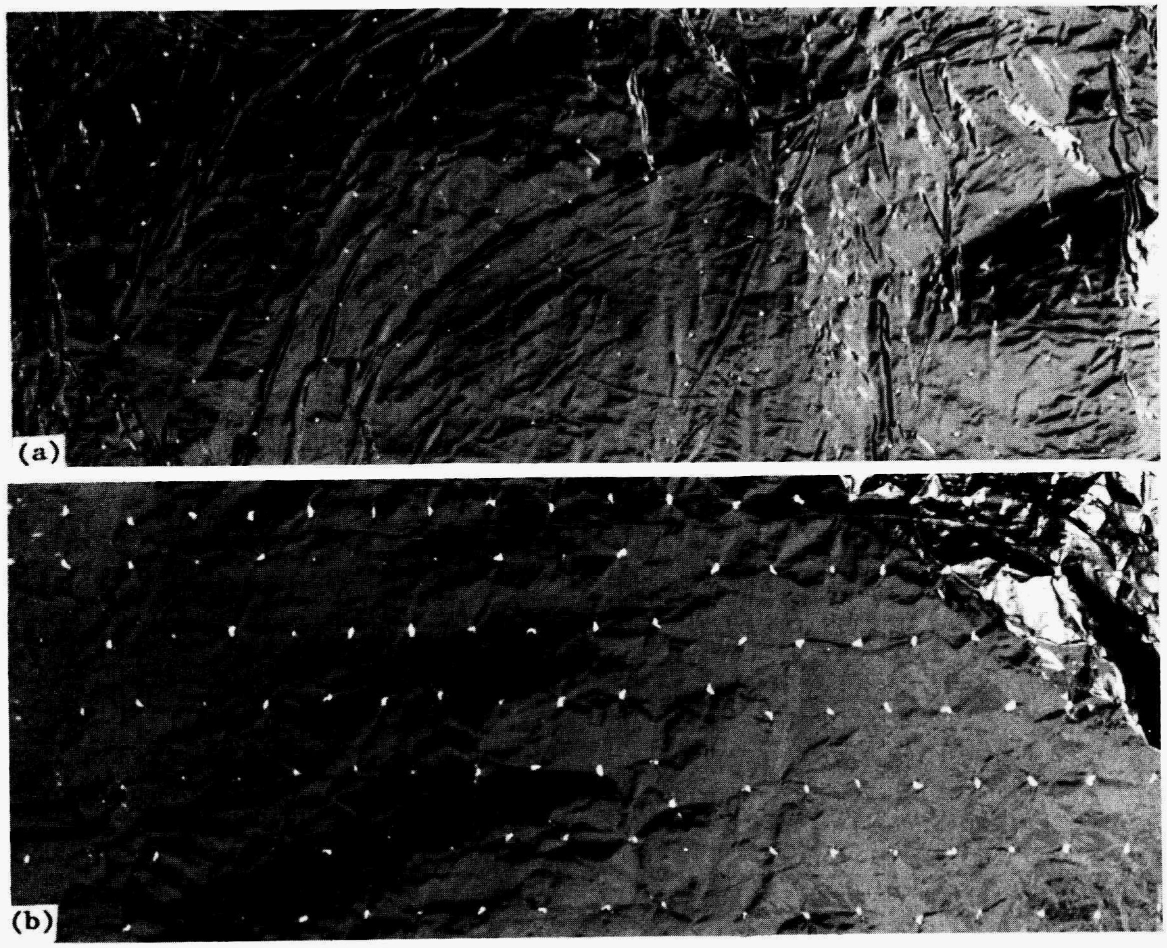
It is somewhat ironic that we were trying to determine the conditions that would lead to a "problem situation" in the houses, yet the definition of a "problem situation" was not clear. Previous experience had shown that condensation on an HRB did not necessarily signify a problem. We agreed that water spots on the ceiling or that insulation saturated with water would indeed signify an immediate problem situation and that the indoor RH should be lowered to alleviate such conditions.

Four different types of measurements were to be made throughout the testing. The first of these was the constant monitoring of many sensors by the data acquisition system. In addition to these, humidity and temperature sensors were placed at three locations in each attic directly above the center of the great room (the humidifiers were located in the great rooms). One set of sensors was put under the insulation on the attic side of the ceiling, the second set was put on the top surface of the attic insulation under the RB, and the third set was hung about 2 feet in the attic air above the HRB.

Visual observations of conditions in the houses, in the attics, and under the RBs were made on an approximate daily basis. The visual observations helped to ensure that the humidity sensors were recording accurate data. Wood moisture content in the bottom chords of the roof trusses (the part under the RB) was recorded manually using a moisture probe each time a visual inspection of attic conditions was made.

The fourth type of data collected was the weight of 12 x 12-in. sections of blotting paper placed at four locations under the RB in each attic. A fifth blotter was fastened to a truss in the open attic air in each house as a control.

The perforated RB material used in this work was different from that used in the 1985-86 winter testing. Although the material had come from the same source, the size of the perforations was different. Figures 3.1(a-b) are photographs of sections of each of the two materials and show the differences in the hole sizes. Table 3.1 compares data obtained from a surface scan analysis of the two barriers. Material #1 had been used in the previous winter testing, and material #2 was used in this current work. Figures 3.2(a-b) are bar graphs depicting the data from Table 3.1. The average hole size had increased from 0.012 to 0.040 in. The percentage hole area increased from 0.05 to 0.46%. The number of perforations in the barrier essentially was unchanged -- the holes were located on about 5/8-in. staggered centers. Also, the holes in material #2 appeared to be more triangular in appearance than those in material #1. We assumed that the manufacturer of the material had increased the hole size to cope with moisture dissipation.

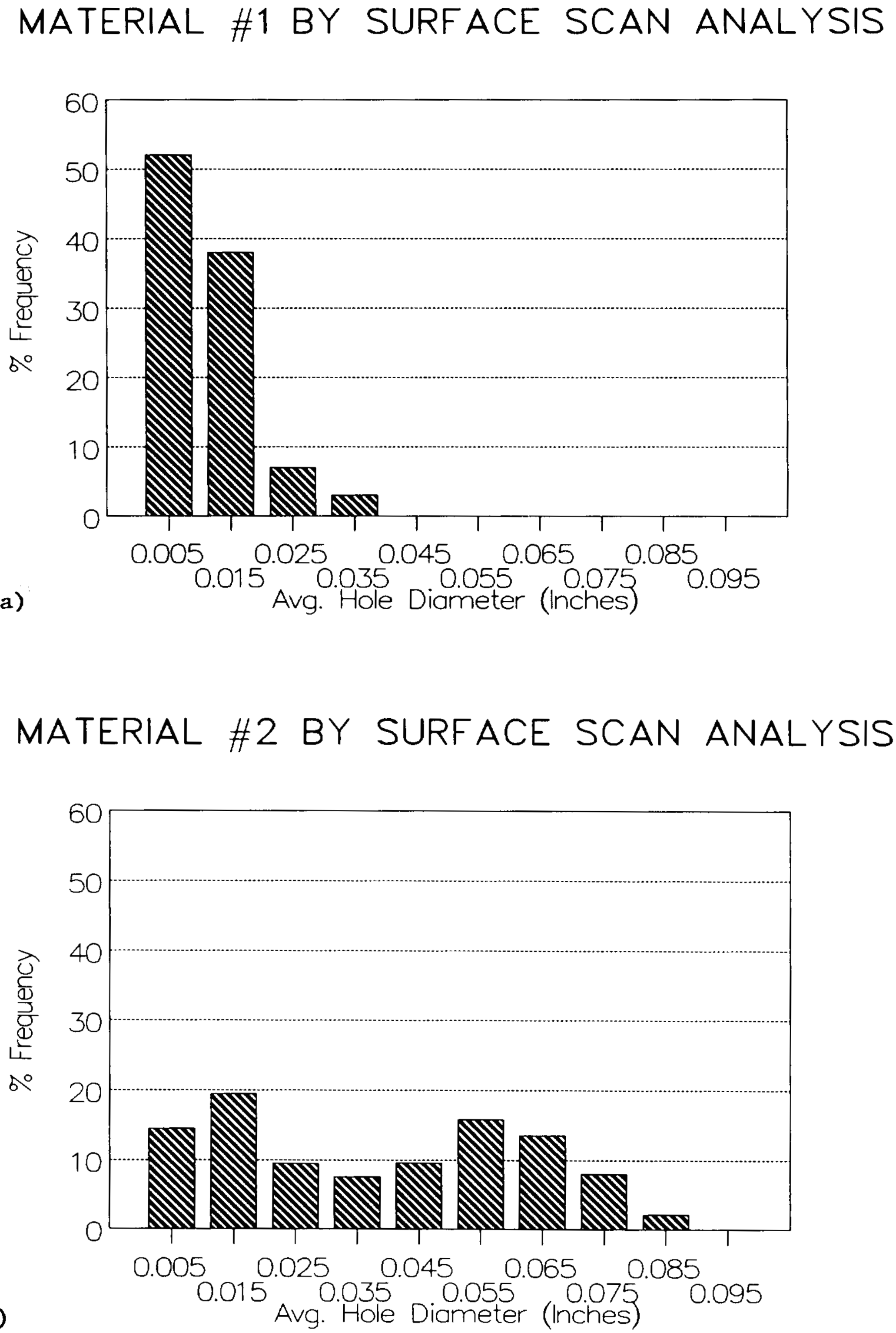


Figs. 3.1 (a-b) Perforated radiant barrier materials with different hole sizes.

Table 3.1 Surface scan analysis results of Karns radiant barrier hole size distributions

	AVERAGE HOLE SIZE (MILS) DISTRIBUTION (%)									Avg Dia	Hole
RB ID	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	(Mils)	Area (%)
1	52.0	38.0	7.0	3.0						12.7	0.05
2	14.5	19.5	9.5	7.5	9.6	15.8	13.5	8.0	2.1	39.9	0.46

Notes: Emissivity RB A = 0.035
Emissivity RB B = 0.035



(a)

(b)

Fig. 3.2(a-b) Hole size distributions in perforated radiant barriers.

The following sections present the findings of the various measurements made throughout the course of the experiment, along with our interpretation of the data. As is usually the case in experimental work, all the data cannot be conveniently presented. Therefore, specific periods will be singled out as being either typical or unique, and detailed comment or analysis carried out on those periods are included. The weather data for all time periods during the testing are presented in Appendix B. Table A.1 in Appendix A contains the average values of various parameters for each weekly period.

4. EXPERIMENTAL RESULTS

4.1 HOUSE HUMIDITY CONTROL

Humidity was added to the houses by means of free-standing humidifiers (Fig. 4.1). A 15-gallon plastic jug next to each humidifier served as a makeup water reservoir to keep the water in each humidifier at the same approximate level. Two floats, located in the left corner of each humidifier, actuated a small solenoid pump when approximately 200 ml of water had been added to the house air. Water was pumped from the plastic jug to the humidifier in this manner. The stroke of each solenoid pump was adjusted to give a constant delivery volume of 2 ml per stroke. Pump repeatability was very good and held constant throughout the winter. Each stroke of the pump generated a pulse that the data collection system used to monitor the dynamic addition of water to each house. Table 4.1 shows the average conditions under which the houses were maintained along with the dates of operation for each phase of the testing.

One thing that became apparent during the testing was that the output capacity of one humidifier (approximately 6 gallons per day) during cold (less than 25°F) weather was not sufficient to maintain the indoor RH at 55% at 70°F. Therefore, during the second phase of the testing, the RH of house No. 3 was raised to 55% and a second humidifier was added to ensure that this high level of indoor RH could be maintained.

Figures 4.2 and 4.3 are plots that illustrate the amount of moisture which was added to house No. 3 and the corresponding outdoor dry bulb temperature for a warm week and a cold week respectively. The cycling of the humidifier is clearly shown in Fig. 4.2, while the essentially constant on condition of the humidifier is shown in Fig. 4.3.

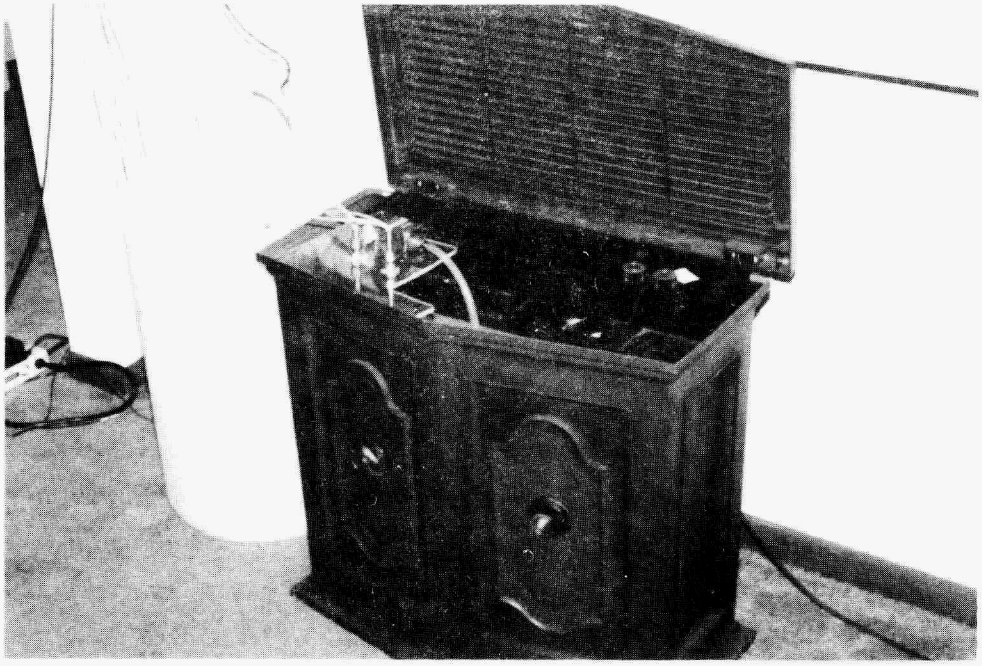


Fig. 4.1 **Humidifier setup used to supply moisture to test houses.**

Table 4.1 Experimental operation for Karns **humidity testing**

Date Start	Date End	Days	Indoor Relative Humidity at 70°F Dry Bulb (%) House No. 1	House No. 2	House No. 3
Dec 04 -	Jan 14	41	53	46	46
Jan 14 -	Feb 04	21	53	46	55 (2 humidifiers used)
Feb 04 -	Feb 18	14	floating[a]	46	55 (vapor barrier in attic)
Feb 18 -	Mar 24	35	floating[a]	46%/half attic vent rate	55 (vapor barrier in attic)
	Total	111			

[a]Approximately 30 lb/day added by humidifier.

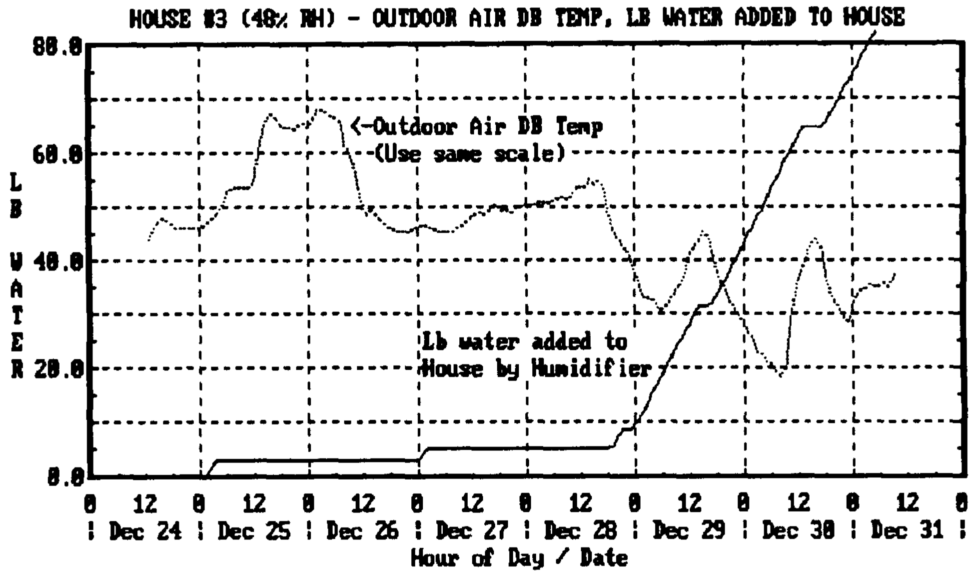


Fig. 4.2 House No.3 (Dec. 24-31) humidifier water addition and outdoor air temperature.

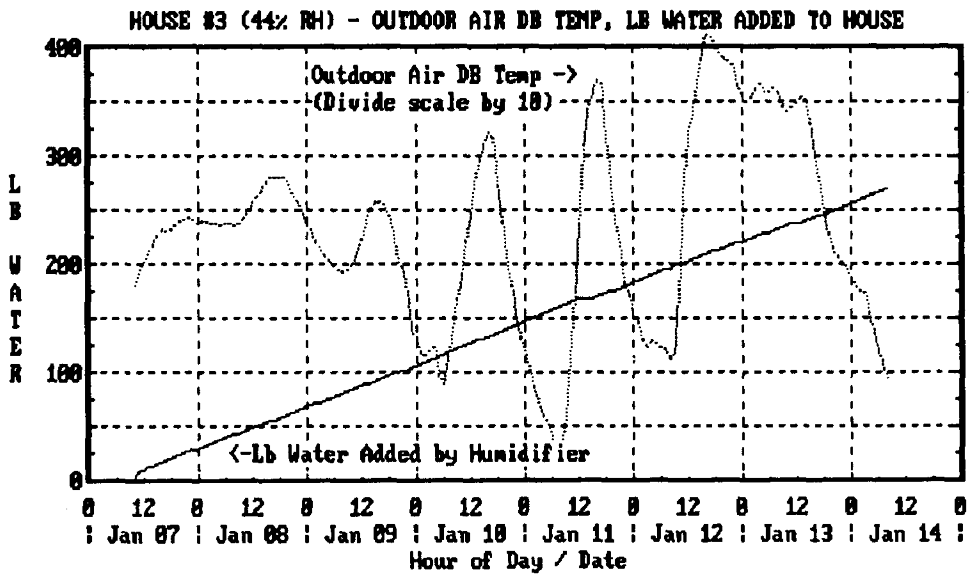


Fig. 4.3 House No.3 (Jan. 7-14) humidifier water addition and outdoor air temperature.

The third phase of the testing was designed to test in house No. 1 the 25 lb/day estimated water generation in a typical home. However, the actual experimental water generation rate was close to 30 lb/day because of humidifier control limits. Also, the unfaced R-19 in house No. 3 was replaced that had R-19 with a kraft paper vapor barrier facing. The RH in house No. 1 was therefore allowed to float, and that in house No. 3 was maintained at 55% with only one humidifier. Figure 4.4 is a time series plot for approximately a week of the inside RH in house No. 1 and the outside temperature. The indoor RH was about 35% at about $7^{o}F$ and 55% at $55^{o}F$. Figure 4.5 shows the cumulative amount of water added to the house air over the same weekly period. Note that the relatively constant slope signifies a uniform rate of water addition to the house.

The same RH conditions in houses No. 2 and No. 3 were maintained in the fourth phase of the testing. The attic vent area in house No. 2 was halved (from 1/150 to 1/300 ratio) by blocking off half of the soffit vents and half of each of the two gable vents. The humidity level in house No. 2 was kept at approximately 45%.

Table 4.2 contains a summary of the humidifier addition of water to the houses along with dates and average indoor RHs. Figures 4.6(a-c) are plots that attempt to show the data in Table 4.2 more clearly and to illustrate that the data are somewhat consistent.

4.2 WOOD MOISTURE CONTENT MEASUREMENTS

The most logical place to start describing the results of the experiments is with the visual observations made throughout the testing. However, while in the attic making visual observations, it was also convenient to take moisture content measurements of sections of the wood truss members which were underneath the RB. Since wood moisture measurements are more quantitative than visual observations, they will be discussed first.

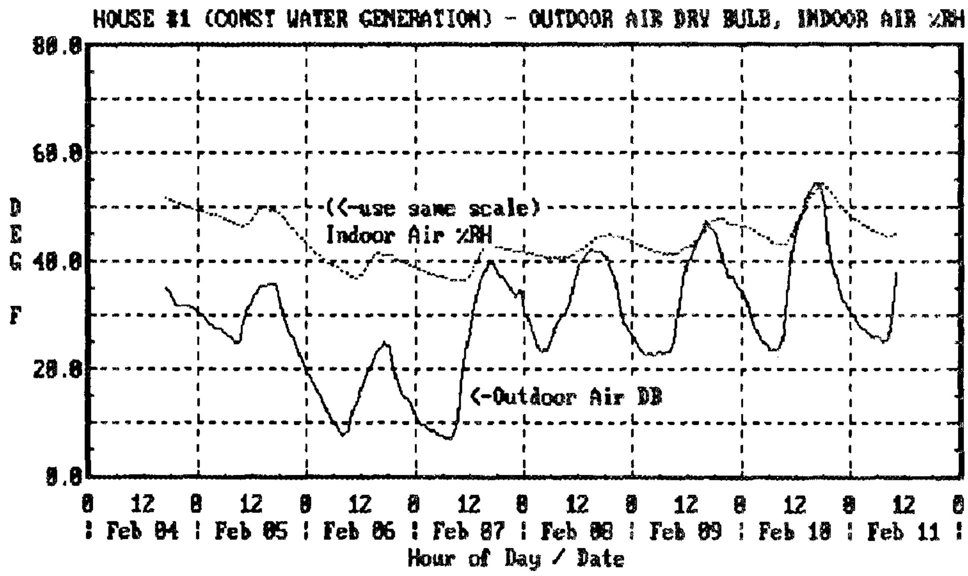


Fig. 4.4 House No.1 (constant water generation)--indoor relative humidity and outdoor air temperature.

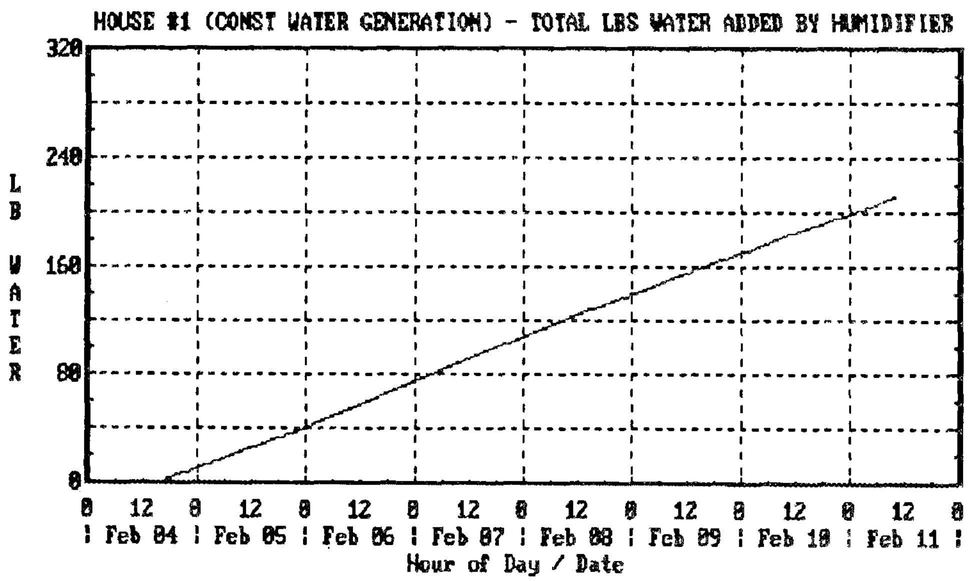
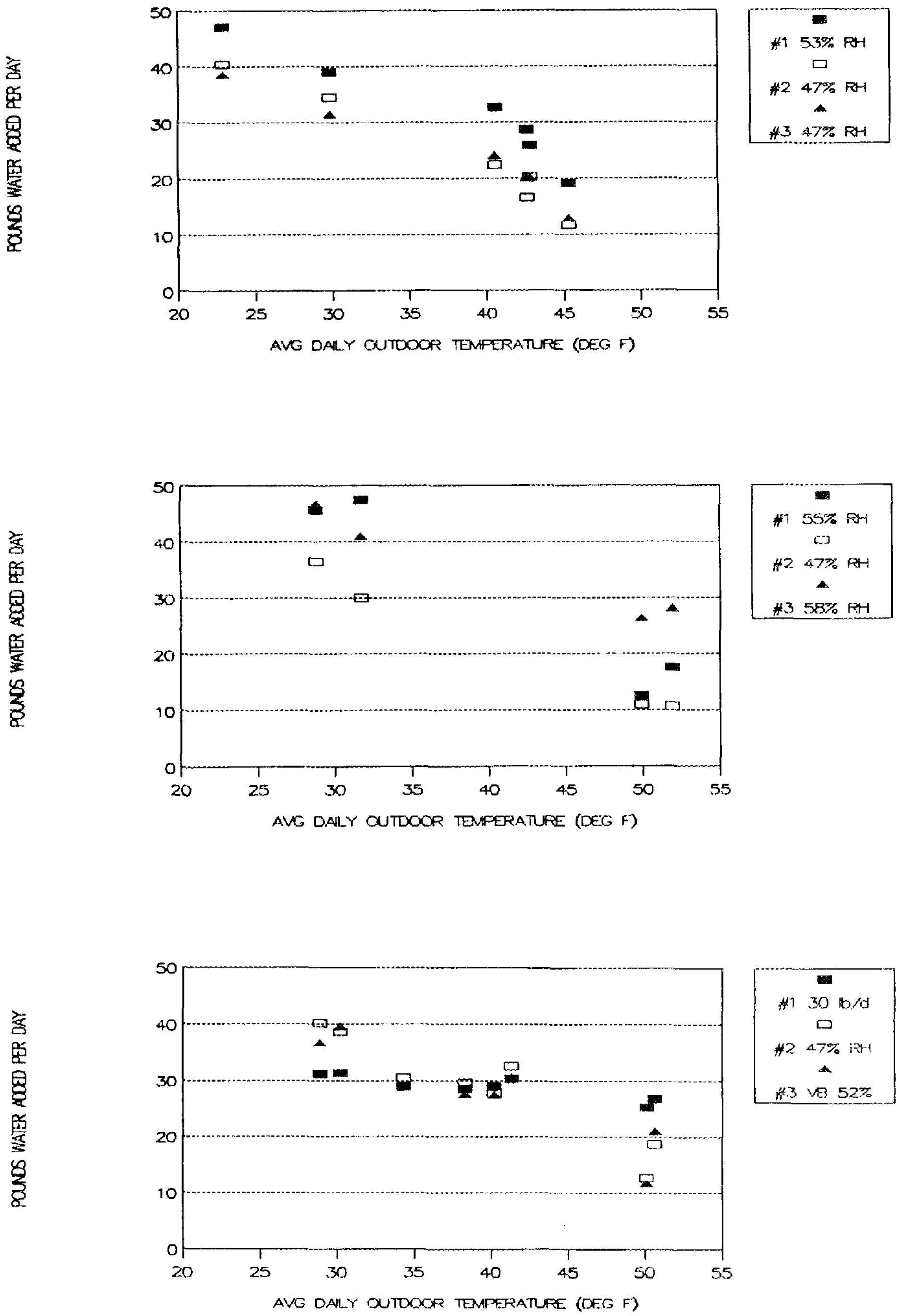


Fig. 4.5 House No.1 (constant water generation)--water input by humidifier.

Table 4.2 Summary of humidifier daily water addition and house relative humidity

	Avg OD	Pounds Water/Day Added to			% Relative Humidity in		
Dates	Temp F	House 1	House 2	House 3	House 1	House 2	House 3
Dec 04-11	42.8	25.8	20.2	20.1	54.2	46.8	50.1
Dec 11-18	40.5	32.6	22.4	24.0	53.7	47.1	47.8
Dec 18-24	42.6	28.7	16.6	20.0	55.7	48.2	49.9
Dec 24-31	45.3	19.1	11.6	12.8	55.4	48.0	48.6
31-Jan 07	29.8	39.0	34.5	31.4	52.7	46.7	46.1
Jan 07-14	22.9	47.2	40.4*	38.5	51.0	47.7	45.3
Jan 14-17	28.8	45.6	36.5*	46.7	54.5	49.1	52.3
Jan 19-21	49.9	12.5	11.0*	26.4	54.1	55.3	64.2
Jan 21-28	31.7	47.5	30.0	41.0	55.1	46.1	55.3
28-Feb 03	51.9	17.6	10.7	28.1	55.2	46.9	63.5
Feb 04-11	28.9	31.2	40.2	36.7	46.0	47.4	50.4
Feb 11-15	30.2	31.3	38.7	39.6	44.0	47.1	53.0
Feb 16-18	34.3	29.1	30.4	28.8	48.3	49.4	53.8
Feb 18-25	40.2	28.9	27.7	27.4	51.5	48.4	54.0
25-Mar 03	41.3	30.4	32.6	30.6	49.4	48.3	53.2
Mar 03-10	50.1	25.2	12.6	11.6	59.5	46.7	53.0
Mar 10-17	38.3	28.5	29.7	27.5	51.6	48.2	54.0
Mar 17-24	50.6	26.8	18.7	20.9	55.2	47.4	56.7

Note: * = Estimated Value



Figs. 4.6 (a-c) Average daily water addition to Karns houses vs average outdoor temperature.

A model J-1/C wood moisture content measuring instrument manufactured by the Delmhorst Instrument Company was used to manually take the moisture content data (Fig. 4.7). The instrument had a range of from 6 to 30 wt% water and was calibrated for Douglas fir at 70°F by the manufacturer. Temperature and wood type (our trusses were made from southern yellow pine -- see Fig. C.2 in Appendix C) corrections had to be made to all readings before they were meaningful. Measurements below 7% moisture content (uncorrected meter readings) are not as accurate as higher readings in the 8-12% range, although Delmhorst states an estimated accuracy of +/-0.5% for the 6-12 wt% range. All moisture measurements were taken in approximately the same four locations in each house (Fig. 4.8).

Table 4.3 is a chronological listing of the uncorrected wood moisture readings taken throughout the testing on the top surface of the bottom attic truss, the top surface temperature of the attic insulation under the RB (assumed to be the same as the top surface of the truss member), and also visual observations of the bottom surface of the HRB.

Figures 4.9(a-c) are plots of the corrected wood moisture measurements made in each of the three houses at location 1 (see Fig. 4.8). The most obvious thing about the plots is that the measurements appear to be very similar. The initial 20 days of data are not plotted because they registered at or just below the lowest (6% uncorrected) range of the meter. However, a best guess of the corrected moisture content during that period would be about 7.5-8.0%. All of the testing periods are plotted, and the moisture content of house No. 1 at 55% RH appears to be slightly higher than that at house No. 2 (46% RH). Also, the presence of a vapor barrier (added for Phase 3 of the testing) in house No. 3 at 55% RH appears to lower the wood moisture content very slightly. The maximum moisture levels peak out at about 11%, which is

Fig. 4.7 Delmhorst probe.

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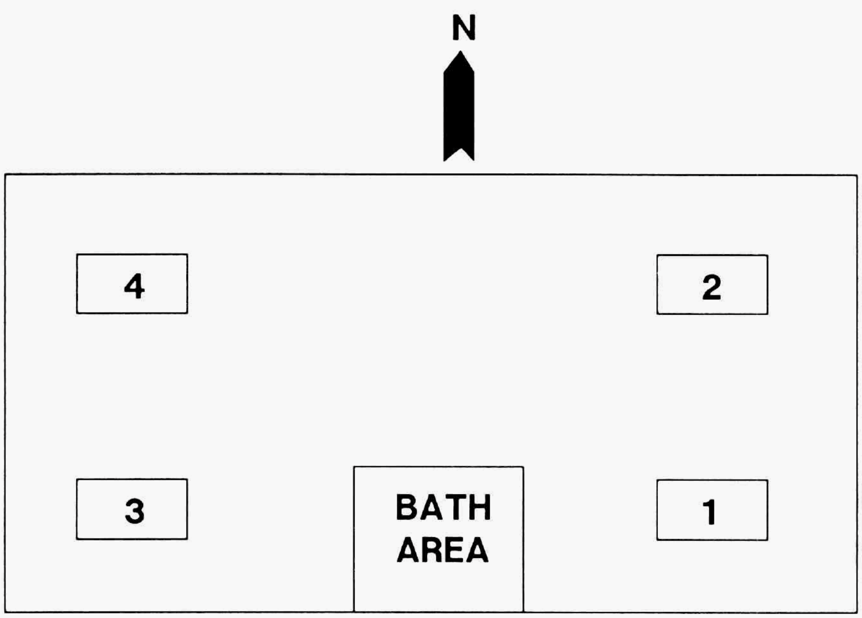


Fig. 4.8 Attic locations of wood truss moisture measurements.

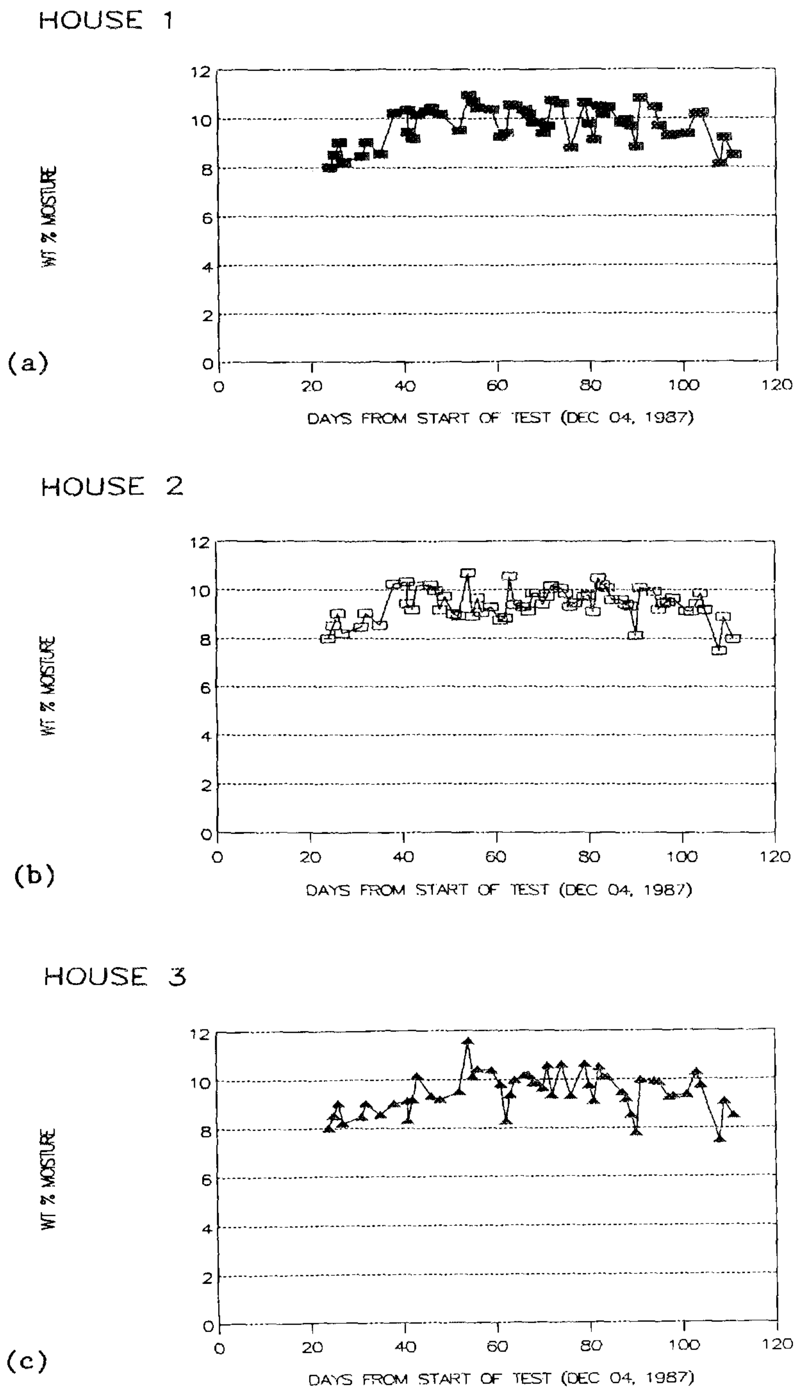
Table 4.3 Moisture measurements of attic trusses under horizontal radiant barriers at Karns using Delmhorst probe

				HOUSE #1				HOUSE #2				HOUSE #3				House #3
Total Days	Date	Time	Temp	1	2	3	4	1	2	3	4	1	2	3	4	Water to Hum
0	04-Dec-87	1200		6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
3	07-Dec-87	0945		6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	
4	08-Dec-87	0930		6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
6	10-Dec-87	0930		6.0				6.0				6.0				
7	11-Dec-87	0830		6.0	(light moist)			6.0	(light moist)			6.0	(light moist)			
10	14-Dec-87	0920		6.0	(dry)			6.0	(dry)			6.0	(dry)			
12	16-Dec-87	1000		6.0				6.0				6.0				
13	17-Dec-87	1115		6.0	(light moist)			6.0	(light moist)			6.0	(light moist)			
14	18-Dec-87	1345		6.0	(med moist)			6.0	(light moist)			6.0	(light moist)			
17	21-Dec-87	1100		6.0	(dry)			6.0	(dry)			6.0	(dry)			
18	22-Dec-87	0900		6.0	(light moist)			6.0	(light moist)			6.0	(light moist)			
19	23-Dec-87	1030		6.0	(light moist)			6.0	(light moist)			6.0	(light moist)			
24	28-Dec-87	1200	58	6.0	(dry)			6.0	(dry)			6.0	(dry)			
25	29-Dec-87	0745	44	6.0	(light moist)			6.0	(light moist)			6.0	(light moist)			
26	30-Dec-87	0830	32	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
27	31-Dec-87	0915	52	6.0	(med moist)			6.0	(light moist)			6.0	(light moist)			
31	04-Jan-88	1030	45	6.0	(med moist)			6.0	(light moist)			6.0	(light moist)			
32	05-Jan-88	0845	32	6.0	(heavy moist)			6.0	(med moist)			6.0	(med moist)			
35	08-Jan-88	0945	43	6.0	(heavy moist)			6.0	(med moist)			6.0	(heavy moist)			
38	11-Jan-88	0900	32	7.0	(heavy moist)			7.0	(heavy moist)			6.0	(heavy moist)			
41	14-Jan-88	0900	30	7.0	(heavy moist)			7.0	(heavy moist)			6.0	(heavy moist)			
				(#1 53% RH)				(#2 46% RH)				(#3 55% RH Hum On @ Low Sp)				
41	14-Jan-88	1345	49	7.0	7.0	7.5	7.5	7.0	7.0	7.5	7.5	6.0	6.0	8.0	8.0	Start Hum On
42	15-Jan-88	1330	55	7.0	(heavy in spots)			7.0	(heavy in spots)			7.0	(heavy in spots)			11.5 Liters
43	16-Jan-88	1510	58	8.0	(med moist)			8.0	(med moist)			8.0	(heavy in spots)			12.0 Liters
45	18-Jan-88	1000	55	8.0	(med,10% deck)											24.0 Liters
46	19-Jan-88	0900	52	8.0	(med,10% deck)			7.8	(v light spots)			7.0	(med, 10%deck)			14.0 @ 1500
47	20-Jan-88	1500	62					8.0	(dry, wet bath)							11.0 Liters
48	21-Jan-88	1000	55	7.9	(lt,spots,bath)			7.0	(vlsp,9%deck)			7.0	(light, med bath)			12.0 @ 1530
49	22-Jan-88	1400	50					7.3	(dry lt over bath)							12.0 Liters
50	23-Jan-88	1330	58													12.0 Liters
51	24-Jan-88	1410	65					7.2	(dry lt over bath)							12.5 Liters
52	25-Jan-88	0900	48	7.0	(med)	8.0	8.0	6.5	(dry)	6.5	6.5	7.0	(med)	7.0	8.0	12.75 @ 1400
53	26-Jan-88	1030	32													10.5 Liters
54	27-Jan-88	1100	30	7.5	(heavy)			7.3	(med)			8.0	(heavy)			14.0 @ 1400
55	28-Jan-88	0915	35	7.5	(med-hvy)		7.5	6.0	(med)		7.0	7.0	(med-hvy)		7.0	12.75 @ 1400
56	29-Jan-88	1415	52	8.0	(med,dry spots)			7.3	(dry,lt spots)			8.0	(med)			11.5 Liters
57	30-Jan-88	1230	58					7.0	(dry)							12.0 @ 1500
59	01-Feb-88	0945	58	8.2	(dry)			7.2	(dry)			8.2	(dry-med bath)			22.0 @ 1300
60	02-Feb-88	1400	64													8.5 Liters
61	03-Feb-88	1335	66	7.5	(dry)	7.5	7.0	7.0	(dry)	7.0	7.0	8.0	(lt spots)		9.5	9.5 @ 0900
62	04-Feb-88	1300	50	7.0	(dry)	7.0	7.0	6.5	(dry)	7.0	7.0	6.0	(dry-no HRB)			Avg=11.84L/d
				(#1 Hum Full ON-Low Sp)								(#3 R-19/Vap Barr)				(or 26.1 #/d)
63	05-Feb-88	1020	38	7.5	(lt-med)			7.5	(very lt)			6.5	(80% dry-wet areas)			
64	06-Feb-88	1600	50	8.0	(dry, wet bath)			7.0	(dry,wet areas)			7.5	(dry,wet areas)			

Table 4.3 (continued)

Total Days	Date	Time	Temp	HOUSE #1 1	2	3	4	HOUSE #2 1	2	3	4	HOUSE #3 1	2	3	4	House #3 Water to Hum
66	08-Feb-88	1415	58	8.2 (dry, lt areas)				7.2 (dry, wet bath)				8.0 (dry, wet bath)				
67	09-Feb-88	1430	62	8.2 (dry, wet bath)				7.2 (dry, wet bath)				8.2 (dry, wet bath)				
68	10-Feb-88	0830	40	7.0 (light)				7.0 (lt, dry areas)				7.0 (lt, dry areas)				
69	11-Feb-88	0930	40	7.0 (lt)		7.0	7.0	7.0 (lt)		7.0	7.0	7.0 (lt)		8.0	7.0	
70	12-Feb-88	1345	45	6.8 (lt,spotty)				6.8 (lt,spotty)				7.0 (dry,wet bath)				
71	13-Feb-88	1000	38	6.8 (dry,wet bath)				6.8 (lt,spotty)				7.5 (lt,spotty)				
72	14-Feb-88	1115	46	8.0 (lt,spotty)				7.5 (lt,spotty)				6.8 (dry,wet areas)				
74	16-Feb-88	1400	60	8.5 (dry,wet bath)				8.0 (dry)				8.5 (dry,wet bath)				
75	17-Feb-88	0920	40					7.0 (light,dry spots)								
76	18-Feb-88	1300	65	7.0 (dry)			7.0	7.5 (dry)			8.0	7.5 (dry)			7.5	
				(#1 Hum Full ON-Low Sp)				(#2 1/2 Vent Area)				(#3 R-19/Vap Barr)				
77	19-Feb-88	1000	54					7.2 (dry)								
79	21-Feb-88	1030	48	8.0 (lt,spotty)				7.2 (dry,lt bath)				8.0 (light)				
80	22-Feb-88	0900	42	7.0 (lt-mod)			7.0	7.0 (lt,spot)			7.0	7.0 (med,spot)			7.5	
81	23-Feb-88	0815	57	7.0 (med)			7.0	7.0 (light)			7.0	7.0 (med,spot)			7.5	
82	24-Feb-88	0830	27	7.0 (med)			7.3	7.0 (med)			7.0	7.0 (med)			7.3	
83	25-Feb-88	0915	40	7.3 (lt-med)			7.3	7.3 (lt-med)			7.0	7.2 (med)			7.3	
84	26-Feb-88	0930	40	7.5 (lt-med)				7.2 (lt-med)				7.2 (lt-med)				
85	27-Feb-88	0900	51					7.2 (dry)								
87	29-Feb-88	1200	71	8.2 (dry-vlt bath)				8.0 (dry)				7.9 (lt,spotty)				
88	01-Mar-88	1130	63	8.0 (dry-vlt bath)				7.5 (dry)				7.3 (dry-lt bath)				
89	02-Mar-88	0800	44	7.0 (dry-lt sp)				6.7 (dry)			7.0	6.0 (sp,lt-med)				
90	03-Mar-88	1230	64	7.0 (dry)			7.0	6.3 (dry)			7.0	6.0 (dry)			6.8	
91	04-Mar-88	1040	62	8.8 (dry)				8.1 (dry)				8.0 (dry)				
94	07-Mar-88	1050	63	8.5 (dry-lt bath)				8.0 (dry)				8.0 (lt-spotty)				
95	08-Mar-88	1425	81	8.5 (dry)				8.0 (dry)				8.7 (dry)				
96	09-Mar-88	1425	70					7.8 (dry)								
97	10-Mar-88	0945	53	7.0 (dry)			7.5	7.2 (dry)			7.0	7.0 (dry)			7.0	
98	11-Mar-88	0930	52	7.0 (dry)			7.2	7.3 (lt,spot)			7.0	7.0 (lt-med)			6.8	
101	14-Mar-88	0930	51	7.0 (lt bath)			7.1	6.8 (v light)			7.0	7.0 (light)			7.0	
102	15-Mar-88	1510	57					7.0 (dry)								
103	16-Mar-88	1055	55	7.9 (dry,lt bath)				7.2 (dry)				8.0 (dry,wet bath)				
104	17-Mar-88	1015	52	7.8 (dry,wet bath)				7.5 (lt,spotty)				7.4 (lt,spotty)				
105	18-Mar-88	1500	55					7.0 (dry)								
108	21-Mar-88	1530	89	7.2 (dry)			7.0	6.5 (dry)			7.0	6.5 (dry)			7.0	
109	22-Mar-88	0915	57	7.1 (dry)				6.8 (dry)				7.0 (dry)				
111	24-Mar-88	1245	73	7.0 (dry)			7.0	6.5 (dry)			7.0	7.0 (dry)			7.0	

Note: Wood moisture measurements shown are not corrected for wood type or temperature. Measurements were taken at identical locations in each attic. Visual observations of radiant barrier surface are in parentheses.



Figs. 4.9 (a-c) Measured attic truss moisture (wt%) under horizontal barriers.

well below the maximum fiber saturation value of about 28-30%. These moisture levels are very similar to those reported for the winter in a New Jersey house[1] with no RBs installed.

Figure C.2 in Appendix C is a drawing of an attic truss at Karns. Since each truss weighs approximately 180 lbs and there are 21 trusses in the attic over the living area, an estimate of the total water absorbed by the attic trusses in the winter may be calculated. Assuming a uniform moisture content rise from 7 to 11%, the additional water absorbed by the wood trusses is

$$180 \times 0.04 \times 21 = 151.2 \text{ lbs} \quad .$$

This value seems rather small compared with the amount of water added to the houses by the humidifiers (discussed in the following sections).

It should also be mentioned that random wood moisture content readings taken on the upper (above the HRBs) truss members were not significantly different from those of trusses below the barrier; on several occasions they were actually higher than those under the barrier. Also, there is a diurnal cycle to the readings (especially those in the open attic), which appeared to be higher in the early morning than in the afternoon. This variance is probably the result of higher temperatures and increased attic ventilation during the day (the weather plots in Appendix B show the wind usually blowing stronger during the day than at night) and colder temperatures and lower ventilation rates at night and in the early morning.

One item of importance that was not measured (it was simply overlooked) during the testing was the dimensional stability of the trusses. Dimensional changes in trusses can cause ceilings to crack if they are plaster or to become wavy if the ceilings are gypsum board. It did seem that the gypsum board ceilings at Karns appeared slightly wavy in certain rooms during cold weather, but they seemed to be just as wavy in the latter part of July. No definite statement of the degree of wave can be made for the comparison before, during, and after testing.

4.3 VISUAL OBSERVATIONS

Visual observations were made in the attic of each house by the actual lifting of sections of the barrier to see if any condensation was present on the underside of the HRB and if so, how much. The "how much" part of the observation was, of course, a subjective judgment on the part of the observer, but an effort was made to consistent (Table 4.3). Some observations were made in the morning and some in the afternoon, and on many days we made both (although only one is noted in Table 4.3). The most obvious conclusion from the observations is that moisture conditions change in the course of a day, especially if the sun is shining. Usually when moisture was detected on the under surface of a barrier in the morning, it was dry (or at least much less wet) in the afternoon.

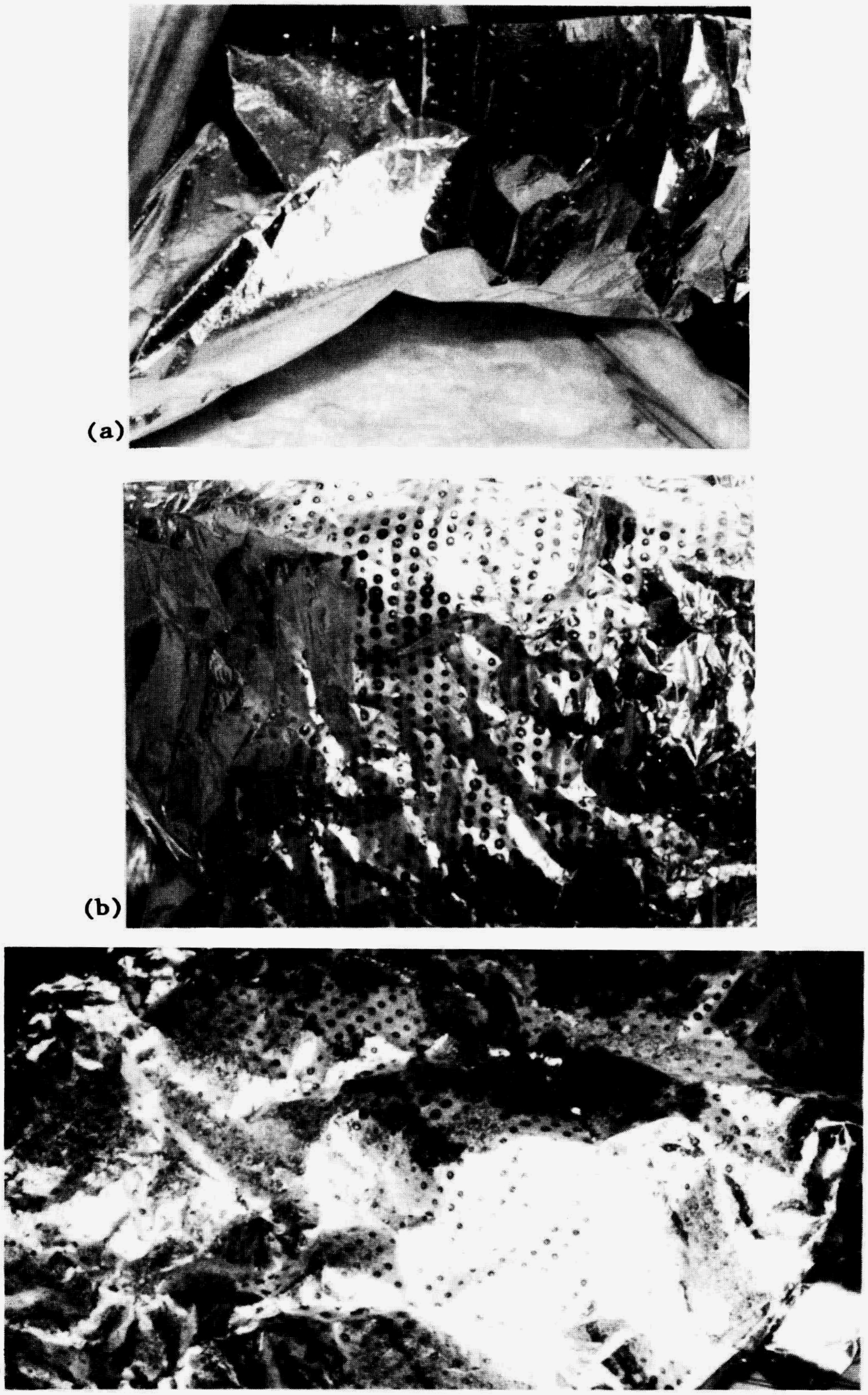
Figures 4.10(a-c) are photographs (taken in the morning hours) of a dry RB, a moderately wet RB, and a heavily wet RB taken during the course of the testing. The perforations do show on the dry barrier [Fig. 4.10(a)]. The moderately wet barrier, Fig. 4.10(b), presents an interesting story, because dry circular areas surround most of the perforations on the barrier, indicating that condensed moisture was being vaporized and was passing through the perforations into the attic air. Evidently perforations in an RB do facilitate the transfer of moisture from an HRB to the attic air.

Figure 4.10(c) shows a barrier with a heavy amount of condensation on the underside. Drops of water can be seen in several locations on the barrier, and several large drops also can be seen on the top surface of the insulation. No significant dry areas are visible around

(a)

(b)

(c)



Figs. 4.10 (a-c) Photographs of dry/wet horizontal radiant barriers.

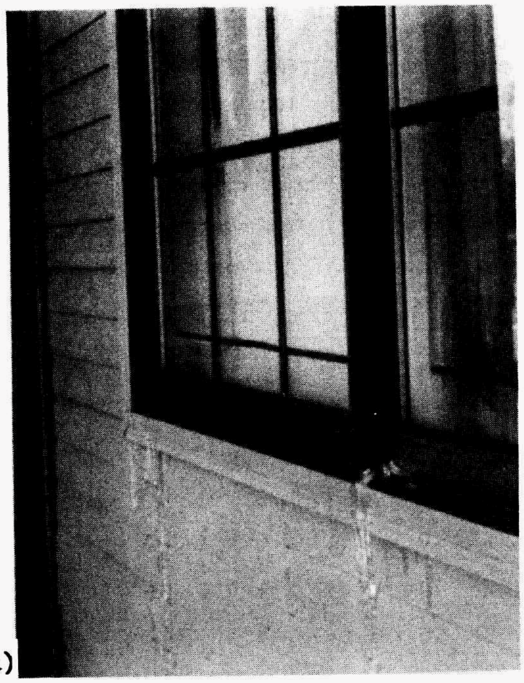
the perforations, leading one to conclude that moisture is forming on the barrier much faster than it can be dissipated. Therefore, a net accumulation of moisture was taking place at that time.

It should be noted that at no time in the course of the experiment was any moisture noticed on the underside of the insulation nor were any wet spots noted on either side of the ceiling. Any moisture that was on the attic insulation appeared to penetrate it no deeper than 1/8-in. or less. As noted above, moisture shedding conditions (either partial or complete) usually occurred during the warmer afternoon hours.

The attics themselves were hardly ever uniformly wet during the testing. The central part of the attic over the bathroom area was the most moist area in each of the three houses. There are more ceiling penetrations into the attic in this area due to bathroom fans and sewer vent pipes than elsewhere in the house. The periphery of the houses adjacent to the walls was probably the driest area. Many of the observations varied with both dry and wet areas in the same attic.

One particularly cold week during the testing (January 7-14) when the average outside temperature was 23^{o}F, to our visual observations, the heaviest moisture conditions occurred (Table 4.3). As the weather warmed up in the following weeks, the moisture level decreased significantly.

In addition to attic conditions, one of the more significant observations was the condition of the windows. Often one could predict how the underside of an HRB would appear in the attic by observing the amount of condensation on the windows inside the house. Figures 4.11(a-b) are photographs taken on a cold January morning of the great room window in house No. 3, with an indoor RH of 55%. The icicles on the outside window frames formed from condensed water leaking from the inside of the double-pane windows. Conditions were the same at the



(a)

(b)

Figs. 4.11 (a-b) Photographs of house No.3 windows with condensation.

other two houses during this period. The plaster board on the lower inside of the window frame was extremely moist in house No. 3 during these cold periods. Clearly, 55% RH is much too high an indoor humidity to maintain in a house during cold periods. Figure 2.1 shows that the inside dew point is 55°F when the inside dry bulb temperature is 70°F and the RH is 55%.

Short-term bathroom shower simulation tests were conducted in house No. 1 (constant moisture generation of 30 lb/day conditions) and house No. 3 (55% RH) on February 26 at about 10 a.m. The shower water temperature was adjusted to about 105°F, the bathroom fan was turned on, and the bathroom door was closed in each house. A 20-minute shower was simulated in this manner, while conditions were observed in the attic. The fan/ceiling light fixtures were not vented above the insulation or the RB, although neither insulation nor RB covered the vent/fixture (there was a 1-in. cutout around it). A moisture plume from the fan exhaust was visible in the attic, condensation rapidly formed on the RB in the vicinity of the exhaust, and the insulation became wet. Obviously, this was not a good situation for the attic. A quick calculation showed that approximately one-half to one pound of water was capable of being vented into a small area of the attic during this 20-min. period. Two hours later, some insulation was still wet, and spotty condensation was on the barrier of house No. 1, while house No. 3 showed both wet insulation and a wet barrier. At 3 p.m., these conditions at house No. 1 were completely dry, while house No. 3 still had some wet insulation but a dry barrier.

These tests show that to avoid any condensation problems, the bathroom fans should be vented at least to above the surface of any insulation and any RB that are present and preferably vented to the outside of the attic. Also, since the bathroom area was always the wettest area in the attic, any protrusions there from vent pipes, light fixtures, etc., should be well sealed at the edges with a proper caulk or sealant.

The unfaced R-19 insulation in house No. 3 was removed on February 4, and kraft paper faced R-19 fiberglass batt insulation was installed in its place. The kraft paper facing is a vapor barrier for this insulation and is intended to impede moisture transport between the house living area and the attic. The RH was maintained at 55% in house No. 3. During the remainder of the visual observations, the RH of house No. 3 appeared to be similar to that of house No. 2, which was at 46%. The vapor barrier was evidently more effective at keeping moisture transport levels lower in the attic of house No. 3 (with a vapor barrier) than house No. 2 with the same R-value insulation (without a vapor barrier).

The humidity level in house No. 1 was altered from 53% to a constant daily input of approximately 30 lb. This adjustment was to simulate the estimated amount of moisture generated by a family of four (Sect. 2). On February 4, the humidifier in house No. 1 was set to run continuously at a low fan speed setting. The humidity level in house No. 1 fluctuated as a function of the outdoor temperature. Figure 4.4 in Sect. 4.1 shows the variation of the inside RH in house No. 1 with the outside temperature. Visual observations for the same time period showed the amount of condensation under the barrier in the attic roughly equivalent to that in house No. 2 at 46%. The amount was equivalent in house No. 3 at 55% and this house had a vapor barrier.

In summary, the visual observations made during the course of the high humidity testing showed that moisture does condense on the underside of an HRB during cold weather periods. However, the moisture vaporized partially or completely in the afternoon hours, especially if the outdoor temperature rose above 40°F. Condensation on windows gives a good indication that it will be present on the underside of an HRB. An inside RH of 55% (at 70°F) is too high a value during cold weather periods, as window frames tend to get wet as well as interior wall areas. The exhaust from vent fans should be vented at least above any insulation and any HRB, with outside venting preferred. Areas around the edges of ceiling-mounted light fixtures and pipes protruding into the attic should be sealed properly. A vapor barrier helps to reduce the amount of moisture entering the attic from the house living area. Moisture generation levels simulating occupied houses produced RHs ranging from 35 to 55% during Tennessee cold and warm winter weather, respectively. Heavy condensation on the barriers noted.

4.4 BLOTTING PAPER WEIGHINGS

Four sections of 12 x 12-in. blotting paper (each section weighed approximately 40 g when dry) were placed in the attic of each house on the top surface of the insulation under the RB in proximity to those locations where the wood moisture measurements were made. A fifth control blotter was pinned to an attic truss so that it was exposed to the free attic air space. Figure 4.12 is a photograph of one of the control blotters in place. It was thought that the blotters would indicate any moisture accumulation that might occur in the insulation under the barriers. The control blotter would be reference for any changes in blotter weight that occurred as a result of natural attic ambient conditions.

The blotters were removed from their locations at approximate one-week intervals, weighed on a triple beam balance, and returned to their respective attic locations for another weekly cycle. Table 4.4 contains a summary of the average blotter weight changes, while Figs. 4.13(a-b) in the bar graph form depict the weight changes. Table A.3 in Appendix A contains a complete listing of each individual weighing, which indicates variation in the blotter weights. This result agrees with the conclusions from the visual observations that the attics were not uniform so far as moisture content is concerned.

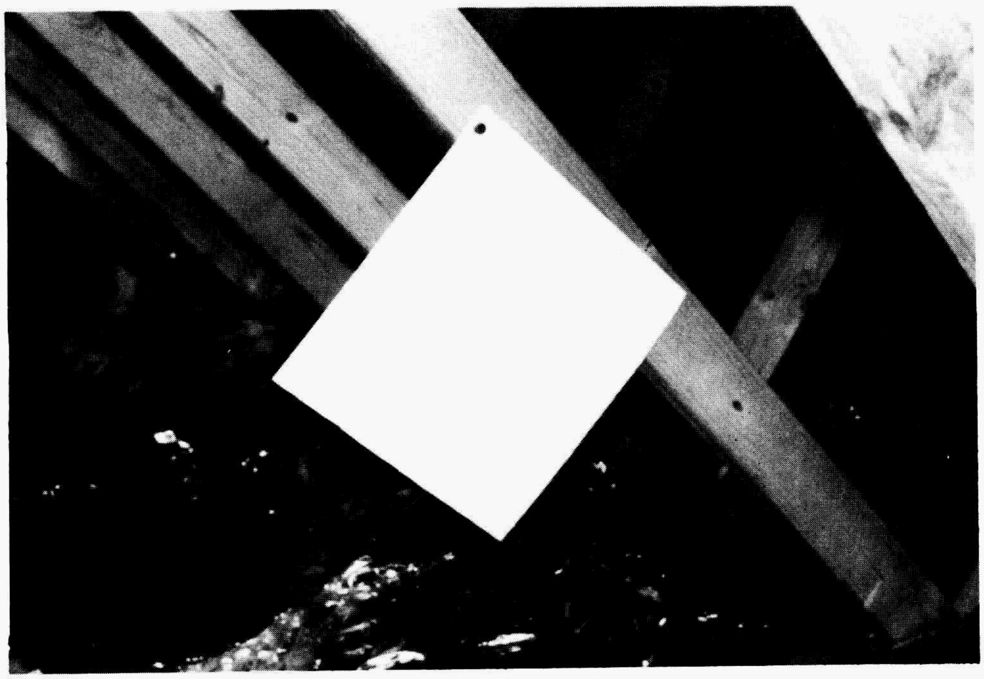
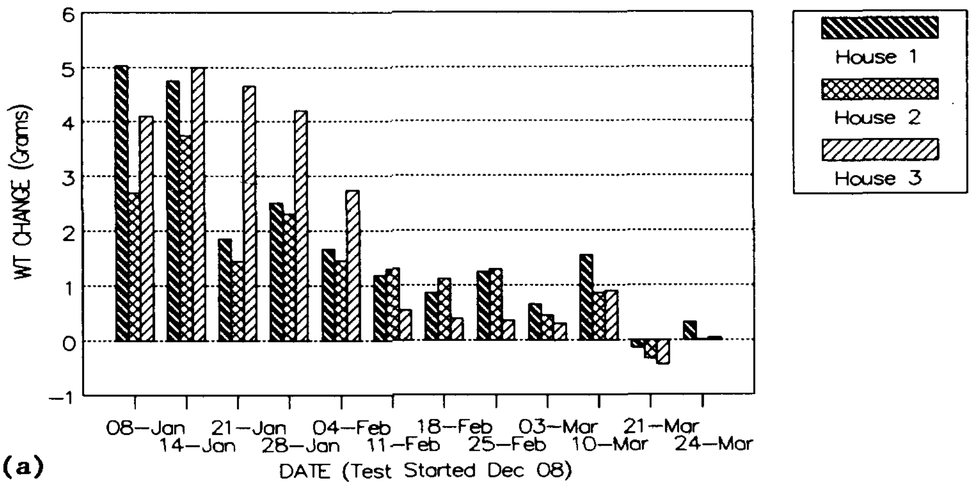


Fig. 4.12 Photograph of attic control blotter.

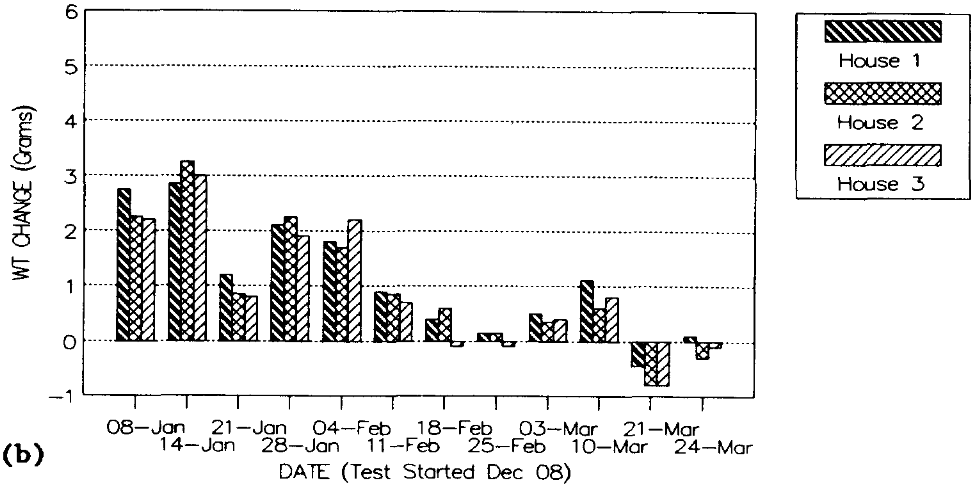
Table 4.4 Summary of blotter paper weighings at Karns

	Average of Four Under HRB Wt. Change in Grams			Control (in Attic Air) Wt. Change in Grams			(Blotter Under HRB - Control) Wt. Change in Grams		
Date	House 1	House 2	House 3	House 1	House 2	House 3	House 1	House 2	House 3
23-Dec	2.61	1.84	2.10	----	----	----	----	----	----
08-Jan	5.03	2.69	4.10	2.75	2.25	2.20	2.28	0.44	1.90
14-Jan	4.76	3.74	5.00	2.85	3.25	3.00	1.91	0.49	2.00
21-Jan	1.84	1.44	4.65	1.20	0.85	0.80	0.64	0.59	3.85
28-Jan	2.50	2.30	4.20	2.10	2.25	1.90	0.40	0.05	2.30
04-Feb	1.66	1.45	2.73	1.80	1.70	2.20	-0.14	-0.25	0.53
11-Feb	1.19	1.30	0.54	0.90	0.85	0.70	0.29	0.45	-0.16
18-Feb	0.86	1.12	0.39	0.40	0.60	-0.10	0.46	0.52	0.49
25-Feb	1.24	1.29	0.36	0.15	0.15	-0.10	1.09	1.14	0.46
03-Mar	0.65	0.45	0.30	0.50	0.35	0.40	0.15	0.10	-0.10
10-Mar	1.54	0.86	0.90	1.10	0.60	0.80	0.44	0.26	0.10
21-Mar	-0.14	-0.34	-0.44	-0.45	-0.80	-0.80	0.31	0.46	0.36
24-Mar	0.32	0.01	0.04	0.10	-0.30	-0.10	0.22	0.31	0.14

Notes: Each house had four 12"x12" blotters under HRB.
Each blotter initially weighed approximately 40 grams.
Initial blotter weighings were at 70 Deg F and 45% RH.
Control blotters added in attic air space on 22-Dec.



(a)



(b)

Figs. 4.13 (a-b) Average weight changes in blotters in Karns attics.

Figure 4.13(a) shows the weight changes of the blotters under the HRB, while Fig. 4.13(b) shows the weight changes of the control blotters. Figure 4.14 is a comparison between the two plots, showing the interesting result that the change in the weight of the blotters under the barrier was not much different than the control blotters. On those occasions when there is a significant difference between the weight changes from under the HRB blotter and the control blotter, the weighings showed that one of the four blotters in the attic had wet areas on it (Table A.2). The wet areas were caused by condensation dripping from the HRB. Table A.4 also shows that the attic is not uniform in its moisture content; some areas appear to be wetter than others. This fact agrees well with the conclusion drawn from visual observations.

A comparison of Figs. 4.13 and 4.14 with Table 4.2 shows that the average Under Horizontal Radiant Barrier Blotter (UHRBB) weight gains are higher for higher indoor humidities than for lower humidities. This comparison is in agreement with the visual observations. The period from February 18 - March 24 for house No. 2 at a reduced attic ventilation area ratio (1/300 compared to the normal 1/150 ft^2 effective vent area per ft^2 attic floor area) shows a slight relative increase in the UHRBB weights compared to that of house No. 3 from the preceding two weeks (February 4-18). This increase suggests that the higher attic vent rate may be helpful in reducing the accumulation of moisture in the attic. However, the differences are slight, since the absolute values of the weight gains are small. Colder weather over an extended period would probably accentuate the difference.

A quantitative interpretation of the blotter weighings is not very straightforward. If one assumes that the UHRBB weight gain is equal to the amount of water retained by each square foot of attic insulation, then a surprisingly small amount of water is contained in the attic insulation. For instance, a weight gain of 5 g/ft^2 would amount to

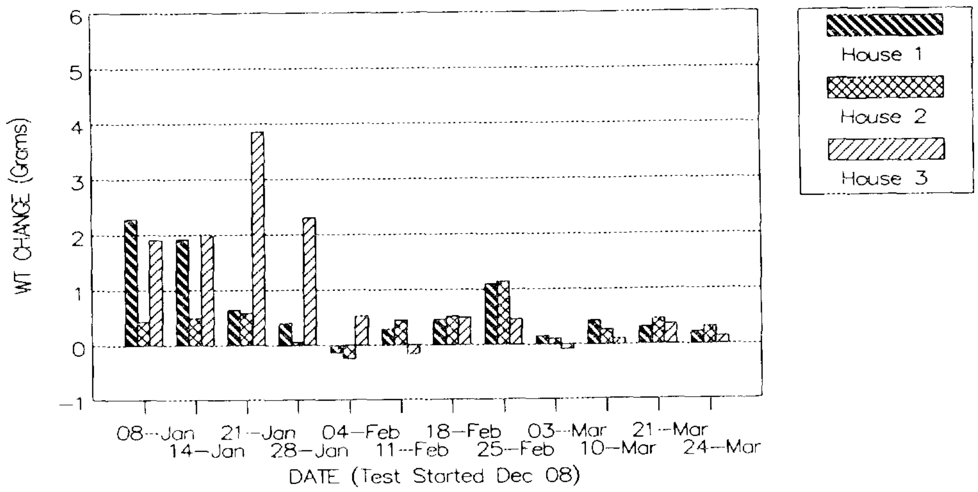


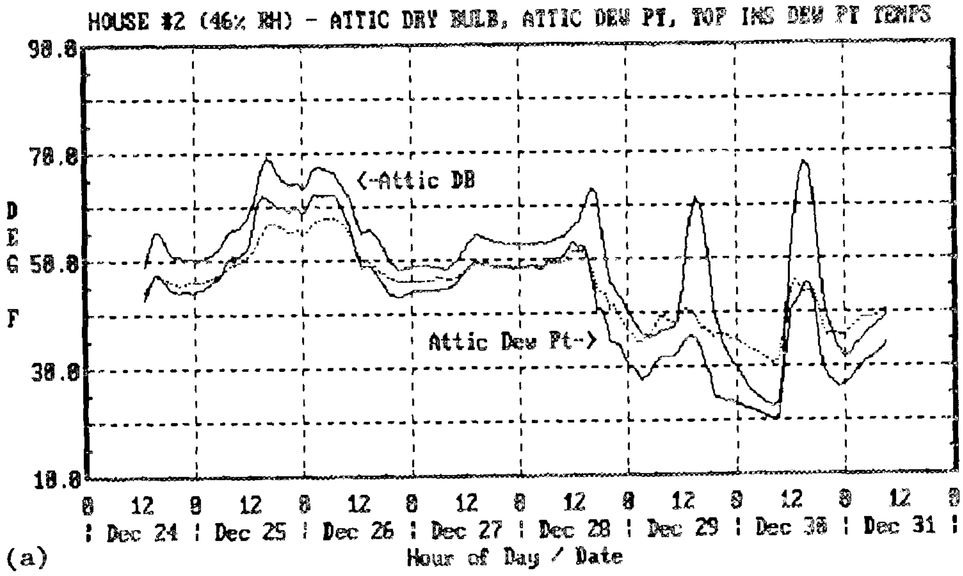
Fig. 4.14 Difference in weight between blotter under horizontal radiant barrier and control blotter.

13.2 lbs or 1.6 gallons of water in the 1200 ft^2 attic. However, if one assumes that each equivalent thickness of insulation contains the same amount of moisture as the UHRBB, then a surprisingly large amount of water is contained in the attic insulation. The same UHRBB weight gain of 5 g/ft^2 would amount to 2505 lbs or 300.4 gallons of water in the attic (the blotting paper is 0.033-in. thick and the insulation was 6.25-in. thick). The latter amount is obviously too high and the former is perhaps too low. The authors believe that the low amount is somewhat close to the actual weight of condensed water that drips from the HRB to the insulation below it.

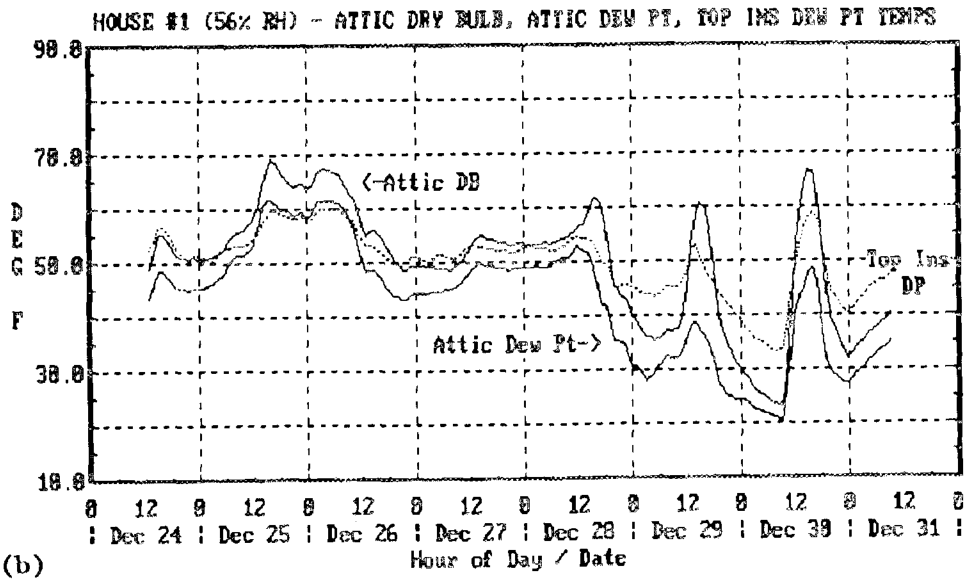
In summary, the blotter weighings do show that moisture is able to drip off the HRB onto the insulation and that certain areas of the attic are wetter than others. More moisture accumulates in cold weather periods than during warm weather periods and a diurnal cycle is definitely in operation. The attic insulation moisture level appears to return to its pre-winter value when spring arrives. Higher inside RH values result in higher moisture content of the blotters, and a vapor barrier in the attic reduces the weight gain of the blotters compared to the gain in an attic with no vapor barrier. Reducing the attic ventilation area ratio from 1/150 to 1/300 appears to increase the UHRBB weights slightly.

4.5 RADIANT BARRIER CONDENSATION AND INSTRUMENT DATA

The test houses and their attics were well instrumented, and the data collected from these measurements can quantitatively describe the RB condensation and vaporization processes that were taking place during the course of the experimental testing. RH sensors and dry bulb temperature sensors were located in the attic under the insulation, on top of the insulation under the HRB, and 12 in. above the HRB in the attic free air space. All sensors were in the same vertical space approximately above the center of the great room. Figures 4.15 to 4.17

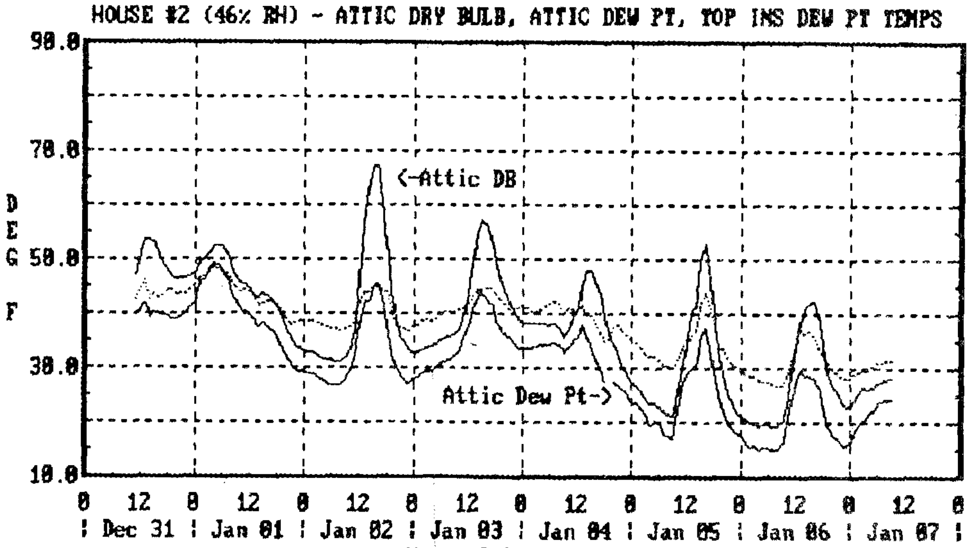


(a)

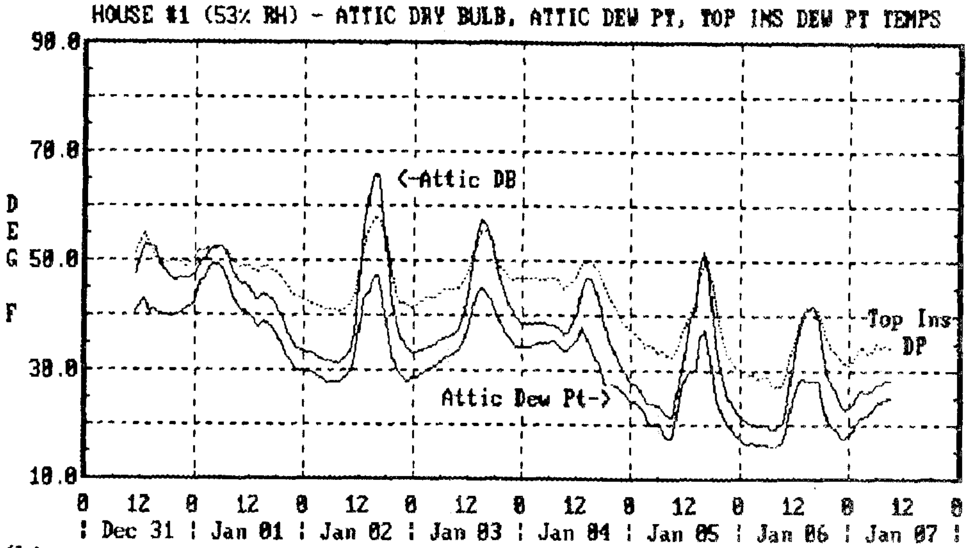


(b)

Figs. 4.15 (a-b) Houses No. 2, No. 1--attic dry bulb, attic dew point, and top of insulation dew point temperatures (Dec. 24-31).

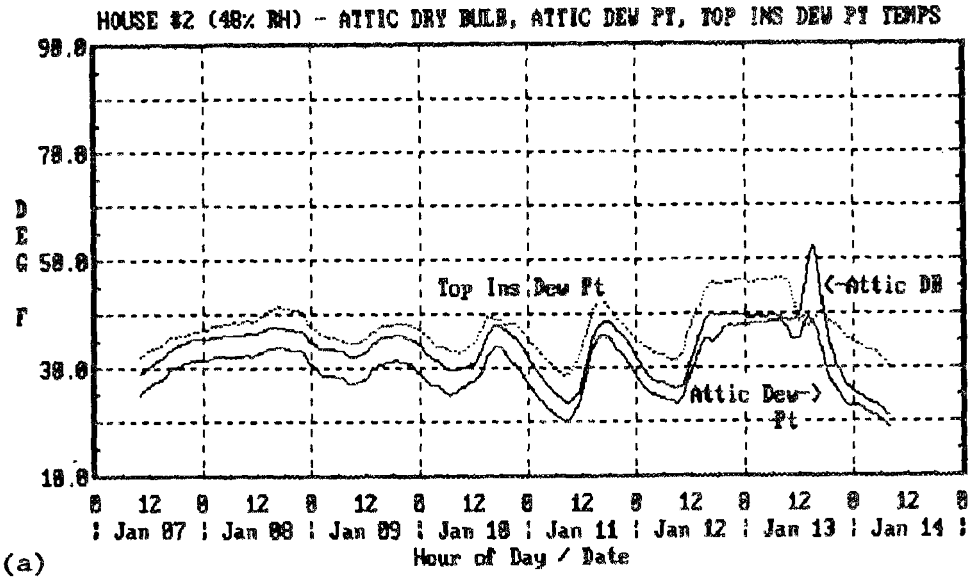


(a)

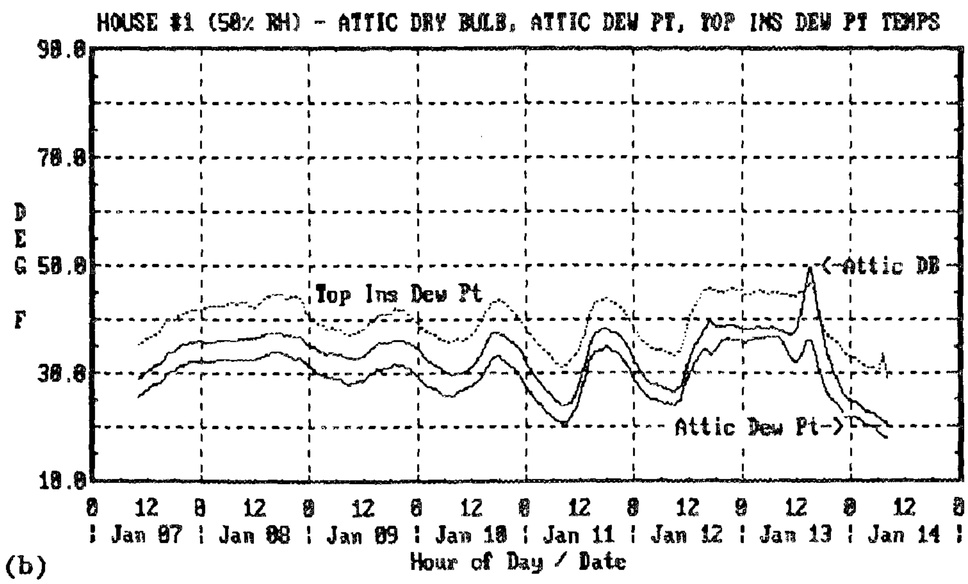


(b)

Figs. 4.16 (a-b) Houses No.2, No.1--attic dry bulb, attic dew point, and top of insulation dew point temperatures (Dec. 31-Jan.7).



(a)



(b)

Figs. 4.17 (a-b) Houses No.2, No.1--attic dry bulb, attic dew point, and top of insulation dew point temperatures (Jan. 7-14).

are presented to help explain and illustrate the condensation/ vaporization of moisture under an HRB.

Figures 4.15(a-b) are time series plots for house No. 2 (46% RH) and house No. 1 (56% RH), respectively, on which the attic air dry bulb, top of insulation under HRB dew point, and attic air dew point are plotted for the week between December 24-31. The average outdoor dry bulb temperature for this period was 45.3°F, a relatively warm value. Plotting these values shows that conditions should be favorable for condensing moisture on the bottom of the HRB whenever the attic air dry bulb temperature was less than the dew point temperature at the top of the attic insulation under the RB.

Figure 4.15(a) shows that the attic air dry bulb temperature (top solid line) did not go below the top of insulation dew point temperature (dotted line) until the morning hours of December 29. When moisture could form on the bottom surface of the HRB. A visual observation (Table 4.3) confirmed that a light coating of moisture was present under the HRB in house No. 2. In the afternoon hours the attic temperature warmed up and the condensed moisture vaporized from the HRB into the attic air. Note that so long as the attic dew point temperature (bottom solid line) was below that on the top surface of the insulation that a water vapor partial pressure driving force existed to promote the transport of water vapor from the HRB to the attic air through the perforations in the HRB.

The fact that a water vapor partial pressure-driving force existed between the bottom surface of the HRB (assumed to be the same as that of the top surface of the attic insulation) and the adjacent attic air means that moisture can be transported from under the HRB to the attic air at the same time it is condensing on the HRB. This fact explains why condensed moisture does not necessarily accumulate in the attic insulation. Also, since vapor pressure is an exponential function of temperature, warmer temperatures provide greater driving forces for moisture transport.

The size and number of the holes in a perforated HRB provide resistance to moisture mass transfer from the HRB to the attic air. Obviously larger holes (and more of them) will reduce this resistance, but will increase convective heat transfer from an HRB in winter and will increase radiant heat transfer to attic insulation in summer. The optimum hole size and pattern would appear to be that which is able to dissipate moisture adequately in winter and yet not adversely affect summertime radiant heat transfer reduction. More information must be gathered before an HRB optimum hole size configuration can be suggested.

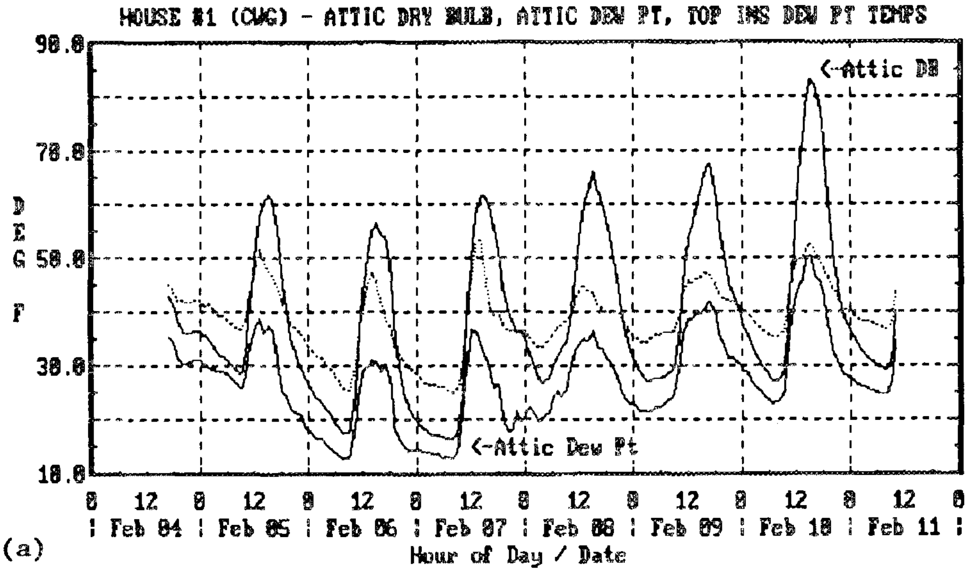
Figure 4.15(a) shows that condensation occured again in house No. 2 from about 6 p.m. on December 29 until about noon on December 30. The outdoor air temperature dropped sharply on December 29 (Fig. B.4 in Appendix B), causing conditions favorable for condensation.

Figure 4.15(b) is similar to Fig. 4.15(a) except that house No. 1 at a higher 56% RH is featured. A comparison of the two plots shows that the dew point temperature on top of the insulation in house No. 1 was usually higher than that in house No. 2. This means that the attic dry bulb temperature was able to cross the HRB dew point line more often than it could in house No. 2. This occurrence is only logical as more moisture was being generated in house No. 1.

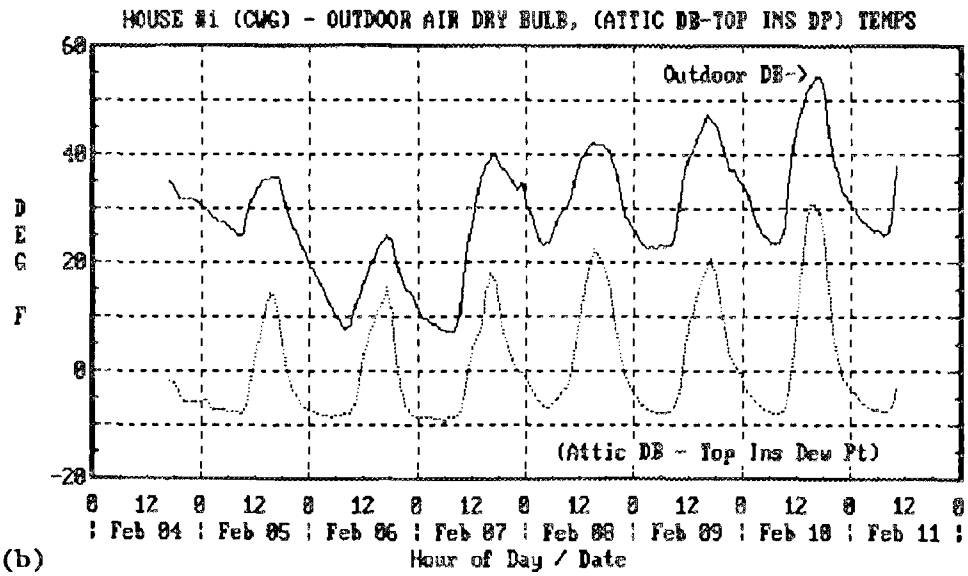
Figures 4.16(a-b) covering the period December 31-January 7, are similar to Figs. 4.15(a-b), differing in that the average temperature during this week was 29.9°F, somewhat colder than the 45.3°F of the previous week. The RHs in both houses were similar to those from the previous week when house No. 2 at 46% and house No. 1 was 53% RH. It is apparent from Figs. 4.16(a-b) that condensation was forming more often on the HRB in both houses than during the warmer week depicted in Figs. 4.15(a-b). House No. 1 with the higher RH shows a greater tendency to condense moisture on the HRB than did house No. 2. The diurnal nature of the condensing and vaporizing moisture cycle is nicely illustrated by Fig. 4.16(a).

Figures 4.17(a-b) showing data of January 7-14 are also similar to the previous two sets of figures, except that the average temperature during this period was 22.9^{o}F, much colder than the previous two weeks. The plots show that the attic dry bulb temperature was almost always below the top of the insulation dew point temperature, so that condensation was present continually. Visual observations from Table 4.3 are in agreement with these data. Note that the humidifier in house No. 1 could not maintain a RH above 50% during this period (Table 4.2). The HRB blotter weight gains discussed in Sect. 4.4 were extremely high for this week, suggesting that moisture may have formed under the HRB faster than it dissipated. This suggests that prolonged cold weather conditions similar to those of January 7-14, which are common in northern climates, may be a cause for concern if a HRB is installed in a humid northern home. Testing of HRBs in colder climates is definitely recommended. Note, however, that prolonged cold weather is unusual for southern locations and that no permanent ill effects on our houses were noted during our testing.

Figures 4.18(a), 4.19(a), and 4.20(a) are plots similar to Figs. 4.15 to 4.17, except for the week of February 4-11. Corresponding plots 4.18(b), 4.19(b) and 4.20(b) include the outdoor dry bulb temperature as well as the temperature difference (attic dry bulb/top insulation dew point) for all three houses. The (b) plots of these three figures make it somewhat easier to see when condensation under the HRB occurred. Whenever the temperature difference (attic dry bulb/top insulation dew point) becomes negative, condensation can occur. Some end effects may be noted in houses No. 1 and No. 3 for the beginning of the week, since house No. 1 was changed from 53% indoor RH

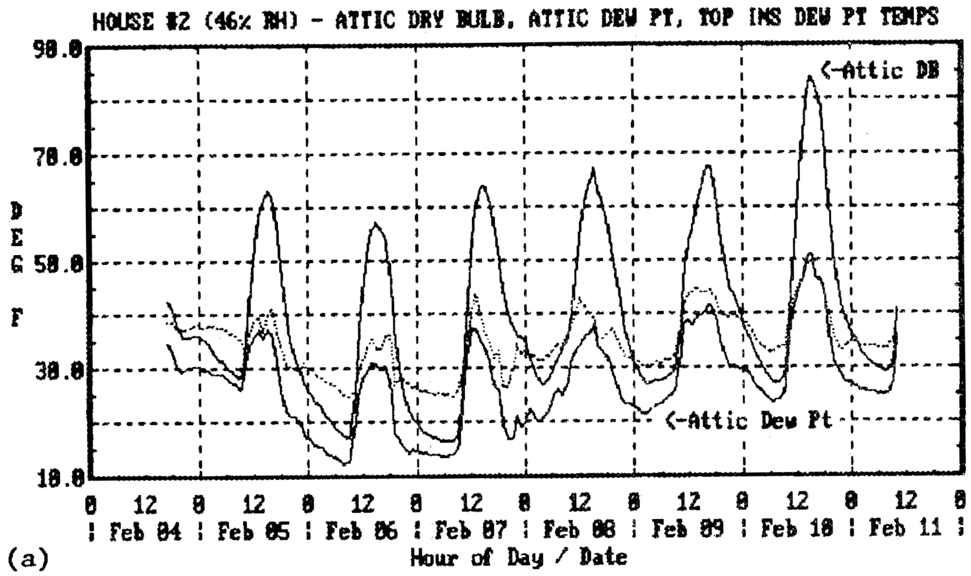


(a)

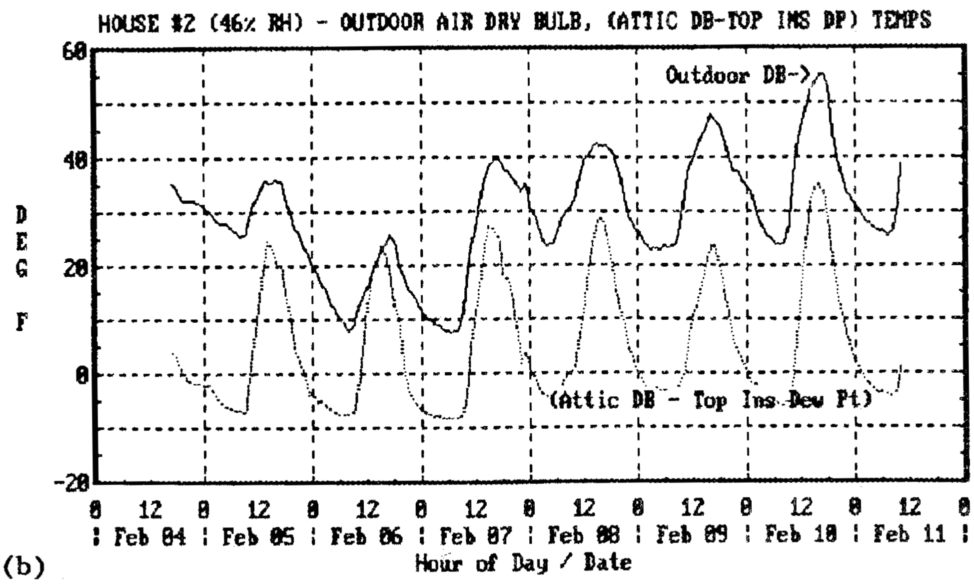


(b)

Fig. 4.18 (a) House No.1--outdoor dry bulb temperature, attic dew point, and top of insulation dew point temperatures (Feb. 4-11) (b) House No.1--outdoor dry bulb temperature, temperature difference (attic dry bulb--top insulation dew point).

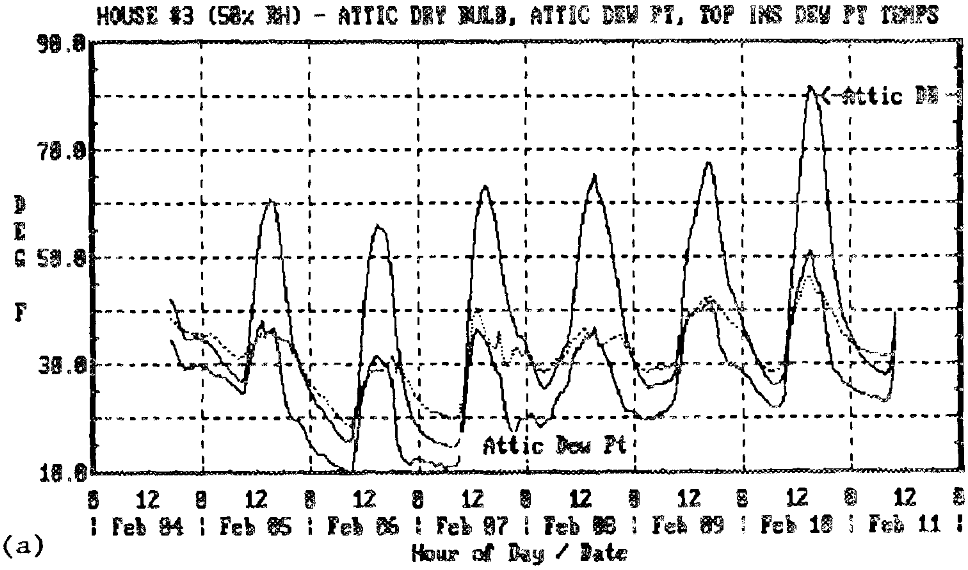


(a)

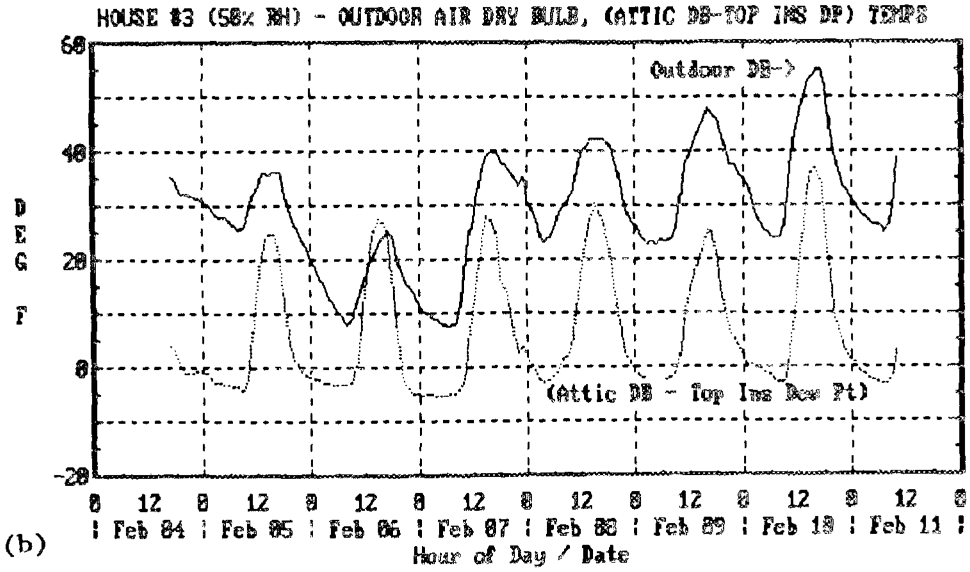


(b)

Fig. 4.19 (a) House No.2--attic dry bulb temperature, attic dew point, and top of insulation dew point temperatures (Feb. 4-11)
(b) House No.2--outdoor dry bulb temperature, temperature difference (attic dry bulb--top insulation dew point).



(a)



(b)

Fig. 4.20 (a) House No.3--attic dry bulb temperature, attic dew point, and top of insulation dew point temperatures (Feb. 4-11)
(b) House No.3--outdoor dry bulb temperature, temperature difference (attic dry bulb--top insulation dew point).

to a constant moisture generation of 30 lb/day. Also, house No. 3 had the R-19 attic fiberglass batt insulation changed from one with no vapor barrier to one with a vapor barrier, and a new HRB was installed in house No. 3.

The average temperature during the week of February 4-11 was 29.0°F, very close to the 29.9°F indicated in Figs. 4.16(a-b). The (b) plots of Figs. 4.18 to 4.20 once again show the diurnal nature of the condensing/vaporization moisture cycle. The figures also show that during normal daily temperature swings moisture tended to condense on HRBs at an outdoor temperature of about 30-35°F.

In summary, the instrument data agree very well with the visual observations and the blotter paper weighings. When visual observations revealed condensation on an HRB during periods of cold weather, the instrument data also predicted that condensation should be present. The psychrometric data collected also clearly showed the diurnal moisture cycle and revealed a mechanism for the escape of moisture from under an HRB to the attic air. A water vapor partial pressure driving force existed and allowed water vapor to enter the attic air through the perforations and any other open areas (loose edge connections, etc.) in an HRB. Moisture appeared to begin condensing on an HRB at about 30-35°F during normal Tennessee winter weather. However, moisture appeared to build up under a HRB in prolonged subfreezing temperatures in humid houses. Caution is suggested before HRBs are indiscriminately added to humid houses in cold climates.

4.6 EMISSIVITY MEASUREMENTS

Table 4.5 lists the measured emissivities of samples of HRB material removed from the Karns test house attics. Samples were taken from the attic locations depicted in Fig. 4.21 and were analyzed with a Devices and Services Model AE Emissometer, shown in Fig. 4.22. The perforations in the HRB appear to add some variability to the readings,

Table 4.5 Measurements of emissivity of perforated radiant barrier surfaces

Location Number	House #3 HORIZ INSTALLATION (4 Dec'87 - 3 Feb'88) Top Side (EU)	House #3 HORIZ INSTALLATION (4 Dec'87 - 3 Feb'88) Bot Side (EU)	House #3 HORIZ INST (3 Feb-28 Mar) Top Side (EU)	House #1 HORIZ INSTALLATION (4 Dec'87 - 28 Mar'88) Top Side (EU)	House #2 HORIZ INSTALLATION (4 Dec'87 - 28 Mar'88) Top Side (EU)
1 SE	0.020	0.010	0.030	0.030	0.050
2 S	0.020	0.040	0.030	0.040	0.030
3 SW	0.010	0.010	0.030	0.050	0.030
4 NW	0.020	0.010	0.040	0.030	0.030
5 N	0.030	0.030	0.030	0.040	0.040
6 NE	0.040	0.040	0.050	0.040	0.040

Note: Unused RB Measured 0.03 Emissivity Units (EU)
A Change of +/-0.02 EU Is Within Measurement Error

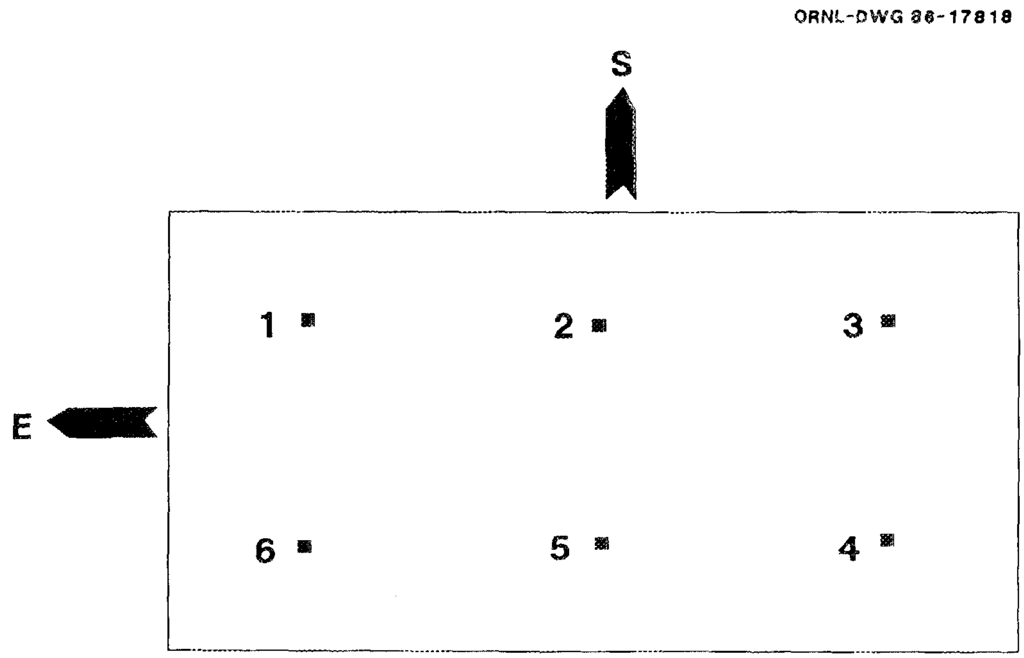


Fig. 4.21 Locations of samples taken from horizontal radiant barrier for emissivity measurements.

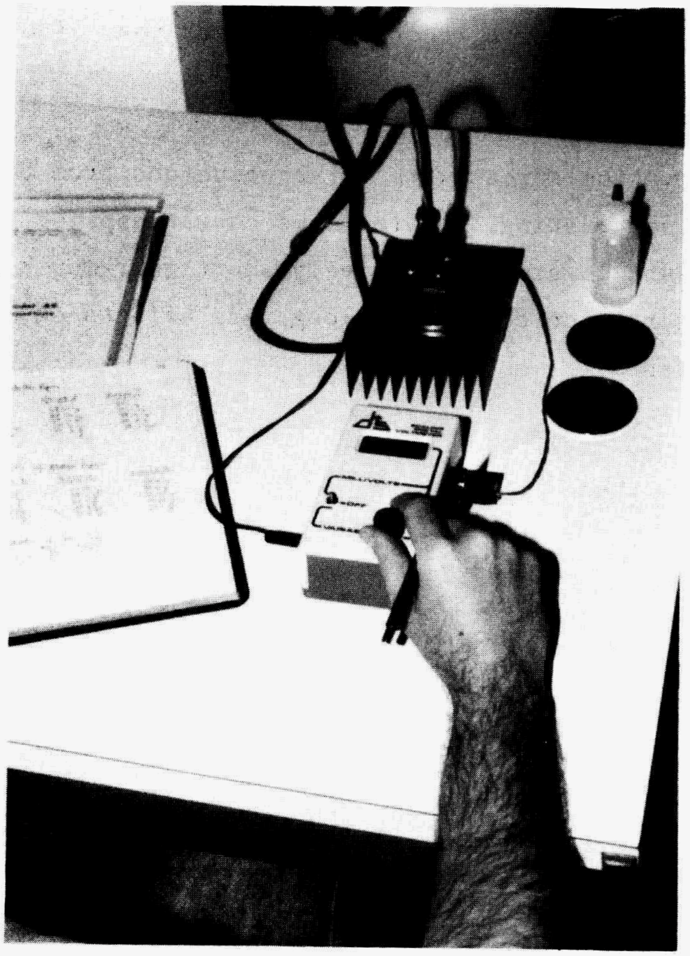


Fig. 4.22 Photograph of an emissometer.

but the net conclusion from the results in Table 4.5 is that no significant change in emissivity occurred on either surface of the HRB material during the course of our testing. Condensation did not appear to adversely affect the underside surface emissivity. Several samples were monitored that are not recorded here, and they also showed no significant degradation.

This observation agrees with our conclusions from previous heating and cooling season testing, but the same caveat applies here as did before. Our tests covered a relatively short four-month period and provided no information concerning long-term effects of dust and/or airborne pollutants.

5. CONCLUSIONS AND RECOMMENDATIONS

The main conclusion reached from this moisture/radiant barrier study at the Karns research houses was that attic moisture appeared to go through a diurnal cycle. Moisture could condense on the under surface of an HRB in cold (below 35°F) weather but could also dissipate during a normal winter afternoon in Tennessee, leaving the barrier dry. If the weather was continuously in the subfreezing range, all the condensation would not dissipate, although it did appear to abate somewhat during the afternoon. However, our testing showed that the moisture cycle occurring on a perforated HRB during a typical Tennessee winter did not appear to pose any structural, wet insulation, or stained ceiling problems to the Karns test houses, even though the houses were operated at higher than normal indoor RHs.

Another conclusion reached was that a normal range of indoor RH for Tennessee Valley houses (at 70°F) in winter is 30-40% RH, with the median being about 36%. Houses with indoor RHs above 45% in freezing weather are not common, and their windows will contain large amounts of condensed moisture during subfreezing temperatures.

Perforations in HRBs are effective in providing an outlet for condensed moisture, although an optimum hole size or pattern was not determined. The material used in this study had an average hole diameter of 0.040 in. and an open hole area of 0.46% of the total area. The vapor pressure of water under an HRB is usually greater than that in the free attic air, and this difference provides a driving force to convey water vapor from under a barrier into the attic air. We recommend perforations in RB material that is used for horizontal installations, but we cannot recommend an optimum hole size or open hole area. More research is needed in this area.

More moisture condensed on the barrier of a house at 55% indoor RH than on that of a house with 45% RH. We do not recommend installing HRBs in houses with consistent winter indoor RHs greater than 50% at 70°F.

A vapor barrier in the attic under the insulation reduced the amount of moisture entering the attic. We recommend attic vapor barriers in this climate (Tennessee) for attic moisture control. Reducing the effective attic ventilation area ratio from 1/150 to 1/300 did not show any significant change in attic moisture parameters. This does not mean that the attic ventilation area is not important, but only that a 1/300 ratio may be sufficient for the Karns houses.

More moisture condensed on barriers in the central portion of the attic than at the periphery. The area over the bathroom, which had holes cut for several plumbing vent pipes and a ventilation fan, was usually the last attic area to become dry. Therefore, we recommend that holes around vent pipes from a house living area to the attic be sealed with a proper sealant. We also recommend sealing the perimeter of ceiling light fixtures and venting bathroom fans at least to above the top of the attic insulation.

The moisture content of attic truss members under an HRB started at about 7 wt% and reached a maximum value of 11 wt% before returning to lower values. Their moisture content did not appear much different from that of those truss members above the barrier. These numbers are well below the danger point (28-30%) for wood fiber saturation.

We do not recommend extrapolating the observations of this experimental work to areas with prolonged periods of subfreezing weather. The diurnal moisture cycle under an HRB could be quite different in colder climates. Further testing of HRBs in colder climates is recommended.

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APPENDIX A

Table A.1 Average values of various parameters during test periods

Dates	OD Air (Deg F)	OD Air (% RH)	Solar (Btuhsf)	Wind Sp (mph)	HOUSE #1 Gr Rm DB (Deg F)	HOUSE #1 Gr Rm WB (Deg F)	HOUSE #2 Gr Rm DB (Deg F)	HOUSE #2 Gr Rm WB (Deg F)	HOUSE #3 Gr Rm DB (Deg F)	HOUSE #3 Gr Rm WB (Deg F)
Dec 04-11 '87	42.8	71	20.2	1.5	69.1	58.9	69.6	57.3	69.2	57.9
Dec 11-18	40.5	73	26.1	3.6	69.9	59.5	68.5	56.5	69.5	57.7
Dec 18-24	42.6	77	16.0	2.3	69.8	59.9	69.0	57.3	69.7	58.2
Dec 24-31	45.3	88	11.6	3.3	69.9	59.9	69.0	57.2	69.6	57.9
Dec 31-Jan 07	29.9	81	15.6	3.0	69.6	58.9	69.8	57.5	69.3	57.0
Jan 07-14 '88	22.9	94	21.3	2.0	69.2	58.2	70.1	58.0	69.1	56.6
Jan 14-17	28.8	88	24.5	1.0	69.2	59.0	71.5	59.6	69.3	58.6
Jan 19-21	50.0	80	20.3	3.6	70.0	59.6	71.1	60.8	69.5	61.7
Jan 21-28	31.7	68	32.0	4.0	69.5	59.3	69.4	57.1	69.1	59.1
Jan 28-Feb 04	51.9	70	20.5	3.5	70.1	60.0	70.4	58.1	69.6	61.6
Feb 04-11	29.0	64	37.5	1.3	69.7	57.2	69.3	57.3	69.3	58.1
Feb 11-18	32.4	80	33.6	1.5	69.7	57.2	69.6	57.8	69.3	58.9
Feb 18-25	40.2	76	35.2	4.1	69.8	58.8	69.9	58.0	69.6	59.3
Feb 25-Mar 03	41.3	66	58.5	3.0	69.8	58.2	69.8	58.0	69.5	58.9
Mar 03-10	50.1	78	39.6	3.3	70.1	61.1	70.8	58.4	70.0	59.2
Mar 10-17	38.3	69	60.1	4.4	69.8	58.8	69.8	57.9	69.5	59.2
Mar 17-24	50.6	63	61.2	3.5	70.6	60.4	71.1	58.8	70.6	60.7

Table A.2 Results of blotter paper weighings at Karns houses

	House 1 - Wt (g) of Blotters			House 2 - Wt (g) of Blotters			House 3 - Wt (g) of Blotters		
Location	08-Dec	23-Dec	Delta (g)	08-Dec	23-Dec	Delta (g)	08-Dec	23-Dec	Delta (g)
Control		39.60	***		39.15	***		38.70	***
1	38.60	41.40	2.80	38.20	39.90	1.70	38.80	40.80	2.00
2	37.95	40.30	2.35	38.60	40.30	1.70 *	38.00	40.80	2.80
3	38.90	40.70	1.80	38.90	40.20	1.30	39.10	40.50	1.40
4	38.80	42.30	3.50	38.65	41.30	2.65	38.10	40.30	2.20
Avg. wt gain (g/sq ft)			2.61 g/sq ft			1.84 g/sq ft			2.10 g/sq ft
Tot Attic Gain (lb Water)->			6.91 lb water			4.86 lb water			5.56 lb water

	House 1 - Wt (g) of Blotters			House 2 - Wt (g) of Blotters			House 3 - Wt (g) of Blotters		
Location	08-Dec	08-Jan	Delta (g)	08-Dec	08-Jan	Delta (g)	08-Dec	08-Jan	Delta (g)
Control	39.60	42.35	2.75	39.15	41.40	2.25	38.70	40.90	2.20
1	38.60	44.70	6.10	38.20	39.70	1.50	38.80	41.60	2.80
2	37.95	43.10	5.15	38.60	42.70	4.10 **	38.00	42.30	4.30
3	38.90	41.15	2.25	38.90	40.80	1.90	39.10	40.30	1.20
4	38.80	45.40	6.60 **	38.65	41.90	3.25	38.10	46.20	8.10 **
Avg. wt gain (g/sq ft)			5.03 g/sq ft			2.69 g/sq ft			4.10 g/sq ft
Tot Attic Gain (lb Water)->			13.29 lb water			7.11 lb water			10.85 lb water

	House 1 - Wt (g) of Blotters			House 2 - Wt (g) of Blotters			House 3 - Wt (g) of Blotters		
Location	08-Dec	14-Jan	Delta (g)	08-Dec	14-Jan	Delta (g)	08-Dec	14-Jan	Delta (g)
Control	39.60	42.45	2.85	39.15	42.40	3.25	38.70	41.70	3.00
1	38.60	43.20	4.60	38.20	41.60	3.40	38.80	42.30	3.50
2	37.95	43.30	5.35	38.60	42.30	3.70	38.00	40.50	2.50
3	38.90	45.10	6.20 **	38.90	42.00	3.10	39.10	40.90	1.80
4	38.80	41.70	2.90	38.65	43.40	4.75 **	38.10	50.30	12.20 **
Avg. wt gain (g/sq ft)			4.76 g/sq ft			3.74 g/sq ft			5.00 g/sq ft
Tot Attic Gain (lb Water)->			12.60 lb water			9.89 lb water			13.23 lb water

Notes: -> House 1 %RH ~ 53% House 2 %RH ~ 46% House 3 %RH ~ 46%

* = Wt gain was only 1.2g at 1500 on 22-Dec

** = Wet spots on blotter

*** = Controls installed in attic air on 22-Dec

Table A.2 (continued)

Location	House 1 - Wt (g) of Blotters 08-Dec	21-Jan	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	21-Jan	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	21-Jan	Delta (g)
Control	39.60	40.80	1.20	39.15	40.00	0.85	38.70	39.50	0.80
1	38.60	39.40	0.80	38.20	39.00	0.80	38.80	40.35	1.55
2	37.95	40.00	2.05	38.60	40.20	1.60	38.00	43.00	5.00
3	38.90	40.10	1.20	38.90	40.10	1.20	39.10	40.25	1.15
4	38.80	42.10	3.30	38.65	40.80	2.15	38.10	49.00	10.90 **
Avg. wt gain (g/sq ft)			1.84 g/sq ft			1.44 g/sq ft			4.65 g/sq ft
Tot Attic Gain (lb Water)->			4.86 lb water			3.80 lb water			12.30 lb water

Location	House 1 - Wt (g) of Blotters 08-Dec	28-Jan	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	28-Jan	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	28-Jan	Delta (g)
Control	39.60	41.70	2.10	39.15	41.40	2.25	38.70	40.60	1.90
1	38.60	40.60	2.00	38.20	39.90	1.70	38.80	40.90	2.10
2	37.95	41.65	3.70 **	38.60	41.40	2.80	38.00	44.85	6.85 **
3	38.90	40.70	1.80	38.90	40.40	1.50	39.10	40.15	1.05
4	38.80	41.50	2.70	38.65	41.85	3.20 **	38.10	44.90	6.80 **
Avg. wt gain (g/sq ft)			2.55 g/sq ft			2.30 g/sq ft			4.20 g/sq ft
Tot Attic Gain (lb Water)->			6.75 lb water			6.08 lb water			11.11 lb water

Location	House 1 - Wt (g) of Blotters 08-Dec	04-Feb	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	04-Feb	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	03-Feb	Delta (g)
Control	39.60	41.40	1.80	39.15	40.85	1.70	38.70	40.90	2.20
1	38.60	40.10	1.50	38.20	39.65	1.45	38.80	41.00	2.20
2	37.95	39.50	1.55	38.60	40.10	1.50	38.00	41.35	3.35
3	38.90	40.60	1.70	38.90	40.30	1.40	39.10	41.10	2.00
4	38.80	40.70	1.90	38.65	40.10	1.45	38.10	41.45	3.35
Avg. wt gain (g/sq ft)			1.66 g/sq ft			1.45 g/sq ft			2.73 g/sq ft
Tot Attic Gain (lb Water)->			4.40 lb water			3.84 lb water			7.21 lb water

Notes: -> House 1 %RH ~ 53% House 2 %RH ~ 46% House 3 %RH ~ 52% Hum On

Table A.2 (continued)

Location	House 1 - Wt (g) of Blotters 08-Dec	11-Feb	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	11-Feb	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	11-Feb	Delta (g)
Control	39.60	40.50	0.90	39.15	40.00	0.85	38.70	39.40	0.70
1	38.60	39.80	1.20	38.20	39.30	1.10	38.80	39.30	0.50
2	37.95	39.20	1.25	38.60	40.20	1.60	38.00	38.70	0.70
3	38.90	39.90	1.00	38.90	39.90	1.00	39.10	39.40	0.30
4	38.80	40.10	1.30	38.65	40.15	1.50	38.10	38.75	0.65
Avg. wt gain (g/sq ft)			1.19 g/sq ft			1.30 g/sq ft			0.54 g/sq ft
Tot Attic Gain (lb Water)->			3.14 lb water			3.44 lb water			1.42 lb water

Location	House 1 - Wt (g) of Blotters 08-Dec	18-Feb	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	18-Feb	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	18-Feb	Delta (g)
Control	39.60	40.00	0.40	39.15	39.75	0.60	38.70	38.60	-0.10
1	38.60	39.15	0.55	38.20	39.05	0.85	38.80	39.10	0.30
2	37.95	38.70	0.75	38.60	39.90	1.30	38.00	38.40	0.40
3	38.90	39.90	1.00	38.90	40.30	1.40	39.10	39.35	0.25
4	38.80	39.95	1.15	38.65	39.60	0.95	38.10	38.70	0.60
Avg. wt gain (g/sq ft)			0.86 g/sq ft			1.12 g/sq ft			0.39 g/sq ft
Tot Attic Gain (lb Water)->			2.28 lb water			2.98 lb water			1.03 lb water

Notes: -> House 1 Hum on @ Low Sp House 2 %RH ~ 46% House 3 %RH ~ 52% Faced R-19

Table A.2 (continued)

	House 1 - Wt (g) of Blotters			House 2 - Wt (g) of Blotters			House 3 - Wt (g) of Blotters		
Location	08-Dec	25-Feb	Delta (g)	08-Dec	25-Feb	Delta (g)	08-Dec	25-Feb	Delta (g)
Control	39.60	39.75	0.15	39.15	39.30	0.15	38.70	38.60	-0.10
1	38.60	39.85	1.25	38.20	39.10	0.90	38.80	39.00	0.20
2	37.95	39.15	1.20	38.60	39.90	1.30	38.00	38.45	0.45
3	38.90	39.60	0.70	38.90	39.50	0.60	39.10	39.25	0.15
4	38.80	40.60	1.80	38.65	41.00	2.35	38.10	38.75	0.65
Avg. wt gain (g/sq ft)			1.24 g/sq ft			1.29 g/sq ft			0.36 g/sq ft
Tot Attic Gain (lb Water)->			3.27 lb water			3.41 lb water			0.96 lb water

	House 1 - Wt (g) of Blotters			House 2 - Wt (g) of Blotters			House 3 - Wt (g) of Blotters		
Location	08-Dec	03-Mar	Delta (g)	08-Dec	03-Mar	Delta (g)	08-Dec	03-Mar	Delta (g)
Control	39.60	40.10	0.50	39.15	39.50	0.35	38.70	39.10	0.40
1	38.60	39.10	0.50	38.20	38.55	0.35	38.80	39.10	0.30
2	37.95	38.60	0.65	38.60	39.00	0.40	38.00	38.40	0.40
3	38.90	39.55	0.65	38.90	39.40	0.50	39.10	39.20	0.10
4	38.80	39.60	0.80	38.65	39.20	0.55	38.10	38.50	0.40
Avg. wt gain (g/sq ft)			0.65 g/sq ft			0.45 g/sq ft			0.30 g/sq ft
Tot Attic Gain (lb Water)->			1.72 lb water			1.19 lb water			0.79 lb water

	House 1 - Wt (g) of Blotters			House 2 - Wt (g) of Blotters			House 3 - Wt (g) of Blotters		
Location	08-Dec	10-Mar	Delta (g)	08-Dec	10-Mar	Delta (g)	08-Dec	10-Mar	Delta (g)
Control	39.60	40.70	1.10	39.15	39.75	0.60	38.70	39.50	0.80
1	38.60	40.00	1.40	38.20	39.00	0.80	38.80	39.80	1.00
2	37.95	39.70	1.75	38.60	39.40	0.80	38.00	39.05	1.05
3	38.90	40.35	1.45	38.90	39.80	0.90	39.10	39.65	0.55
4	38.80	40.35	1.55	38.65	39.60	0.95	38.10	39.10	1.00
Avg. wt gain (g/sq ft)			1.54 g/sq ft			0.86 g/sq ft			0.90 g/sq ft
Tot Attic Gain (lb Water)->			4.07 lb water			2.28 lb water			2.38 lb water

Notes: -> House 1 Hum on @ Low Sp   House 2 50 % Vent %RH ~ 46%   House 3 %RH ~ 52% Faced R-19

Table A.2 (continued)

Location	House 1 - Wt (g) of Blotters 08-Dec	21-Mar	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	21-Mar	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	21-Mar	Delta (g)
Control	39.60	39.15	-0.45	39.15	38.35	-0.80	38.70	37.90	-0.80
1	38.60	38.20	-0.40	38.20	37.70	-0.50	38.80	38.35	-0.45
2	37.95	37.80	-0.15	38.60	38.30	-0.30	38.00	37.60	-0.40
3	38.90	38.80	-0.10	38.90	38.50	-0.40	39.10	38.50	-0.60
4	38.80	38.90	0.10	38.65	38.50	-0.15	38.10	37.80	-0.30
Avg. wt gain (g/sq ft)			-0.14 g/sq ft			-0.34 g/sq ft			-0.44 g/sq ft
Tot Attic Gain (lb Water)->			-0.36 lb water			-0.89 lb water			-1.16 lb water

Location	House 1 - Wt (g) of Blotters 08-Dec	24-Mar	Delta (g)	House 2 - Wt (g) of Blotters 08-Dec	24-Mar	Delta (g)	House 3 - Wt (g) of Blotters 08-Dec	24-Mar	Delta (g)
Control	39.60	39.70	0.10	39.15	38.85	-0.30	38.70	38.60	-0.10
1	38.60	38.75	0.15	38.20	38.10	-0.10	38.80	38.80	0.00
2	37.95	38.25	0.30	38.60	38.60	0.00	38.00	38.10	0.10
3	38.90	39.30	0.40	38.90	38.95	0.05	39.10	39.05	-0.05
4	38.80	39.25	0.45	38.65	38.75	0.10	38.10	38.20	0.10
Avg. wt gain (g/sq ft)			0.32 g/sq ft			0.01 g/sq ft			0.04 g/sq ft
Tot Attic Gain (lb Water)->			0.86 lb water			0.03 lb water			0.10 lb water

APPENDIX B

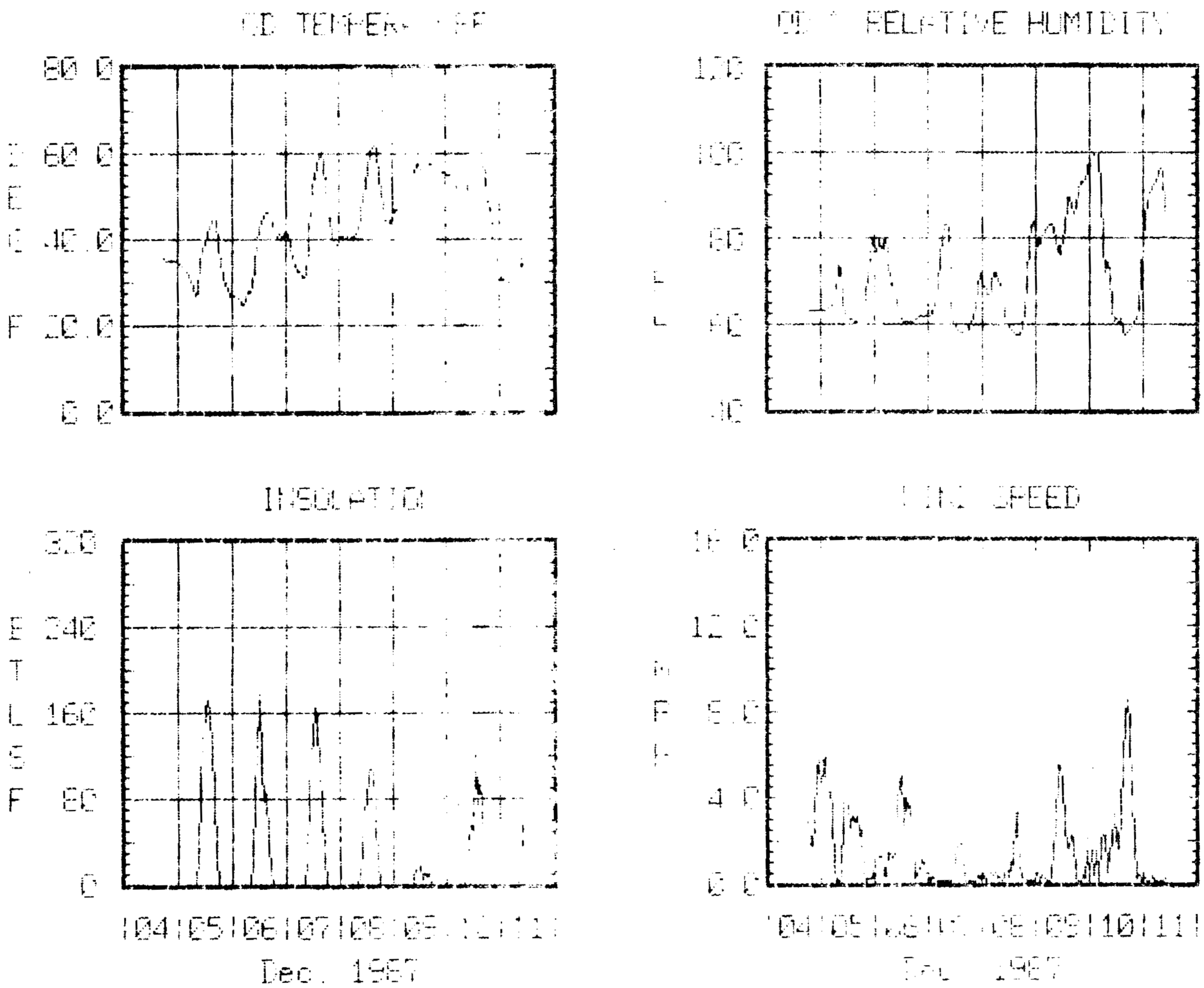

Fig. B.1 Weather data (Dec. 4-11, 1987).

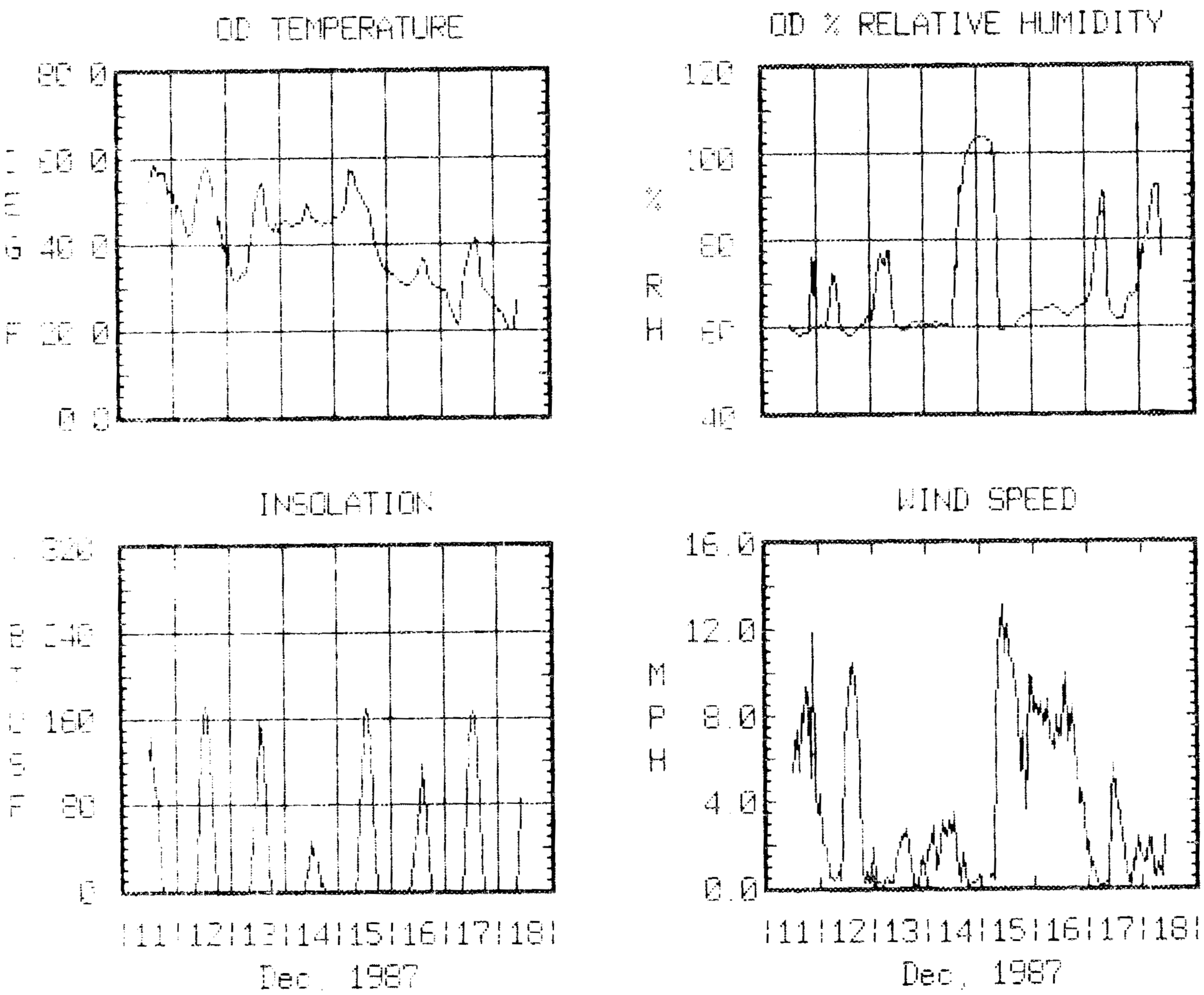

Fig. B.2 Weather data (Dec. 11-18, 1987).

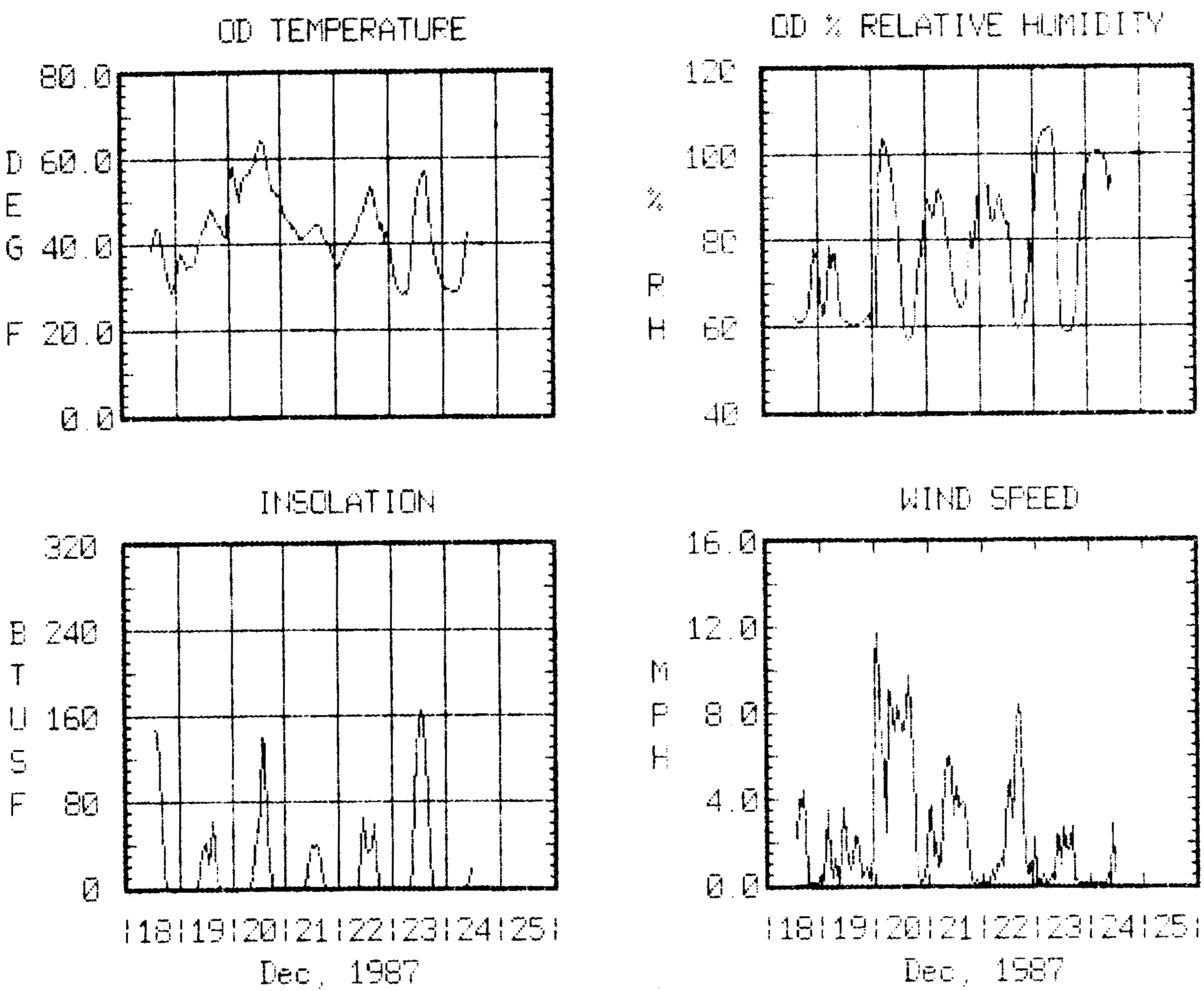

Fig. B.3 Weather data (Dec. 18-24, 1987).

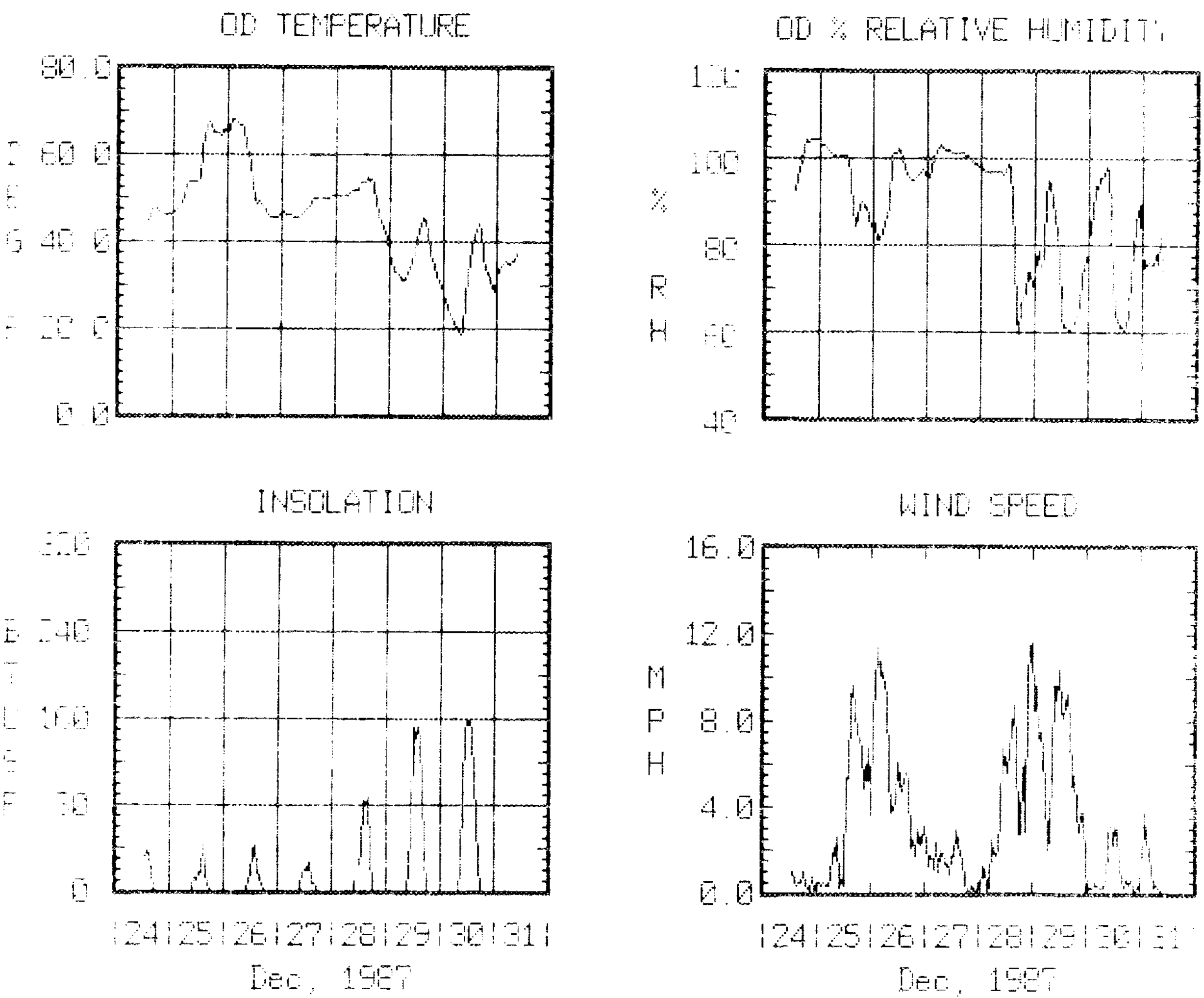

Fig. B.4 Weather data (Dec. 24-31, 1987).

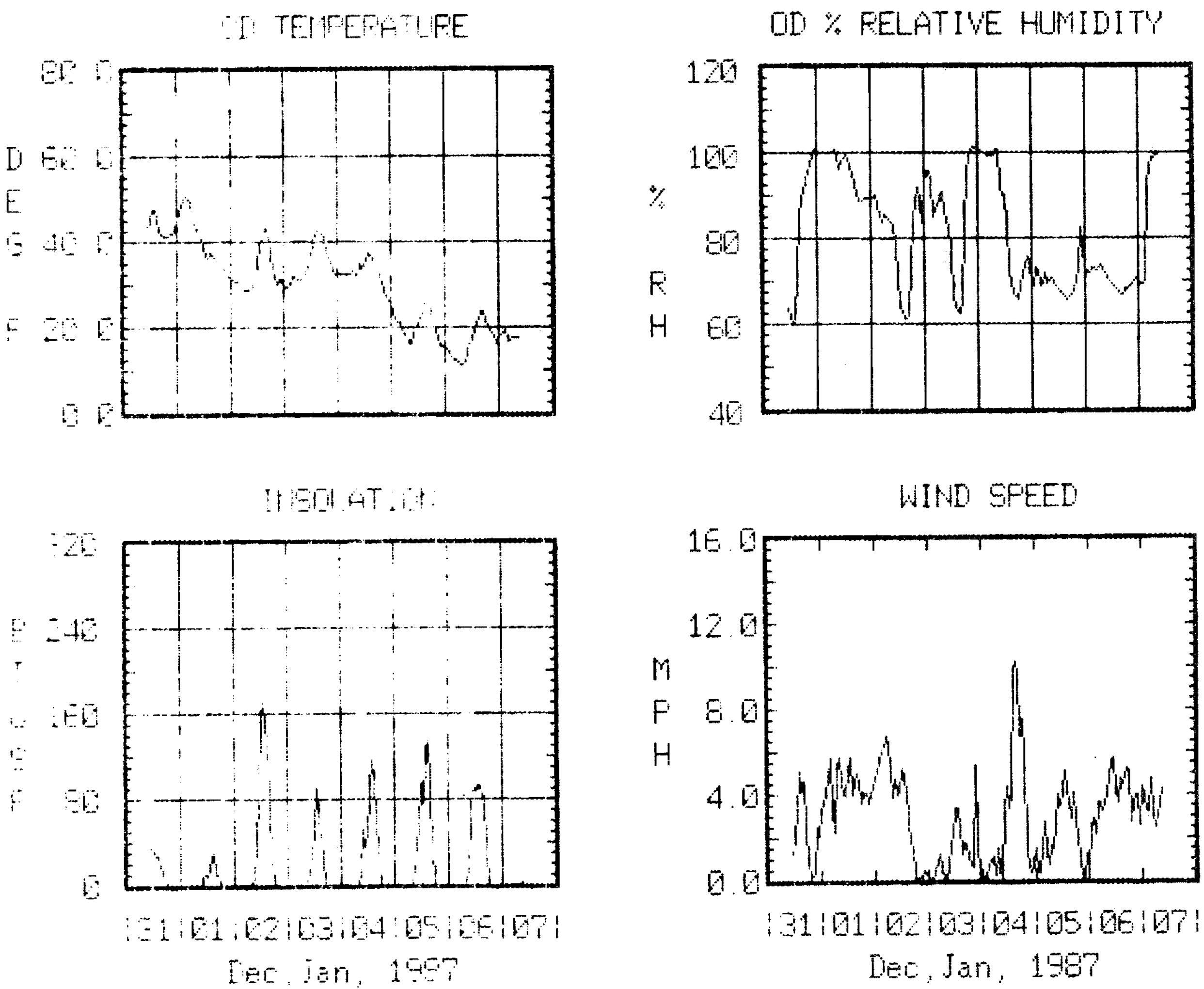

Fig. B.5 Weather data (Jan. 1-7, 1988).

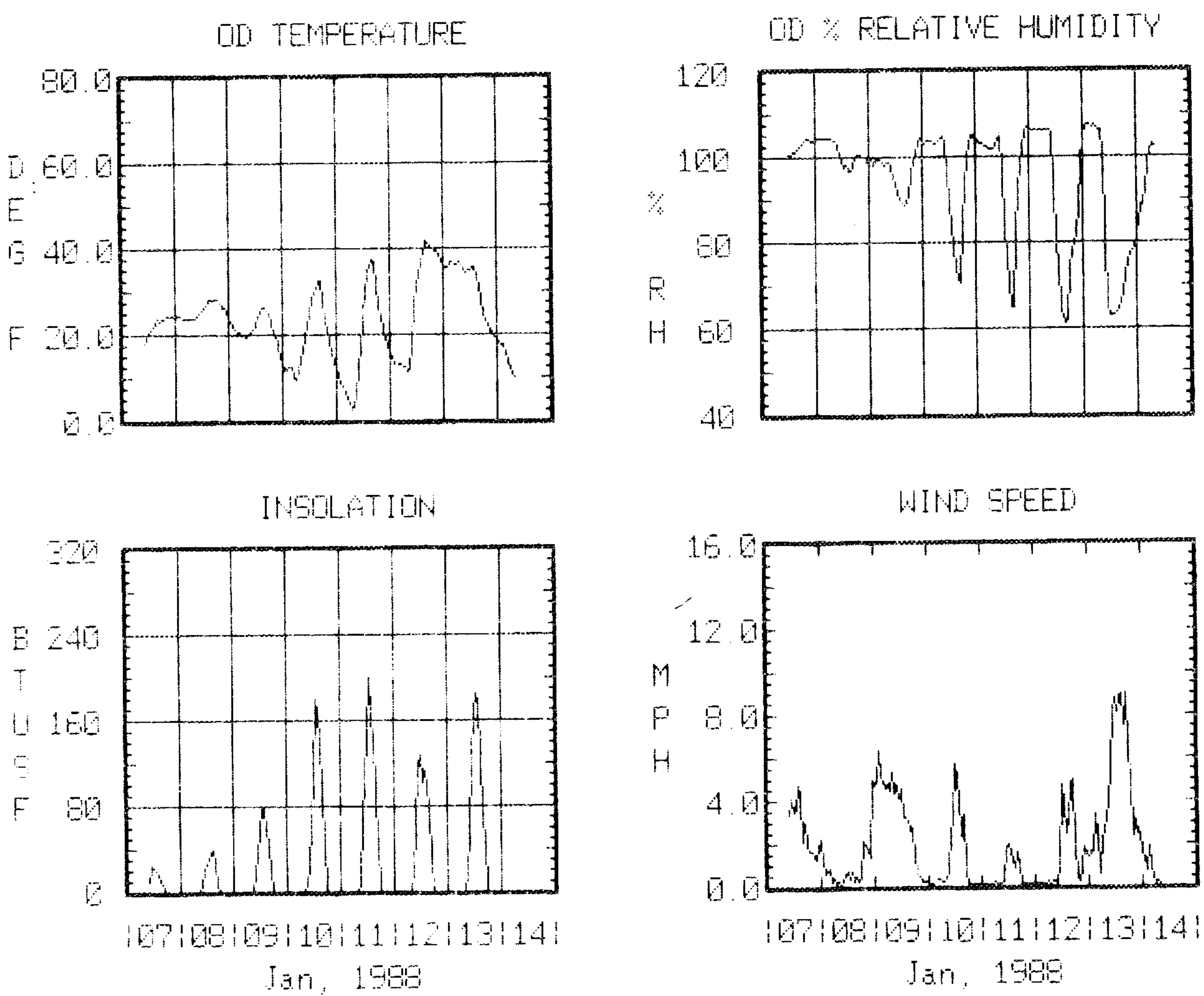

Fig. B.6 Weather data (Jan. 7-14, 1988).

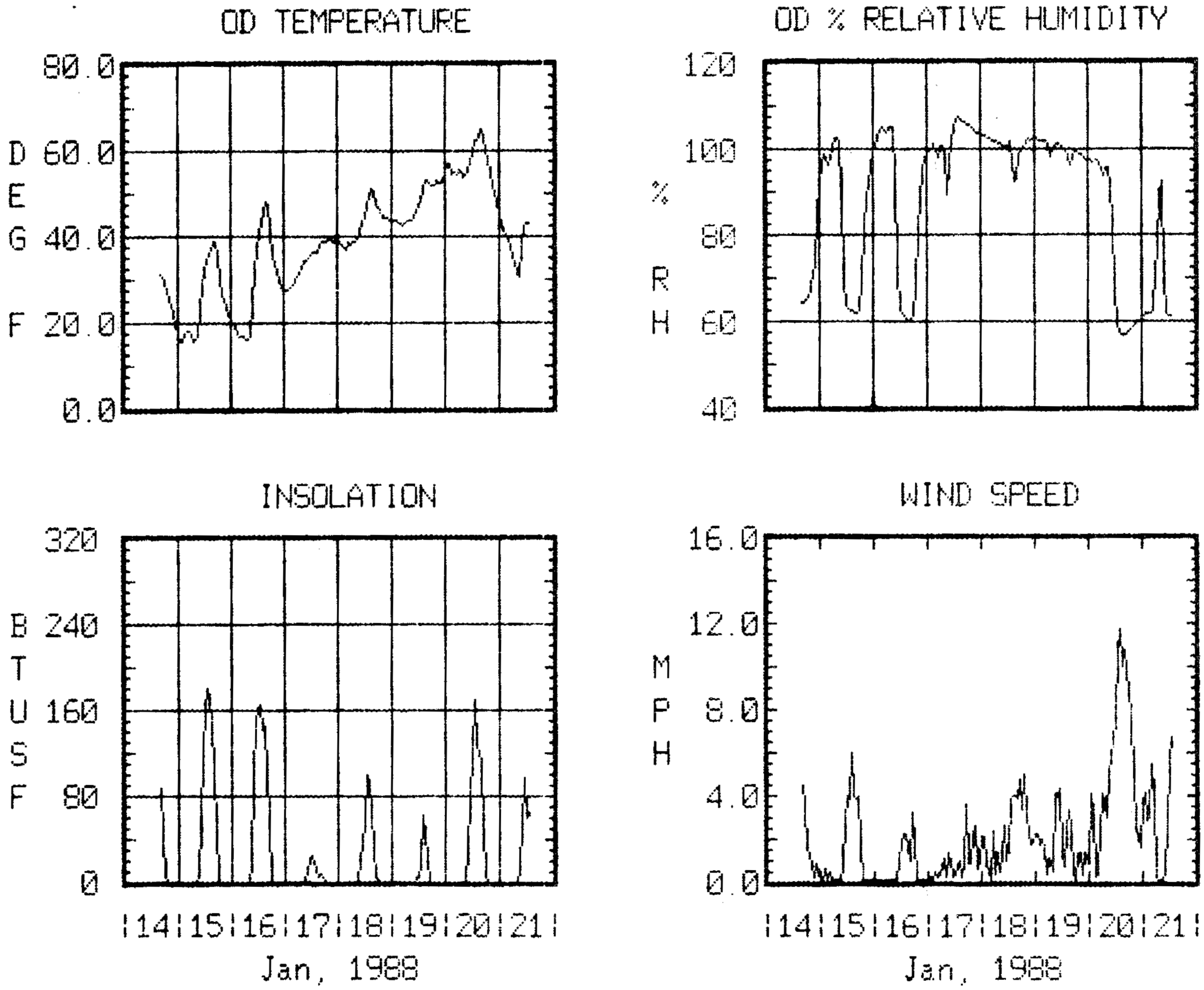

Fig. B.7 Weather data (Jan. 14-21, 1988).

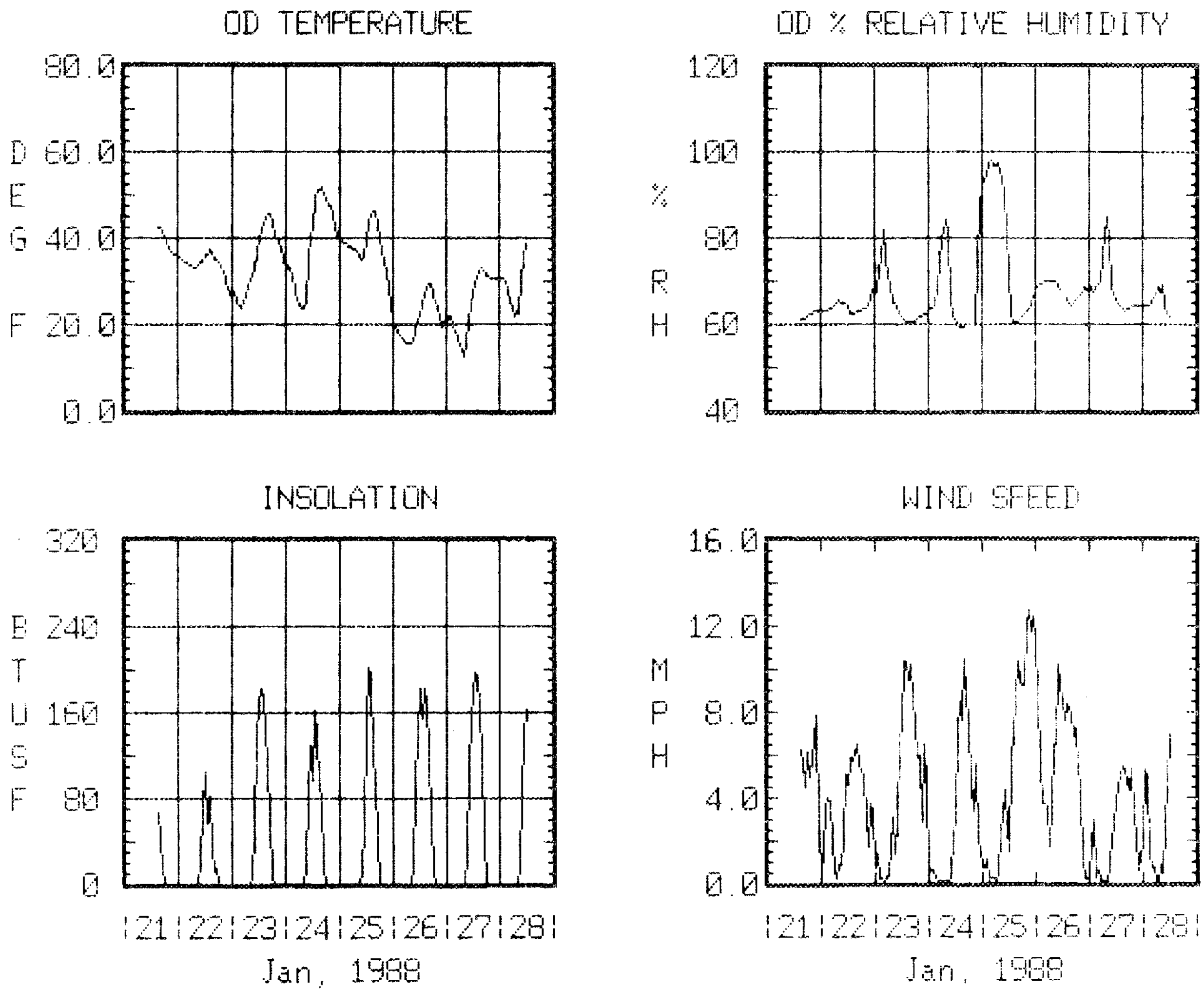

Fig. B.8 Weather data (Jan. 21-18, 1988.

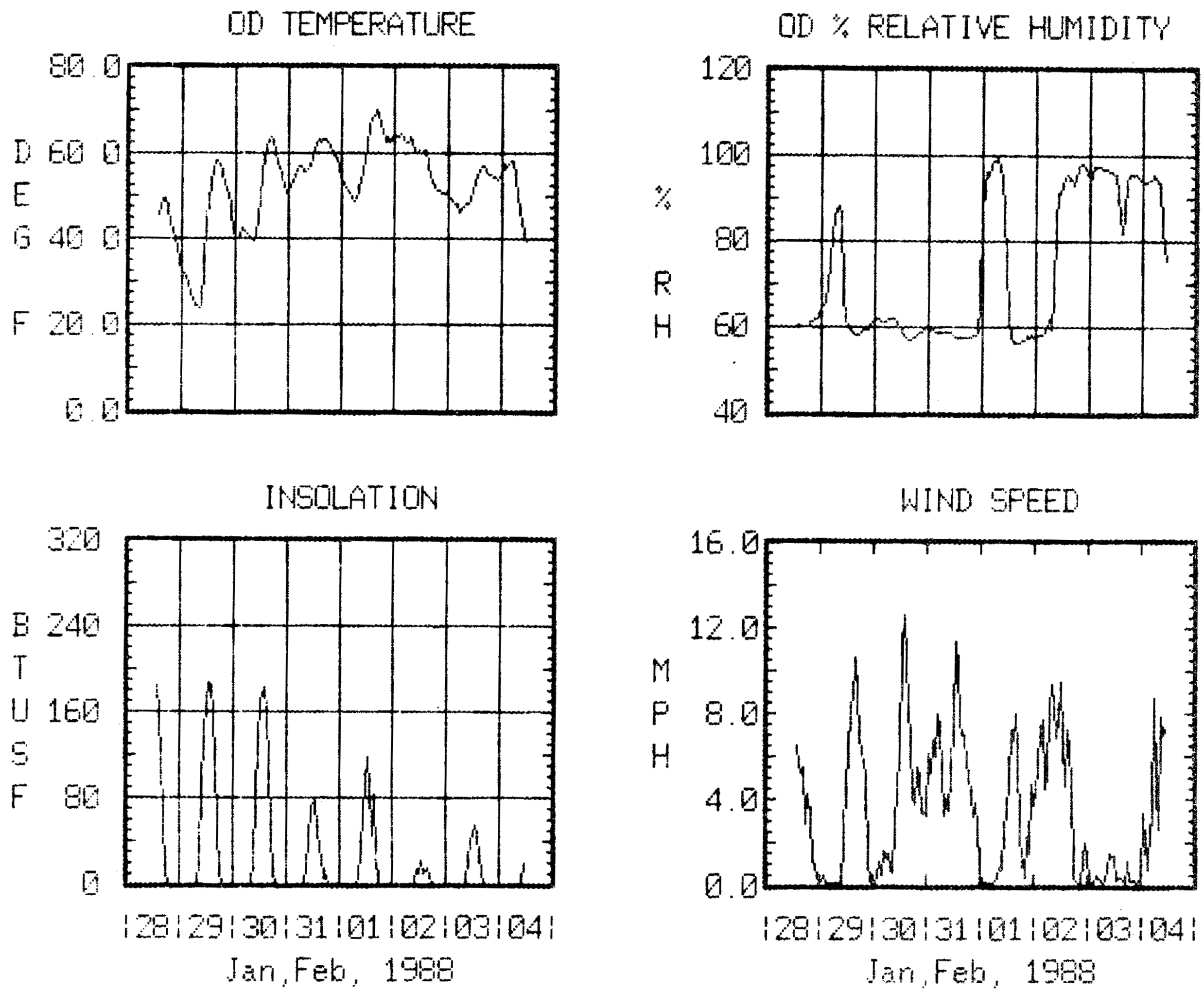

Fig. B.9 Weather data (Jan. 28-Feb. 4, 1988).

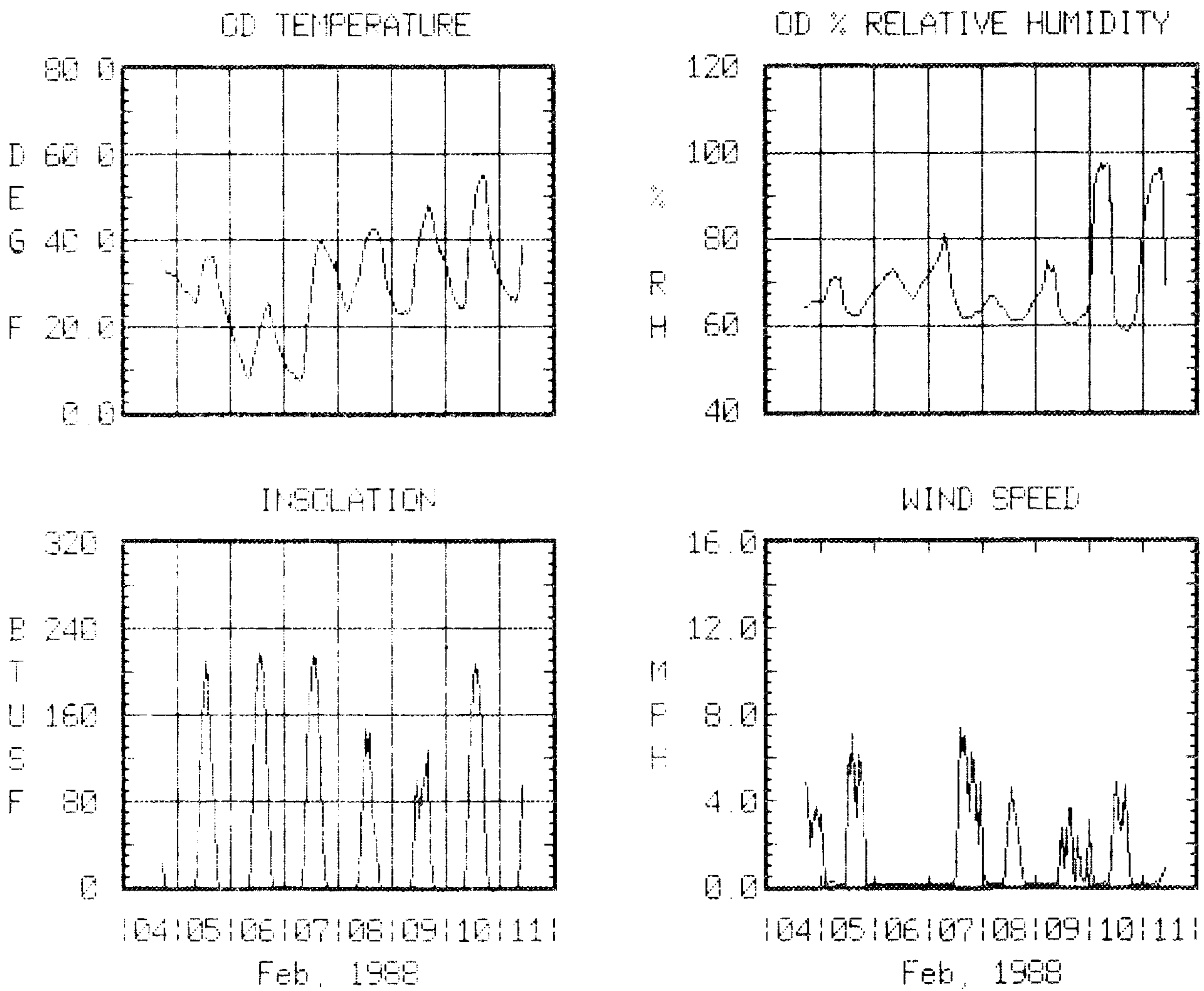

Fig. B.10. Weather data (Feb. 4-11, 1988).

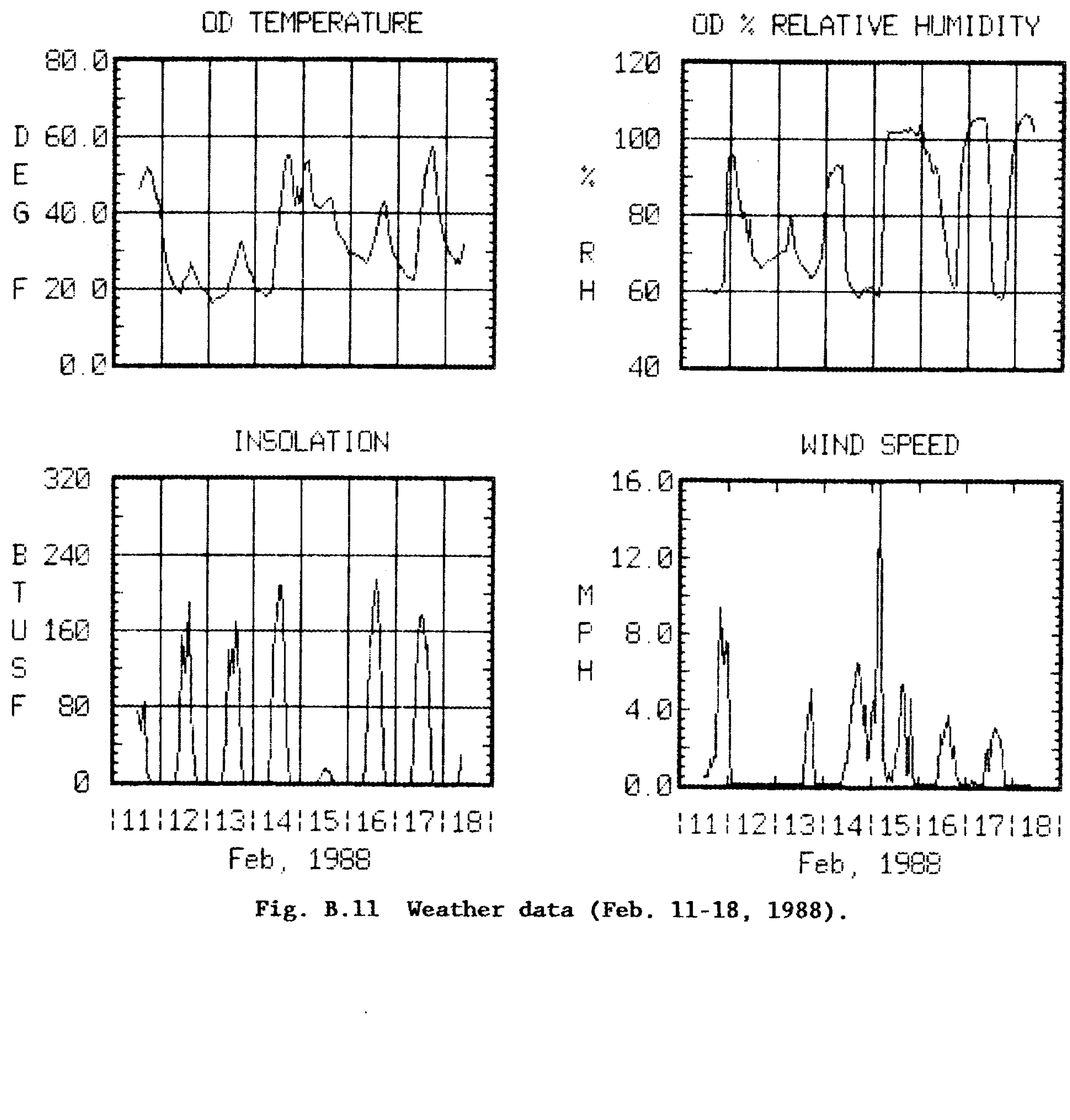

Fig. B.11 Weather data (Feb. 11-18, 1988).

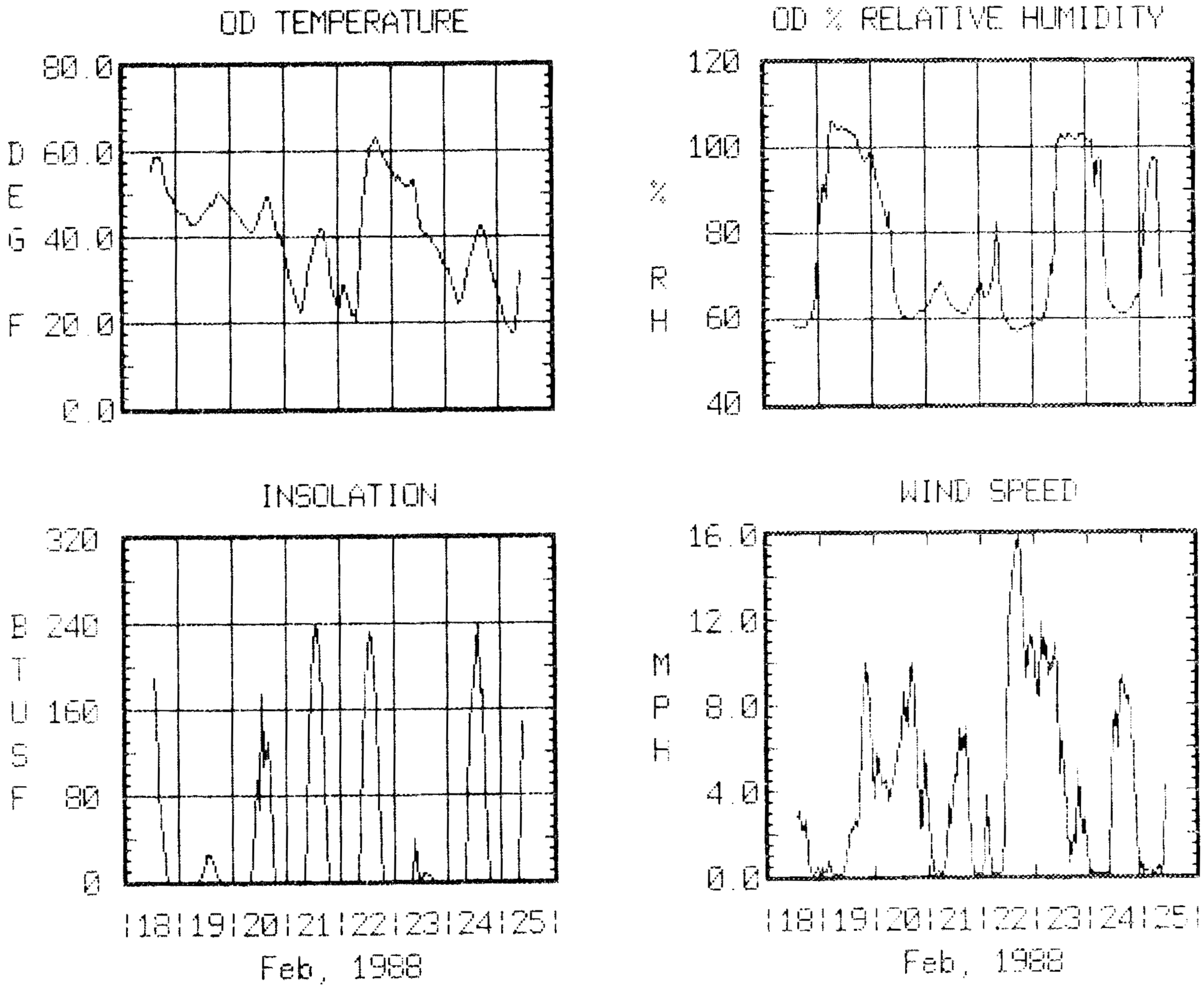

Fig. B.12 Weather data (Feb. 18-25, 1988).

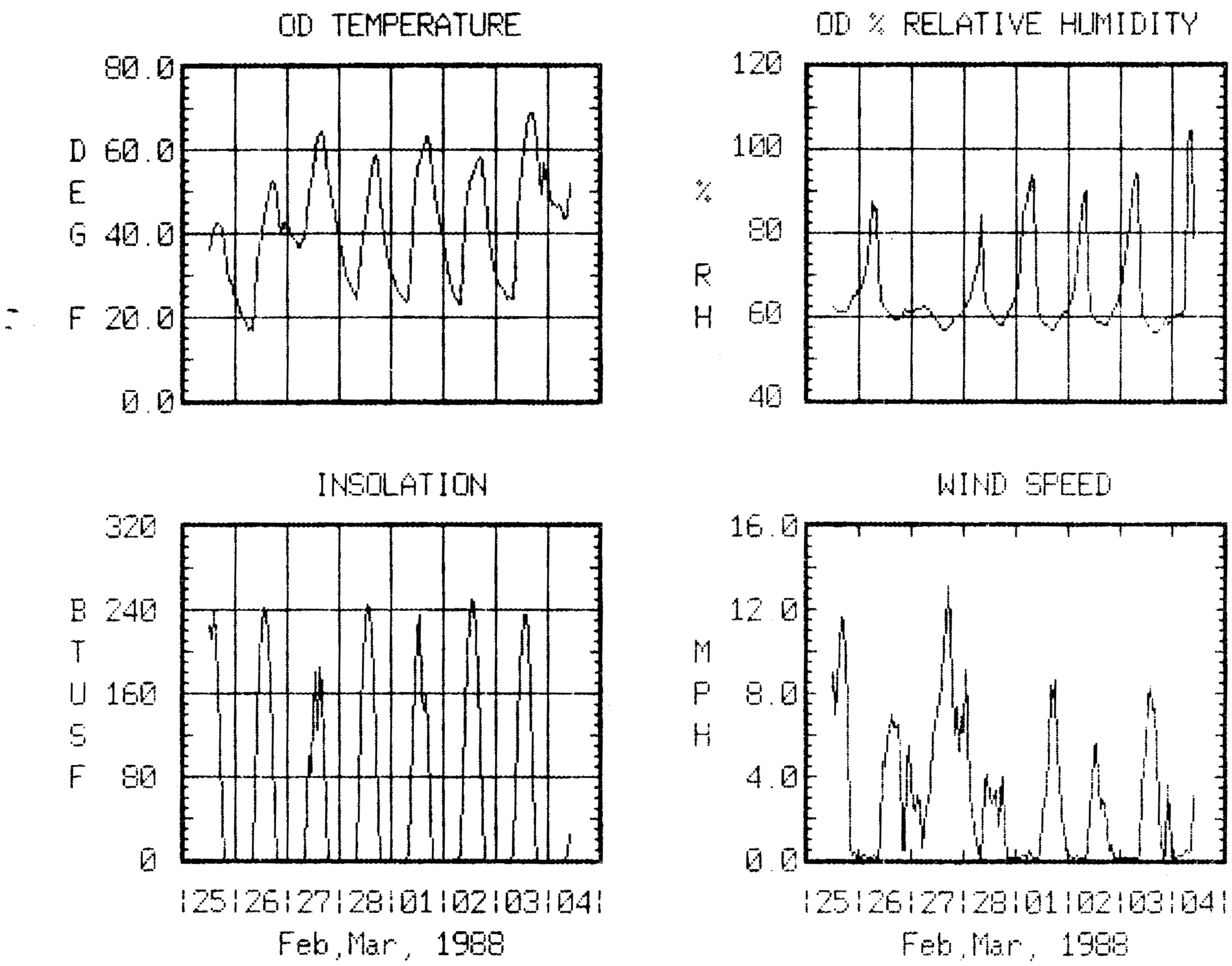

Fig. B.13 Weather data (Feb. 25-Mar. 4, 1988).

APPENDIX C

Fig. C.1 Front view of the Karns houses.

ORNL-DWG 84-17110

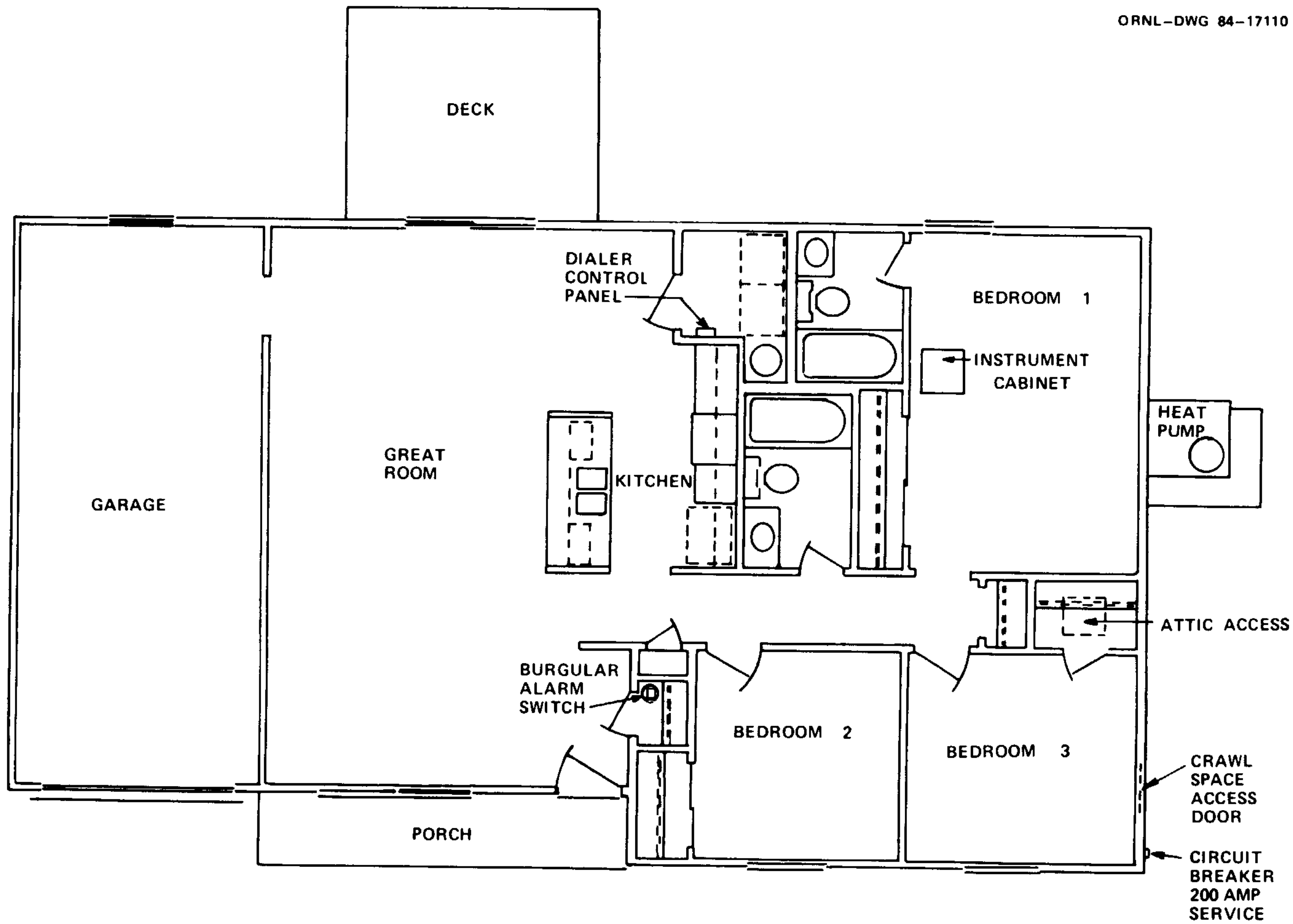

Fig. C.2 Floor plan for a Karns house.

ORNL-DWG 86-7845

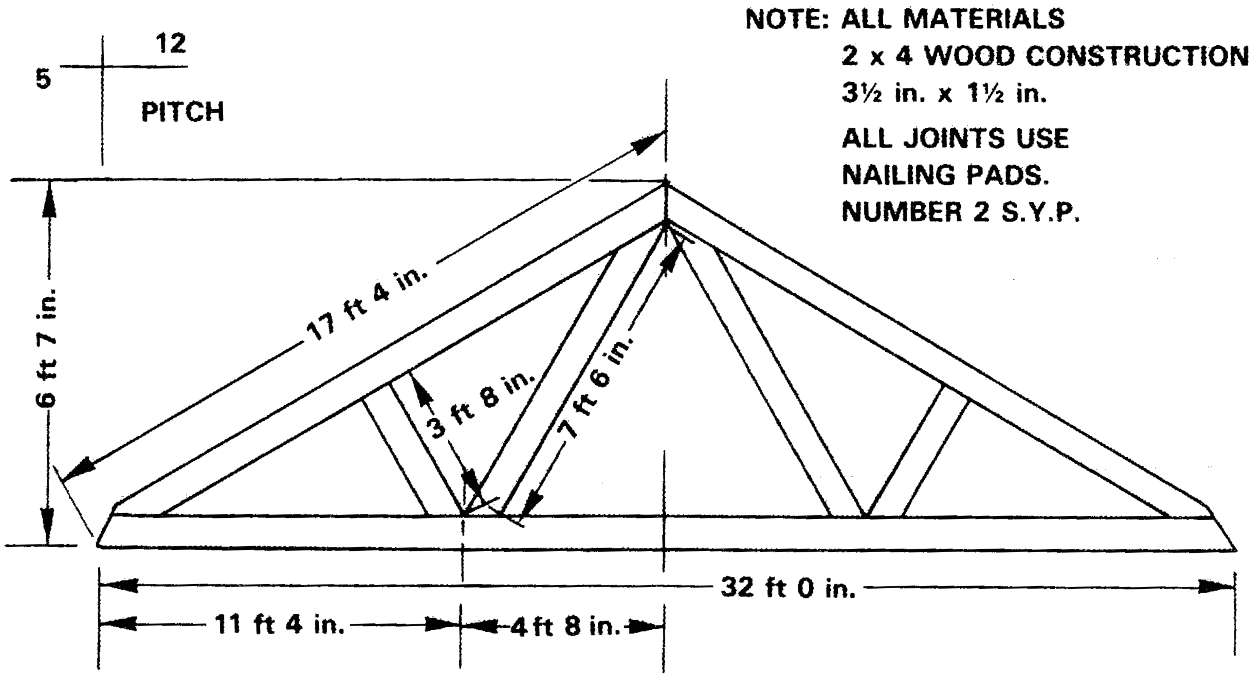

Fig. C.3 Typical Karns house attic truss.

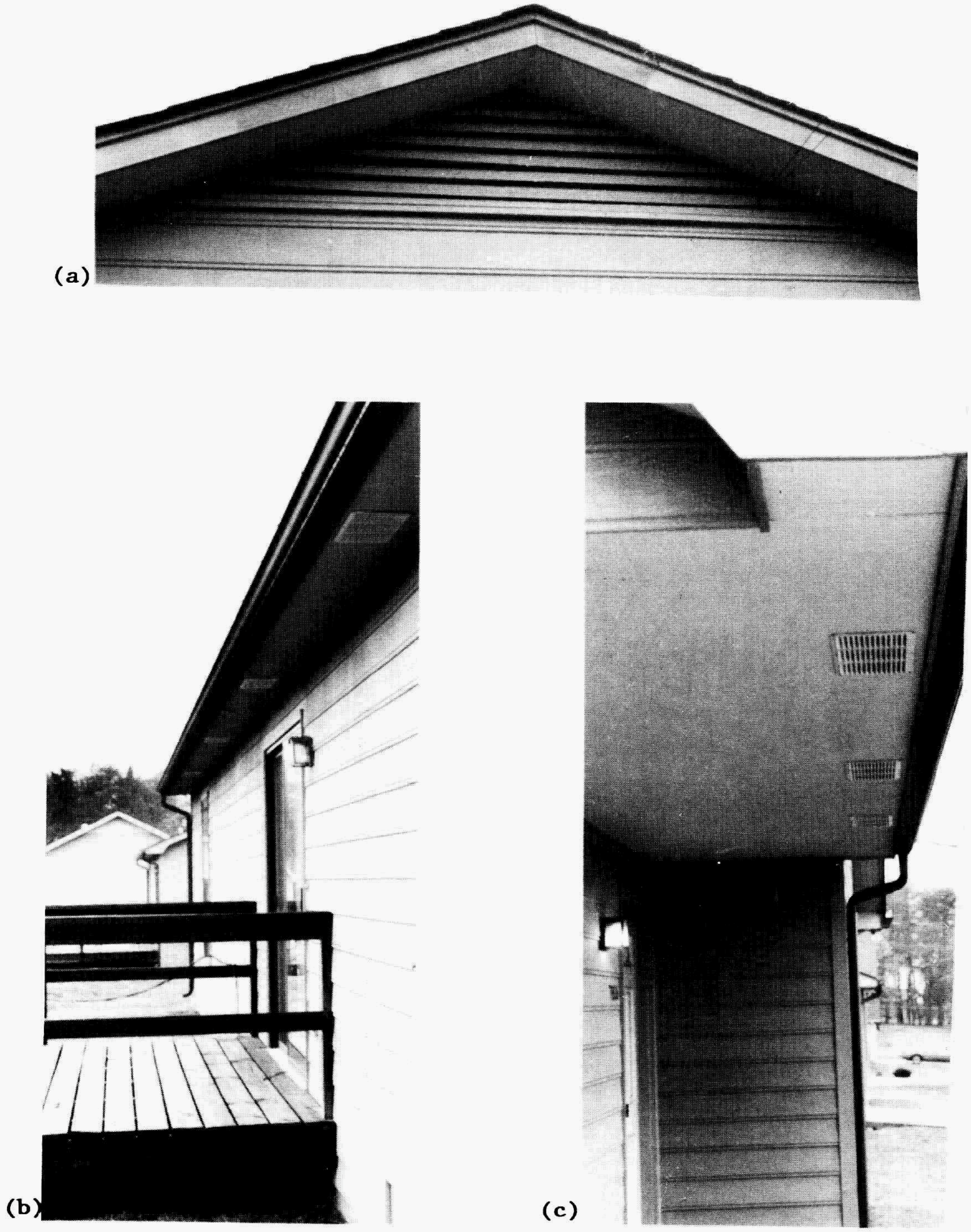

Fig. C.4 Attic ventilation setup at Karns.

Table C.1 Additional construction details on Karns houses

ADDITIONAL INFORMATION ABOUT KARNS HOUSES	
ROOF	
Roof Pitch	: 12 Horizontal, 5 Vertical
Type Construction	: Asphalt Shingles (Brown, Std Seal-Tab,240#) 15# Felt 1/2 in. CD Plywood Sheathing
Overhang	: 12 in.
EXTERIOR WALLS	
Type Siding	: 8 in. Horizontal Hardboard Siding 15# Felt 1/2 in. Sheathing 2x4 Studs @ 16 in. on Center 1/2 in Gypsum Board R-11 Fiberglass Batt Insulation
CEILING DETAILS	
Construction	: 1/2 in. Gypsum Board Wood 2x4 Trusses @ 24 in. on Center Fiberglass Batt Insulation (R-Value varies)
FLOOR DETAILS	
Construction	: 1/2 in. CD Plywood Sub-Floor 2x12 Floor Joists @ 16 in. on Center R-19 Fiberglass Batt Insulation
ATTIC VENTILATION	
Types	: Eight 8x16 in. Soffitt Vents (4 Front, 4 Rear) Two Base Louver Gable Vents (8.83 Sq Ft Area)
CRAWL SPACE VENTILATION	
Type	: Five 16x8 in FON Vents (Always Closed) Polyethylene Sheeting over Dirt Floor
ATTIC DUCTING	
Type	: None
SHADING	
Type	: None - No Trees or Other Tall Structures

Table C.2 Description of instrumentation at Karns house No.2

Channel Number	Slot Number	Instrumentation Information Number	Location and/or Description	Range	Accuracy (+ or -)
000	001	TE-014	Outside Air Temp (Rear)	0-200 F	1F
001	002	TE-082	Great Room Wet Bulb	0-200 F	1F
002	003	TE-083	Great Room Dry Bulb	0-200 F	1F
003	004	RE-070	Pyranometer (Horiz Solar)	0-500 BTUSF	3%
004	005	TE-081	Hall Ceiling Under HMF1	0-200F	1F
005	006	HFT3	Under Insulation at HFM3	0-200 F	1F
006	007	TE-087	#2 Bedroom Dry Bulb	0-200 F	1F
007	008	HFM3	Ht Flux Mtr #3 - Ctr Gr Room	100 BSFH	5%
008	009	TE-089	#3 Bedroom Dry Bulb	0-200 F	1F
009	010	TE-001	Crawl Space Air Temp	0-200 F	1F
010	011	TE-002	Crawl Space Earth 6 in	0-200 F	1F
011	012	HFT1	Ht Flx Mtr #1 Temp	0-200 F	1F
012	013	HFM1	Ht Flux Mtr #1 - Hall T'stat	100 BSFH	5%
013	014	HFT2	Heat Flux Meter #2 Temp	0-200 F	1F
014	015	HFM2	Ht Flux Mtr #2 - BR #1	100 BSFH	5%
015	016	TE-026	Outside Earth 36 in	0-200 F	1F
016	017	TE-028	Hall Closet (Carpet Top)	0-200 F	1F
017	018	RHM2	RH Mtr #2-Top Ins (Under RB)	20-95 %	5%
018	019	RHM2T	Temp at RHM2	0-200 F	1F
019	020	TE-033	Garage Inside Wall	0-200 F	1F
020	021	TE-034	Great Room Wall	0-200 F	1F
021	022	TE-035	Kitchen Air	0-200 F	1F
022	023	RT1	Roof (Under Shingles)	0-200 F	1F
023	024	TE-037	Attic Top of Insulation	0-200 F	1F
024	025	TE-038	Attic Top of Foil	0-200 F	1F
025	026	TE-039	Attic Air Above Foil	0-200 F	1F
026	027	XE-044	Wind Direction House #2	0-360 DEG	5%
027	028	XE-043	Wind Speed (House #2 Only)	0-30 MPH	5%
028	029	RHM1T	Attic Air Temp over RHM1	0-200 F	1F
029	030	RHM3T	Temp in NE Corner Under GR Ins	0-200 F	1F
030 | 039			Channels not Used		
040	HWI	ME-040	Outside Relative Humidity	10-95 %	5%
041	HWI	ME-041	Crawl Space Rel Humidity	10-95 %	5%
042	HWI	ME-042	Hallway Relative Humidity	10-95 %	5%
043 | 049			Channels not Used		

Channel Number	Slot Number	Instrumentation Information Number	Location and/or Description	Range	Accuracy (+ or -)
050	031	RHM1	Attic Air RH Mtr #1	10-95 %	5%
051	032	RHM3	NE Corner Under Ins RHM #3	10-95 %	5%
052	033	------	Not Used		
053	034	------	Not Used		
054	035	TE-031	HP Indoor Unit Return Air	0-200 F	1F
055	036	TE-032	HP Indoor Unit Supply Air	0-200 F	1F
056	037	TE-027	Thermostat (Hall Air)	0-200 F	1F
057	038	TE-023	Front Ent Outside Air	0-200 F	1F
058	039	------	Not Used		
059	040	------	Not Used		
060	HWI	------	Compressor Cycles	-	<.5%
061	HWI	JE-060	Total House W-h	-	<.5%
062	HWI	JE-061	Total Heat Pump W-h	-	<.5%
063	HWI	JE-062	Total Resistance W-h	-	<.5%
064	HWI	JE-063	HP Defrost/Cooling Run Time	-	1 Sec
065	HWI	JE-064	HP Heating Run Time	-	1 Sec
066	HWI	JE-065	HP Defrost/Cooling W-h	-	<.5%
067	HWI	JE-066	HP Heating W-h	-	<.5%
068	HWI	JE-067	Resistance Defrost W-h	-	<.5%
069	HWI	JE-068	Resistance Normal W-h	-	<.5%
070	HWI	JE-069	Sensible Heat/Cool Delivered	-	2%
071	---	------	Damaged Channel	-	
072	HWI	------	Water Added to Humidifier	-	2%
073	HWI	------	Resistance Run Time	-	1 Sec

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