#2557

#2557 AIVC 207

LBL-17591

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Presented at the American Society for Testing Materials Symposium on Thermal Insulation, Materials and Systems, Dallas, TX, December 2-6, 1984

A METHOD TO PREDICT THE HOUR BY HOUR HUMIDITY RATIO OF ATTIC AIR

P. Cleary and R. Sonderegger

December 1984

AIVC

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL 17591
EEB-epb-85-02

Presented at the American Society for Testing Materials Symposium on Thermal Insulation, Materials and Systems on December 2-6, 1984, Dallas, Texas.

A METHOD TO PREDICT THE HOUR BY HOUR HUMIDITY RATIO OF ATTIC AIR

Peter Cleary* and Robert Sonderegger**

*Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

**President, Morgan Systems Incorporated
Berkeley, CA 94707

December 1984

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

A METHOD TO PREDICT THE HOUR BY HOUR HUMIDITY RATIO

OF ATTIC AIR

ABSTRACT

Long term measurements of attic wood moisture content have shown that at least fifty kilograms of water may be stored in roof sheathing members over the course of the winter, to be released in the spring. Overlaid on this seasonal cycle there is a daily variation driven by temperature changes in the attic. A dynamic model is required to predict the resulting attic air humidity ratio. Hourly moisture flows in a typical attic - from ventilation and from the wood - are examined, and a simple first-principles dynamic mathematical model to relate them is developed. The model predicts the hour-by-hour attic air humidity ratio. Results are compared with measured data. The implications for attic ventilation rates at different levels of attic insulation are discussed.

KEY WORDS: attic, humidity, moisture, modelling

Introduction

An attic is usually naturally ventilated, its temperature and relative humidity being determined both by the weather, and by air, heat and moisture transport from the living space. The aim of ventilation is to prevent condensation in winter, and to reduce cooling loads in summer. Moisture enters the attic from the house (both by convection and diffusion), and mixes with the usually drier ventilation air. During the day, the attic is heated by solar radiation. At night, the roof sheathing cools down by radiating heat to the sky; its temperature can drop below the outside air temperature.

It was thought that the sheathing was an inert surface. Thus if its temperature were to drop below the attic air dew point temperature, condensation would form. It was believed that good ventilation could prevent condensation, since more ventilation would result in a generally drier air mixture in the attic.

Recent studies have found that the wood in an attic is not inert, but that it adsorbs and desorbs moisture continually. Ford [1], Dutt [2], and Cleary [3] investigated houses in New Jersey and California, and showed year-long cycles in which wood dried in the summer and adsorbed moisture in the winter. This cycle is illustrated in Figure 1 for a single-family unoccupied house in Oroville, California [3]. Approximately 60 kg of water was adsorbed during the winter. To investigate the driving forces behind this cycle, the attic was monitored over the six-month period December 1983 - May 1984.

Experimental Procedure

Oroville is located in the northeast Sacramento valley, approximately 120 km northwest of Sacramento itself. The winter is mild. Chico, about 30 miles away in the same climate-zone, has a January 30-year average minimum temperature of 2.2 ^{o}C [4].

The house was a single-storey, 7.9m by 7.9m with a gable roof sloped at 33.7 degrees to the horizontal. Ventilation was by approximately 3000 cm^2 of soffit vents. There was no ceiling vapour retarder, and the attic floor was insulated with 15 cm thick fiberglass batts. Parameters measured continuously at the site included outside dew point, wind speed and direction, attic sheathing temperature at four points, wood electrical resistance at three points, and attic air dew point. Periodic measurements of attic ventilation rate were made by sulfur hexafluoride injection and decay.

The concentration of moisture in the attic and outside air was measured by means of aspirated chilled-mirror hygrometers. Roof sheathing temperatures were measured inside the attic with calibrated solid-state sensors, two terminal integrated circuits which produced a current of 1 micro-ampere per degree Kelvin. The sensors were epoxied to copper discs, and the copper disks nailed on the undersurface of the sheathing. Wood moisture content (kg of water per kg of dry wood) was derived from measurements of the electrical resistance between pairs of electrodes inserted 10 mm into the wood. Details of the method may be found in [3]. It was not possible to remove wood samples from the attic to check the results, but research by Burch and co-workers at the National Bureau of Standards [5] has given an accuracy of $\pm$ 1.4 percentage points for wood resistance measurements.

There were no sources of moisture in the house except for that caused by the periodic visits of researchers (e.g. showers, washing), approximately once every two weeks. Air flow between the house and the attic was small; on the one occasion when it was measured by SF_6 injection into the attic, a flow of 4 m^3/h from the attic to the house was found.

Results

The ventilation rate was not measured continously. A number of measurements were made at different windspeeds and an average value of an empirical area V was found, where V is defined by $R = V \times S$. R is the ventilation rate, m^3/s, S is the windspeed, m/s, and V is an empirical constant, m^2. V was found to be 0.023 m^2; the physical area is approximately 0.030 m^2. Temperature differences between the house, the attic and outside were not found to have a significant effect on the ventilation rate.

Figure 2 shows the roof sheathing temperature for three days in January, 1984. The outdoor and attic air humidity ratios for the same period are shown in Figure 3. There is a distinct 24-hour periodicity to the data. The same periodicity can be seen in Ford

[6], for a New Jersey attic in September, and a similar pattern was observed by Burch and co-workers in an environmental chamber study [op cit.].

It was postulated that the source of the peaks in humidity ratio was moisture desorbed from the roof sheathing, caused by warming by solar radiation. The wood in the attic weighs approximately 1100 kg, and in mid-January contained an estimated 124 kg of water. Thus a fractional variation in the percentage wood moisture content can change the air humidity ratio by more than one hundred percent.

This dynamic flow of moisture is in contrast to the classic picture, where the attic humidity ratio is equal to that of the outside air unless condensation occurs on some surface inside the attic. The amount of water desorbed from the wood can be calculated by a mass balance for water entering and leaving the attic. (In an occupied house, a third term would have to be added for transport into and out of the living space.) Assuming that the wood is the sole source of moisture and that the attic air is perfectly mixed, the mass balance gives:

$$m = M(W_{attic} - W_{outside}) \tag{1}$$

where

- m = rate of water flow from the wood, kg/s,
- M = (dry) mass flow rate of ventilation air, kg/s,
- W_{attic} = attic air humidity ratio, unitless,
- $W_{outside}$ = the outside air humidity ratio, unitless.

The calculated water flow rate for this period is shown in Figure 4. It can be seen that the flow peaks just after noon each day, and that during the night the attic actually absorbs water from the ventilation air. The magnitude of the flows is rather large, up to 2 kg/h. This may be compared with a typical moisture generation rate for an occupied house of 0.4 kg/h. [7]

Theoretical Model

A simple model has been developed to predict the flow of water into the wood. For a more complete analysis of moisture and heat flow, see [8]. Following standard models [9] the flow of water from the wood is given by:

$$m = k\,A\,(W_s - W_{attic}) \tag{2}$$

where

m = flow of water, kg/s,

k = transfer coeffficient, $kg/m^2.s$,

A = transfer surface area, m^2 ,

W_s = humidity ratio of the air surface film, unitless,

W_{attic} = humidity ratio of the air in the attic air, unitless.

Assuming a Lewis relationship of 1.0 [10] the transfer coefficient is:

$$k = h_c/C_p \tag{3}$$

where

h_c = convective heat transfer coefficient, $W/m^2.{}^oC$,

C_p = specific heat of moist air, $J/kg.{}^oC$.

A constant value of 0.08 $kg/m^2.s$ for k was used in this study. The surface humidity ratio may be found from data on wood properties. (For example, Table 3-4 of [11] gives the moisture content of wood at various temperatures and relative humidities. It is said to apply to any species of wood.) If it is assumed that the wood is homogeneous, and that the surface film humidity ratio is a function solely of temperature and wood moisture content, this data can be used to find W_s. The data from Table 3-4 was transformed into humidity ratio for various combinations of temperature and wood moisture content, and an empirical correlation made to the data. A good fit was found of the form:

$$W_{surface} = e^{T/a} \{b + cu + du^2 + eu^3\} \quad (4)$$

where

T = wood temperature, ^oC,

u = weight of water in the wood divided by the dry-weight of the wood, (unitless),

a	=	15.8 ^oC	b	=	-0.0015	c	=	0.053
d	=	-0.184	e	=	0.233			

The term for water flow may be eliminated from Equations 1 and 2, giving an equation for the attic air humidity ratio:

$$W_{attic} = \frac{\dfrac{A\,k\,W_s}{M} + W_{outside}}{1 + \dfrac{A\,k}{M}} \qquad (5)$$

This equation predicts attic humidity ratio as a function of wood area (sheathing area and truss area), ventilation rate, outside humidity ratio, and wood surface film humidity ratio (itself a function of wood moisture content and temperature). The unitless parameter Ak/M gives a measure of whether the attic is dominated by the wood surface humidity ratio ($Ak/M \gg 1$) or by the outside air humidity ratio ($Ak/M \ll 1$). For the three-day period examined here, windspeeds were low and Ak/M was approximately 10; thus the attic was surface dominated.

The wood in the roof consists of two main components, the roof sheathing and the roofing trusses. It was assumed that all the roof sheathing was at one temperature and moisture content, and all the roofing trusses at another temperature and moisture content. A comparison of the predicted and measured attic air humidity ratio is shown in Figure 5. The measured wood moisture content was almost constant for the three day period. Daily values for the west sheathing were 12.9%, 12.8% and 12.8%; for the truss, 9.6%, 9.4% and 9.4%. Fixed values of 12.8% and 9.4% were used for the prediction. Good agreement is seen between measured and predicted attic air humidity ratio, though the prediction is always lower than the measurement at night.

Sensitivity Studies

To see how errors in attic ventilation rate and wood moisture content might affect the results, two sets of sensitivity runs were made.

The effect of errors in the windspeed/ventilation rate correlation was investigated by varying the windspeed by a factor of two above and below the measured value, i.e. the ventilation rate was varied by a factor of four. The results are shown in Fig. 6. It can be seen that the effect on the prediction is minor. As discussed above, the attic air humidity ratio was dominated by the wood surface humidity ratio, not by the ventilation rate.

The wood moisture content was varied by 2% above and below the measured values of 12.8% for the sheathing and 9.4% for the trusses. The results are shown in Fig. 7. It can be seen that this variation in wood moisture content causes approximately a 25% change in the predicted attic air humidity ratio.

Discussion

Guidelines for attic ventilation are in a state of flux. The 1981 American Society of Heating, Refrigerating and Air-Conditioning

Engineers (ASHRAE) Handbook of Fundamentals [12] gives only what it calls "Past Practice", and notes that it may not apply to new construction.

In the classic picture of an attic, the roof sheathing is inert and does not store moisture. The measurements described above indicate that there is in fact a constant flow of moisture into and out of the wood in an attic. In the attic of the house that was monitored, flow rates of as high as 2 kg/h were measured. Current attic ventilation guidelines do not allow for the possibility of moisture storage and release, and may either under- or over-estimate the amount of ventilation needed for moisture control.

By chance, the old guidelines appear to work well for attics with low levels of insulation. For well-insulated attics, the model presented above could be used to test various ventilation strategies.

A more general problem is that the purpose of winter attic ventilation is now unclear. It was thought that ventilation removed the moisture that leaked into the attic from the house. In the Oroville case, the house was not occupied and all the moisture that was stored in the wood of the attic came from the ventilation air. Thus more ventilation may not help.

The old rationale of preventing the sheathing temperature reaching the dew point is inadequate; a new rationale for ventilation is required. Two obvious candidates are (1) the prevention of wood moisture content levels above some threshold, or (2) the prevention of conditions which are known to be conducive to fungal or bacterial growth.

Conclusion

Measurements have been made which show that there is considerable flow of water into and out of the roof sheathing and trusses of a residential attic. This is in contrast to the classic picture of attics, and agrees well with studies carried out recently by other researchers.

A simple model has been presented which treats the moisture flow in an attic as a function of wood temperature, wood moisture content, outside humidity ratio, and attic ventilation rate. The model is shown to predict the attic humidity ratio well.

ACKNOWLEDGMENTS

The author is grateful for the assistance of his colleagues at the Energy Performance of Buildings Group at Lawrence Berkeley Laboratory.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the US Department of Energy under contract No. DE-AC03-76SF00098.

REFERENCES

1. Ford, J.K. "Heat Flow and Moisture Dynamics in a Residential Attic" a thesis submitted as part of the requirements for a degree of Master of Science in Engineering from Princeton University, 1981

2. Harrje, D.T., Gibson, R.G., Jacobson, D.I., Dutt, G.S., and Hans, G., "Field Measurements of Seasonal Wood Moisture Variations in Residential Attics", Report No. 173, The Center for Energy and Environmental Studies, Princeton University, January 1984.

3. Cleary, Peter, "Moisture Control by Attic Ventilation - An In-Situ Study", Report No. LBL-18062, Lawrence Berkeley Laboratory, University of California, Berkeley, July 1984.

4. Climatology of the United States No. 81 (By State), "Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951-1980, California", National Oceanic and Atmospheric Administration, September, 1982.

5. Burch, D.M., M.R. Lemay, B.J. Rian, and E.J. Parker, "Experimental Validation of an Attic Condensation Model", presented at the ASHRAE 1984 Annual Meeting, Kansas City, Missouri, June 17-20, 1984, to be published in the transactions.

6. Ford, J.K. "Humidity Measurement And Modeling in a Residential

Attic", in Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds., American Society for Testing and Materials, 1982, pp 160-190

7. American Society of Heating, Refrigerating and Air-Conditioning Engineers, "Environmental Control Principles", 1977, p 82

8. Kohonen, R., and J. Maatta, "Transient Analysis of the Thermal and Moisture Physical Behaviour of Building Constructions", Technical Research Center of Finland, Report #168, reproduced with permission by US National Technical Information Service as report # PB83-227454

9. Kays, W.M. and M.E. Crawford, "Convective Heat and Mass Transfer", McGraw-Hill Book Company, 1980

10. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Handbook of Fundamentals, 1981, p. 3.10

11. "Wood Handbook", Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, 1974

12. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Handbook of Fundamentals, 1981, p. 21.15

FIGURE 1

Oroville Attic Conditions
West Roof Sheathing, winter 1983-84

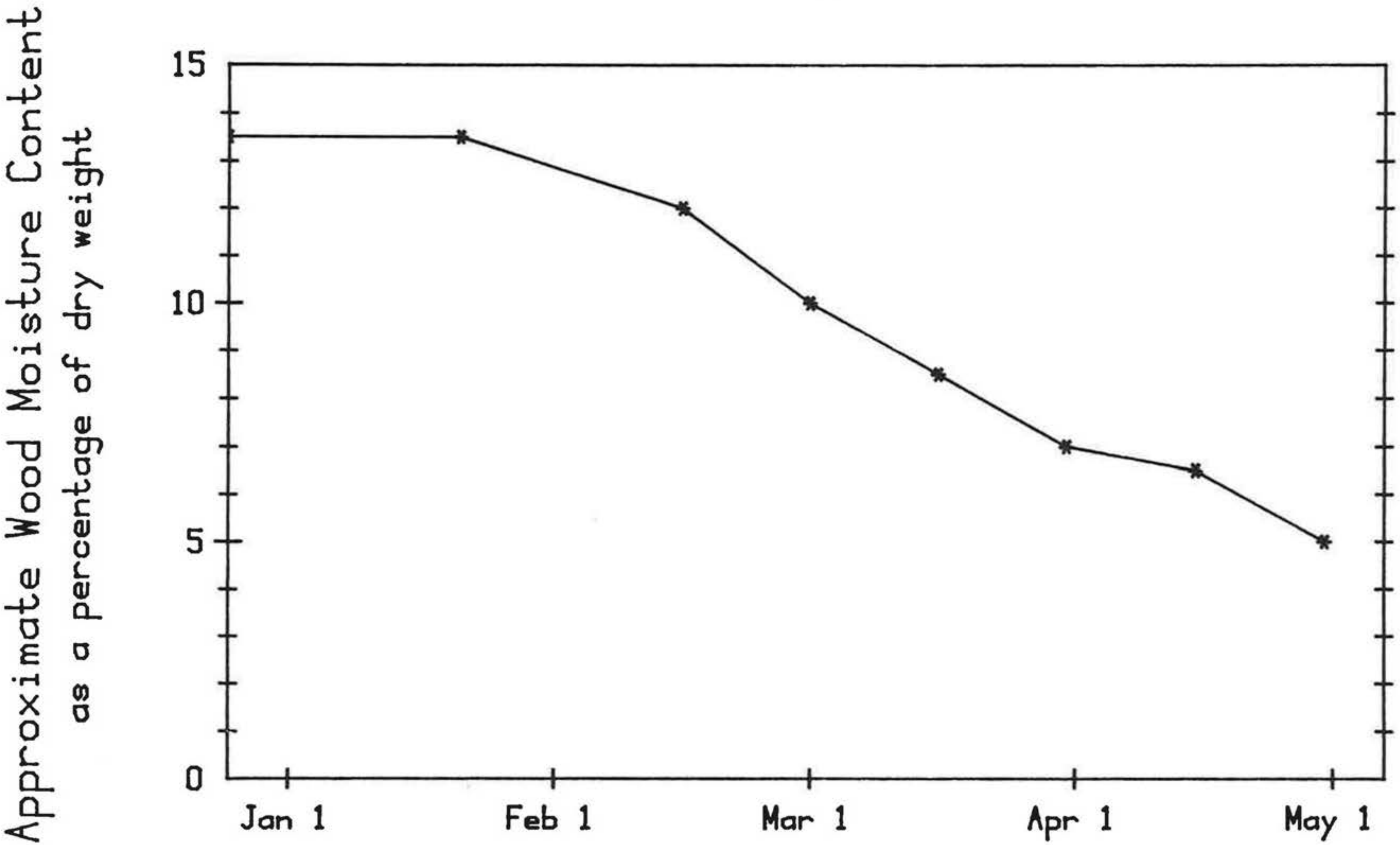

FIGURE 2 Oroville Roof Sheathing Temperatures

January 22 to 24, 1984

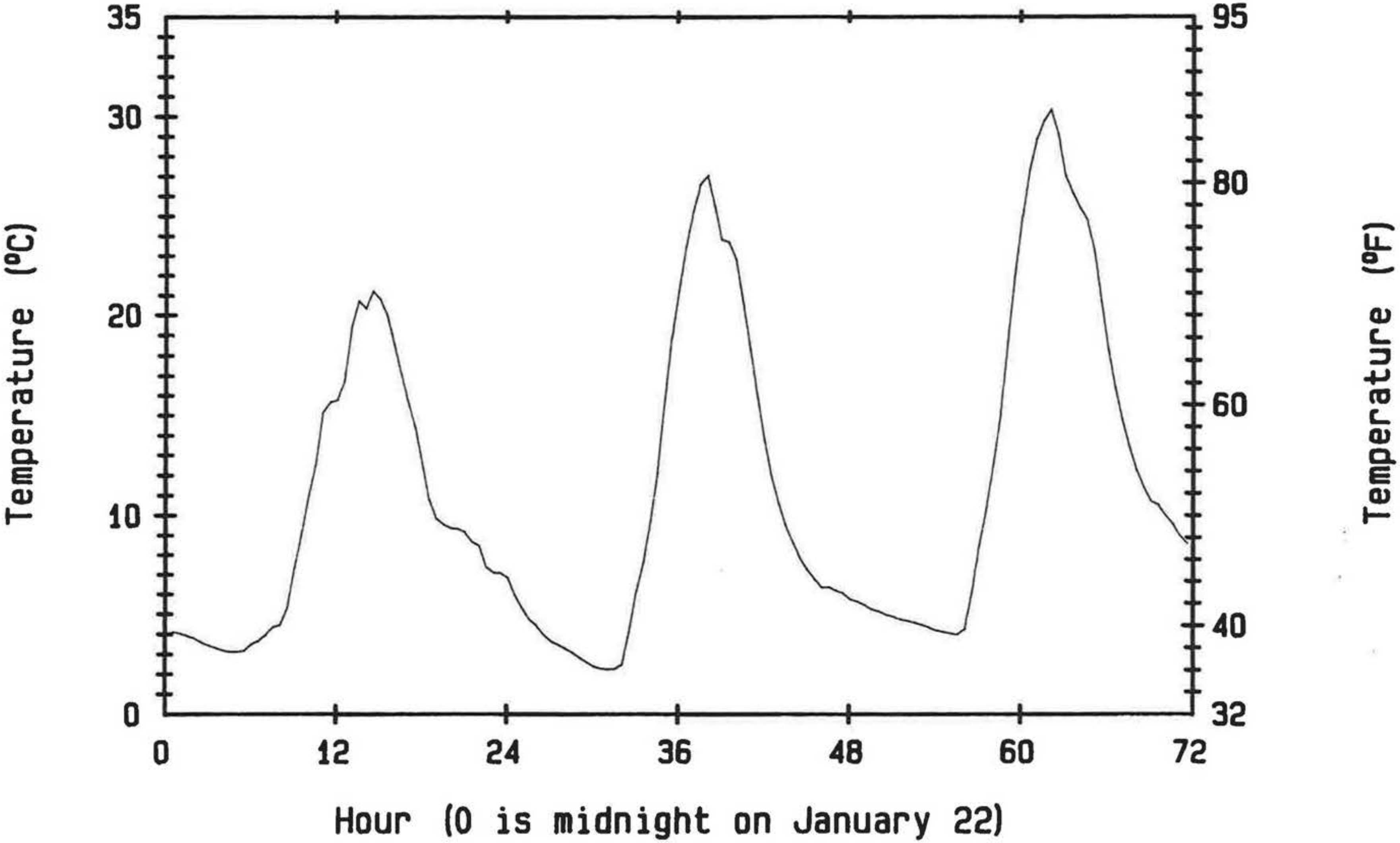

FIGURE 3 Oroville Attic and Outside Conditions
January 22 to 24, 1984

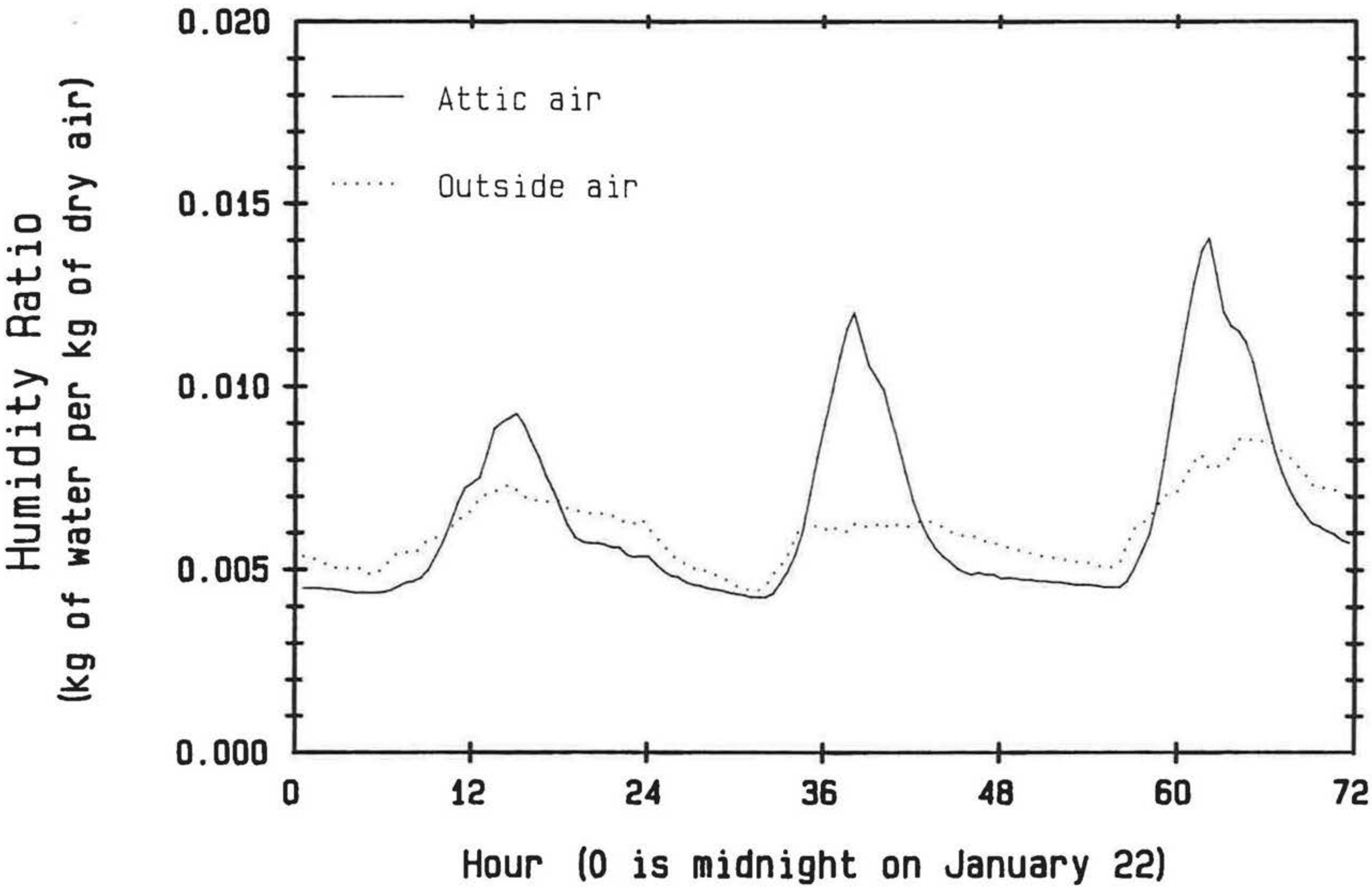

FIGURE 4 Moisture Flow in the Oroville Attic

January 22 to 24, 1984

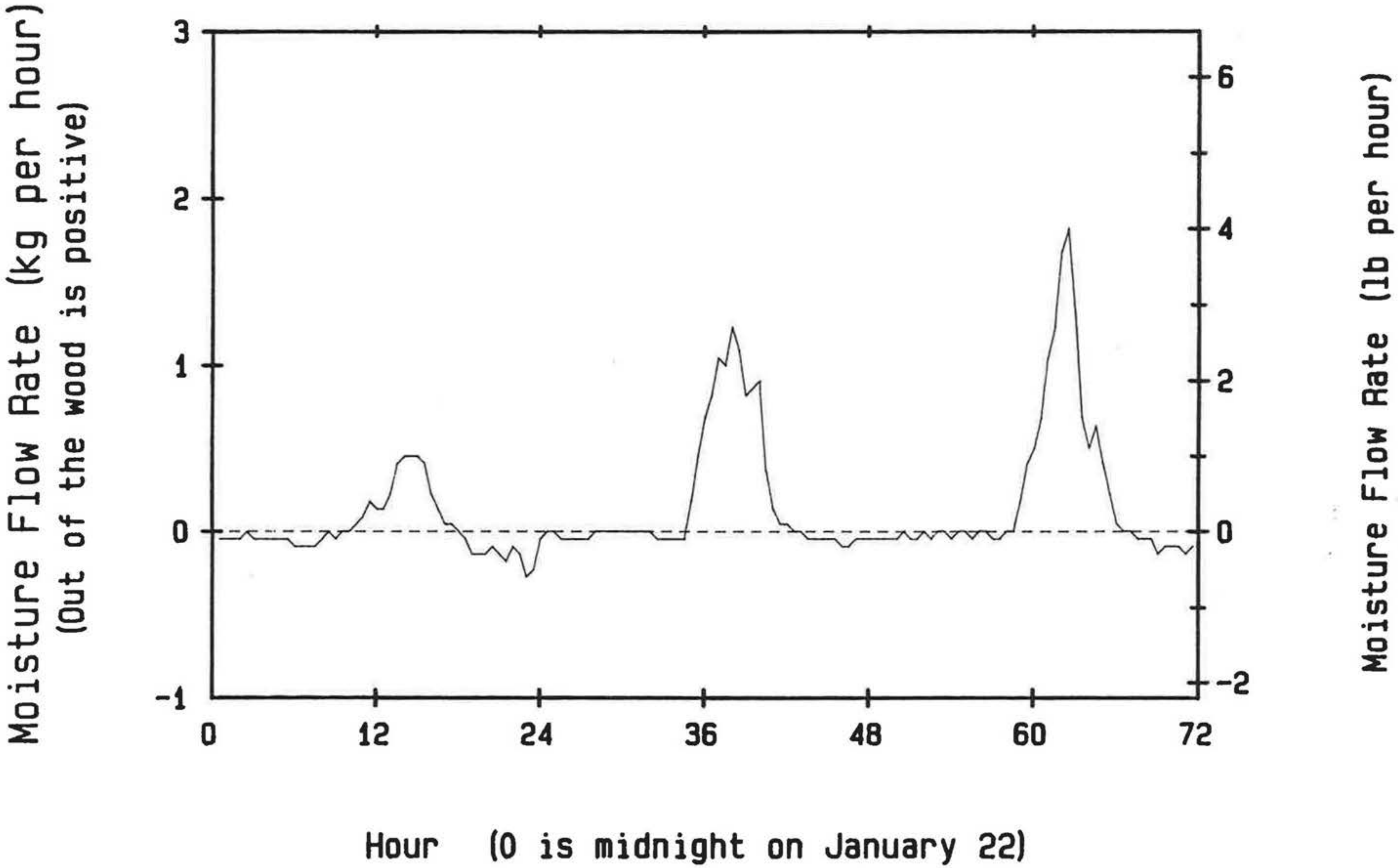

FIGURE 5 **Oroville Attic Conditions**

January 22 to 24, 1984

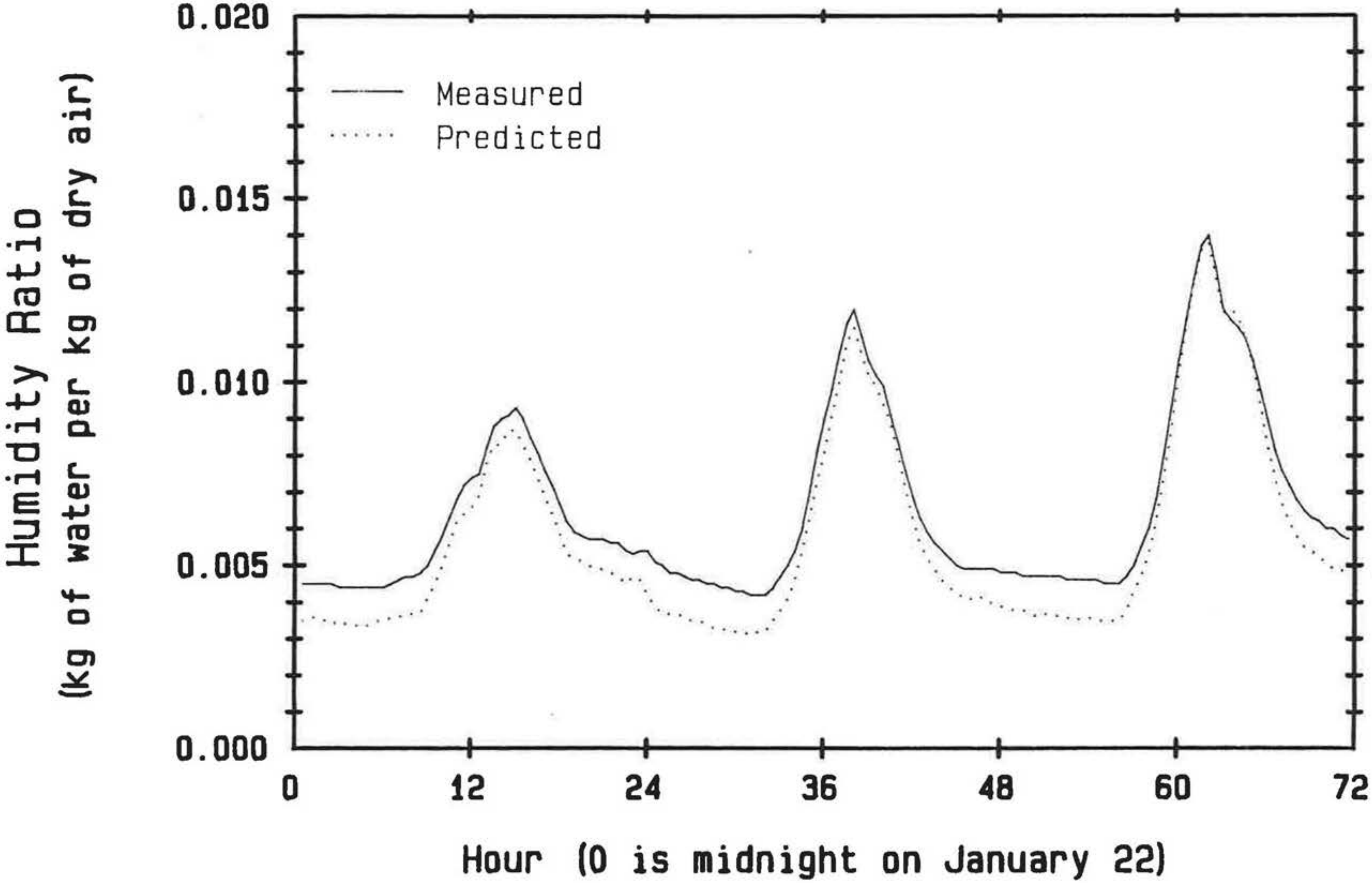

FIGURE 6 Oroville Attic Conditions
January 22 to 24, 1984

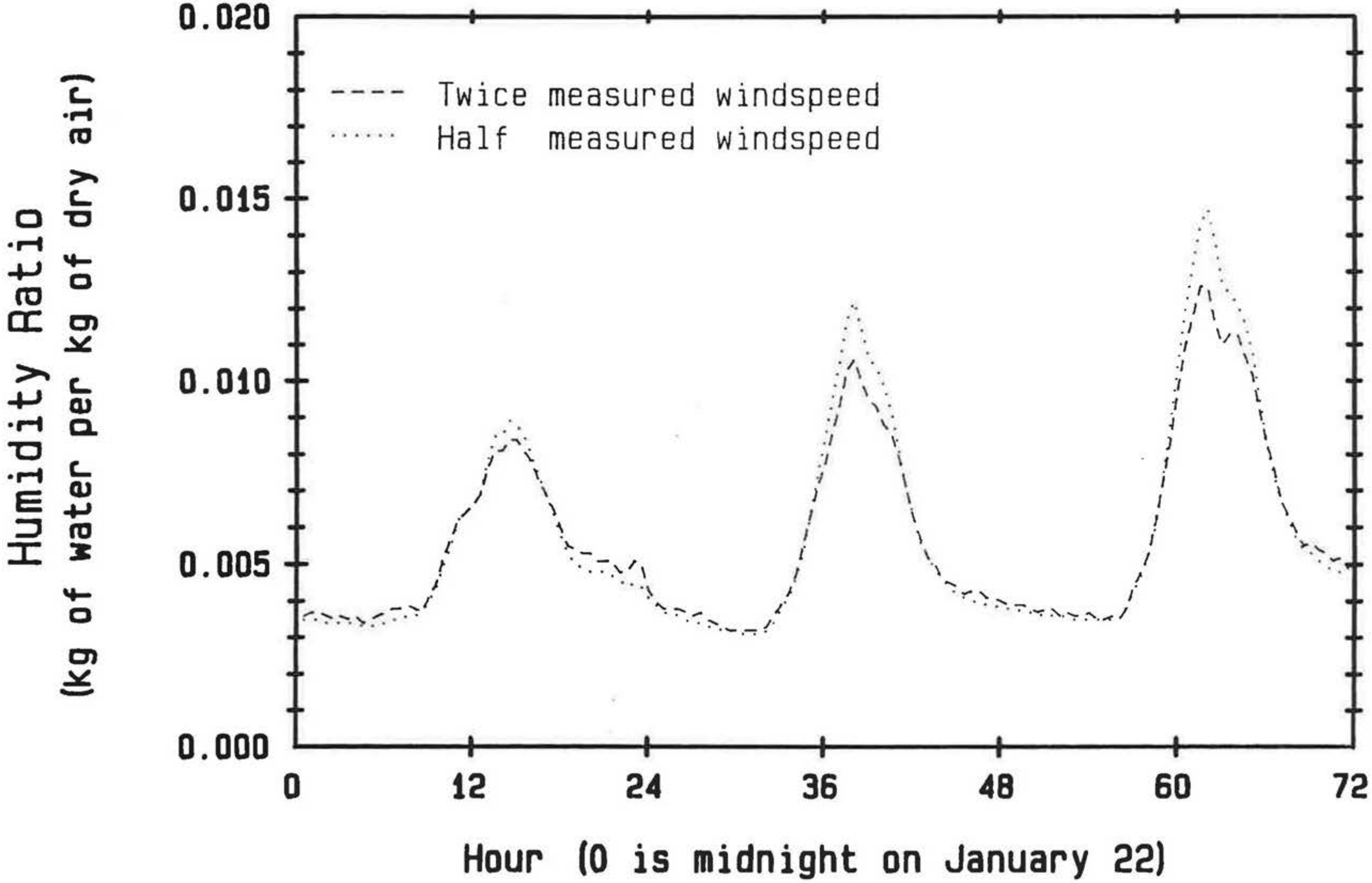

FIGURE 7 Oroville Attic Conditions
January 22 to 24, 1984