Hygrothermal Performance of Attics

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1. SUMMARY

THIS PAPER DESCRIBES the results of measurements of temperature and relative humidity in six different attics (roof spaces) under controlled conditions. All six attics have the same dimensions and have been constructed adjacent to each other in a single line, but with different insulating materials and ventilated in different ways.

Using this fund of measured data, a number of researchers have attempted to apply their mathematical models and, starting from the basis of measured ambient climatic conditions, have calculated expected values of temperature, relative humidity, and, in one case, the moisture ratio in the attics. The results of these calculations showed difficulties in matching the performance of the models to real conditions.

Summarising the measurements and the calculations, we can note that:

- There is some degree of moisture buffering in hygroscopic insulation materials (cellulose materials) compared with non-hygroscopic insulation (mineral wool). However, the difference is not particularly large.
- There are considerable differences in moisture and temperature variations in roofs with high and low ventilation rates. The higher the amount of ventilation using outdoor air, the greater the variations.
- The climate in the attic becomes drier the less it is ventilated. This result needs to be interpreted with considerable care. In the experimental structure, moisture from inside the building has been eliminated partly by an essentially totally airtight ceiling structure beneath the attic and partly by negative pressure in the structure beneath, maintained by extra fans. In an attic of this type, the ventilation air supplies moisture which, during clear cold nights, can condense and remain in the attic. Under these conditions, the ventilation is therefore a drawback. In an attic above a normal house, the risk of moisture finding its way into the attic from the house must be considered.

The following recommendations can be given, against the background of the work performed to data:

- The above views and results of the project are applicable to attics without a moisture input.
- Moisture can be introduced during the building stage or in normal use. Building moisture must be allowed to dry out before it can cause damage.
- During the subsequent use stage, convection of moist air up into the attic must be prevented. This is done by ensuring that the structure is airtight in combination with an internal negative pressure.

2. BACKGROUND

The majority of detached houses have unheated attics, i.e., a structure comprising a thermally insulating ceiling structure, an unheated, outdoor-air-ventilated attic (roof space), and a sloping outer roof to shed water.

The problems of ventilated attics are accentuated in new buildings through the constantly increasing amounts of thermal insulation applied to the ceiling and the reduction of what used to be a slight heat input from the chimney passing through the roof space by a switch away from oil firing to electric heating (Samuelson, 1992).

This project is a continuation of earlier work concerned with ventilation of roof spaces and laboratory investigations of moisture buffering in different types of thermal insulation materials and of the thermal insulation performance of loose-fill insulation with different moisture contents (Samuelson, 1992; Magnusson and Tobin, 1992; Sandberg, 1992; Löfström, 1994).

3. VENTILATION

Historically, the purpose of ventilation has been to keep the outer surface of the roof sufficiently cold to prevent snow from melting. Nowadays, no ventilation is needed for this purpose, as the amount of heat leaking through a

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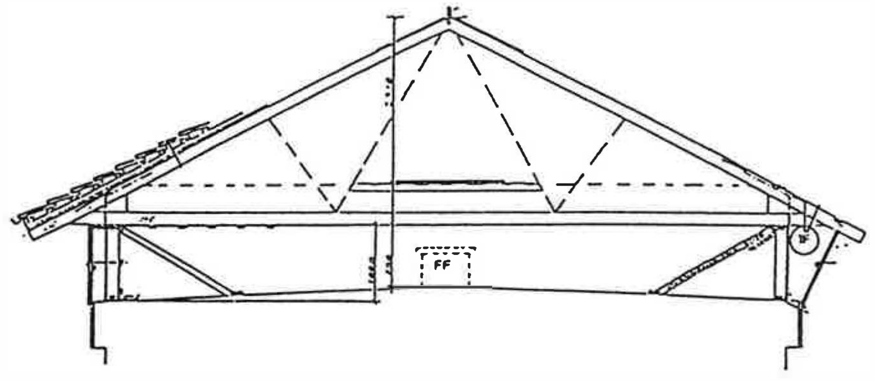

FIGURE 1. Sections through the attic (schematic).

well-insulated ceiling and roof is very small. Instead, attics are now ventilated in order to remove any moisture. If any moisture does find its way in, it must also be possible to remove it so that the materials can dry out. However, the provision of ventilation is not solely beneficial. Under certain conditions, ventilation can introduce more moisture than it removes. This applies during the winter, when the outdoor air has very little ability to absorb moisture. It can therefore be questioned as to whether the roof space should be ventilated at all during the winter and, if so, whether the area of the ventilation openings is justified. During the summer, however, ventilation is important in order to carry away any moisture, as the attic is heated by the sun, which means that the air can pick up water vapour and dry out the attic.

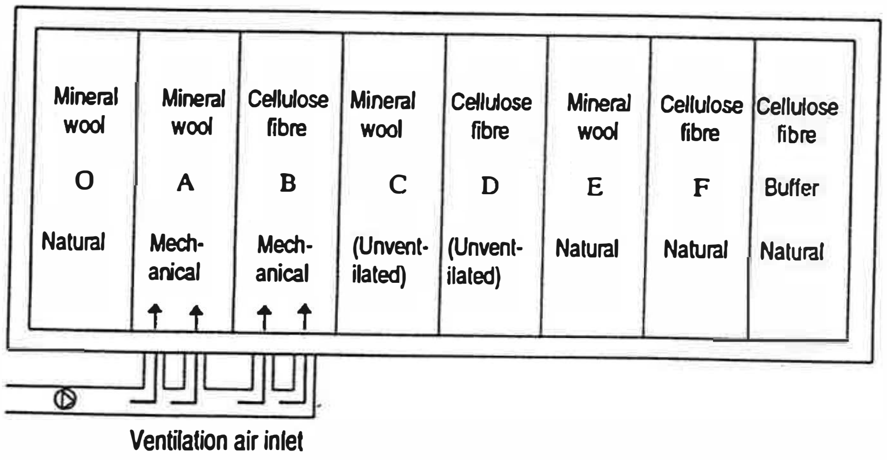

FIGURE 2. The various

This project has measured conditions in eight attic sections, separated from each other, and of which two have ventilation in accordance with the requirements of the Swedish Building Regulations, two have mechanical ventilation (2 air changes/h) and two are unventilated. The outer sections serve as protection zones (see Figures 1 and 2).

The naturally ventilated sections have an air gap of about 50 mm along the eaves. There is no air gap at the ridge. The mechanically ventilated sections have fans that produce an air change rate of 2 air changes/h. No intentional openings have been provided in the two unventilated sections.

4. INSULATION MATERIALS

The insulation materials that have been investigated in this project are loose-fill materials of cellulose fibre and of mineral wool. The characteristics of the materials used in the attics are listed in Table 1. Note that the characteristics listed here are those obtained under laboratory conditions: no allowance has been made for moisture or standard of workmanship. The characteristics listed in the table are those that have been used in the calculations.

5. MEASUREMENTS

Physically, the experimental roof has been constructed above a flat-roofed

Table 1. Material characteristics for the materials in the roof spaces.

Material	Density kg/m³	Thermal Conductivity λ, W/m·K	Water Vapour Permeability $\delta \cdot 10^{-6}$ m²/s	Comments
Polyethene film			~0	Plastic film (above ceiling)
Plywood		0.14	~2.0	Above ceiling
Wood	450	0.14	~2.0	Roof trusses
Mineral wool I	22	0.040	20	Loose fill

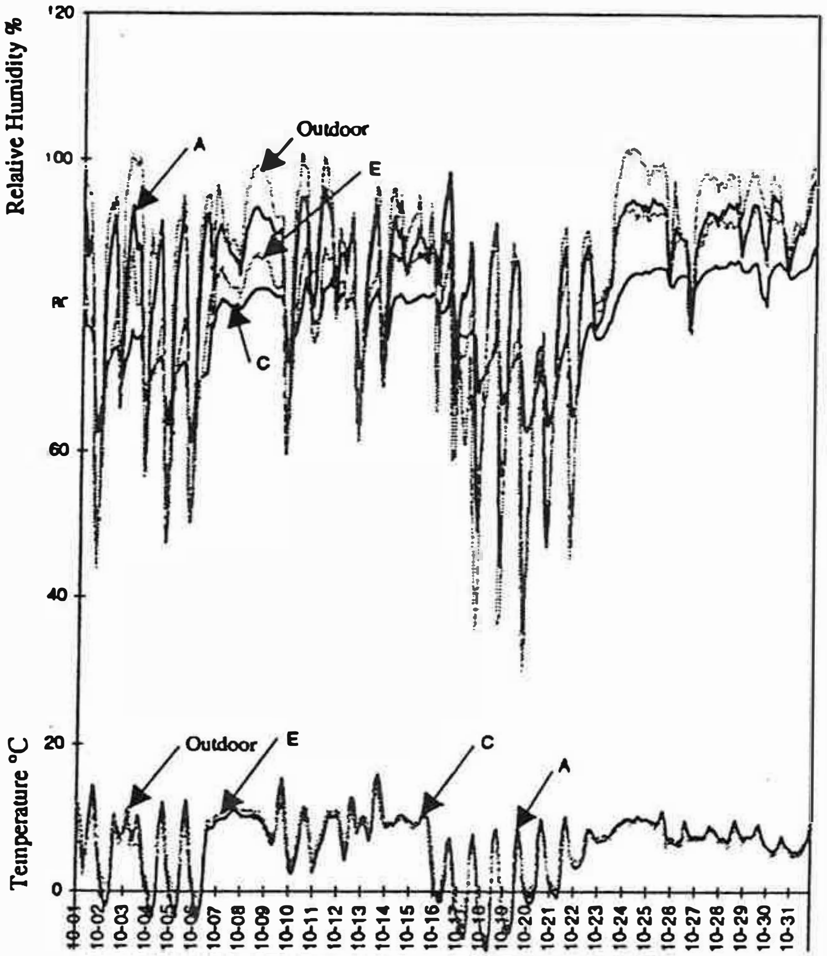

FIGURE 3. Measured temperature and relative humidity in roof sections A, C, and E (having mineral wool insulation) during October 1994.

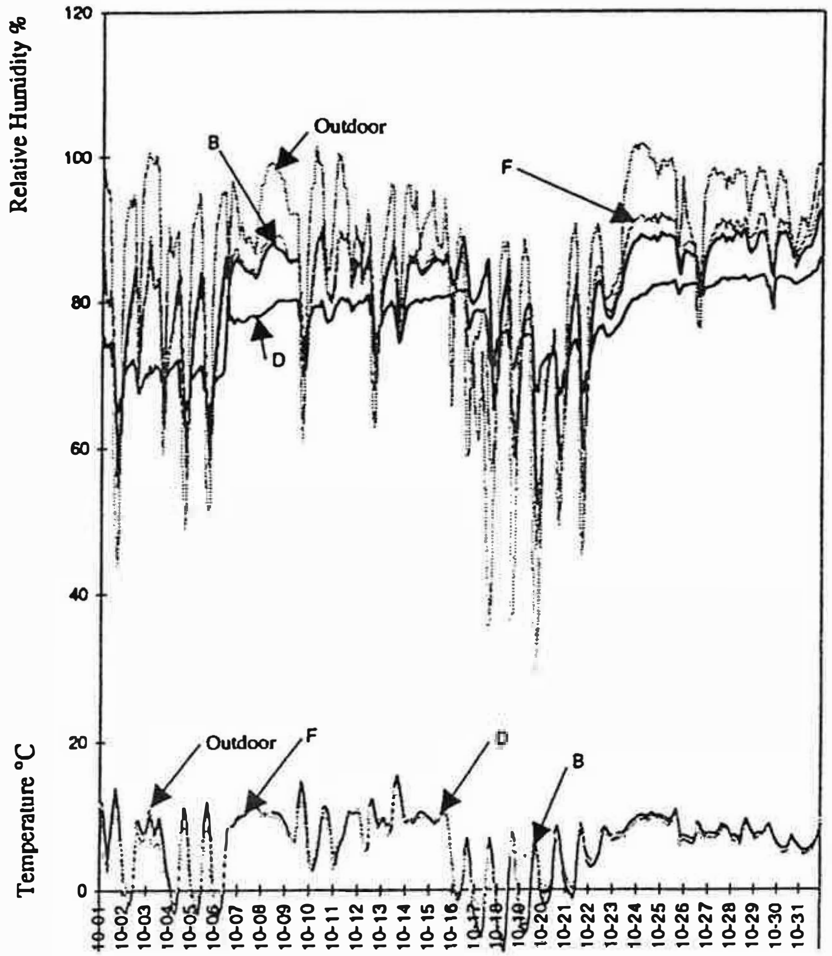

FIGURE 4. Measured temperature and relative humidity in roof sections B, D, and F (having cellulose fibre insulation) during October 1994.

Table 2. Monthly mean values of temperature and relative humidity, June 1994–June 1995.

		June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
. Mech vent (Minwool)	Temp.	19.7	24.9	19.5	12.4	6.3	4.0	2.4	−1.8	1.5	2.1	6.7
	RH	56	43	59	80	82	91	96	91	91	81	67
. Mech vent (Cellulose fibre)	Temp.	20.2	25.4	20.1	12.9	6.4	4.0	2.4	−1.9	1.5	2.2	6.7
	RH	51	41	53	75	81	89	93	90	89	82	68
. No vent (Minwool)	Temp.	20.5	25.8	20.4	13.2	6.2	3.5	1.8	−2.4	1.0	1.9	6.9
	RH	50	40	52	72	77	86	90	89	88	83	67
. No vent (Cellulose fibre)	Temp.	19.8	25.0	19.9	12.8	6.1	3.4	1.8	−2.4	1.0	1.8	6.8
	RH	48	40	49	68	76	85	89	90	89	84	68
. Natural vent (Minwool)	Temp.	19.9	24.8	20.2	13.9	6.5	3.6	1.9	−2.3	1.0	1.6	6.4
	RH	54	43	56	73	79	91	95	93	92	83	67
. Natural vent (Cellulose fibre)	Temp.	19.0	24.2	19.3	12.3	6.1	3.6	2.0	−2.2	1.1	1.6	6.1
	RH	57	43	56	76	80	90	94	91	90	82	68
utdoor climate	Temp.	16.8	20.9	17.1	11.4	6.0	3.9	2.2	−2.1	1.3	1.5	5.0
	RH	72	58	73	89	84	90	94	89	88	80	72
ndoor climate	Temp.	21.7	23.9	21.8	18.6	20.2	19.9	18.6	16.2	17.7	19.6	21.4
	RH	47	42	49	55	43	43	42	38	40	31	25

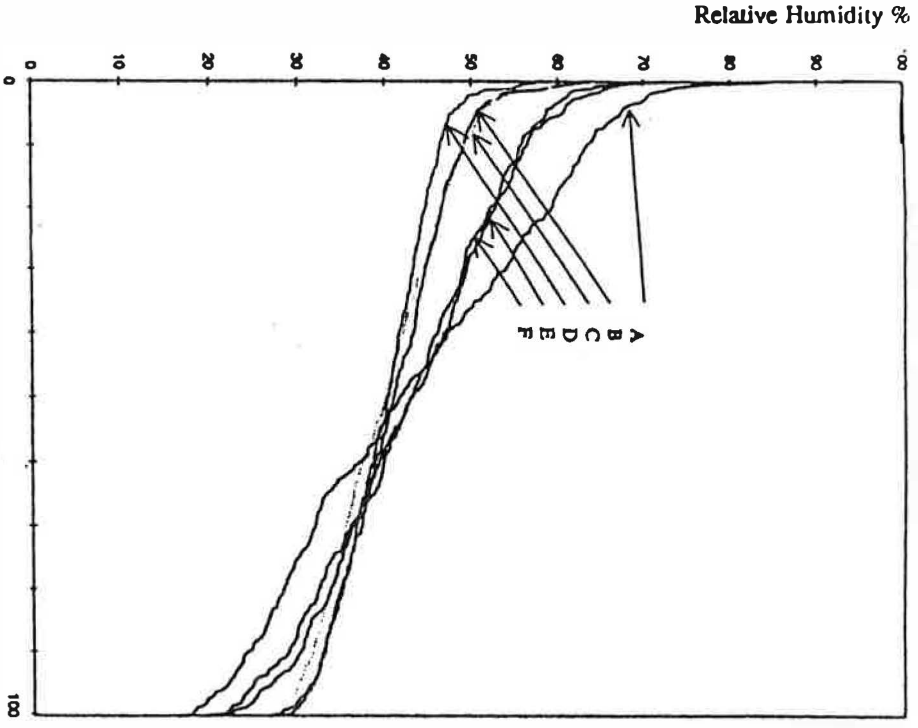

FIGURE 5. All measured values for the month of July 1994, arranged in decreasing order for all roof sections.

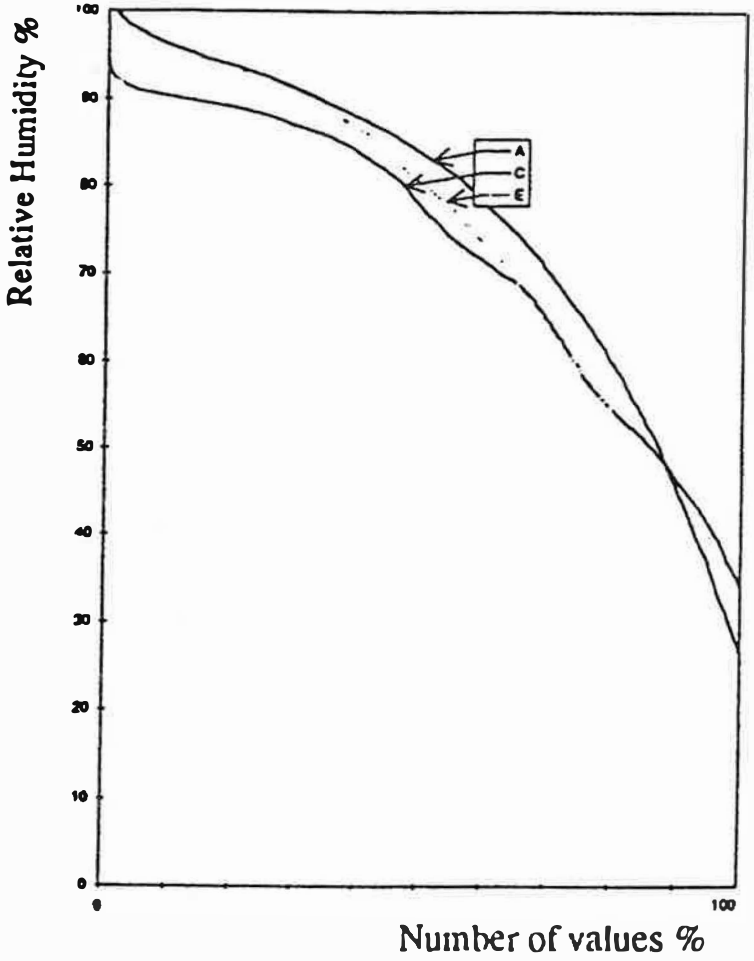

FIGURE 6. All measured values for one whole year, arranged in decreasing order, for roof sections insulated with mineral wool (A, C, and E).

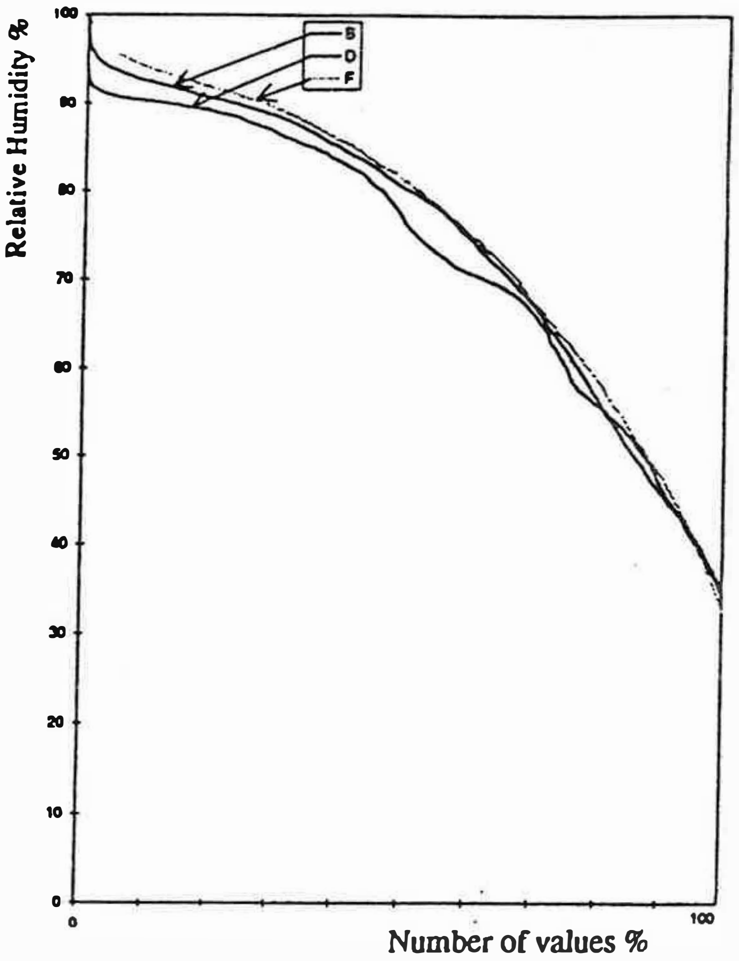

FIGURE 7. All measured values for one whole year, arranged in decreasing order, for roof sections insulated with cellulose fibre (B, D, and F).

office building at SP in Borås. The ceiling structure incorporates 500 mm of loose-fill insulation, laid above a plastic film, secondary spaced boarding, and gypsum plants. The plastic film has virtually no penetrations. Two exhaust fans create an internal negative pressure in the structure beneath, which ensures that there is no convection of warm air up into the roof space.

Temperatures and relative humidities have been measured outdoors, in the air inside the attic, at different depths in the insulation and beneath the ceiling (=inside the building). Measurements of the outdoor air conditions (temperature and RH) have been made in shadow under the eaves on the east side as well as on the surface of the roof (temperature) in order to obtain a measure of equivalent outdoor temperatures.

Precipitation, wind speed, wind direction, and insolation have been recorded. Temperatures have been measured using thermocouples, while relative humidity has been measured with capacitive electric sensors. The moisture ratio has been measured by electrical resistance measurement between metal pins inserted in pieces of wood.

All sensors have been connected to a data-logger that has measured conditions for five seconds every five minutes.

Of the eight sections, six are used for measurements as described in this project.

6. RESULTS

Figures 3 and 4 show measured values in the different sections of the roof during October 1994. The results for those sections having mineral wood insulation and those having cellulose fibre insulation are shown separately.

Measurements have been made since June 1994, and stored as two-hourly mean values. Figures 3 and 4 provide a visual impression of the variations in the different attic sections. Table 2 shows the outdoor, indoor, and individual sector measured monthly mean values of temperature and relative humidity. The values in the table show the difference between different types of ventilation and different materials.

7. EVALUATION OF MEASURED RESULTS

Figure 5 shows the measured values for July 1994. Figures 6 and 7 show the values for the period from June 1994 to June 1995. The results have been arranged as curves, with the entire measured data for the period having been arranged in decreasing order

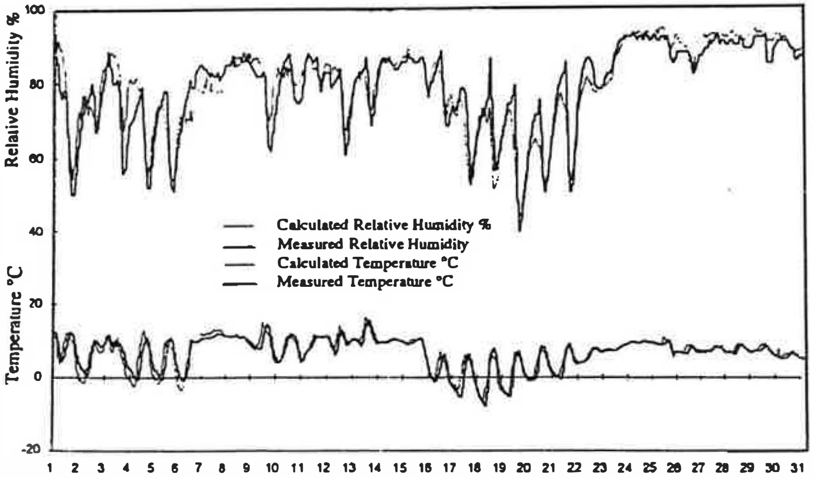

FIGURE 8. Calculated relative humidity and temperature, compared with measured values, in section E for October 1994. The section is ventilated through air gaps and is insulated with mineral wool.

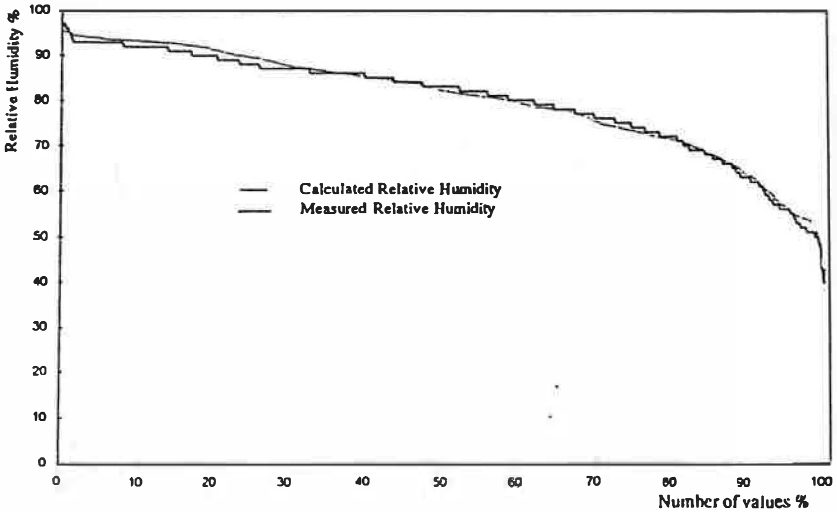

FIGURE 9. Calculated and measured values of relative humidity for October 1994 arranged in decreasing order, for roof section E insulated with mineral wool and natural ventilation.

A completely horizontal line shows that all the values during the period have been the same, i.e., that the climate has been stable with no variation. The steeper the curve, the greater the variations during the period. The slope of the curves provides good information for comparing conditions in ventilated attics with those in unventilated attics, and the same method can also be applied for comparing the moisture buffering effect of different materials. The relative levels of curves having the same slope indicate different humidities, e.g., depending on whether one attic has been colder than another.

8. CALCULATIONS

Four different researchers have used their methods or have developed new mathematical models of the moisture balance in attics. The parameters include material characteristics, the sizes of the roof spaces, outdoor temperature and relative humidity, precipitation, wind, and insulation. Starting from these parameters, but without knowing the results of the actual measured values, the researchers have calculated expected moisture and temperature variations in the various roof spaces during the year, or for the month of October 1994, and particularly during the twenty-four-hour period of 22nd October 1994.

Lars-Erik Larsson has developed a computer program for temperature and moisture in an unheated roof space (Larsson, 1995a, 1995b). After calculating the temperature, the program calculates the moisture absorption in 12 mm of the wooden panelling. These calculations have assumed a ventilation rate of 0.2 air changes/h in Sections C and D, and of 0.8 air changes/h in Sections E and F.

Figures 8 and 9 show calculated and measured values for section E, October 1994.

9. DISCUSSION OF THE CALCULATION RESULTS

The theoretical (=calculated) values are based on the measured outer climate conditions. However, the various models simulate ventilation, heat transport, radiation, and moisture conditions in air and materials in somewhat different ways. This means that they allow for, say, moisture buffering in materials in different ways and that different ventilation rates are simulated differently.

When calculating programs are working satisfactorily, and the results shown in Figures 8 and 9 are promising, it will be possible to use the programs

the effects of moisture input by leakage or convection. Such calculation should make it possible to assess the risk of damage. It will also be possible to investigate the effects of varying the parameters, in order to study the effects of more ceiling insulation or external roof insulation.

10. FURTHER WORK

Further work in this section should be concentrated on the risks of damage caused by inward leakage of precipitation or by moisture input from convection or diffusion from inside the house. With reliable mathematical models, verified by comparison with actual measurements, it should be possible to make good forecasts.

The resulting necessary R&D work should contain the following components:

- complementing and correction of the mathematical models
- measurement of moisture balance in the roof spaces with the addition of water (leakage)
- measurement of moisture balance in the roof spaces with the addition of moist air (convection, diffusion)
- calculation of moisture balance under these conditions
- comparisons between measured and calculated values

Hopefully, this continued work will show that it is possible to forecast the moisture conditions in roof spaces to a good degree of accuracy. At this stage, the programs will be suitable for use.

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