Moisture Control in a Ventilated Attic

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ABSTRACT

Temperature and relative humidity in the roof space above a well-insulated ceiling depend mainly on the outdoor climate. During the winter, the roof space is cold and humid, while during the summer, it is warm and dry. However, if the ceiling between the interior of the house and the roof space is permeable to air, warm and moist air can find its way into the roof space and raise the relative humidity. This may result in the growth of mildew and, in severe cases, rot.

In well-insulated houses, it is an unconditional demand that the ceiling must be airtight or that the air pressure in the house must be maintained at a slight negative pressure relative to the air pressure in the roof space (assured by an exhaust fan) in order to prevent moisture damage.

One way to decrease the risk of damages during winter conditions is to choose moisture-resistant materials. Another way is to modify the construction and employ additional thermal insulation beneath the roof tiles. This will result in the temperature in the roof space being higher, thus decreasing the relative humidity.

Measurements made in a test roof space, employing five different forms of construction, bear this out. Insulation beneath the roofing tiles improves the roof space climate.

THE PURPOSE OF A ROOF

This report relates to effects in, and the design of, ventilated roof spaces in houses in a cold climate (Sweden).

An unheated roof consists of a thermally insulated ceiling structure, a ventilated, unheated roof space, and a sloping outer roof surface off which water runs. The main purpose of the outer roof layer is to get rid of water, and this is done by the tiles in combination with some form of inner roof layer beneath them. The tiles, shingles, or metal cladding ensure that most of the water runs off, although a certain amount of water can find its way into the roof structure under conditions of severe wind or driving rain, even through steep roofs. This water must be conducted away by the underlying inner roof layer, which may consist of roofing felt supported on sheets or a layer of some sort of sheet material, e.g., fiberboard, plywood, or chipboard. Plastic film, too, may be used beneath the tiles.

PROBLEMS OF THE UNHEATED ROOF

The various types of damage that can occur to a roof can be graded as follows, with the most common forms shown first and the least common shown last:

- leakage of water from the outside;
- condensation resulting from convection of moist air from inside the house;
- condensation resulting from exhaust fan flows that are not ducted out of the attic space and add moist air directly to the attic air;
- condensation of residual building moisture;
- condensation resulting from diffusion of moisture from inside the house; and
- release of moisture from items, installations, etc., in the roof space.

The most common fault is leakage of water from the outside through weak points in the outer roof, e.g., around penetrations. This often results from poor detailing in combination with substandard workmanship. Another common form of damage results from moisture convection from inside the house. If the indoor air is moist and if there is a positive pressure in the interior of the house with respect to the roof space, moist air can find its way up into the roof space through leaks and raise the moisture content there. At low ambient temperatures, condensation can form, giving rise in due course to problems such as the growth of mildew or, in severe cases, even rot.

Residual building moisture can cause severe problems while it is drying out. In the case of materials such as lightweight concrete and ordinary concrete, with particularly high moisture levels, special precautions need to be taken in order to prevent damage arising from residual building moisture.

Diffusion of moisture from the interior of the house normally presents only a very slight problem. Even without a vapor retarder, the moisture diffusion flow will be limited, but the normal form of construction, with a plastic film on the warm side of the ceiling structure, permits the passage of such small quantities of moisture that they can be ignored.

An unheated roof above a well-insulated ceiling structure is vulnerable to moisture-related damage. The better the standard of thermal insulation, the greater the risk and the smaller the margin for error because of lower attic temperature and thereby higher relative humidity. Even minor breaks in the ceiling barrier and small quantities of moist air from the inside of the house can result in severe problems. There is a risk that moisture will collect in the roof space, giving rise to the growth of mildew, discoloration, and, in serious cases, rot—particularly on the inner roof layer. In addition, materials stored in the roof space,

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such as suitcases, cartons, etc., may often develop mildew and become damaged.

IDEAS FOR BETTER ROOFS

This project has demonstrated two ways in which roof designs can be improved. By insulating the outside of the inner roof layer, an improved climate can be obtained for the roof space and for the inner roof layer itself. Secondly, reducing the amount of outside air ventilation in the roof space can provide further improvement of the microclimate. At the same time, however, this also reduces the potential for carrying away undesirable moisture, e.g., resulting from a temporary leak. This risk must be considered and evaluated (see Figure 1).

MOISTURE BALANCE IN A COLD ROOF SPACE

Temperature and relative humidity in the roof space are determined by the indoor and outdoor climates, the insulating properties of the surrounding structures, moisture buffering and weathertightness, the amount of ventilation, and any input of warmth or moisture.

Calculations of temperature and relative humidity in the roof space have been made. The model was created by Bengt Elmarsson, who also made the calculations. The calculations (in the form of mean monthly values) were based on a roof with the following design features and parameters:

- Width of house, 10 m;
- Gable roof, 2 m high at the ridge;
- Air change rate, 2 air changes per hour (ach);
- Outer roof consists of concrete tiles on 12 mm plywood sheet;
- 500 mm of loose-fill fiber insulation on the ceiling structure, with an airtight plastic film on the underside (no air leakage from house to attic);
- Indoor temperature, 20°C;
- Moisture input, 2 g/m^3; and
- Solar insolation, outdoor temperature, and relative humidity as in central Sweden.

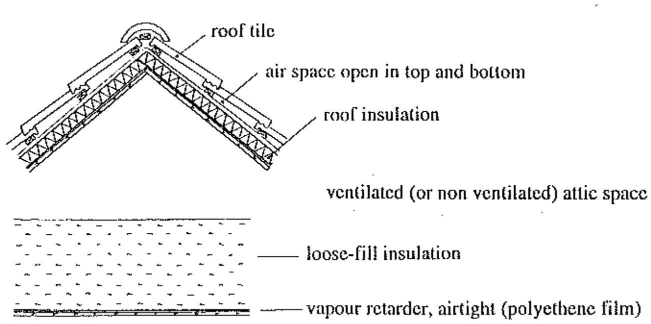

Figure 1 *If the outside of the inner roof layer is insulated, the inner roof layer itself and the roof space will become somewhat warmer and dryer. If, in addition, inner roof ventilation is reduced or stopped entirely, there will no longer be the adverse effects that can arise from ventilation, particularly during cold, clear nights. However, stopping ventilation entirely involves a risk of damage if moisture finds its way into the roof space.*

The model is based on a normal type of roof space above a well-insulated ceiling structure. It is assumed that no damage has occurred and that no residual building moisture is left.

The model allows for the effect of insulation. Heat transfer within the roof space is assumed to occur via radiation, conduction, and convection.

Figure 2 shows the calculated relative humidity in the roof space for (A) normal conditions and (B) sunless conditions. Figure 3 shows the calculated moisture ratio (kg water/kg dry material) during a year, with the same conditions for (A) and (B). Note that the calculation does not allow for short-term variations in temperature or relative humidity but gives only mean monthly values.

MEASUREMENTS OF MOISTURE IN THE TEST ROOF

Measurements have been made in a test roof structure above a hut used for office premises at a Swedish research facility in Borås.

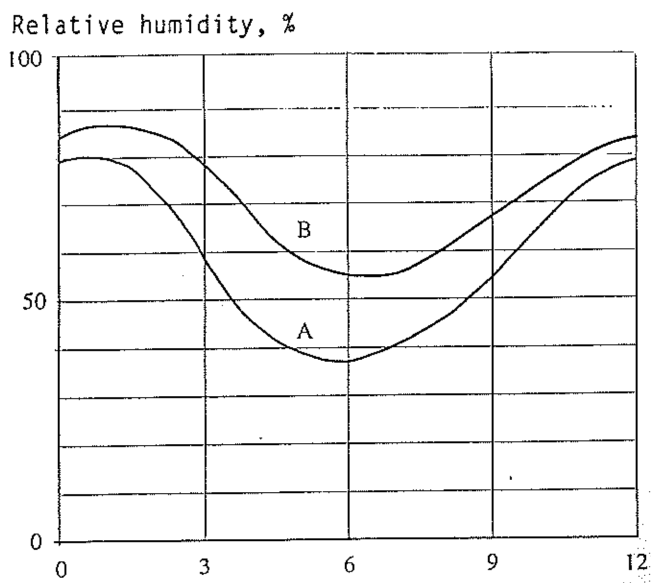

Figure 2 *Calculated mean relative humidity in a roof space over a period of one year. Curve A indicates normal conditions, and curve B indicates a roof without its solar input. Measured values during a year should fall between the two curves.*

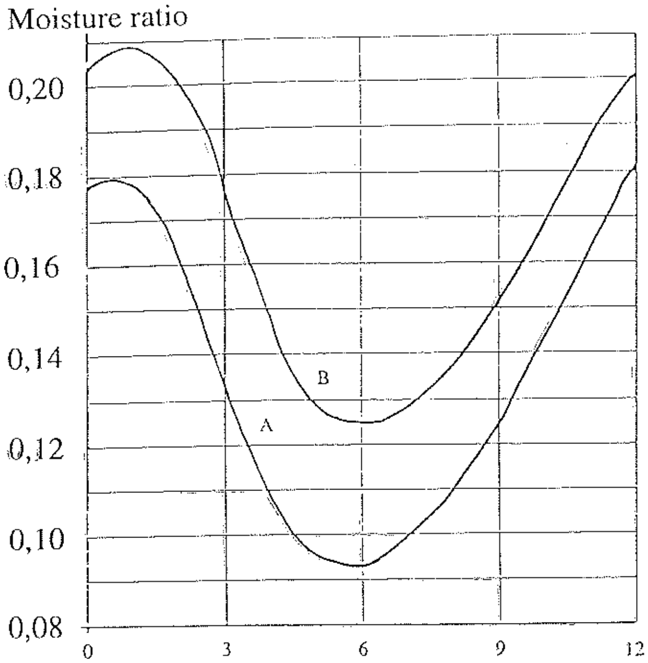

Figure 3 *Calculated moisture ratio in the inner roof layer over a period of one year. Curve A indicates normal conditions, and curve B indicates a roof without solar input.*

The roof was constructed by mounting a 1-m-high "frame" around the edge of the existing outer roof, which is 30 m long and 10 m wide. New roof trusses were then mounted on this frame, with insulation laid between the ceiling joists, thus producing a cold roof space. This cold roof space was then divided into eight sections, separated from each other by means of insulation and airtight interior walls at center distances of 3.60 m. The ceiling structure above the heated space and the cold roof consists of 500 mm of loose-fill fiber insulation on plastic film with, secondary spaced boarding and gypsum planks. There were almost no penetrations through the plastic film.

The ventilation exhaust air from the offices in the hut below was discharged to the 1-m-high space beneath the joist structure, thus raising its temperature to 20° to 25°C. Two exhaust air fans extract air from the space, thus preventing a differential pressure across the ceiling structure between the heated area beneath and the cold roof space. Externally, the sloping roof was clad with concrete tiles.

Along half its length, the hut building adjoins a higher laboratory building. In order to ensure that ventilation of the various sections was the same, mechanical ventilation was installed. Where a particular section was to be ventilated, outdoor air was blown in on the west side by means of a fan and allowed to exit through a conventional air gap beneath the eaves on the east side. Apart from the two supply air ducts entering each section, eave ventilation on the western side was completely blocked. The ridge was nonventilated, and the air change rate was adjusted to about 2 (ach).

Of the eight sections, five were used for performance measurements of different designs (see Figure 4). The gable end sections were used as protective buffer zones. The five different roof space volumes that were investigated had the following features:

A. Ventilated roof space with an inner roof layer of plastic film.
B. Ventilated roof space with an inner roof consisting of 12 mm plywood with 30 mm of foamed plastic insulation on top of it directly beneath the tiles.
C. Ventilated roof space with an inner roof consisting of 12 mm plywood with 10 mm of foamed plastic insulation on top of it directly beneath the tiles.
D. Reference roof space, of conventional design, i.e., ventilated roof space with an inner roof of 12-mm roofing-grade plywood beneath the tiles. No building paper was used.
E. Unventilated roof space with an inner roof consisting of 12-mm plywood with 30 mm of foamed plastic insulation on top of it directly beneath the tiles.

Temperature and relative humidity in the air of the roof space were measured and recorded (from which the vapor concentration was calculated), as were temperatures and RH outdoors and in the space beneath the ceiling joists. Measurements in the air space within the roof were made at a height of 0.5 m below the ridge. Measurements in the outdoor air were made beneath the eastern side of the eaves. The roof could be exposed to sun during the early morning.

Measurements were also made of the surface temperature and moisture ratio on the underside of the inner roof layer at three points in each roof space. The moisture ratio was measured as the electric resistance in wood. The measurement points were situated on the western long side, 2 m from the ridge, at the ridge, and on the eastern side 2 m from the ridge (see Figure 5).

Moisture ratio in the roof space having an inner roof layer of plastic film was measured in the roof truss, about 1 cm from its upper edge. This means that these values cannot be compared with the moisture ratios and temperatures for the other inner roofs.

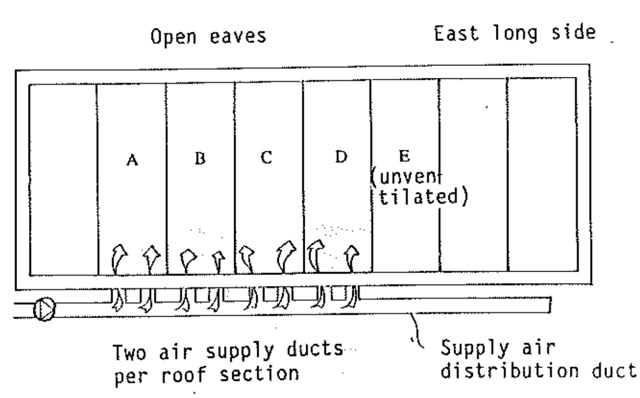

Figure 4 *Plan of the roof spaces.*

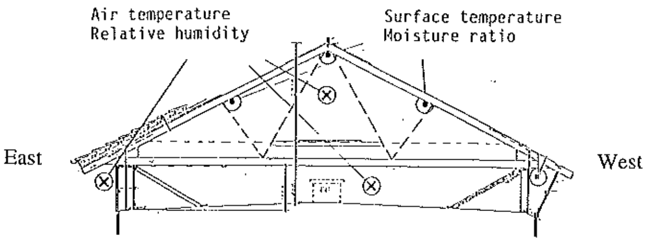

Figure 5 *Schematic arrangement of sensor positions.*

MEASURED RESULTS

Measurements were made between July 1991 and January 1992. The values shown in Figures 6, 7, and 8 are for the week of September 9-16, 1991, with varying temperatures between day and night.

Discussion of the Measured Results

The relative humidity is lowest in all cases in roof section E, i.e., the unventilated section having thermal insulation on the upper surface of the inner roof layer. The microclimate in this section of the roof does not change as rapidly in response to rapid changes of the outdoor climate as it does in the other roof sections. This means that, generally, the relative humidity in the unventilated roof space is lower than in a ventilated roof space, although for brief periods it can remain at a higher level than in the other roof spaces. However, averaged over a week, the mean value of relative humidity was always lower than in the other roof spaces and outdoors. This can be seen most clearly in Figure 6.

Evaluation of measured values from the week of September 10-16 and from the week of November 19-26 (for which the measured results have not been shown here) gives the weekly mean values of air temperature and relative humidity in the different roof spaces shown in Table 1. These figures should be compared with Figures 6 and 7.

From Figure 8 it can be seen that the measured moisture ratio during this week in September varies between 0.14 and 0.16. Calculated values in Figure 3 show that the mean moisture ratio during September is 0.12 to 0.15. The measured moisture ratio in November varies between 0.16 and 0.21. Calculated values are 0.165 to 0.19.

CONCLUSIONS

The conclusions that can be drawn from the measurements are that additional thermal insulation of the upper side of the inner roof layer results in a slight improvement of the moisture conditions in a roof space. The thickness of this additional roof insulation is of lesser importance—we did not observe any major differences between the sections with 10 mm and with 30 mm of insulation.

More important for moisture conditions in roof space is ventilation. An unventilated roof space, to which there are no "external" inputs of moisture, will have a mean microclimate that is considerably better than the microclimates in the other roof spaces. This applies particularly during periods when the outdoor climate varys between cold damp nights and warm days.

It must be pointed out that this work studied a roof with no air leakage from the house. Most Swedish houses are built and ventilated in that way. The buildings are very airtight, and the room ventilation system normally creates an indoor underpressure.

Any disadvantages, such as workmanship problems, overheating, and reduced roof tile lifetime or strength due to the extra insulation beneath the tiles, have not been studied.

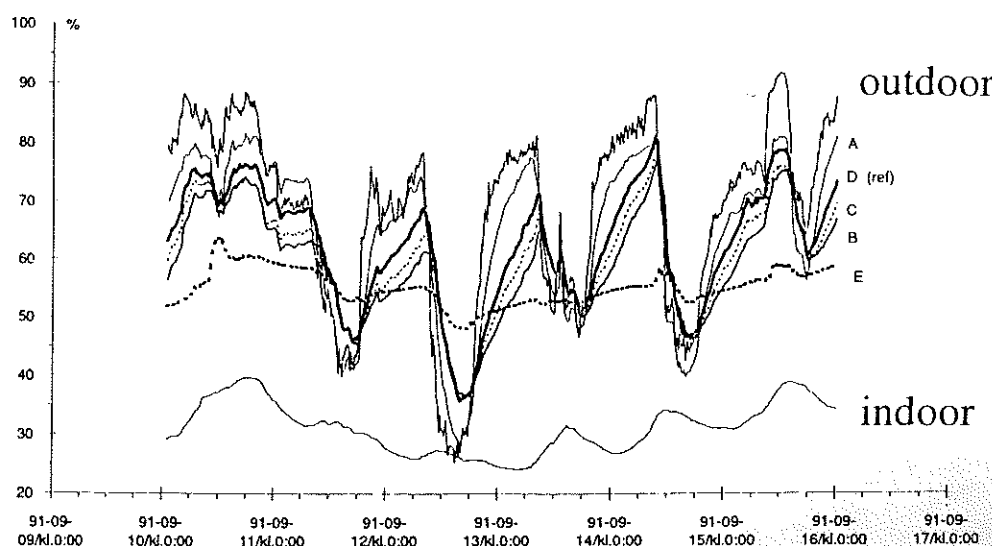

Figure 6 *Relative humidity in the five roof spaces, outdoors and indoors, September 9-16, 1991.*

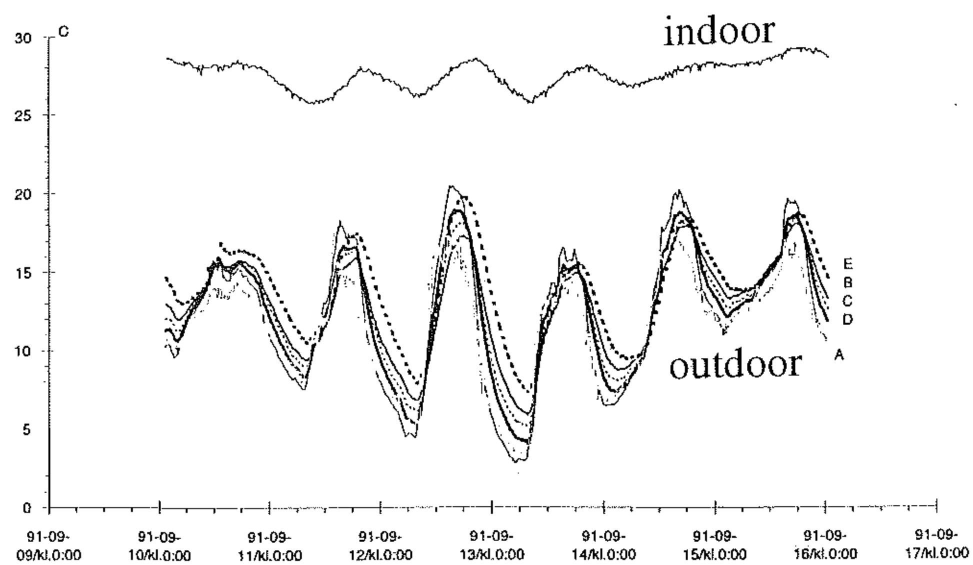

Figure 7 *Air temperatures in the five roof spaces, outdoors and indoors, September 9-16, 1991.*

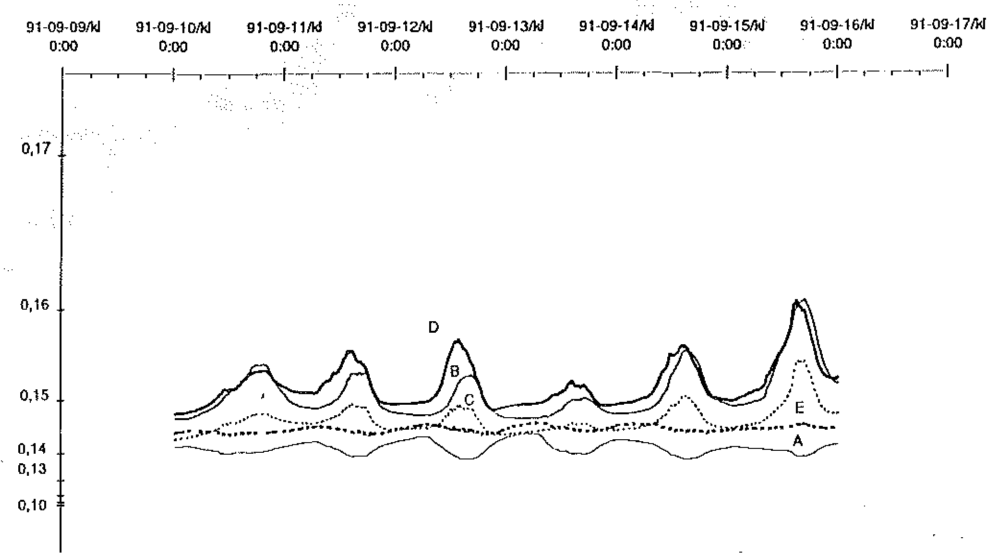

Figure 8 *Moisture ratios in the inner roof structure of the five roof spaces during the period September 9-16, 1991. The moisture ratio in roof space A has been measured about 1 cm from the plastic film (Monarfol) on the upper side of the joist. Values are expressed as mean values of the three measurement points in the roof space.*

TABLE 1

				10-16th Sept.		19-26 Nov.	
Measure-ment point	Venti-lation	Inner roof	Addi-tional insulation	Temp., °C	RH, %	Temp,. °C	RH, %
Outdoors			-	11.6	68	2.4	87
A	Yes	Plastic	-	12.2	64	2.6	85
D	Yes	Plywood	-	12.5	63	3.0	82
C	Yes	Plywood	10 mm	12.8	60	3.5	78
B	Yes	Plywood	30 mm	13.0	59	3.7	78
E	No	Plywood	30 mm	13.9	55	4.4	74
Calculated mean value for case D (from figure 2)					55-65		75-83