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Measured temperature and moisture conditions in the roof attic of a one-and-a-half story house

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Abstract

Temperature and moisture measurements were made in a ventilated attic on a house with 200 mm mineral wool insulation. The measurements showed that 1) solar radiation had a great effect on the temperature in the attic; 2) moisture content reached a level below the risk of mold formation – no mold was seen. The measurements were compared with simulations for insulation thickness from 50 to 500 mm. The calculations indicated that the temperature was nearly the same when the attic was insulated with 200 to 500 mm; hence increased insulation was not a problem. The important assumption was that the roof was constructed with a moisture barrier.

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Keywords: Moisture design; Roof attic; Thermal insulation; Measurements; Simulations

1. Introduction

The Danish Building Regulations stipulates rules for the energy demand of a whole building and the transmission heat losses through the building envelope excluding windows and doors. This gives the possibility of selecting building envelope components with different U-values which comply with the requirements set out in the Danish Building Regulations. Typically the roof has the lowest U-value corresponding to insulation thicknesses of approx. 350 mm. For the future regulations to be used from 2020 a reduction in the transmission heat loss through the roofs, walls and floors is needed. Therefore, it is very important to find out, if an increased insulation gives a higher risk of moisture problems, like an increased risk of mold growth. A research project [1] on moisture problems in constructions with large insulation thicknesses was conducted by the Danish Building Research Institute on several typical constructions

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used in Denmark. In this paper, we concentrate on ventilated attics, where it is easy to increase the thickness of the thermal insulation. The result is also relevant if extra insulation is added in existing houses. The evaluation of ventilated attics is based on a combination of measurements, simulations and literature study [1].

2. Measurements on building

The measurements in a ventilated attic were made in a one-and-a-half story house from 1962 with added insulation installed later (figure 1a). The roof construction was traditional and built of wood with tiles made of concrete. The roof construction was oriented towards south and north with a 45-degree slope. The attic floor was insulated with 200 mm mineral wool and had a typical plastic moisture barrier with overlays between the attic and the rooms below. The measurements of temperature were made with a thermo-couple and the moisture content was measured in a wood sample with two pins to measure electric resistance. Each set was connected to a box (figure 1b) with wireless connection to a central data logger in the house. The data logger [2] had a SIM card and a GSM antenna, so that it could be controlled from a PC with a phone call to the logger. The electric resistance was converted to wood moisture content in weight%. The measuring points were inside the attic on the south and north side in different heights. Figure 1b shows one measuring box placed near the top of the attic. Measuring was also made inside the house and outdoor (outside).

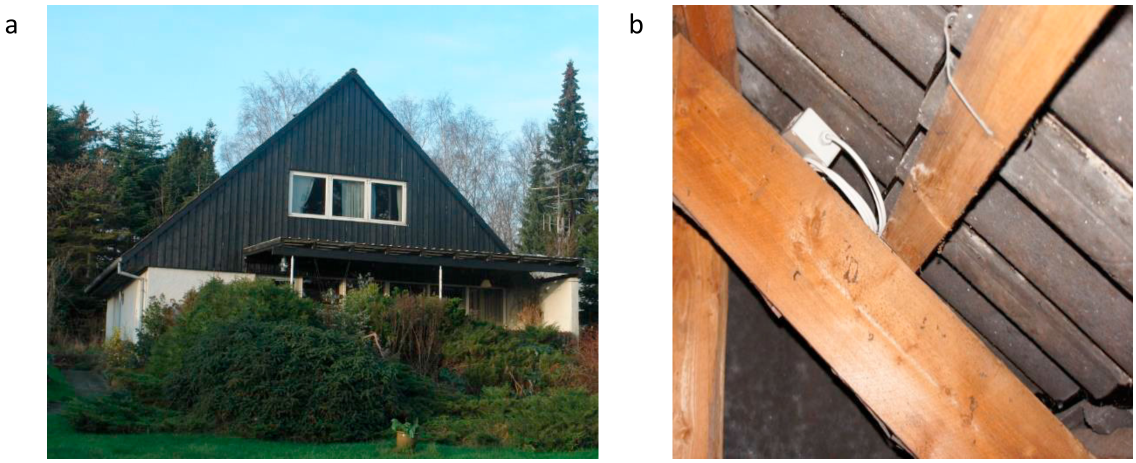

Fig. 1. (a) house; (b) measuring box in roof attic.

3. Results of measurements in attic

The results from the attic and outdoors are given in figure 2. The indoor temperature was measured to 20-22 °C. It is seen that there were large variations in the attic temperature. This was caused by solar radiation on the roof. The attic temperature can increase by 10 °C in a few hours in the winter and by 20 °C in the spring. Normally the attic was warmer than the outdoor temperature, but for very short periods of time it was colder due to radiation on clear nights. The temperature at the top of the attic was 1-10 °C warmer than at the bottom of the attic. This temperature difference increased with the length of the period with solar radiation as the warm air rose. There was a difference in temperature between the north-facing inner roof surface and the one facing south, but typically not more than a few degrees. Temperatures up to 50 °C were measured in the attic in the summer.

Figure 3 shows the moisture content measured in the house, attic and outside. The wood moisture content in weight% in the house was constant during the year at around 9%. This was expected for a normal dry indoor climate. The wood moisture content outdoor (the box was placed so that it was not rained upon) was the highest in the winter (15-20%) as seen in figure 3 and only goes down to 10% for a short period of time. In the winter, the moisture content in the attic and outdoors was almost coinciding, whereas the outside moisture content was higher than in the attic during spring. The highest moisture content (around 20%) was measured at the north side of the attic in January and February, but it was a period with low temperatures so there would be no risk of mold growth. From March, the solar radiation increased the temperature and dried the moisture from the wood in the attic. Hence, most of the year, the attic was warmer and drier than outdoors. There was no moisture problem in this roof. Mold growth was not detected or seen in the attic. The attic was built with a typical plastic moisture (air and vapor) barrier.

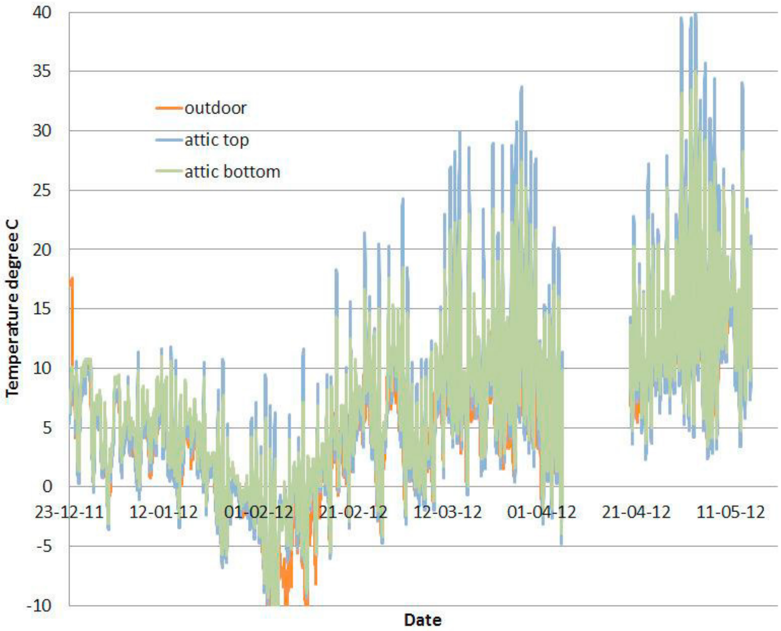

Fig. 2. Temperature measurements from the attic and outdoor. Selected data from [1].

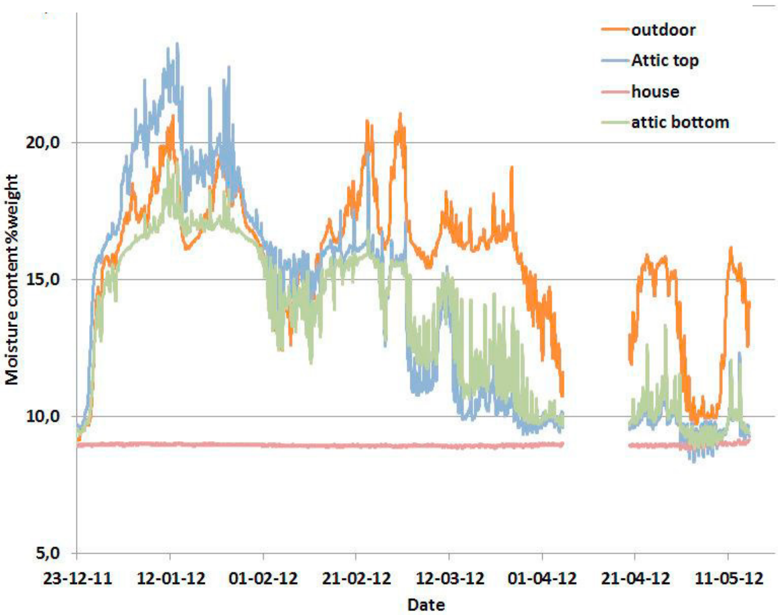

Fig. 3. Moisture content in the attic, house and outdoor. Selected data from [1].

Figure 4 left shows the corresponding temperature and moisture content, and it is seen that high values of moisture content occur at temperatures below 10 °C. Only for short periods (as part of a day with solar radiation) both

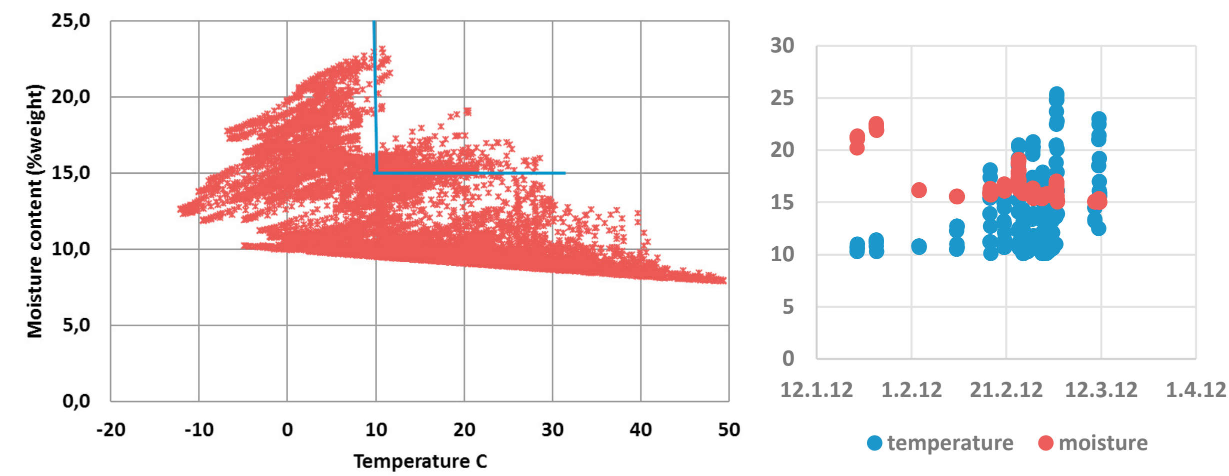

Fig.4 Left: Relationship between temperature and moisture content in the attic. Right – days with critical levels.

temperature and moisture content were above the critical levels (blue lines). This is confirmed in the left part of figure 4, showing critical values in January to April. There is no mold growth in the attic probably because the time of exposure is short in the critical area.

4. Results of simulation of a ventilated attic

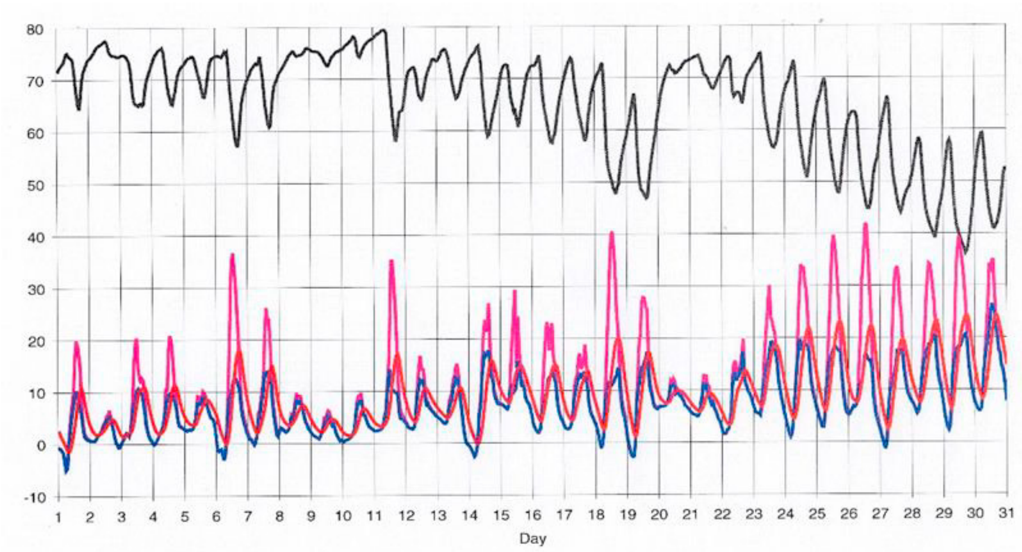

Fig. 5. Calculated relative humidity (black line) and temperatures (highest red line – temperature in attic, the other two are internal surface temperatures (blue facing north – red facing south)) in April

One of the aspects pointed out with thicker insulation in ventilated attic is that the temperature tends to be lower in the winter and increases the moisture content and the risk of moisture damages. The temperature is lower as there is less heat loss from the rooms below the attic. However, it is interesting to investigate the effect on the temperature that follows larger insulation thicknesses. A simulation model for temperature calculations in the ventilated attic was build up that corresponded to the test house; a house of 80 m^2 with a roof with a 45-degree slope as seen in figure 1a. The roof had roof tiles on wooden laths. The ventilation rate of the attic was estimated to be 0.5 times per hour. It was estimated that the moisture barrier was of such a quality and workmanship that no moisture penetrated from the rooms below the attic.

The calculation was done with the BSIM program [3] with the Danish reference year. The first calculation was done with 150 mm mineral wool insulation between the attic and the room below. Figure 5 shows temperature and relative humidity in the attic as well as the interior surface temperature on the north- and south-facing roof.

The relative humidity at the beginning of April is 70% and at the end of the month going down to 50% due to the higher temperature in the attic. Days with solar radiation sharply increase the temperature and therefore cause a drop in the relative humidity. The temperature in the attic can increase to 40 °C, as it was also seen in the measurements. There is a difference in the surface temperature between the south- and north-facing roof on sunny days of 5-10 °C in summer. On overcast days, the difference is 1-2 °C. The average temperature in the attic in April is 9.0 °C.

Similar calculations were done for 450 mm mineral wool for a highly insulated house. The average temperature was 8.7 °C in April. This was compared with a case with 50 mm mineral wool like older buildings. The result is shown in table 1 including temperatures in January and July.

Table 1. Average temperature in attic (degree C)

Insulation thickness (mineral wool)	January	April	July
50 mm	1.54	9.7	20.59
150 mm	0.29	9.0	20.64
450 mm	-0.34	8.7	20.68
450 mm (house rotated E-W)	-0.40	8.85	20.72

The effect of thicker insulation is most important during the coldest periods. For January, the average temperature in the attic will be 0.6 °C lower if the insulation thickness is increased from 150 to 450 mm. In the summer, the average temperature is the same. A calculation with 450 mm insulation was also done for a 90-degree rotation with the roof facing east and west. No practical difference was observed.

The results of these calculations show that the lowering of the temperature in winter from larger insulation thickness is of minor influence on the drying-out rate. If we have no moisture influx from the rooms below, then an increased thermal insulation will not give an increased risk of moisture damage. In practice, it is very seldom that moisture damage occurs in this type of ventilated roofs in Denmark, if they are constructed in a proper way as recommended in the SBi Guideline 224, which is a moisture design handbook [4]. Problems can occur if we have moisture from below, but then the building is not constructed correctly.

5. Comparison with other results

The discussion of possible moisture problems for highly insulated houses is addressed in other Nordic countries [5] and [6]. A report [5] from the Norwegian Building Research Institute also considers the effect of larger insulation thickness and the risk of moisture damage. The calculation was done for a ventilated attic located in Oslo as seen in figure 6.

Calculations were done for 100 to 750 mm thermal insulation. The relative humidity in the winter rises to 95%, but the temperature is low and unfavourable for mould growth. In the summer, the relative humidity is low and the temperature in the attic high and presents no risk of mould growth. The critical periods for the ventilated roof construction are March to April and September to November. Most of the increase in relative humidity from thicker insulation comes from going from 100 mm to 250 mm. Going from 500 mm to 750 mm has practically no effect.

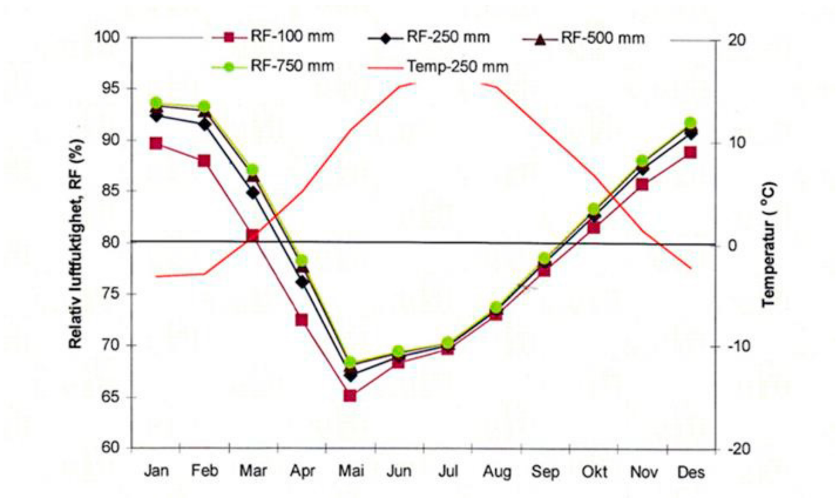

Fig. 6. Calculated relative humidity (RF) for different insulation thicknesses (100 mm to 750 mm) during the year and attic temperature (Temp) for 250 mm insulation. Illustration from [5].

The report also looks at changes in the ventilation of the roof, the moisture load in indoor climate in the room below and leakages in the moisture barrier. Larger air changes and more airtight moisture barriers would reduce the risk of moisture damage. Critical cases can come from higher moisture loads, leakages, and lower ventilation of the attic.

6. Conclusions

The measurements in the attic show that the risk of mold problems only occurs in short periods during the winter and that the wood in the attic is drier most of the year than wood placed in the outdoor air. The calculations for an attic with different insulation thickness show that the temperature in the attic is nearly the same, if the thermal insulation is more than 150 mm mineral wool. The lower temperature for higher insulation such as 500 mm in winter is not at a level that will increase the risk of mold. This is in line with the results reported for the Norwegian calculation and similar data from other Nordic countries.

It is important to stress that the conclusion is based on the moisture barrier being made in a proper way without the possibility of moist air flowing from the house to the attic. Furthermore, airflow should be prevented in new Danish houses as airtightness must be tested before the house is approved. In this way major air leakages are avoided. For existing houses, an increased insulation thickness for instance from 150mm to 500 mm mineral wool is possible, if an inspection shows that there are no moisture problems in the attic and that the roof does not have water leakages.

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