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Towards moisture safe ventilated cold attics – Monitored conditions in a full-scale test building

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Abstract. Existing building stock in Europe accounts for approx. 40% of the total energy consumption. Upgrading the thermal insulation of the existing buildings is an important measure to reduce heat losses through the building envelope. In some cases, increasing the thermal resistance of the construction may compromise the hygrothermal performance of the retrofitted construction. In particular, if vapour barrier is necessary for the good performance and it is practically difficult, if not even impossible, to install a well-sealed air- and vapour tight layer. To investigate the robustness of the hygrothermal performance of ventilated cold attics – with or without a vapour barrier – a monitoring campaign in a full-scale test building was set up. Also role of number of other parameters like moisture buffering capacity of the insulation material and thermal resistance was investigated. This paper presents part of this measuring campaign, which includes conditions both in the attic space and inside the insulation layer. The monitored data covers a period with two winters. The results show that it in temperate climate is practically indifferent for the hygrothermal performance of the monitored, well-ventilated attics with air-tight ceilings whether there is a vapour barrier or not and if the insulation material has moisture buffering capacity or not.

1 Introduction

Roof construction with ventilated cold attic has traditionally been good building practice in many countries including the Nordic countries, see Fig. 1 for a cross section of a typical attic construction. A combination of the sloped, watertight roofing and a load bearing structure of timber has been widely used in both small and larger buildings. From the moisture safety point of view the sloped roofing has ensured protection of the building from rain loads while the ventilated attic has ensured necessary removal of any excess moisture from the interior environment to the attic space. Transport of the moisture from the living space to the attic space has been controlled by ensuring that the ceiling construction was airtight. Traditionally the airtightness of the ceiling has been ensured by a plastered ceiling without cracks. Vapour barrier was introduced in this type of constructions in the 1960's and was expected to ensure air and vapour tightness of the construction [2]. However, limited focus was paid on the sealing of the connections and details, and in practice the vapour barriers were not as tight as they nominally should.

Upgrading the thermal insulation of the existing buildings is an important measure to reduce heat losses through the building envelope. Adding thermal insulation to the floor of the attic space could be one of

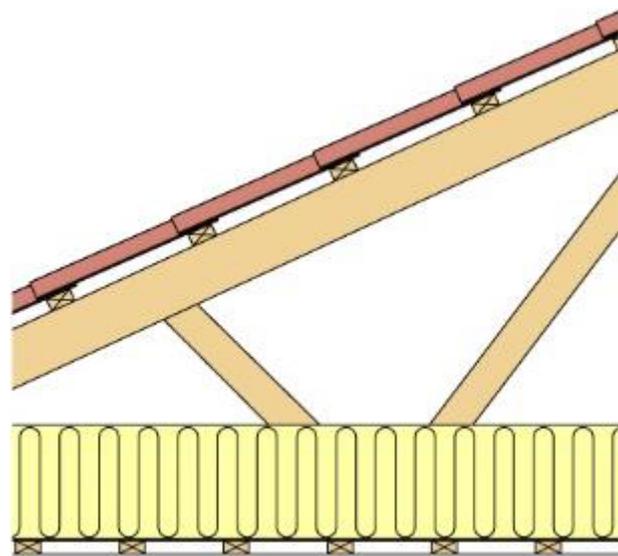


Fig. 1. Cross section of a typical construction with ventilated cold attic space. Ventilation of the attic space is ensured with necessary openings in the eaves and in the top. Air tightness of the ceiling construction is ensured by either vapour barrier below the insulation or by an airtight ceiling. From [1].

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the easiest and most cost-effective measures to improve the thermal insulation of the building envelope.

Increasing the thermal resistance of an existing construction may, however, compromise the hygrothermal performance of the retrofitted construction as exterior parts of the construction become colder and the relative humidity as well as the risk of interstitial condensation correspondingly may increase [3, 4].

In particular, if vapour barrier is necessary for the good hygrothermal performance of the construction, it may be too risky to rely on the existing vapour barrier that is both old and often also of unknown quality and performance. Therefore, the official guidelines in Denmark has recommended to install a new and airtight vapour barrier when increasing the thermal insulation of the attic floor if the total amount of insulation exceeds 150 mm [5]. It is – however - practically difficult and expensive, if not even impossible, to install a well-sealed air and vapour tight layer in an existing building.

This paper presents a systematic full-scale measurement campaign and selected monitoring results. The purpose of the measurements was to investigate the role of the vapour barrier for hygrothermal performance of the retrofitted, ventilated cold attics. In addition, the role of the moisture load as well as the moisture buffer capacity and the thickness of the insulation material was studied. Mineral wool and cellulose based insulation material were used as materials with low and high moisture buffering capacity, respectively. A detailed description of the experimental set-up as well hypotheses are found in [6]. This paper presents a selected part of the monitoring results.

2 Methods

A full-scale test building with six different designs of attics was constructed (see Fig. 2 and 3) and equipped with temperature and moisture sensors (see Fig. 4). The house is located in the outskirts of Copenhagen, Denmark. Each of the six designs were exposed to three different humidity classes (HC) according to [7], in total 18 different attic cases were studied. The building has ground dimensions of 7 x 22 m and height of 4.6 m from ground to top of the roof. The pitched roof has a slope of 30 degrees and is oriented both South and North. Adequate ventilation of the attic was ensured by following the design rules in the Danish guidelines [2], in this case 2 x 50 cm² openings per metre at ridge, and effective opening area of 15 x 440 mm/m corresponding to 132 cm²/m at the two eaves. The air change rate per hour (ACH) was measured with passive tracer gas during several periods to 4 – 10 h⁻¹, which corresponds to values found in other studies, e.g. [8].



Fig. 2. South facade of the full-scale test house.

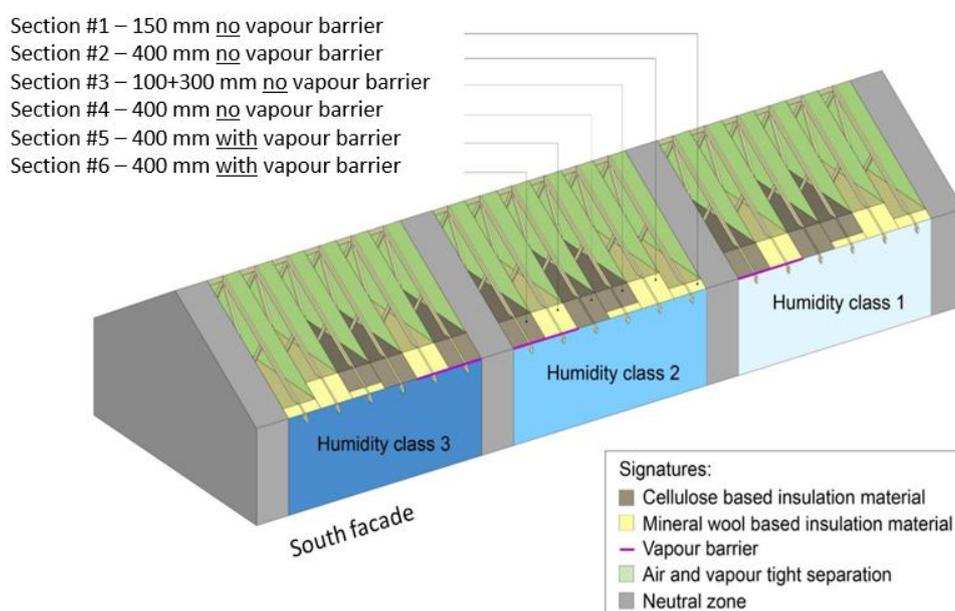


Fig. 3. Full-scale test house with 6 different attic designs with varying insulation type and thickness, presence of vapour barrier or not, and 3 different humidity classes of the indoor environment. Figure from [6].

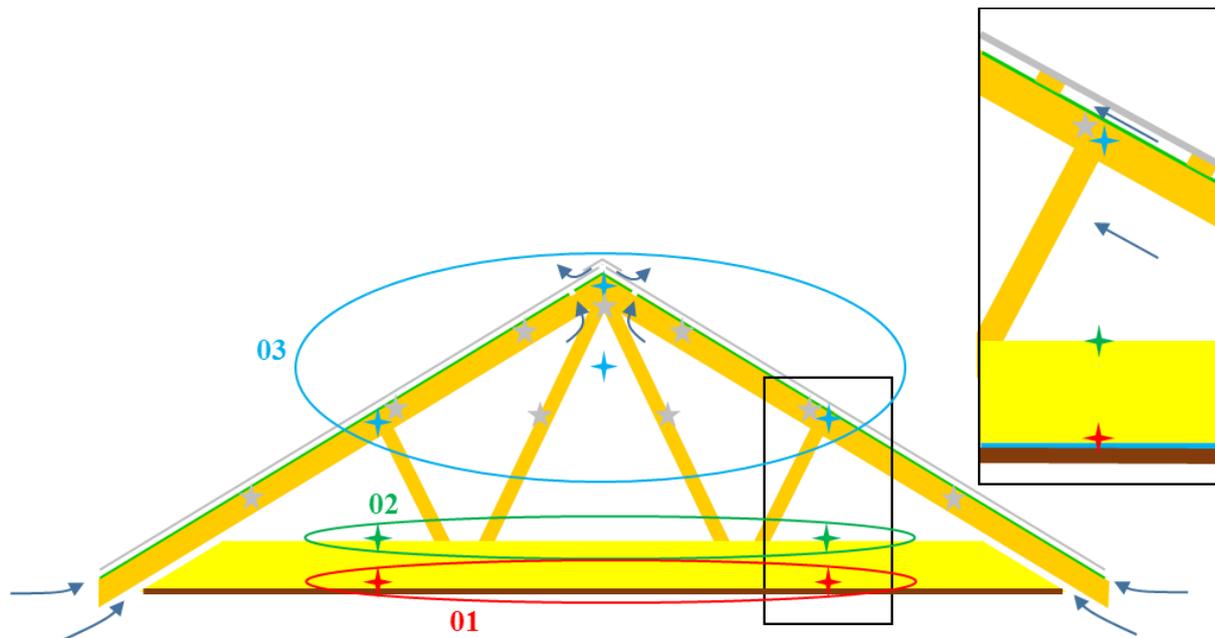


Fig. 4. Overview of the sensor positions. Grey stars denote wood moisture measurements while coloured stars represent temperature and relative humidity sensors. 01= sensors located below the insulation. 02= sensors located above the insulation. 03= sensors located in the attic space. Figure from [6].

For reliable analysis of the performance of the attics, every attic space was built to be independent on the hygrothermal conditions of the adjacent attic spaces. Air and vapour tightness was ensured by construction of vertical walls of plywood between every attic space and sealing these with vapour barrier and tape against each other. In the end of every series of attics, a dummy guard zone was established.

Ceiling construction against the indoor environment was airtight, as well, and finished with gypsum boards with airtight sealing of joints between boards. In attics with vapour barrier, a standard PE foil with $s_d = 140 \text{ m}$ was used. Loose fill mineral wool and cellulose was used as insulation material.

For monitoring of temperature (T) and relative humidity (RH) eight “HTemp-1 wire” sensors with an accuracy of $\pm 1.0^\circ\text{C}$ (-10°C to 70°C) and $\pm 2,5\%$ RH (20% to 80% RH) were used in each attic section, 144 in total. These sensors were connected to dataloggers that recorded continuous measurements every hour. Sensors were calibrated before installation and again after ended measurement period of 2-3 years. A linear relation between these calibrations was assumed and used for calculation of the presented values.

Wood moisture content measurements were based on measurement of the electric resistance of wood as a function of moisture content. For that purpose, two 15 mm screws were mounted in the timber roof trusses for every sensor location described in Fig. 4 (seven in each attic section, 126 in total). The resistance was manually read every 7-14 days and converted to moisture content.

3 Results and Discussion

Monitoring results cover a period with more than two years. An overview of the measured conditions in the attics is seen in Fig. 5 that presents temperature and relative humidity for all attics in humidity class 2. Results are average values for sensor position 03 and one week running mean values.

Results show that the temperature is the same – and practically identical with the outdoor temperature – in all six attic spaces, including space #1 where there was only 150 mm insulation material while all the other spaces had 400 mm insulation material. In the first winter the relative humidity varied approximately within 10% RH between the different spaces, generally with lowest values in spaces with vapour barrier (#5 and #6), the difference was reducing to approximately 5% RH the second winter. This difference is probably due to build in moisture; the building was closed in November and heated from December, apparently, the attic was not totally dried out until after the first summer.

Although results according to Fig. 5 seem to prove the benefit of vapour barriers, the picture was not equally clear in other humidity classes, and as described in [6], there was no statistical evidence that vapour barriers reduced the relative humidity in airtight attics.

An overview of the wood moisture content in all attics is seen in Fig. 6. Results are an average of the measurements from the north side of the attic and represent the worst case. Corresponding values from the South side are 1-3 weight-% lower.

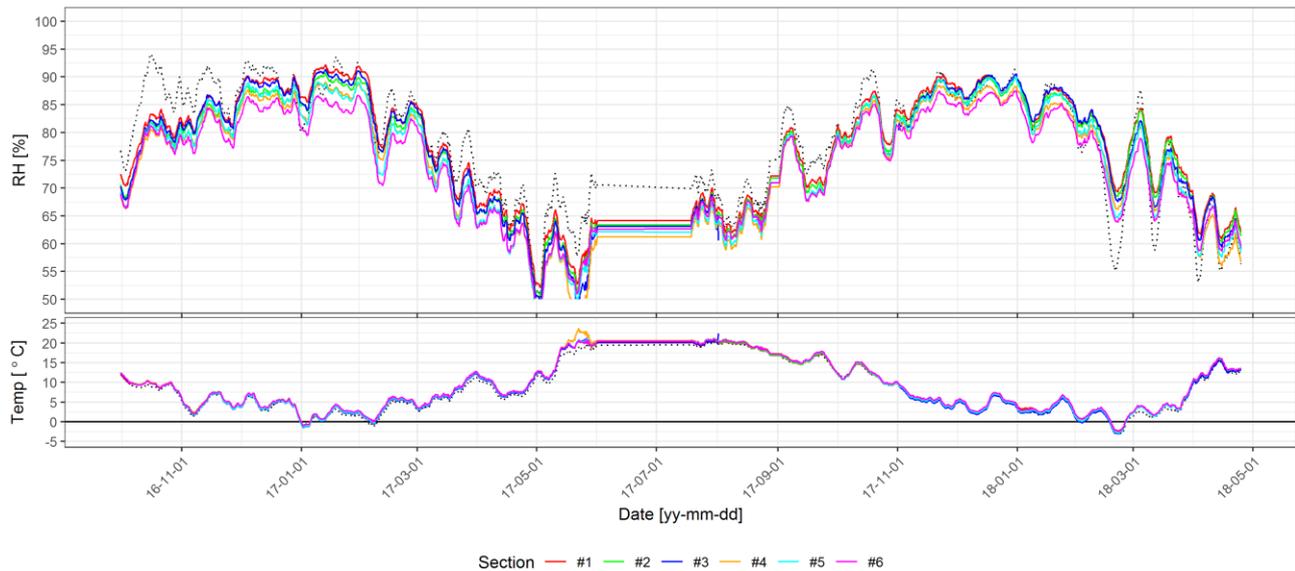


Fig. 5. Relative humidity and temperature in the attic space for attics #1 - #6 above humidity class 2. Average values for sensor position 03 (one week running mean). Black dotted lines describe outdoor relative humidity and temperature. Lack of measurements in the summer of 2017 was because the test house was moved to a different location and measurements therefore interrupted.

After the first winter with built-in moisture, these results show that moisture content is not critical in any of the attics as moisture content stays below 18 weight-%, which represents a common limit for mould growth risk in wooden constructions (here spruce), corresponding to relative humidity of 80-85% and temperature around 10°C.

In order to be able to identify, which role factors like vapour barrier, insulation material moisture buffer capacity and moisture load from indoor environment play, a comparison of selected attics is presented in the

following and shown in Fig. 7-9, focus has been on winter conditions, as this is the season with high relative humidity in attics.

Fig. 7 shows relative humidity measurements for attics #2, #4, #5 and #6 during the last year. These values are an average of measurements in the attic space, i.e. sensor position 03 according to Fig. 4. This figure illustrates differences between insulation materials and the influence of vapour barrier as well as the role of humidity class.

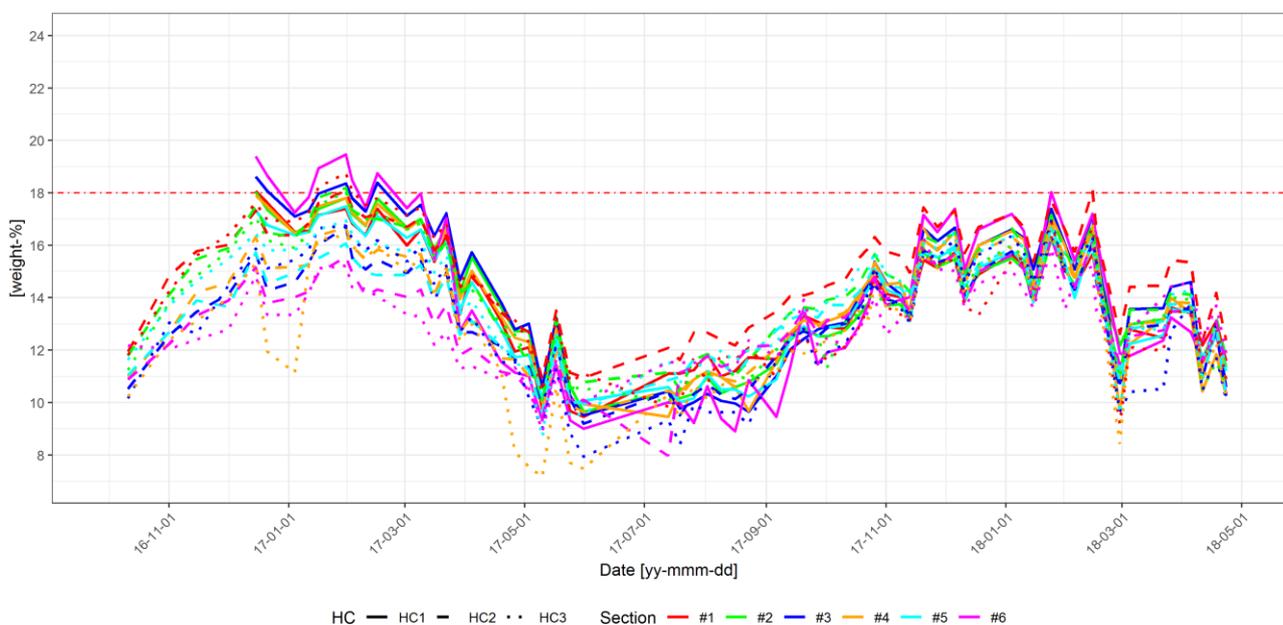


Fig. 6. Wood moisture content. Average for North side. Comparison of all attics. The test house section with HC1 was built one year later than the first two sections, hence the missing values for HC1 the first year.



Fig. 7. Relative humidity in the attic space for attics #2, #4, #5 and #6 in all humidity classes (HC). Average values for sensor position 03 during the last year of measurements. Black dotted line describes outdoor relative humidity.

Results show very little differences in relative humidity and no clear picture, as the order of sections with highest relative humidity is not the same in all humidity classes, e.g. in HC1 #6 has the highest relative humidity but in HC2 it has the lowest. Furthermore, many of the curves are so close together, it is difficult to distinguish them from each other. Statistical analyses made in [6] showed no statistical significant difference between spaces with or without vapour barrier or between the different insulation materials.

Fig. 8 shows measured relative humidity in top of the insulation layer in sensor position 02. By comparing

Fig. 5 and 8, it is clear that the relative humidity in attics with vapour barrier was almost the same just above insulation as higher up in the attic space, while the relative humidity in attics without vapour barrier increased just above the insulation layer. While the hygroscopic insulation material seemed to reduce the relative humidity in position 02 if there was no vapour barrier (#4 compared to #2) the opposite was seen when there was a vapour barrier (#5 compared to #6). However, the differences were small and probably not statistically significant.

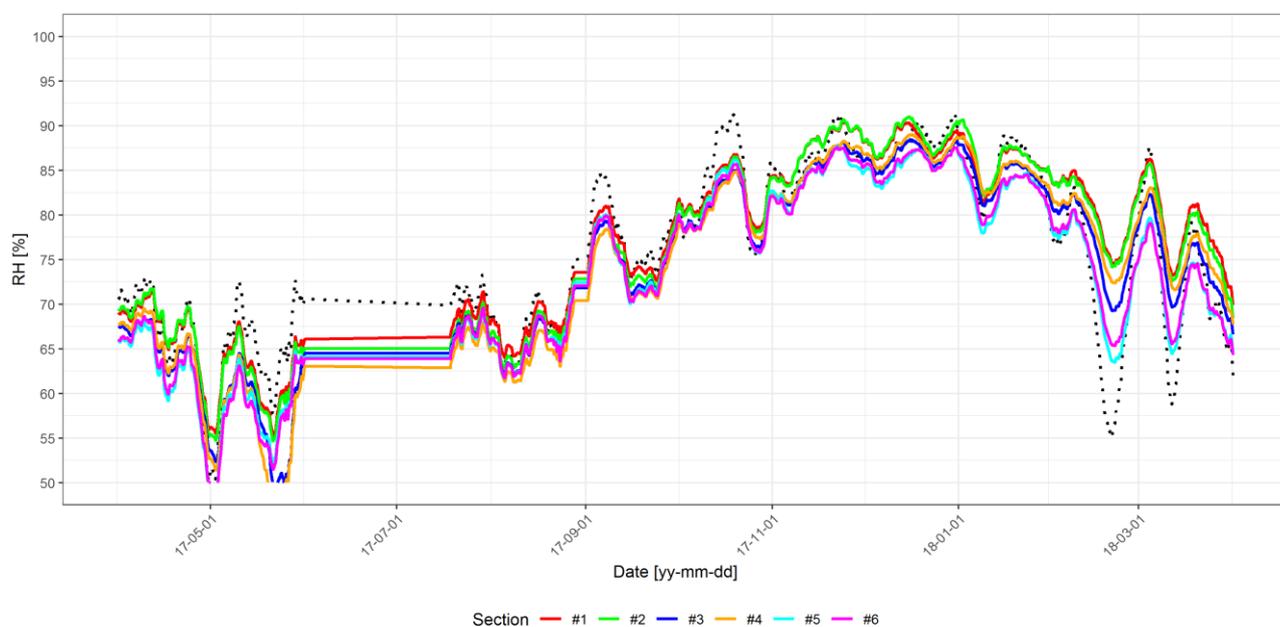


Fig. 8. Relative humidity in the attic space for attics #2, #4, #5 and #6 in humidity class 2. Average values for sensor position 02 (above insulation) during the last year of measurements. Black dotted line describes outdoor relative humidity.

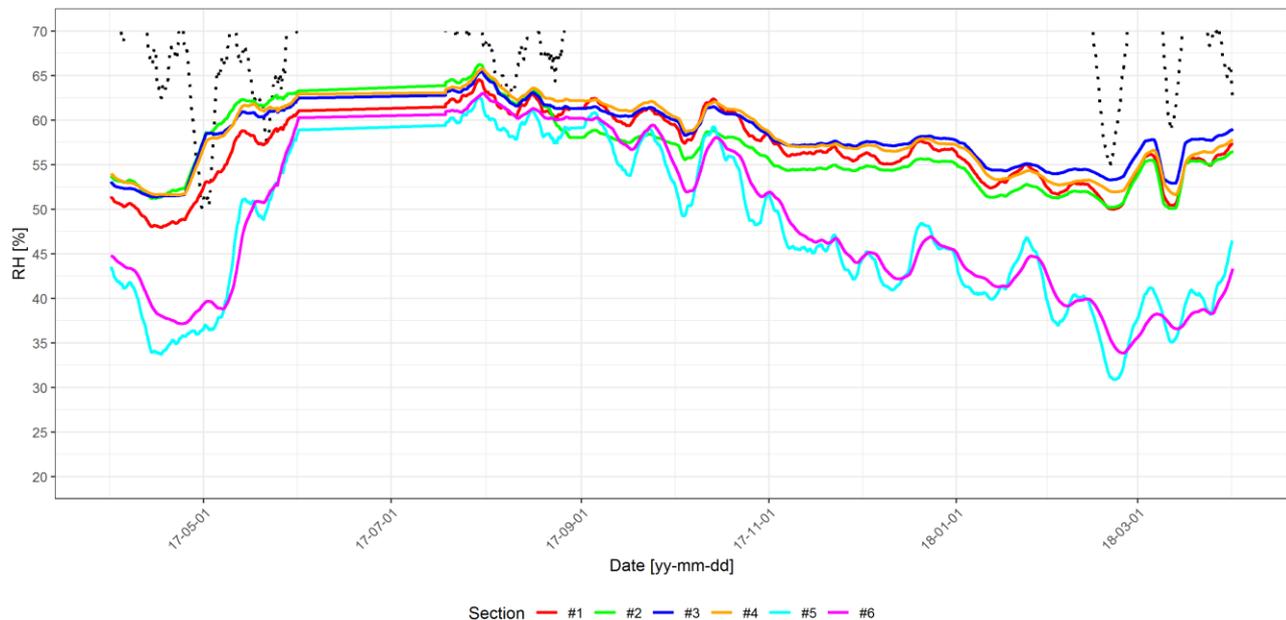


Fig. 9. Relative humidity in the attic space for attics #2, #4, #5 and #6 in humidity class 2. Average values for sensor position 01 (below insulation) during the last year of measurements. Black dotted line describes outdoor relative humidity.

Fig. 9 shows the relative humidity just below the insulation material i.e. position 01 in Fig. 4.

Here the difference between having a vapour barrier or not was very clear, as the relative humidity in this position for attics with vapour barrier (#5 and #6) is much lower than for those without vapour barrier. In attics with vapour barrier the relative humidity below the insulation material is independent of the moisture buffering capacity of the insulation material. Contrary, in attics without vapour barrier, the higher buffering capacity of cellulose (#4) increases the relative humidity compared to the comparable attic with mineral wool (#2). However, the relative humidity is very low in all cases, and there is therefore no risk of mould growth below the insulation in any of these cases.

Although the relative humidity in the attic space was not significantly affected by the presence of a vapour barrier or the moisture buffering capacity of the insulation material, there seem to be differences closer to and below the insulation material. This is probably because the influence of ventilation is reduced in these areas, especially below the insulation; while ventilation overruled possible differences in the attic space, this effect is not present below the insulation material. If the long-term hygrothermal performance of the ceiling construction itself is dependent on the presence of vapour barrier or moisture buffering capacity of the insulation should be part of future studies.

4 Conclusion

This paper presents an experimental study where six different attic designs with airtight ceilings regarding need for vapour barrier, choice of insulation material together with different moisture loads from the interior environment to attic space was evaluated.

Below the insulation material the relative humidity was very dependent on a vapour barrier; a vapour barrier reduced the relative humidity, however, in none of the cases was the relative humidity high enough to cause mould growth. Just above the insulation material the conditions only showed minor insignificant differences to what was measured in the attic space.

The results show that it is practically indifferent for the hygrothermal performance of the monitored, well-ventilated attics with airtight ceilings whether there is a vapour barrier or not and if the insulation material has moisture capacity or not. Furthermore, humidity class did not play any significant role either for the studied attic design.

The overall conclusion is therefore that in temperate climates, as in Denmark, there is no need to establish a new vapour barrier in the ceiling when increasing the thermal insulation of an existing cold well-ventilated attic if the airtightness of the ceiling so far has been sufficient enough to minimize the moisture load from the living space and thus to prevent mould growth in the attic space. It is important to keep in mind that this conclusion is only valid if neither ventilation of the attic nor air-tightness of the ceiling is compromised when adding new insulation material to the attic.

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