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Measurements of Temperature Dependency on Thermal Insulation Thickness in Ventilated Attics

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ABSTRACT

The main objective of this paper is by measurements to investigate whether increased thermal insulation thickness reduces the temperature in ventilated attics. With lower heat flux through the ceiling in the winter, the theory is that the temperature in the attic decreases and consequently the relative humidity increases which may cause mold growth. While some simulations support this theory, others do not. To test the theory in practice, measurements were performed in 29 dwellings, mainly older single family houses with ventilated attics and insulation thicknesses varying between 150 and 600 mm (6“ and 23“). The temperature was measured for more than one year in the attic, the living space below and outdoors.

All measured attics were ventilated as recommended in guidelines; i.e. with openings at the top and the bottom. The measurements in the attics showed high dependency on the outdoor temperature, while indoor temperature and the thickness of insulation were not significant.

Consequently, the thermal insulation thickness alone cannot explain possible increasing mold problems. However, extra insulation in attics may obstruct the ventilation openings and therefore, reduce the ventilation rate. Measurements of ventilation rates in non-problematic and moldy attics should therefore be the next step.

KEYWORDS

Ventilated attics, temperature, thermal insulation thickness, heat flux, energy efficiency

INTRODUCTION

Our recent, paper (Hansen & Møller, 2017) showed some indication that the measured temperature in the attics of the case buildings was independent of the thermal insulation in the ceiling. Another paper (Nielsen & Morelli, 2017) presented simulation results for temperature variation in cold ventilated attics, with insulation thicknesses varying from 50 to 450 mm, where the average temperature in the attic in January was 1.54 °C (50 mm), 0.29 °C (150 mm) and -0.39 °C (450 mm). In April the average temperatures in the attic were 9.7 °C (50 mm), 9.0 °C (150 mm) and 8.7 °C (450 mm). This indicates that an increased insulation thickness from 150 mm and up, has a minor influence on the temperature in a cold ventilated attic during winter time. Hagentoft & Sasic-Kalagasidis (2010) state that additional attic insulation leads to a colder attic space, but does not indicate the magnitude. Geving & Holme (2010) have made simulations with average monthly values of tempererature and relatively humidity for Oslo; they also conclude that the temperature in the attic decreases with increased insulation, but they do not state how much. However, from the increase in relative humidity the temperature difference can be calculated to be approxemately 0.5 °C when the insulation thickness is changed from 100 mm to 500 mm. The outdoor temperature in Oslo in January is approxemately 3 °C lower than in Denmark.

The general perception that energy–saving will decrease the temperature in a ventilated attic substantially and consequently increase the risk of mould growth is challenged in this paper. Instead of simulations, measurements of temperature were performed in 29 case buildings with different amounts of insulation on the ceiling against af ventilatede attic.

METHODS

To assess the effect of the insulation thickness on the temperature in a cold ventilated attic, a series of field measurements was carried out in 29 Danish case buildings grouped in three groups depending on the insulation thickness:

- Group A: 7 case buildings with an insulation thickness ranging between 150-250 mm
- Group B: 9 case buildings with an insulation thickness ranging between 300-400 mm
- Group C: 13 case buildings with an insulation thickness ranging between 450-600 mm

The thermal insulation was applied either at construction or later as a part of improving the energy efficiency. When looking at temperature difference, the thermal resistance for the insulation material is the relevant parameter. As the insulation materials used in the case buildings had approximately the same thermal conductivity, the thickness was proportional to the thermal resistance. Most of the case buildings had a vapor barrier installed; some of them were old and probably not tight. However, this article only considers temperatures; the effectiveness of the vapor barriers is therefore not considered.

In each attic, a series of sensors (EL-USB-2+ from Lascar Electronics (Lascar electronics)) were installed in order to register the temperature and relative humidity for at least one year. Measurements were performed from July 2015 to June 2017. Not all houses were measured at the same time, and therefore two winters were covered. Sensor positions are shown in Figure 1. The sensors were controlled for uncertainty of measurements, which was registered to be within the 0.45 °C stated by the manufacturer. The sensors registered the climate every hour. Beside the sensors in the attic, one sensor registered the indoor climate and another sensor measured the outdoor climate.

The data analysis showed that the temperatures at the ridge and at the roof underlay were very much alike; the same applied for the two sensors located on top of the insulation material. The hypothesis that the temperatures in the attic space and above the insulation were the same in the groups was tested statistically by t-tests and test of correlation.

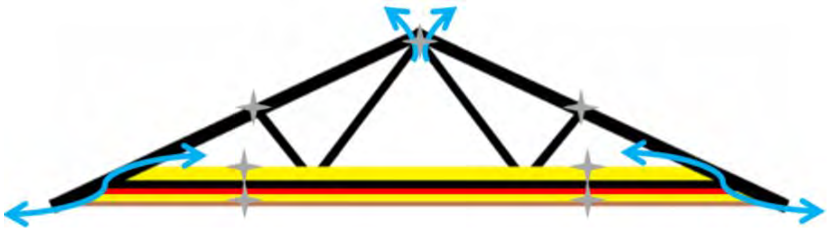

Figure 1. Principle sketch of a cold ventilated attic with sensor location (grey stars). Blue arrows indicate ventilation; red line indicates position of possible vapor barrier.

Ventilation rates in the attic were measured in seven of the case buildings by two passive tracer gasses (Heiselberg and Bergsøe, 1992) placed in attics and living spaces, respectively.

RESULTS

Data collected from the mounted loggers in the case buildings are presented in Figure 2 and Figure 3. In each group the case building has its own color so the legend in Figure 2 represents both figures. To avoid fluctuating data, moving average for a period of one week, is used for evaluating data.

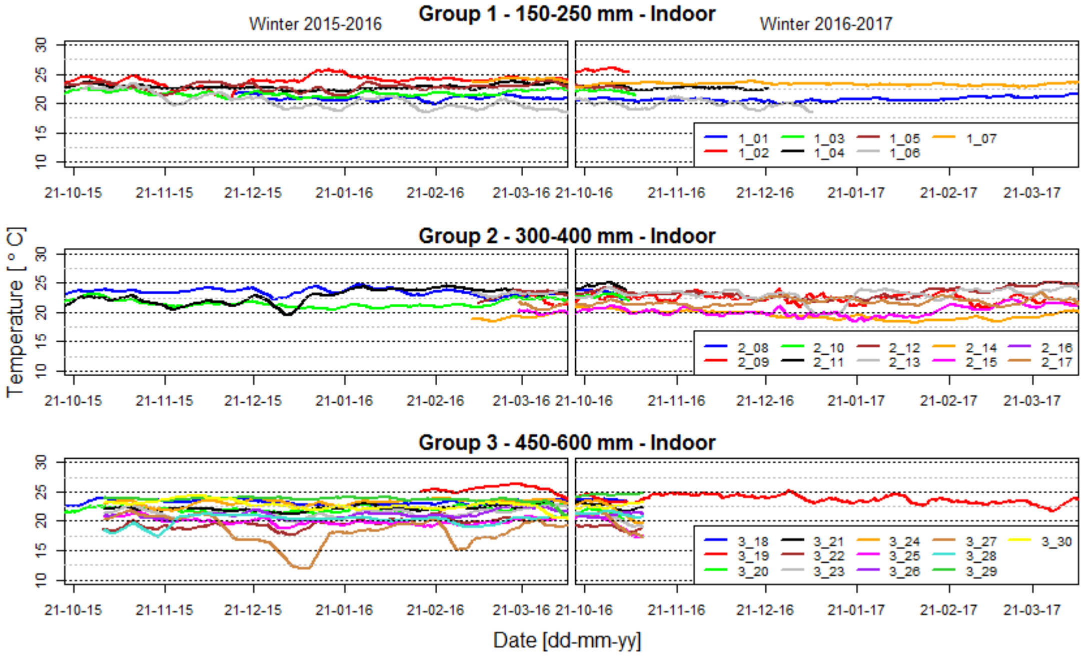

Figure 2. Measured indoor climate in every case building for the two winter periods 2015/16 and 2016/17 (November to March, both included) for the three different groups

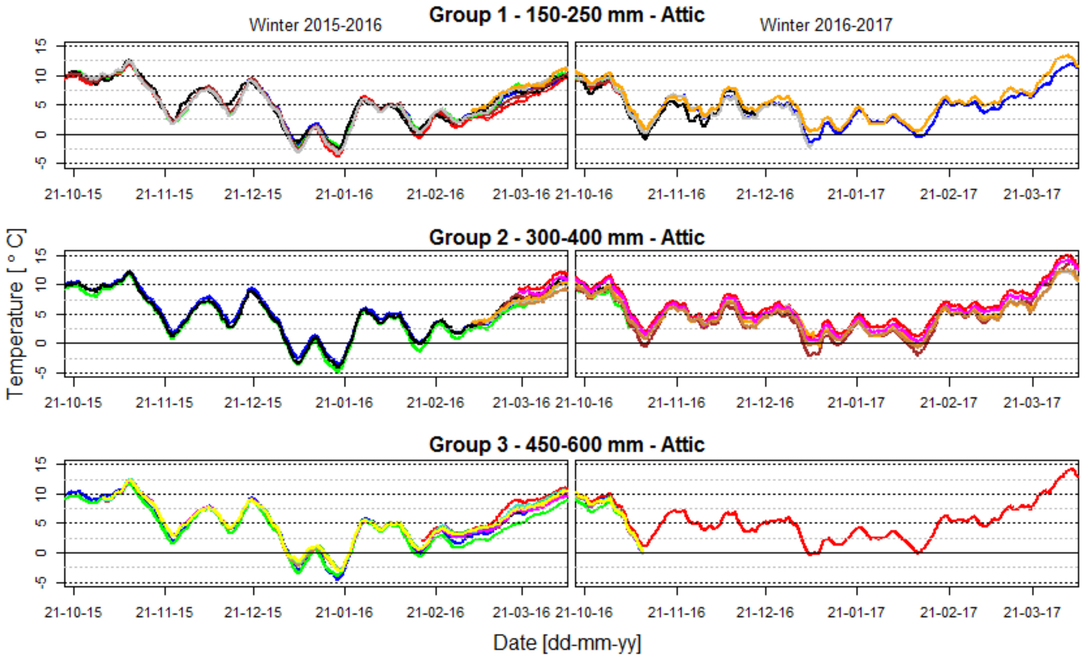

Figure 3. Measured attic temperature in every case building for the two winters 2015/16 and 2016/17 for the three different groups, see Figure 2 for legend

Figure 2 and Figure 3 illustrate the measured indoor temperature central in the house, and the average temperatures for the sensors located in the attic space, respectively. In the figures, the measured summer conditions are omitted, as the temperature difference between the indoor climate and the attic space are most significant during the winter period.

Table 1 shows the mean and standard deviation for the measured temperature in the three different groups for both winter periods (from 1 November to 31 March) in the attic and above the insulation. For comparison, the indoor and outdoor temperatures are shown as well.

Table 1. Mean and standard deviation for the measured temperature in the three different groups for both winter periods (from 1 November to 31 March). The numbers in brackets denotes the number of case buildings.

		Group 1 150-250 mm	Group 2 300-400 mm	Group 3 450-600 mm
Winter 2015/2016	Outdoor [°C]	4.9 ± 1.2 (14)		
	Indoor [°C]	22.1 ± 1.4 (6)	22.3 ± 1.5 (3)	21.5 ± 1.9 (12)
	Above insulation [°C]	4.9 ± 0.5 (6)	5.3 ± 0.7 (3)	5.3 ± 0.4 (12)
	Attic space [°C]	4.6 ± 0.4 (6)	4.2 ± 0.5 (3)	4.7 ± 0.4 (12)
Winter 2016/2017	Outdoor [°C]	4.5 ± 1.2 (10)		
	Indoor [°C]	21.8 ± 1.7 (2)	21.4 ± 1.7 (7)	23.6 (1)
	Above insulation [°C]	4.7 ± 1.2 (2)	5.1 ± 0.6 (7)	5.3 (1)
	Attic space [°C]	4.2 ± 0.6 (2)	4.5 ± 0.7 (7)	4.8 (1)

The ventilation openings were visually inspected; most of the case buildings had the recommended size of ventilation openings of 1/500 of the floor area (Brandt, et al., 2013). Only in one case the ventilation was insufficient. In that case, there was visible mold growth in the attic. Measurements of the ventilation rate in seven houses showed ventilation rates between 1.9 h^{-1} and 24 h^{-1}. The ventilation rate was not measured in the attic with visible mold growth.

DISCUSSIONS

The measurements did not support the hypothesis that the attic temperature decreases with higher thickness of insulation. The tendency seems to be the opposite; in the winter 2016/2017 the attic temperature generally increased with higher amounts of insulation material. However, the measurements in Group 3 are only from one case and the indoor temperature was 1.8 °C higher in this building compared with the two Group 1 cases, so this might explain a 0.5 °C higher temperature. Nevertheless, the temperature rise in Group 2 of 0.3 °C compared with Group 1 cannot be explained by a higher indoor temperature as the average indoor temperature in Group 2 was 0.4 °C lower. In the winter 2015/2016, the temperature in the attic space in Group 3 was 0.1 °C higher than in Group 1 although the indoor temperature was 0.6 °C lower.

A series of t-tests shows no significant differences for the mean temperature between the different groups and as shown in Table 2, the temperature in the attics and above insulation were highly correlated within the group and each other. Furthermore, temperature differences of this magnitude in the attic are within the measurement uncertainties. Consequently, the temperatures in the attic space do not differ in the three groups and there is therefore no dependency on the insulation thickness. This corresponds to measured data from a laboratory test building with a controlled indoor climate (Hansen & Moeller, 2016).

Table 2. Correlation coefficients between temperature curves for different sensor positions. Green area indicates significant correlation.

		Out-door	Indoor climate			Above insulation			Attic		
			G1	*G2*	*G3*	*G1*	*G2*	*G3*	*G1*	*G2*	*G3*
Indoor	G1	0.59	1.00								
	G2	0.30	0.44	1.00							
	G3	0.06	-0.33	-0.52	1.00						
Above insulation	G1	0.98	0.64	0.30	0.06	1.00					
	G2	0.98	0.61	0.34	0.04	0.99	1.00				
	G3	0.97	0.62	0.28	0.10	0.99	0.99	1.00			
Attic	G1	0.98	0.65	0.34	0.03	1.00	1.00	0.99	1.00		
	G2	0.97	0.59	0.27	0.12	0.99	0.99	0.99	0.99	1.00	
	G3	0.97	0.61	0.29	0.10	0.99	0.99	1.00	0.99	0.99	1.00

As expected, the temperature above the insulation is generally higher than the temperature in the attic space; the tendency was consistent throughout the two winters and the three groups. That the temperature in the attic space is the same as the outdoor temperature might be due to effective ventilation, but the surface temperature of the insulation should be lower in the case of reduced heat flux i.e. high insulation thickness. This was not the case; all temperatures above the insulation increased with increasing insulation thickness. In the winter 2015/2016 the temperature difference above the insulation was 0.4 °C higher in Group 3 than Group 1 despite a 0.6 °C lower indoor temperature in Group 3. There might be a simple technical explanation as to why the temperatures in Groups 2 and 3 are higher than in Group 1; while the insulation material in Group 1 is in general relatively firm plates, the insulation material in Groups 2 and 3 is more often a granulate. Consequently, the data loggers are more likely to sink a little into the insulation material in Groups 2 and 3 and therefore measure in an area where the temperature is higher. However, this cannot explain why the temperature above the insulation is higher in Group 3 than in Group 2.

Although some of the temperature differences cannot be explained, they are all small compared with the measurement uncertainties and the tendencies are not significant, therefore, the temperature above the insulation should be regarded as independent of the insulation thickness. This does not support simulations made by others. The reason for this discrepancy might be computational difficulties in the simulation of convection or because the ventilation rate in attics fluctuates, depending on wind speed and direction.

Some practitioners claim to have observed an increased number of attics with mold growth. This study shows that the assumption that a temperature decrease because of higher amounts of insulation in the ceiling is responsible for this is not correct. There must be other explanations. One could be that additional insulation in existing attics obstructs some of the ventilation openings and consequently less moisture is removed by ventilation. In some cases, ventilation openings have consciously been closed because of the wrong assumption that ventilation can be omitted in attics if the roof underlay is open for diffusion.

Knowing the appropriate ventilation rate would therefore be helpful. However, the rate varied considerably and no visual mold growth was detected in any of the attics where the ventilation rate was measured. The needed ventilation rate may also change with the season. Therefore, more studies of sufficient ventilation rates are needed. To test the influence of ventilation rates, WUFI (WUFI, 2018) was used for a series of preliminary simulations with insulation thickness of 150, 350, and 600 mm, simulated with two different ventilation rates:

2 and 15 h^{-1}. These showed that the temperature in the attic was influenced by neither the ventilation rate nor the insulation thickness. This supports that higher relative humidity in some attics are not caused by lower temperature. Contrary to the measurements, the simulations of temperature in the top of the insulation layer was influenced by the insulation thickness, winter average was 1 °C higher with 150 mm of insulation compared to 600 mm insulation, regardless of the ventilation rate. This illustrates how difficult it is to measure at intersections between materials when sensors have a size of approx. 2 cm.

CONCLUSIONS

Contrary to our expectations, the measurements showed that the temperature in ventilated attic spaces or just above the insulation material did not depend on the thickness of the insulation material. The assumption that additional insulation in ceilings reduced the temperature, therefore raises the relative humidity, and consequently is responsible for increased mold growth in attics, cannot be corroborated. However, additional insulation may have an influence on the relative humidity anyway e.g. because ventilation openings may be blocked by the additional insulation resulting in insufficient ventilation rates. The consequence of these findings is that if there is no mold problem in an attic, it is possible to increase the insulation limitless if the ventilation is not altered. Measurements of ventilation rates in attics with and without mold growth might bring further insight to why mold growth in attics seems to be an increasing problem.

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