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Ventilated wooden roofs: Influence of local weather conditions - measurements

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Abstract

This study investigates the influence of temperature and air velocity conditions on ventilation and condensation in spring, summer and autumn periods inside a ventilated cavity in a full-scale wooden roof construction. The roof has 81 thermocouples, four air velocity measurement devices, and a weather station to record temperature and wind velocity. The temperature measurements show large periods of below-ambient temperature, especially during the spring and autumn. A strong correlation exists between the wind speed and air velocity inside the air cavity. Eave-to-eave ventilation was found to be effective, even with a roof angle of 40°.

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Keywords: Roof; Pitched; Wooden; Field experiments; wind speed; air velocity

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1. Main text

Pitched load-bearing wooden roof constructions with a ventilated air layer beneath the roofing is a typical construction in Central Europe [1] and Norway [2]. The purpose of the ventilated air layer is to 1) ventilate heat and prevent formation of ice on the eaves and gutters, 2) ventilate humidity from the roof construction and prevent formation of mould and rot inside the construction [3-5]. Hygrothermal conditions inside air cavities in roofs have been investigated by [5-7]. Measurements performed by [5] showed that a ventilation channel with a height between 48 mm and 98 mm was sufficient up to roof lengths of 7–8 m. Eaves-to-eaves ventilation was found to be very effective, given a low roof pitch. During a measuring period of 22 days, it was found that for 86 % of the time, the surface temperature of the roofing was lower than the air temperature. Hens and Janssens [6] found negative effects

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due to air leakages and wind washing for the hygrothermal response and durability of insulated pitched wooden roofs. They stated that a ventilated air layer between the underlayer roofing and insulation was unnecessary [6] in roof constructions with vapour open underlayer roofing materials, as given by [4].

The purpose of this paper is to 1) map the risk of condensation on the interior surface of the ventilation cavity as given in [4] and 2) map the air cavity velocity dependency on the outside wind speed.

2. Method

The measurements were conducted on a full-scale experimental building, ZEB Test Cell Laboratory, located at the NTNU campus in Trondheim, 63°24'52.0"N 10°24'32.3"E, see Figure 1. The rectangular-shaped roof air cavity is 552 mm wide, 48 mm high and 10.8 m long. The roof angle was 40°. The lower surface in the ventilation gap consisted of a flexible underlayer roof on top of a 12.5 mm oriented strand board (OSB) board. The top of the air gap consists of an OSB board with a bitumen membrane roofing. As observed in Figure 2, there is no opening in the ridge of the roof; the roof is ventilated from eaves to eaves through a 48 mm wide opening in the eaves behind the gutter.

The building has a weather station located 10 m above ground level (see Figure 1). The exterior temperature, wind speed and direction were recorded at one-minute intervals.

In total, nine air cavities in parallel had nine thermocouples in each cavity, resulting in a total of 81 thermocouples. In each cavity, the sensors were distributed 0.5 m above the eaves, between the eave and the ridge, and 0.5 m below the ridge (see Figure 2). In the cross-section, the thermocouples were positioned on the lower-facing surface of the roofing, in the middle of the air cavity and on the surface of the underlayer roof. Two of the air cavities also had air pressure devices and omnidirectional remote air velocity probes (see Figure 1). The accuracy and measuring range of the applied devices are given in Table 1. The logger interval was set to one minute.

Table 1. Accuracy and measuring range of applied sensors

Sensor	Manufacturer	Type	Accuracy	Range
Thermocouple		Type T	±0.10 °C	-20–+60 °C
Pressure gauge	Kimo	SPI2-100	±0.2 % of reading	-100–+100 Pa
Air velocity	Kimo	SVO: omnidirectional	0.05 m/s or ±3 %	0.05–5 m/s

Fig. 1. Left: the omnidirectional air velocity measurement device. Right: the ZEB Test Cell Laboratory located at the NTNU campus in Trondheim. The weather station is positioned 10 m above ground level, 1.5 m above the ridge of the roof.

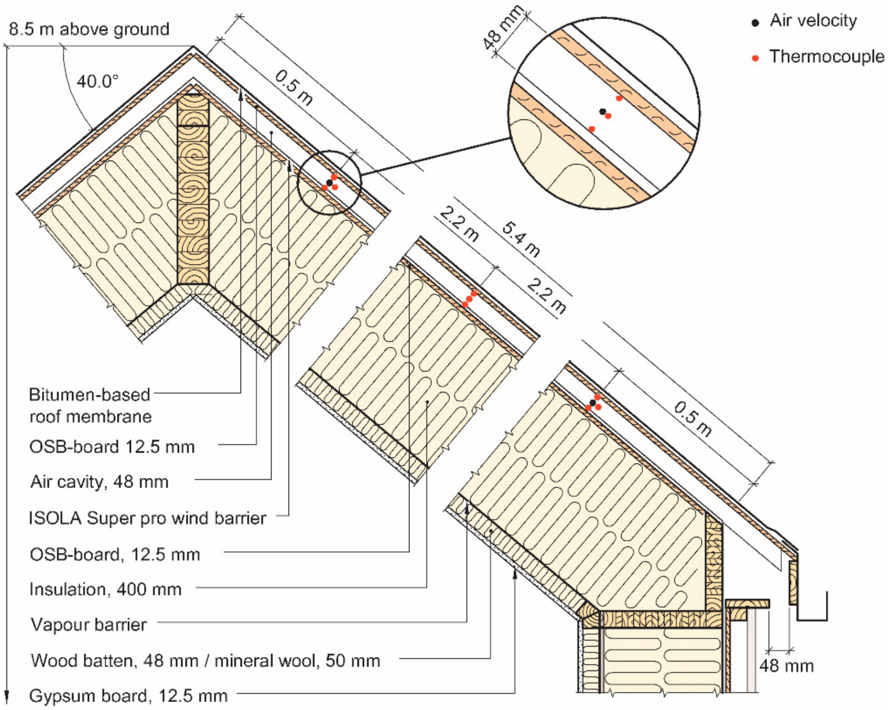

Fig.2. The roof structure in the ZEB Test Cell Laboratory and position of the thermocouples and the air velocity measuring device. The circle indicates the position from which the air velocity data is recorded.

3. Results

The results include temperature, air velocity and wind velocity during spring (March 22nd to March 31st), summer (July 3rd to 15th) and autumn (September 21st to 29th). Figure 3 and 4 shows the temperatures of the south side (160°) of the roof. The outdoor temperature, temperature on the underlayer roof, air temperature inside one of the air cavities and on the lower surface of the roofing during spring and summer are also given in Figure 3. Figure 4 shows the outdoor temperature and temperatures inside the air cavity during an autumn period. Table 2 gives the temperature conditions inside the air cavity.

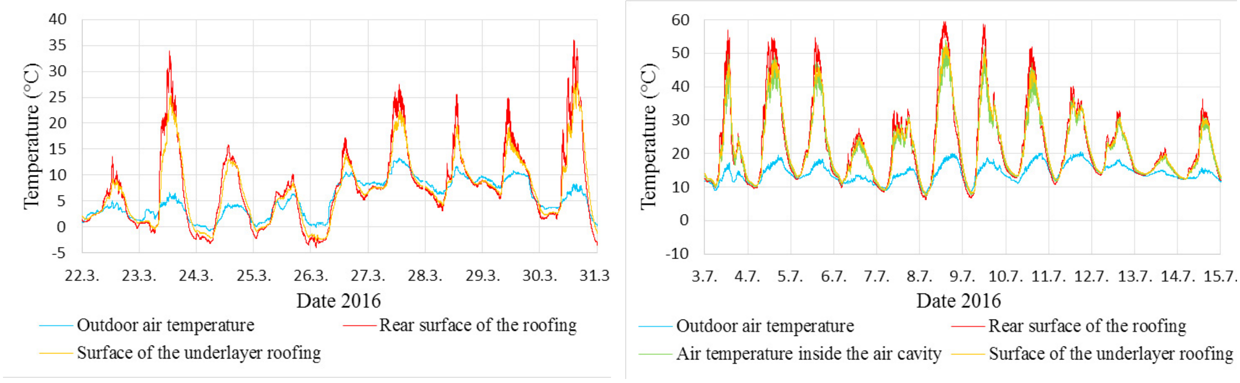

Fig. 3 Left: outdoor air temperature, temperature on the lower surface of the roofing, and temperature on the underlayer roof in the period from March 22nd to March 31st. Right: the air temperature inside the air cavity in the period from July 3rd to 15th. Recorded values are taken 2.2 m from the ridge.

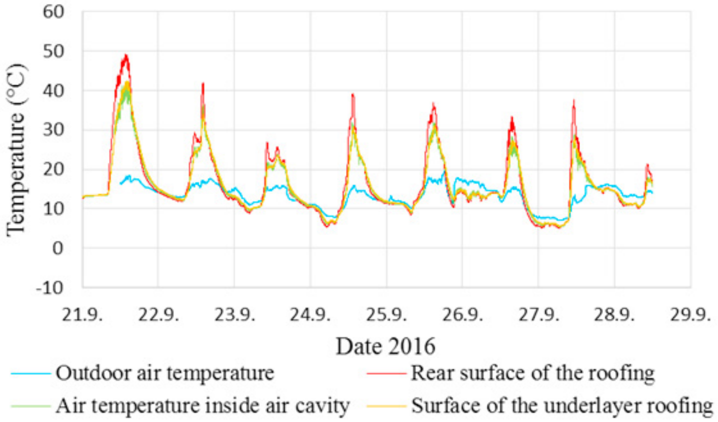

Figure 4: Outdoor air temperature, temperature on the lower surface of the roofing, and temperature on the underlayer roofing in the period from September 21st to 29th. Recorded values are taken 2.2 m from the ridge.

Table 2. Temperature conditions during the three periods inside the roof air cavity of the south side of the roof; measurements from the middle position of the roof.

	Lower surface of roofing			Top surface of the underlayer roofing		
Period	Share of period with temp. lower than outdoor air temp.	Largest temperature difference below ambient temperature	Maximum temperature	Share of period with temp. lower than outdoor air temp.	Largest temperature difference below ambient temperature	Maximum temperature
22.3–31.3	51 %	5 °C	36 °C	50 %	5 °C	28 °C
3.7–15.7	14 %	3 °C	60 °C	5 %	3 °C	57 °C
21.9–29.9	56 %	11 °C	49 °C	55 %	9 °C	47 °C

Figure 5 shows the air velocity inside the air cavity beneath the roofing as a function of the wind speed at 10 m above ground level. The air velocity device is positioned 0.5 m from the ridge at the north side of the roof.

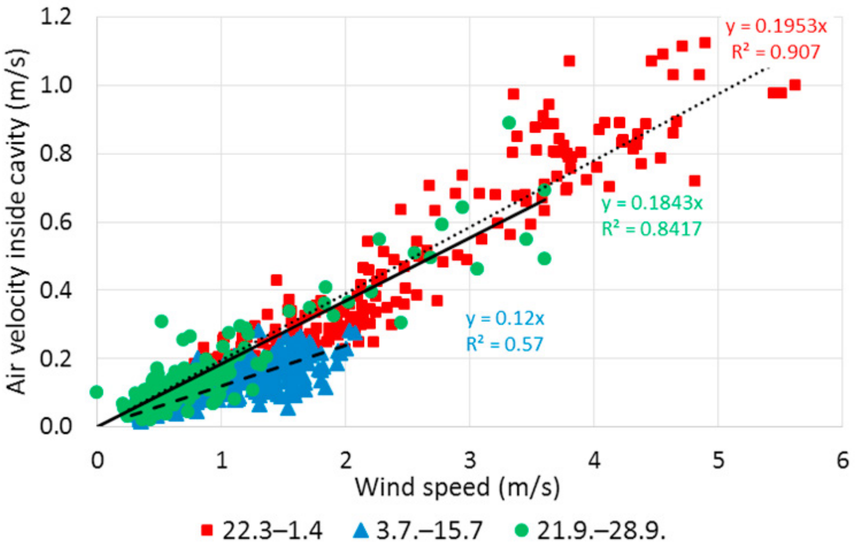

Fig. 5. Air velocity inside the air cavity for different seasons/periods as a function of wind speed at 10 m above ground level. The presented results are hourly averaged values calculated from raw data with a one-minute measuring interval.

4. Discussion

The measured temperatures presented in Figures 3 and 4 and Table 2 are results from the position between the ridge and the eave (mid-position) of the roof facing south. Figure 5 gives the measured air velocities in a position 0.5 m from the ridge in the air cavity for the roof slope facing north. Generally, the air velocity was higher lower down the roof (near the eaves) because of external wind fluctuations.

The measuring periods represent the conditions during a one-week period in the spring and autumn, and a twelve-day period during summer. The weather conditions during the start of the spring period included low temperatures around 0–5 °C, low wind speeds and periods of clear sky conditions, as recorded in Figure 3. At the end of the period, the temperature increased to around 5–10 °C and the wind speed was higher (typically a fresh breeze). During the summer period, the first three days had light sky cover, low wind speed and maximum temperatures of 15 °C. The next two days were cloudy and the last few days had long periods of clear sky and a maximum outdoor air temperature of 18 °C. The maximum temperature on the lower surface of the roofing during this period was close to 60 °C. The low temperatures in the roof structure on July 13th were caused by rainy conditions (see Figure 3). During the autumn period, the temperature ranged from 11 to 17 °C and there were generally low wind speeds. During the first two days, the sky cover was light with some sun (see Figure 4). On September 23rd, the sky was cloudy and for the rest of the period, the sky had a light cover. To summarize, the weather conditions during the measurement periods were quite typical for the seasonal climate in the location. The measuring periods do not include periods with snow on the roof.

The measurements show long periods where the temperature inside the air cavity is below the outdoor air temperature, also including periods of clear sky in the summer. Measurements performed by [5] showed surface temperatures below the ambient temperature for 86 % of the 22-day period with no snow on the roofing in the period from 14.1 to 24.3. An identical roof to the ZEB Test Cell Laboratory roof but with only 200 mm insulation showed surface temperatures below the ambient temperature on the underlayer roof 33 % of the time for a measurement period of 89 days [5].

The results from the ZEB Test Cell Laboratory roof during spring and autumn showed surface temperatures below the ambient temperatures for approximately half of the period. The measurements also show high temperatures in summer periods (up to 60 °C); note that the roofing color was dark. For this specific roof, there is a low risk of visible condensation droplets on the lower surface of the roofing due to the hygrothermal properties of the OSB board. However, high humidity levels increase the risk of mould growth on the OSB board. High summer temperatures, at least for the roof section oriented south, will terminate the mould growth [8]. Given a different roofing material, e.g. metal sheeting, the risk of condensation on the lower surface of the roofing is much larger. With metal sheeting, the condensation will represent an extra strain, and corrosion protection on the lower surface is therefore necessary. Condensation droplets on the underlayer roof also increase the risk of water leakages into the roof construction.

During the spring and autumn, a strong correlation was found between the wind velocity at 10 m above ground level and the air velocity inside the cavity below the roofing. These results are in line with the results from a similar roof construction reported by Blom [5]. However, the current study includes lower air velocities and wind speeds because devices with a higher resolution and better accuracy were used. During the summer, the correlation between the air velocity and the wind speed was less pronounced. A possible reason for this might be that the period only included days with low wind speeds.

Based on the measurements of air velocity, air change rates inside the air cavity were calculated. During the three measuring periods, the average air change rate varied from 38 to 133 h^{-1}. Fluctuating wind speed and air velocity means that the ratio between the air velocity and wind speed also fluctuates. Inside a ventilated air cavity, the air flow pattern is unstable and frequently alters between upward and downward air flows. Consequently, the air change rates estimated using omnidirectional anemometers are overestimated. A reduction factor for the air change rate of 5–40 % was proposed by [9]. The position of the air velocity measurement device is in the center of the air cavity. The middle air velocity is smaller than the air velocity measured at the center of the air cavity. Falk (2010) proposed a relationship between the middle velocity and maximum velocity, measured at the center of an air cavity, of ½ – ⅔ in an air cavity behind a wall cladding [10]. Given the above-mentioned reduction factors, the average air change rate of the three measuring periods can be estimated between 11 h^{-1} and 84 h^{-1}. This imply that eaves-to-eaves ventilation can be exploited effectively for ventilation of gabled roofs.

5. Conclusions

The measurements on the ZEB Test Cell Laboratory roof show long periods with surface temperatures below the ambient temperatures, especially during the spring and autumn periods. A strong correlation was found between the wind speed and air velocity inside the air cavity. The average air change rate of the three measuring periods can be estimated to 11 h^{-1} during periods with low wind speed and 84 h^{-1}during more windy periods. Eave-to-eave ventilation was found to be effective even though the roof angle was rather steep (40°).

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References

[1] Roels S, Langmans J. Highly insulated pitched roofs resilient to air flow patterns: Guidelines based on a literature review. *Energy and Buildings* 2016;120:10-18.

[2] Gullbrekken L, Kvande T, Jelle B, Time B. Norwegian Pitched Roof Defects. *Buildings* 2016;6(2):24.

[3] Bøhlerengen T. *Isolerte skrå tretak med lufting mellom vindsperre og undertak. (Insulated pitched wooden roofs ventilated between the underlayer roof and the wind barrier) (In Norwegian)* SINTEF Building Research Design Guides 525.101. ISSN 2387-6328. SINTEF. Oslo. Norway. 2007

[4] Bøhlerengen T. *Isolerte skrå tretak med kombinert undertak og vindsperre. (Insulated pitched wooden roofs with combined underlayer roof and wind barrier) (In Norwegian)* SINTEF Building Research Design Guides 525.102. ISSN 2387-6328. SINTEF. Oslo. Norway.2012

[5] Blom P. *Ventilasjon av isolerte skrå tak (Ventilation of pitched roofs) (In Norwegian)*. Doctoral thesis. NTH. Trondheim. Norway. 1990:39

[6] Hens H, Janssens A. *Cathedral ceilings: a test building evaluation in a cool, humid climate. Performance of exterior envelopes of whole buildings* IX International Conference Proceedings: ASHRAE Special Publications. 2004.

[7] Roels S, Deurinck M. The effect of a reflective underlay on the global thermal behaviour of pitched roofs. *Building and Environment* 2011;46(1):134-43.

[8] Holme J. *Mould growth in buildings*. Doctoral thesis. NTNU. Trondheim. Norway. 2010:147

[9] Falk J, Sandin K. Ventilated rainscreen cladding: Measurements of cavity air velocities, estimation of air change rates and evaluation of driving forces. *Building and Environment* 2013;59(0):164-76.

[10] Falk J. *Ventilarad luftspalt i yttervegg. (Ventilated air cavity in exterior walls) (In Swedish)* Doctoral thesis. TVBM-3155 Lunds Technical University. Lund. Sweden. 2010.