Indoor Air Temperature and Ventilation in Uninsulated Loose Housing Cowsheds with Different Types of Non-transparent Roofing in Hot Summer

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Abstract. As the indoor temperature of uninsulated cowsheds is in correlation with outdoor temperature, it may happen that indoor temperatures in cowsheds soar in hot summer. Roof temperature and spatial distribution of indoor air temperature at 1m (cow level) was studied in 8 uninsulated cowsheds with three different types of roof – non-asbestos cement sheets (4 cowsheds), metal (2 cowsheds) and insulated with 25 mm mineral wool plate (2 cowsheds) at outdoor air temperatures 26.8...32.0°C in at least 25 points of the cowshed. All openings were open in the cowsheds.

Roof (indoor surface) temperature values of 47.1°C were recorded as highest at non-asbestos cement roof in outdoor air temperature of 30°C. The average indoor surface temperature of the insulated roof (28°C) was about as high as outdoor air temperature (29°C).

Average indoor temperature in cowsheds varied 27.6-29.7°C. Smallest indoor-outdoor air temperature difference (Δt) was 0.8°C and occurred at lowest outdoor temperature (26.8°C). The biggest Δt of -2.3°C occurred at highest outdoor temperature (32°C).

If the roof was insulated, Δt varied -0.5-1.1°C. In four cowsheds with non-asbestos cement sheet roof, Δt of 0.8…-1.9°C was recorded. In cowsheds with metal sheet roof, Δt of -1.2… -2.3°C was recorded.

Standard deviation of indoor temperatures at the measurement points s (describes the ventilation efficiency) was s=0.59…0.84 in the cowsheds with insulated roof and s=0.46…0.66 in the uninsulated ones. The ventilation in cowsheds was good and air moving schemes uniform.

As a result of the investigation, the following conclusion can be made: indoor air temperature and ventilation efficiency in hot summer days are not influenced by roof material (non-transparent) or the presence of insulation..

Key words: Air temperature, uninsulated cowshed, ventilation, summer

INTRODUCTION

Today a lot of cows are kept in loose housing and uninsulated cowsheds. Borders having U-values of 6-7 W m^{-2} K^{-1} are comparable with single glass windows. Investigations carried out in cowsheds show that closing vent openings up to very small ventilation rate in cold weather will lead to significant indoor-outdoor temperature difference (Pajumägi et al., 2003, 2007).

It is well known that cows tolerate cold more than heat. Upper Critical Temperature for cows is given as 25-26 ºC (Berman et al., 1985; Hamada, 1971). Feed intake in lactating cows begins to decline at the ambient temperatures of 25-26ºC and drops more rapidly above 30ºC. At 40ºC, dietary intake may decline by as much as 40% (National Research Council, 1989). Heat will cause stress that may lead to dropping the milk yield and a heart condition. Sczütz et al. (2008) found out that cows preferred standing in a shaded area instead of lying.

There are two main problems in the cowsheds in summer in hot weather: indoor air temperature caused by high outdoor temperature and radiant heat load from the sun-heated roof. Jeppsson and Gustafsson (2001) recorded that absorptance factor for transparent polycarbonate roofing was 0.36 and for non-transparent fibre cement roof 0.20 and ventilation rate was 0.070 and 0.035 $m^3m^{-2}s^{-1}$, respectively.

The roof of uninsulated cowshed offers good shading for cows in hot weather (West, 2003) Shading, which provides protection from direct solar radiation, is one way to minimise the effects of heat stress (Kadzare et al., 2002)

MATERIALS AND METHODS

Tests were carried out at 8 Estonian cowsheds in 5 farms (Table 1) with commonly used design solutions and three different types of roof – non-asbestos cement sheets (4), metal (2) and insulated with 25 mm mineral wool (2). End walls were mostly from metal and walls were covered with plastic material.

Measurements were performed in hot summer with non-cloudy weather. Air temperature was measured outdoors before and after indoor test.

In cowsheds the measurements were carried out at 1m above floor level in at least 25 points (A1–E5 in Fig. 1) in the course of one hour. The following portable measuring devices were used: thermo-hygrometer Testo 615 (range -20…+70ºC and 5…95%, accuracy ±0.7ºC, 3%) and infra-red thermometer Raytek (Raytek Raynger ST™ RAYST2XHCG, resolution 0.1ºC). Infra-red thermometer was also used for measuring the cows' surface temperatures to evaluate the effect of the building as a shade.

Air movement in the cowshed was visualized with smoke using bellows.

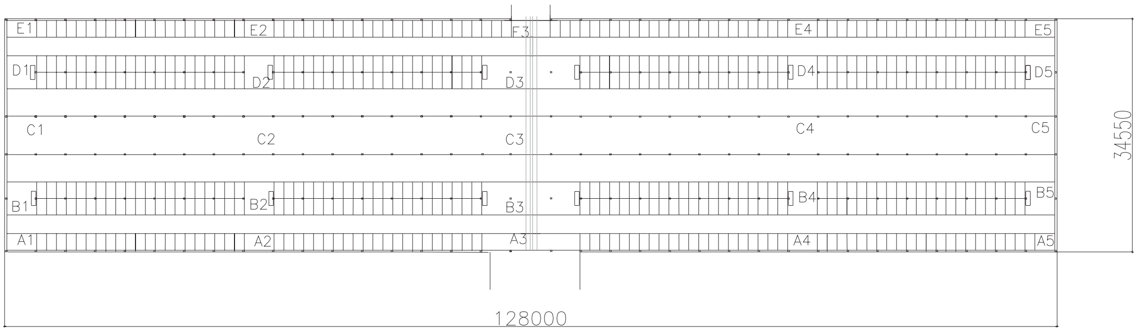


Fig. 1. Typical plan of a cowshed A1…E5 measurement points.

Values of air velocity and relative humidity were recorded as well, but excluded from this analysis, because the use of the spatial temperature distribution is proposed as a measure to assess ventilation efficiency (Pajumägi et al., 2008).

RESULTS AND DISCUSSION

Measurements were carried out at outdoor air temperatures of 26.8...32.0°C in at least 25 points of the cowshed (Table 1). In the cowsheds, all openings were open.

Table 1. Roof surface, outdoor and indoor air temperature (°C)

Cowshed, Roof type	Item	Outdoor	Indoor temperature					Δt*
			Min	Max	Average	Stdev	Range	
No 1	Air	28.6	27.2	29.6	28.1	0.75	2.4	-0.5
insulated	Roof		25.2	33.1	28.5	2.54	7.9	0.4
No 2	Air	28.9	26.7	29.9	27. 8	0.84	3.2	-1.1
insulated	Roof		24.9	31.4	27.9	1.78	6.5	0.1
No 3	Air	26.8	26.5	29.1	27.6	0.59	2.6	0.8
cementos	Roof		25.7	42.5	33.9	4.75	16.8	6.3
No 4	Air	29.2	27.9	30.5	28.7	0.64	2.6	-0.5
cement	Roof		26.7	45.1	38.3	5.56	18.4	9.6
No 5	Air	28.5	27.5	29.5	28.2	0.46	2.0	-0.3
cementos	Roof		29.7	46	38.7	4.4	16.3	10.5
No 6	Air	30	26.7	30	28.1	0.66	3.3	-1.9
cement	Roof		26.3	47.1	36.8	5.61	21.2	8.7
No 7	Air	30.9	28.8	30.8	29.7	0.59	2.0	-1.2
Metal	Roof		21.2	44.4	36.7	5.4	23.2	7.0
No 8	Air	32	28.5	30.9	29.7	0.59	2.4	-2.3
Metal	Roof		30.4	43	36.9	3.45	12.6	7.2

* - Δt for air is calculated by indoor-outdoor air and for roof as roof surface – indoor air temperature

Air temperature

Outdoor temperature varied 26.8…32.0°C, whereas average indoor temperature varied 27.6…29.7°C (Table 1). The smallest indoor-outdoor air temperature difference (Δt) was 0.79°C and occurred at the lowest outdoor temperature (26.8°C). The biggest Δt of -2.33°C occurred at highest outdoor temperature (32°C).

If the roof was insulated (25 mm glass wool plate), Δt varied -0.53…-1.12°C. In four cowsheds with non-asbestos cement sheet roof, Δt of 0.79…-1.91°C was recorded. In cowsheds with metal sheet roof, Δt of -1.22…-2.33°C was recorded.

Indoor-outdoor temperature difference depending on outdoor temperature is given in Fig. 2. At higher outdoor temperatures the Δt was bigger and indoor air temperature was lower than outdoors, which indicates good effect of shade.

There was no correlation between outdoor air temperature and standard deviation of indoor temperature (Fig. 3). Standard deviation of indoor temperature s was 0.59…0.84 in a cowshed with insulated roof (Fig. 4a) and 0.46…0.66 in an uninsulated one (Fig. 4b).

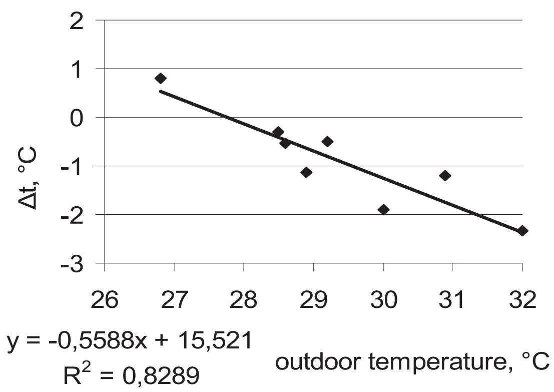


Fig. 2. Indoor-outdoor temperature difference depending on outdoor temperature.

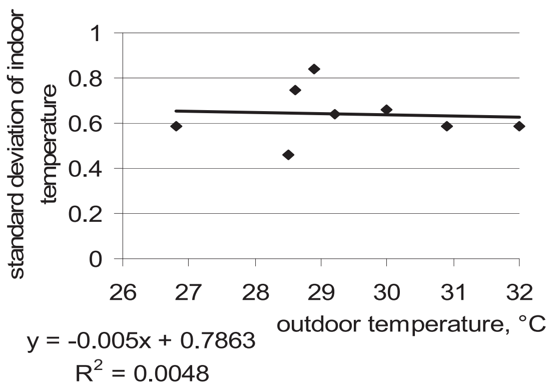
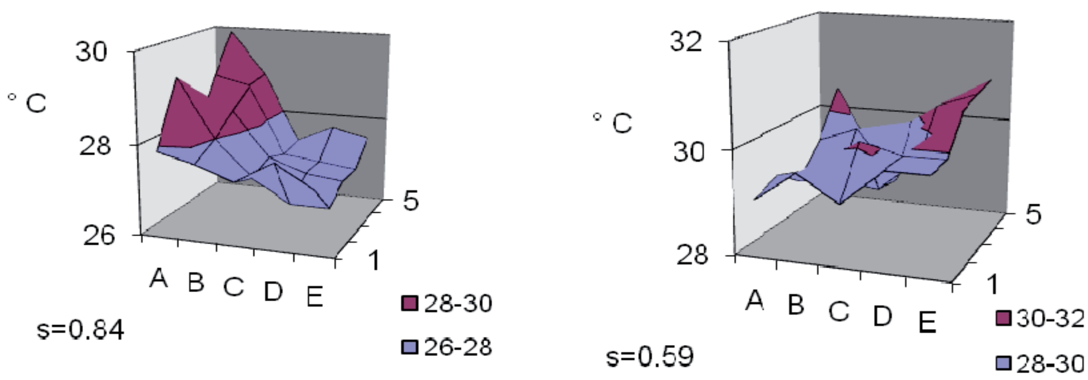


Fig. 3. Dependence of standard deviation of indoor temperature on outdoor air temperature.



a) b)

Fig. 4. Air temperature distribution in the cowsheds: a) insulated; b) metal sheet roof.

The use of spatial temperature distribution is proposed as a measure to assess ventilation efficiency (Pajumägi et al., 2008). Standard deviation of indoor air temperature characterizes ventilation efficiency in the cowshed:

- s<0.8 — ventilation is good — mark 1;
- s = 0.9…1.3 — ventilation is satisfactory (lack of animals in number or ventilation openings are too widely open; effect of chimney does not work) —mark 2;
- s>1.4 — ventilation is unsatisfactory (important ventilation openings are closed) — mark 3.

In all cases the standard deviation of indoor temperature was under 0.9, which indicates good ventilation. In a cowshed with metal sheet roof the air moving scheme was more uniform (Fig. 5), because heated roof activates airflow under the roof and intensifies ventilation.

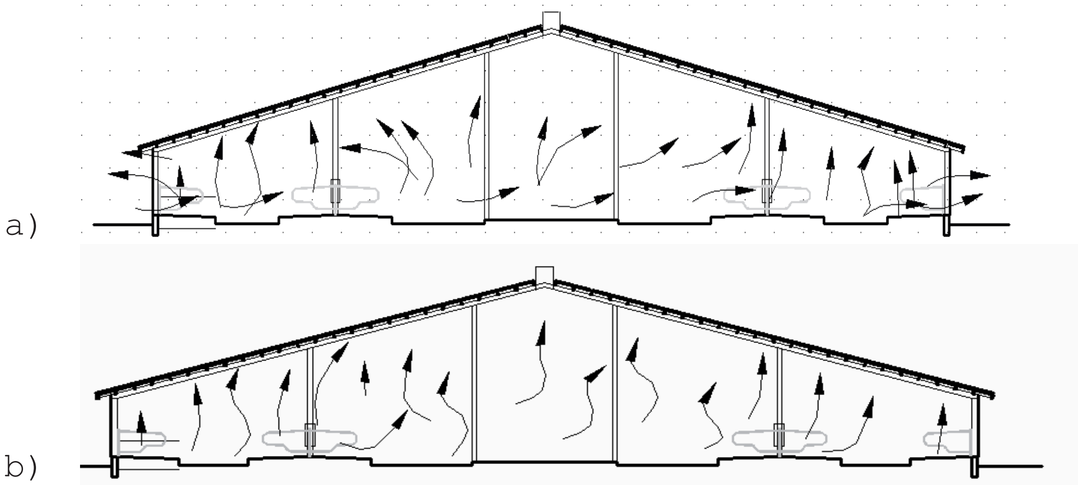


Fig. 5. Air moving schemes: a) insulated roof; b) metal sheet roof.

Roof temperature

Roof (indoor surface) temperature value of 47.1°C was recorded as the highest in case of non-asbestos cement roof at outdoor air temperature of 30°C and average indoor air temperature of 28.1°C. The average roof temperature of cowsheds with non-asbestos cement sheets was 33.9…38.3°C. Difference between average roof surface and indoor air temperature varied 6.3…10.5 in these cowsheds. The average indoor surface temperature of the insulated roof (~28°C) was about the same as outdoor (29°C) and indoor (~28°C) air temperature. Maximum value of 33.5°C was recorded**.** In a cowshed with metal sheet, maximum roof temperature was 44.4°C and difference between average roof surface and indoor air temperatures was about 7°C.

Spatial distribution of roof temperature in cowsheds with insulated and metal sheets is presented in Fig. 6.

There is problem of long wave radiant heat load in cowsheds with high indoor surface temperatures, but that can be regulated by materials or surface paints.

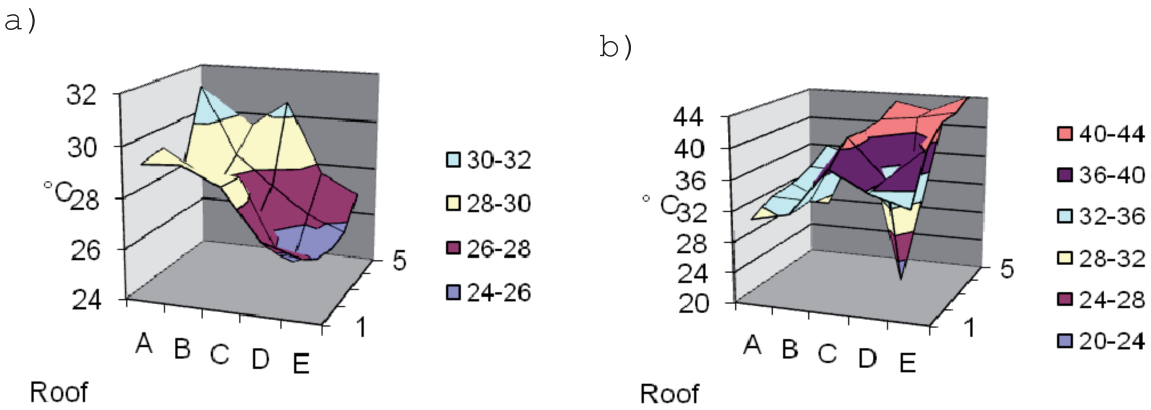


Fig. 6. Roof surface temperatures: a) insulated; b) metal sheet.

One of the possibilities for evaluating the effect of the building as a shade is to measure the cows' surface temperatures. In Fig. 7, cow's hair coat temperatures in a hot summer day are given. The cow is lying by the side wall; the plastic wall curtain is removed. The temperature of dark (52) and bright (40) hair coat exposed to direct sun is 19 and 7°C higher than in the shaded area (33°C).

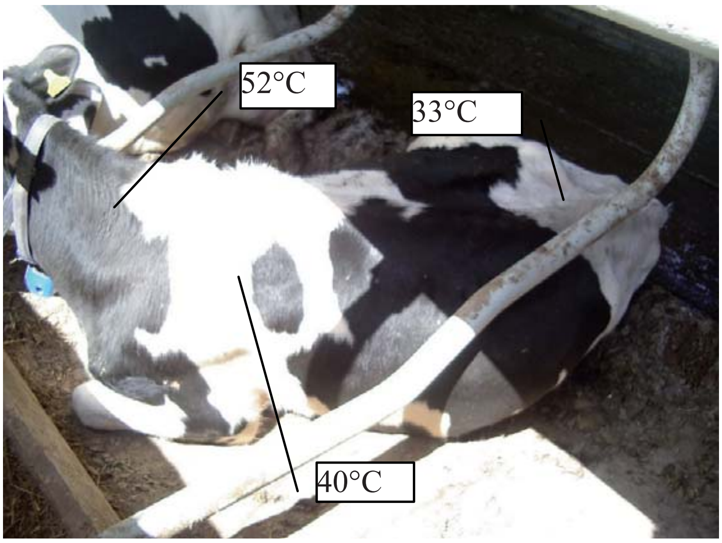


Fig. 7. Cow's hair coat surface temperatures exposed to sun and in the shade.

Relative humidity was recorded 28.7...48.7% outdoors, 30.0...48.7% indoors and 34.9...47.4% as average indoors. Dependence of indoor relative humidity on indoor air temperature is given in Fig. 8.

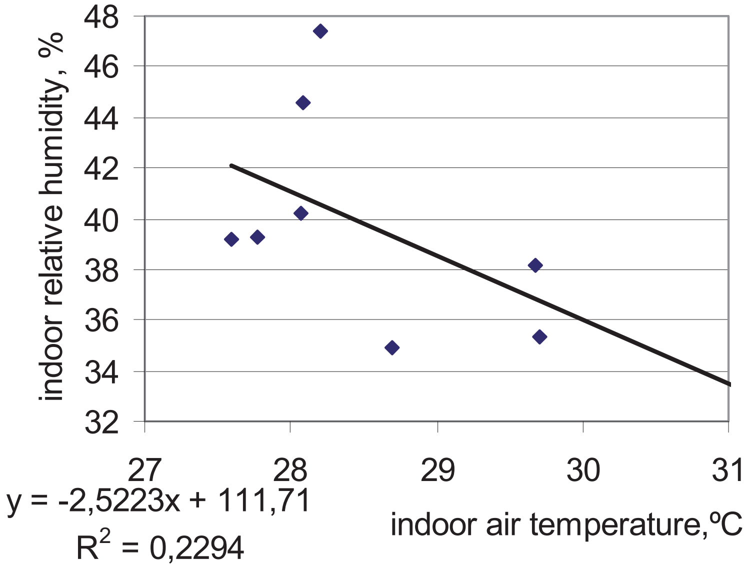


Fig. 8. Dependence of indoor relative humidity on indoor air temperature.

CONCLUSIONS

This study focused on hot summer weather. In spite of high roof temperatures the indoor air temperature was mostly the same or lower than outdoors.

Ventilation was more uniform in a cowshed with higher roof temperatures (metal sheet and non-asbestos cement sheets), but overall ventilation was good in all cowsheds.

Heated roof activates airflow under the roof and intensifies ventilation.

A cowshed (mostly the roof) offers good shade in hot weather in spite of the roof material.

From that point of view uninsulated non-transparent materials like non-asbestos cement and metal sheets are both suitable for roof-covering materials in summer conditions.

Roof insulation will not give better protection in hot weather.

Radiant heat load can be reduced by choosing inner and/or outer surface covering.

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