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Spatial distribution of air temperature as a measure of ventilation efficiency in large uninsulated cowshed

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Abstract

Ventilation in the building is to assure a microclimate suitable for humans and animals as well as the durability of structures. Based on the data from literature theoretical heat and moisture balancing ventilation rate calculations for uninsulated cowshed are presented. At an indoor temperature of −6.7 °C and indoor–outdoor temperature difference of 1 °C, the theoretical ventilation rate of 2300 m^3/h per cow is necessary to remove the water vapour produced by the cows from the building. At a difference of 2 °C the ventilation rate of 1200 m^3/h per cow and at 5 °C 530 m^3/h per cow is needed. But these calculated ventilation rates are probably unrealistic. Traditional methods are unreliable for uninsulated cowsheds and instead of that an alternative method for evaluating the ventilation rate is needed.

A good possibility to evaluate the ventilation is to study air distribution in the room, which is more qualitative than ventilation rate.

From the parameters of air distribution (air temperature, relative humidity and air velocity) air temperature is the most sensible indicator for ventilation.

The use of the spatial temperature distribution is proposed there as a measure to assess the ventilation's efficiency.

Standard deviation of indoor air temperature characterizes ventilation efficiency in the cowshed:

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

Complete closing of ridge vent has a sever impact on the ventilation and must be avoided.

Keywords: Uninsulated; Loose housing; Cowshed; Ventilation; Air distribution; Spatial distribution; Air temperature; Relative humidity; Air velocity

1. Introduction

Uninsulated loose housing cowsheds in Estonia have been in use since 1993. Since 2002, 60 new or renovated cowsheds for 300–600 cows have been completed. Studies of the microclimate in the cowsheds have been carried out since 2002 [1,2]. Results show that microclimate parameters like air temperature and the relative humidity indoors are strongly connected with outdoors, weather conditions and vary accordingly. As outdoor relative humidity of 100% is quite common (annual average in Estonia, however, is 80%) [3] and the difference in air temperatures between indoors and outdoors is a few degrees, low indoor relative humidity requirement cannot be maintained.

The target of ventilation in the building is to assure:

(1) microclimate suitable for humans and animals;
(2) durability of structures.

Cold cowshed (uninsulated and unheated) can be defined as maintaining air temperature a few degrees higher indoors than outdoors [4].

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The microclimate of cattle buildings is a subject of Building Codes in the Soviet Union and the European Union as well. Optimal values of air temperature and the relative humidity, and maximum concentrations of noxious gases (NH_3, CO_2, H_2S and CO) are provided. In the Estonian Building Codes the microclimate and ventilation of livestock housing are not specified.

As cattle is very tolerant to air temperature, thermal requirements are mostly satisfied. Relative humidity has diurnal variance according to outdoor relative humidity. The mean monthly or annual interior relative humidity can significantly affect the durability of building components [5].

Minimum ventilation rates, ranging from 0.15 m^3/h [6] to 0.35 m^3/h [7] per 1 kg body weight of animal, can be found in codes. The maximum ventilation rate can exceed this by a factor of 10. Ventilation rate can be estimated by measuring air velocity in the ventilation openings. Indirect methods are based on the balance of heat or moisture, concentration of carbon dioxide or ammonia. Temperature difference between indoors and outdoors of less than 2 °C or absolute humidity difference of 0.5 g/m^3 makes heat and moisture balance methods unreliable [8]. The rate of ammonia emission increases with ventilation rate [9] and is also not a good basis for ventilation calculation in livestock building. As agriculture and especially cattle are great producers of ammonia [10,11], ammonia emission from the buildings has to be minimized by maintaining the optimal ventilation rate. For an indirect measurement of ventilation rate, CO_2 concentration in the air is the most accurate, but diurnal (24 h) data measured at several places are necessary for this [12]. The ventilation rate has to be known before the rate of gas emission from the cowshed can be determined. Following the theoretical ventilation rate based on heat or the moisture balance is presented. The use of special temperature distribution is proposed there as a measure of ventilation efficiency.

1.1. Thermal resistance of boundaries of uninsulated cowsheds

Theoretical thermal resistance of boundaries of uninsulated cowsheds is provided mostly by the resistance of inner surface. The following theoretical heat and moisture balancing ventilation rate calculation for uninsulated cowshed is presented. The measures of the 300 place loose housing cowshed are 30 × 88 m. The lower part (height 1.25 m) of the side wall is made of reinforced concrete. The roofing is made of corrugated non-asbestos fibre-cement sheets (area 2735 m^2). Ventilation is performed through the eaves, wall-openings and a ridge vent. The wall-openings (height 1.2 m) can be closed by plastic blinds.

The thermal resistance (*R*-value) of the boundaries can be calculated as 0.25 for concrete, 0.17 (plastic) and 0.15 m^2K/W (roof) [13]. As material layers are thin (6 mm) or have high thermal conductivity (concrete), the whole thermal resistance of the boundaries results mostly from inboard film resistance (0.13 walls and 0.10 roof m^2K/W) [13]; 22 600 W/K can be taken as a basic heat loss for whole building. Thermal resistance of the inboard film 0.10 m^2K/W represents 68% of the roof thermal resistance (0.15). At the indoor–outdoor temperature differences of 2 °C and relative humidity over 80%, the probability of inboard surface condensation is high, as the surface temperature is 1.36 °C lower than the indoor air temperature. At the differences of 3 °C, surface temperature is 2.04 °C lower than indoor air temperature. However, a short-term inboard condensation occurs in the morning because of the clear sky radiation of roofing at night.

1.2. Heat production in cowshed

Heat production of cow depends on milk production, body weight, pregnancy, thickness of hair, environmental temperature, etc. The heat generated by a 454 kg cow against cowshed depending on the environmental temperature [14] is presented in Fig. 1. Values for latent heat contain energy demand for wet surfaces.

1.3. Theoretical ventilation rate

Theoretical ventilation rate based on heat and moisture balance is presented in Fig. 2. Fig. 2a shows ventilation rates at indoor–outdoor temperature differences of 1 °C and 2b at 5 °C. Relative humidity is assumed to be 80% as an average in Estonia according to the Estonian climatic atlas [3].

At an indoor temperature of −6.7 °C, 300 cows (body weight 650 kg) produce 403 kW of sensible heat and 130 kg of water vapour per hour. At an indoor temperature of 21.1 °C these values are 213 kW and 261 kg, respectively. At an indoor temperature of −6.7 °C and indoor–outdoor temperature difference of 1 °C (heat loss through boundaries 22.6 kW), theoretical ventilation rate of 2300 m^3/h per cow (Fig. 2a) is necessary to remove the water vapour

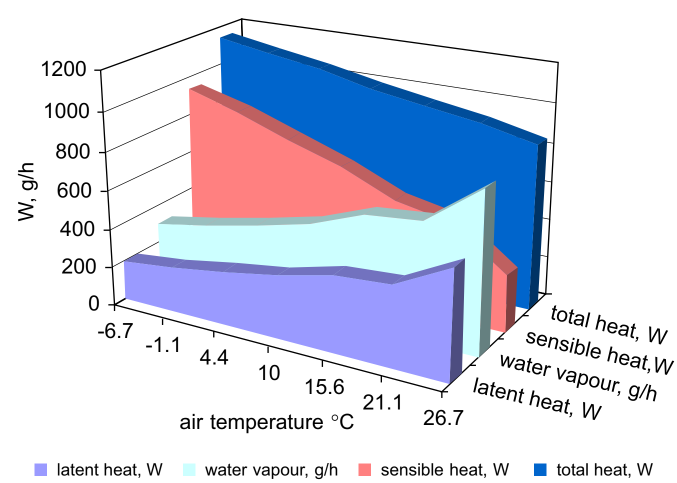

Fig. 1. Heat and moisture produced by a 454 kg (1000 lb) bodyweight cow [14].