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Modelling of heat exchange of milking parlour

S. Toropov, B. Reppo, A. Leola and V. Palge

Institute of Technology, Estonian University of Life Sciences,
Kreutzwaldi 56, 51014 Tartu, Estonia

Abstract. Unheated cowsheds are light constructions and can be referred to as sheds with outdoor climate, because the temperatures in the cowshed and milking parlour are almost identical to the outdoor climate. Control of the complicated temperature conditions in a milking parlour requires an adequate survey of the situation**.** The aim of the present study was to prepare a heat exchange model for a milking parlour and testing its workability by experimentally studying the indoor air temperature of the original object. The dynamic model of the heat balance of a milking parlour of an uninsulated cowshed is presented. Powersim Studio 7 environment was used for modelling the heat situation in a side-by-side milking parlour for 40 cows. Input and reference data of the model consist of the data on indoor climate measured at the original object, the farm for 600 cows, in winter. To get the necessary initial data for compiling the model, the indoor and outdoor temperatures of the milking parlour were measured, their daily values varying 8.75…17.81°C and 1.1…6.2°C, respectively. The composite model describes the actual situation with sufficient adequacy. So, with cows in the milking parlour, the measured indoor temperatures were practically of the same value with those obtained by modelling, the values differed only by 3…4 deg that can be considered acceptable and applicable when evaluating the heat conditions of a milking parlour. The created dynamic heat exchange model for a milking parlour of an unheated cowshed is applicable for making practical decisions and can be used for design and control of the heat situation at the milking parlour.

Key words: uninsulated cowshed, work environment, indoor climate

INTRODUCTION

A cattle farm represents a biotechnical system: man-animal-machine-environment. This system constitutes the work environment for producing milk. The milking station represents the heart of the work environment in the cowshed and it usually consists of a milking parlour with necessary waiting areas, machine rooms, rest rooms and ancillary rooms.

The majority of new cowsheds built today are light structures with uninsulated walls and, in most cases, an uninsulated roof as well. They could be called cowsheds with an outdoor climate, because the climatic situation is more or less the same both inside and outside the premises for keeping animals. A conflict of interests arises where the work environment requirements for effective production are met, because the elements of the system – man, animal, machine, premises – set different requirements for the indoor climate. This conflict becomes more acute at the milking station, where the very intimate biotechnical act of milk production takes place.

Milking is a tending work with the highest level of responsibility with regard to man, animal and technology.

Ancillary and rest rooms located in the milking station are usually insulated and can be heated. The problem arises with the milking parlour and waiting areas that are linked with cowsheds which are subject to outdoor climate. Heat processes at milking parlour are dynamic, because they are affected by mobile sources of heat – cows. Milking parlours are often equipped with heat sources, but constant heating is neither necessary nor purposeful. According to common opinion the recommended air temperature during milking is ca 18°C and should not be lower than 10°C, especially from the human and technical perspective. The temperature could be lower during the period when attendants are not present at the milking parlour, but it still has to be above zero in order to prevent liquids from freezing. Changes in heat flow affect the energy accumulated in and reflecting from the walls of the premises.

The indoor climate of uninsulated cowsheds has been of great interest for the researchers both in terms of the welfare of animals (Bleizugs et al., 2005; Ilsters & Ziemelis, 2005; Kavolelis et al., 2006) and the environment for workers (Reppo et al.; 2004; Mikson et. al, 2006; Tomson et al., 2006). Production areas have also been considered important (Pajumägi & Miljan, 2005).

Adequate awareness of this complicated heat situation is necessary in order to control it. The dynamic model of the heat situation provides efficient assistance for similar situations. System modelling and simulation of thermal energy processes represent necessary facilities for the study of heat energy (Palge, 1999; Kokin, 2003; Bleizugs et al., 2006; Kavolelis, 2006). Outdoor climate, which is the major factor affecting the indoor climate of the premises, depends on the location of the object, i.e. the climatic zone where the object is situated (Peets, 2003; Kavolelis et al., 2006).

For the purposes of studying the potential of preparing the model and the purposefulness of its use in modernised cowsheds in Estonia, this study set an objective to prepare a heat exchange model for a milking parlour and to test its performance on the basis of experimental study of the indoor climate of the original object.

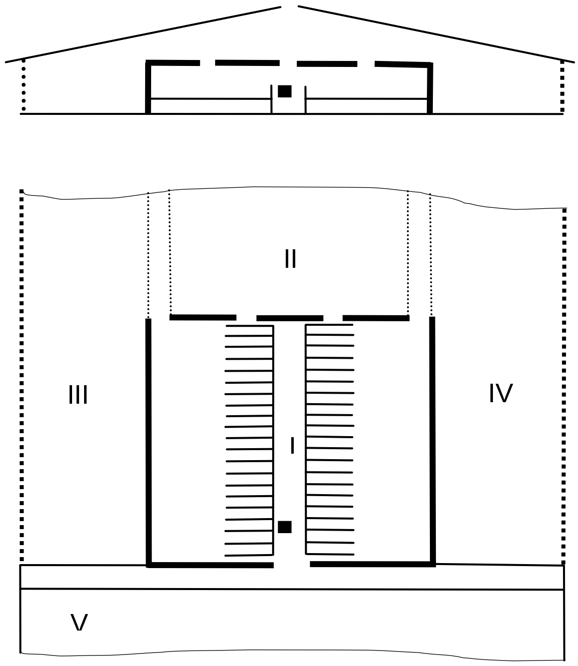
MATERIALS AND METHODS

The object of the study is the milking station in the Tõnumetsa cowshed for 600 cows, belonging to agricultural cooperative Torma PÜ. The cowshed, milking parlour and waiting area have natural ventilation. Ancillary and rest rooms in the milking station (Fig. 1) are insulated; the cowshed, waiting areas and milking parlour are uninsulated. Cows are milked at the side-by-side milking parlour with the milking device Strangko 2x20. The area of the preliminary waiting area is 233 m^2. Cows are divided into 5 milking groups according to production and they stay in the waiting area one group at a time. Milking takes place three times a day; one milking period lasts on average 5 hours. Two milkers work simultaneously.

The study of indoor climate was based on Finnish standards and the Health Protection Act of the Republic of Estonia (Tööruumide mikrokliima ..., 1995). The indoor air temperature and relative humidity were measured in the milking parlour of the farm. Measurements were taken during 24 hours in winter. Outdoor temperature and relative humidity were also measured daily.

Fig. 1. Layout of the milking station: I - milking parlour; II – waiting area; III, IV – selection area; V – ancillary and rest rooms;

■ – point where indoor climate parameters were measured.



The measurement results of air temperature, which was considered the main factor affecting the work environment, were used in preparation and testing of the model presented in this study. Measuring equipment: ALMEMO Data Logger 8990-8 equipment with computer programme AMR WinControl; AMR FH 646-1 temperature sensor with measurement area -20-(+80°C) and measurement accuracy 0.01 °C. Temperature was measured at the height of 1.5 m above the floor of the milking channel at the point indicated in Figure 1 and outdoors at the height of 1.5 m and at the distance of 3 m from the wall of the milking station. HygroLog device manufactured by Rotronic and HygroClip S sensor were used for measuring outdoor temperature and relative humidity (measurement area -40…+85°C and 0…100%, accuracy ±0.3°C and ±1.5%, respectively). The measuring interval was 60 s. Measurement results were processed by using programmes AMR WinControl and MS Excel.

A mathematical heat exchange model was prepared for the milking parlour, and included some simplifications. The balance takes into account the heat losses resulting from heat exchange, the power necessary for evaporation of humidity and also free heat released from animals and the heat flow storage in the air from lighting fittings. Fig. 2 shows the electrical equivalent circuit of heat exchange.

Heat balance formulas were created on the basis of electrical equivalent circuits.

Heat balance of the milking parlour (Liiske et. al, 1998; Liiske, 2002)

$$C_{air}\frac{d\vartheta_s}{d\tau} = P_{air} = P_a + P_{light} - P_{ev} - P_{ex} - P_b\,, \qquad (1)$$

where C_{air}– thermal capacity of the air at milking parlour, $J{\cdot}K^{-1}$;

ϑ_s – air temperature at the milking parlour, ºC;

P_{air} – heat flow stored in the air at the milking parlour, W;

P_a – heat flow released by animals (free heat release from animals), W;

P_{light} – heat release from lighting fittings, W;

P_{ev} – heat flow required for evaporation of water, W;

P_{ex} – heat flows arising from heat exchange, W;

P_b – heat flows through barriers, W.

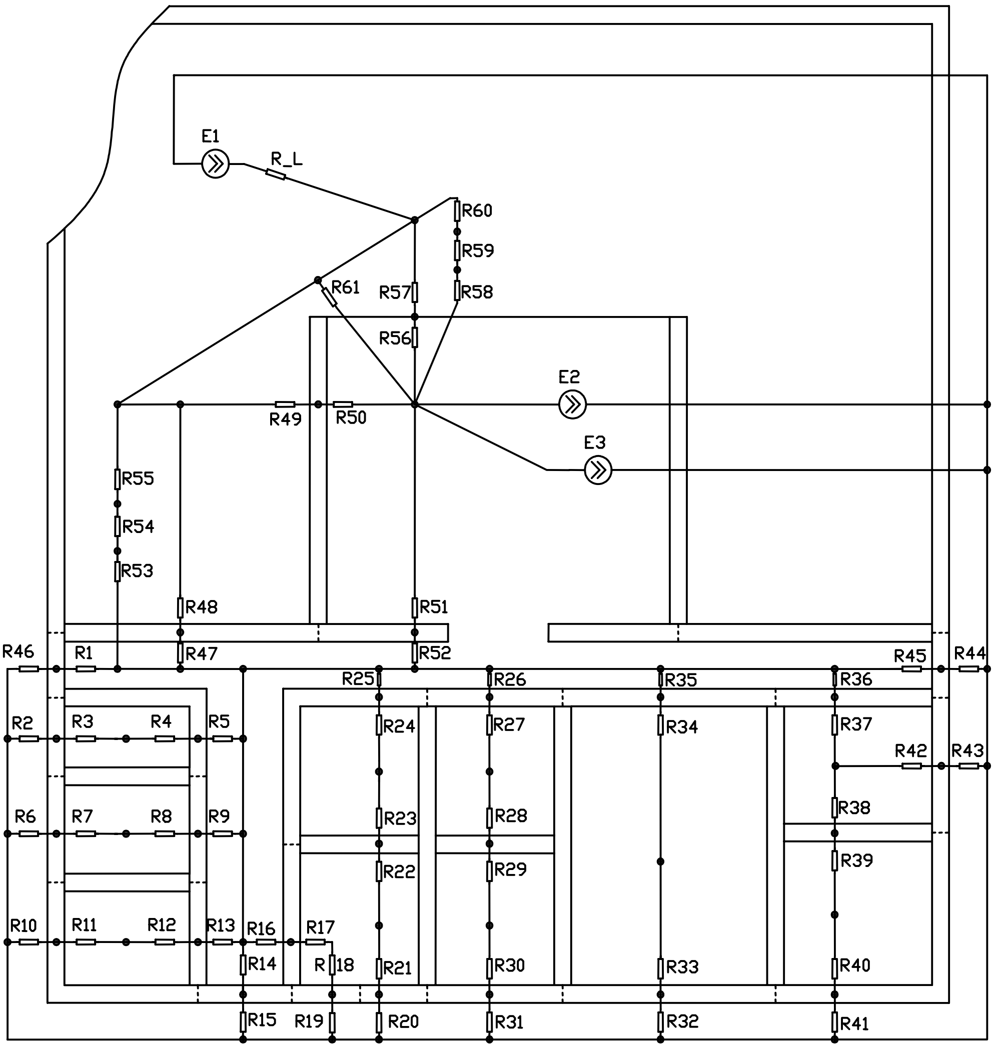


Fig. 2. Electrical equivalent circuit of heat exchange at milking parlour. R – thermal resistance of: R1-R46 – walls of premises; R47, R48 – walls of attic and passageway; R49, R50 – partition walls of milking parlour and attic; R51, R52 – barriers between milking parlour and passageway; R53, R54, R55 – passageway ceiling; R56, R57 – blinds; R58, R59, R60 – milking parlour ceiling; R61 – ventilation; R_L – cowshed and milking station. E – heat flow: E1 – from cowshed (from animals in the cowshed); E2 – from animals at milking parlour; E3 – from lighting fittings.

Free heat released from animals was calculated on the basis of total heat release

$$P_l = z \cdot q_k \cdot (0.8 - 1.85 \cdot 10^{-7} \cdot (\vartheta_s + 10)^4), \quad (2)$$

where z – number of animals in the premises (at milking parlour);

q_k – total heat released from one animal, W.

Heat flow required for evaporation of water was calculated by formula

$$P_a = r \cdot g \cdot (1 - 0.01 \cdot \varphi_s) \cdot 3.9 \cdot 10^{-3} \cdot e^{\frac{\vartheta_s}{15.2}} \cdot F_a, \quad (3)$$

where r – water evaporation heat, $J \cdot kg^{-1}$;

$r = 2.5 \cdot 10^6$ $J \cdot kg^{-1}$;

g – mass flow rate in case of air velocity 0.2 $m \cdot s^{-1}$, $kg \cdot (s \cdot m^2)^{-1}$;

$g = 0.85 \cdot 10^{-2}$ $kg \cdot (s \cdot m^2)^{-1}$;

φ_s – relative humidity of the air, %;

F_a – water evaporation surface, m^2.

The determination of actual ventilation is complicated and the study uses the standard value of 250 $m^3 \cdot h^{-1}$ (0.08 $kg \cdot s^{-1}$) per 600 kg milking cow. Considering that the cows do not leave the milking parlour simultaneously, the average number of animals at the milking parlour is 52. The heat transmission factor is 8 $W \cdot (m^2 \cdot K^{-1})$ on the internal surface of the barrier and 20 $W \cdot (m^2 \cdot K)^{-1}$ on the outer surface of the barrier. The constant value of relative humidity of the air is 70%.

The remaining parameters required for operating the model (wall area, thermal resistance, volumes, heat capacity, etc.) have been calculated on the basis of Fig. 2 using the Scilab programme (http://www.scilab.org) and a heat exchange process modelled by a graphical dynamical system simulator toolbox Scicos (http://www.scicos.org) of the Scilab programme. The heat balance formulas presented above made it possible to prepare the heat exchange model for the milking station in Powersim Studio 7 (http://www.powersim.com) environment using 50 blocks. This was a simplified model as the air exchange and humidity were taken constant; the influence of cowshed was approximate. When drawing up the model the changes in outdoor climate were chosen statistically and approximated by sinus curve. The adequacy of the model as compared to the original object depends on the quality of the input data.

RESULTS AND DISCUSSION

Modelling of animal-keeping premises has been carried out (Liiske, 1998) regarding the number of animals and their heat exchange, emission of harmful gases, calculated outdoor and indoor temperatures and humidity. The heat balance of the milking parlour has also been modelled (Kavolelis, 2006) on the basis of heat flow accumulated in and released from the walls of buildings and equipment, heat release from cows and heat losses with ventilation through outer walls.

A heat exchange model of a milking parlour, which takes into account both the heat capacity of construction of the milking parlour with adjacent rooms and the influence of heat resistances on heat exchange was compiled in the present work. The changes/variations of the milk parlour's indoor and outdoor climate, relative humidity and heat release of cows in the waiting area were also considered.

The model enables study of all heat flows incoming and leaving the milking parlour, storage or reduction of heat in various barriers (objects, blocks), and observation of heat flow from one room to another – monitoring of the processes that are of interest for the researcher.

The performance of the model has been tested on the basis of the air temperature at the milking parlour, because these results are comparable with the study results of indoor climate. The necessary initial data for creating the model were gathered by measuring both the indoor and outdoor temperatures of the milking parlour, which had daily limits of 8.75…17.81 °C and 1.1…6.2°C, respectively (Toropov, 2007).

Figure 3 shows that the changes in indoor air temperature calculated by the model (2) are sufficiently similar to the changes in indoor air temperature collected by means of measurement (1). So, with cows in the milking parlour, the measured indoor temperatures were practically identical to those obtained by modelling: the values differed only by 3…4 deg that can be considered acceptable and applicable when evaluating the heat conditions of a milking parlour. The change in air temperature generally depends on the entry, length of stay and exiting of cows and on the outdoor temperature. A slow decline in indoor air temperature is caused by the residual heat of the milking parlour. The variations in temperatures up to 7 deg (Fig. 3, curves 1 and 2) between milking times are due to ideal entering-exiting schedule of cows in the model. The model also uses mean energy parameters of cows. The section of the model describing the cows' entry-exit schedule and their energy properties needs improving.

This study is focused on operation of the model of a particular original object. In order to study other analogous objects (uninsulated cowsheds, analogous planning of milking station), one has to input necessary data (construction parameters, number of animals, etc.) into the model based on the study results of the original object.

CONCLUSIONS

The study of production processes carried out on an animal farm is essentially an observation, because tests performed in production units are very expensive and complicated. Multiple observations are necessary in order to achieve convincing results. Therefore it requires many resources and is performed over a long period of time. Modelling of the links in the technology for animal-keeping allows achieving a reasonable image of long-term processes within a short period of time and under rather different circumstances.

To get the necessary initial data for compiling the heat exchange model of the milking parlour, the indoor and outdoor temperatures of the milking station were measured, their daily values varying 8.75…17.81°C and 1.1…6.2°C, respectively.

The measured indoor temperatures (with cows in the milking parlour) were practically adequate with the data obtained by modelling, the values differing only by 3…4 deg; that is considered acceptable and applicable when evaluating the heat conditions of a milking parlour.

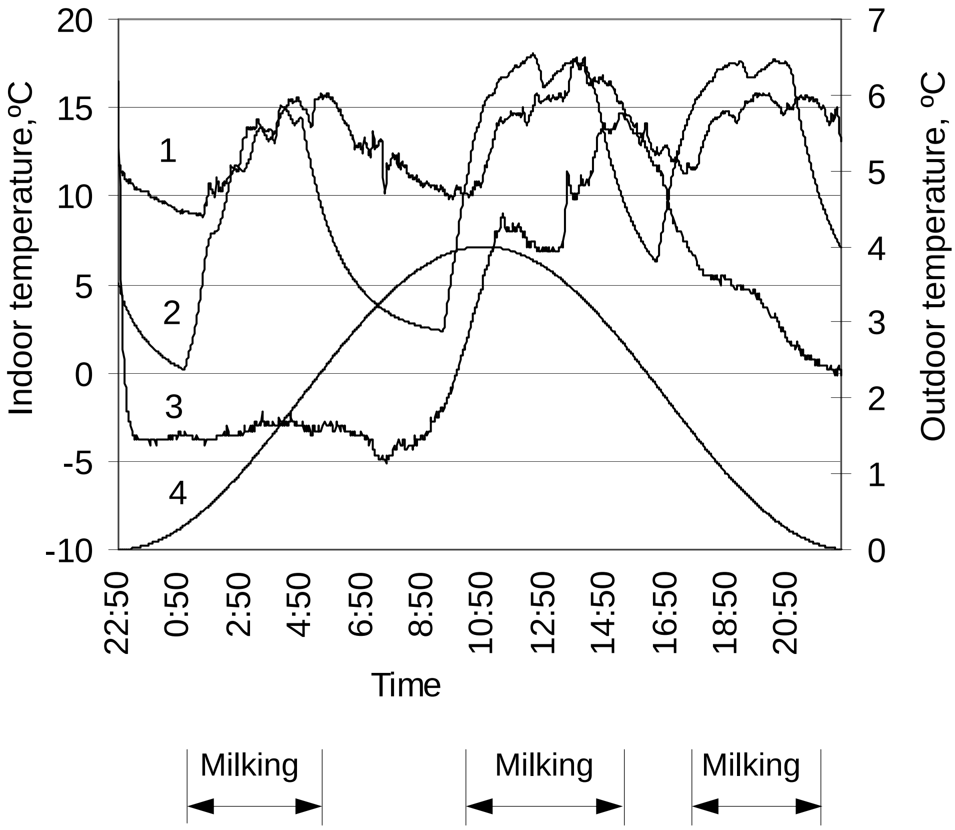


Fig. 3. Daily change in air temperature in winter: 1 – measured indoor temperature, 2 – temperature calculated on the basis of the model, 3 – measured outdoor temperature, 4 – outdoor temperature used in the model.

The described model can be used for improvement (insulation, heating during cold periods, ventilation adjustment, etc.) of farm (milking parlour environment). Upon altering input data (outdoor temperature, period during which cows stay at milking parlour, thickness of walls, etc.) this model enables the examination of all heat flows entering and leaving the milking parlour, storage or reduction of heat in various walls (distinguished objects, blocks), and observation of heat flows from one room to another – in a word, the observation of processes that are of interest for the researcher.

This study is focused on operation of the model in the case of a particular original object. In order to study other analogous objects (uninsulated cowsheds, analogous planning of milking station), one has to input necessary data (construction parameters, number of animals, etc.) in the model based on the study results of original object. The adequacy of the model depends on the quality of input data.

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