Agronomy Research **13**(1), 245–252, 2015

Heating and ventilation in milking parlours

J. Papez* and P. Kic

Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, 16521 Prague 6, Czech Republic; *Correspondence: papez@tf.czu.cz

Abstract. The aim of this paper is to show the results of the measurement of main microclimatic parameters (temperature and relative humidity) in milking parlours and compare the obtained results with values recommended in relevant standards. Temperature and relative humidity can affect animal welfare as well as the well-being of workers. These parameters were measured in three rotary milking parlours with herringbone type of stalls, each for 24 dairy cows. Two of these milking parlours were built in 2001 and one was built in 2009. Measurements were taken during the winter and summer periods, under extremely cold or high temperature conditions. Measurements were taken during the milking process for about two hours using suitable sensors for measurement of indoor temperature and relative humidity. The data of outside temperature and relative humidity were also obtained and compared with indoor data. The final results of the research were generalized. It is obvious from the results of measurements of selected milking parlours that heating and ventilation of milking parlours is insufficient. To set up adequate heating power, the heat balance of milking parlours was calculated. For adequate ventilation, the necessary flow of fresh air was calculated for both winter and summer periods. Also the methods of how to achieve these air flows are presented.

Key words: measurement, relative humidity, temperature, THI.

INTRODUCTION

The aim of this article is to show the results of measurement of main microclimatic parameters (temperature and relative humidity) in milking parlours and to compare the obtained results with the values recommended in relevant standards.

Environmental conditions are determined by characteristic factors, especially by physical factors, chemical factors and biological factors. Thermal condition of the indoor environment is characterized by thermal and humidity variables which affect the resulting mental and physical state of an animal or person in agricultural buildings. The result of the analysis of thermal environment is the formation of optimal conditions for human and animal organisms. Required optimal temperature in milking parlour in the winter period is 14–16 °C (minimum 10 °C). In the summer period, the required optimal temperature should be in the range of 14–22 °C (maximum 26 °C). (Novy et al., 2006; Choupek & Suchy, 2008; Koznarova & Klabzuba, 2008; Zejdova et al., 2014)

Thermal condition of the indoor environment is also influenced by relative humidity. High water vapour content in the air reduces the possibility of cooling the body of a man or an animal by evaporation. It can cause heat stress already at a relatively low temperature of indoor environment. Relative humidity should by ideally in the range of 40–80%. The maximum allowable value of relative humidity according to Czech standard CSN 73 0543–2 is 85%. Wet air is a good conductor of heat. Long-term exposure of relative humidity above 85% adversely affects the organism and apparatus and could damage wooden elements of the buildings. (Kic & Broz, 1995; Kunc et al., 2007; Pavelek & Stetina, 2007; Papez & Kic, 2013; Zejdova et al., 2014)

The effect of combinations of temperature and humidity is included in the temperature–humidity index (THI). This index is widely used to describe the heat stress and it is also a good indicator of stress temperature environment conditions. THI value below 70 is considered comfortable for cattle. THI in the range of 70–78 is considered stressful and values higher than 78 cause extreme suffering (the organism is unable to maintain the thermoregulatory mechanisms, or normal body temperature). (Armstrong, 1994; Zejdova et al., 2014)

MATERIALS AND METHODS

The basic assumption of this research is to perform measurements of main microclimatic parameters (temperature and relative humidity) in milking parlours and to compare obtained results with values recommended in relevant standards. The aim of this paper is also to find and define the methods for the improvement of indoor conditions in milking parlours in case of exceeding (or not reaching) allowable limits (setting up adequate heating power and necessary flow of fresh air).

To avoid big differences between the milking parlours from the point of view of other microclimatic parameters, the thermal comfort in the space was continuously measured by globe temperature (measured by globe thermometer FPA 805 GTS with operative range from –50 to +200 °C with accuracy ± 0.01 K and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FH A646–21 including temperature sensor NTC type N with operative range from –30 to +100 °C with accuracy ± 0.01 K, and air humidity by capacitive sensor with operative range from 5 to 98% with accuracy ± 0.1%. All data were measured continuously and stored at intervals of three minutes to measuring instrument ALMEMO 2590–9 during the measurement (approximately 120 minutes).

Three milking parlours were measured during the winter and summer periods, under extremely cold or high temperature conditions. The measurement during the milking process lasted for about two hours. The data of outside temperature and relative humidity were also obtained and compared with indoor data. The results of measurements were processed by Excel software and verified by statistical software Statistica 12 (*t–test, ANOVA* and *TUKEY HSD Test*)

All three measured milking parlours are rotary with herringbone type of stalls, each for 24 dairy cows. Two of these milking parlours were built in 2001 and one was built in 2009. The differences are in heating and ventilation system.

Milking parlour A

There is only natural ventilation in this milking parlour through the windows with a total area of about 14 m^2 and two skylights, each of size 2 x 2 m. This milking parlour is heated through four radiant heating panels with a total output of 9.6 kW.

Milking parlour B

Forced (over pressure) ventilation with a flow rate 3,240 $m^3\ h^{-1}$ is installed in this milking parlour. This system is equipped with an inlet air heater with power of 24 kW.

Milking parlour C

There is only natural ventilation in this milking parlour through the windows with an area of 6.48 m^2 and four ventilation chimneys; each of size 0.3 x 0.3 m. This milking parlour is heated through two radiant heating panels with a total output of 8 kW.

Theory and modelling

Thermal condition of the indoor environment can be controlled by operational temperature and relative humidity. The operational temperature is defined as a uniform temperature of enclosed space, black in terms of radiation, in which the heat shared by convection and radiation would be the same as in the real thermally unbalanced environment (Kabele & Veverkova, 2003). According to Novy (Novy et al., 2006) the operational temperature is determined by the following equation:

$$t_o = A \cdot t_i + (1 - A) \cdot \left[\sqrt[4]{(t_g + 273)^4 + 1.855 \cdot 10^7 \cdot 1.4 \cdot \left(\frac{|t_i - t_g|}{D} \right)^{0,25} \cdot (t_g - t_i)} - 273 \right], \qquad (1)$$

where: t_o – operational temperature (°C); A – coefficient of velocity (for air velocity up to 0.2 m s^{-1}, A = 0.5); t_i – internal temperature of air (°C); t_g – temperature measured by globe thermometer (°C); D – diameter of globe thermometer (m).

Relative humidity is obtained directly by measuring. Effect of combinations of temperature and relative humidity is included in the THI. This index is widely used to describe the heat stress and it is also a good indicator of stress temperature environment conditions. According to Zejdova (Zejdova et al., 2014), the THI is determined by the following equation:

$$THI = 0.8 \cdot t_i + \frac{(t_i - 14.4) \cdot RH_i}{100} + 46.4\,, \qquad (2)$$

where: THI – temperature-humidity index (–); t_i – internal temperature of air (°C); RH_i – internal relative humidity of air (%).

The average values, including standard deviation, were calculated from the results of measurements for each of the microclimatic parameters (operational temperature and relative humidity) and THI.

RESULTS AND DISCUSSION

The main objective of this article is to show the results of the measurement of main microclimatic parameters (temperature and relative humidity) in milking parlours and to compare obtained results with values recommended in relevant standards.

Summer period

The results of the measurement of main microclimatic parameters and THI in the summer period are shown in Table 1.

Table 1. Average values and standard deviation of operational temperature (t_o), relative humidity (RH_i) and THI in milking parlours A–C in the summer period, including external temperature (t_e) and relative humidity (RH_e)

Parlour	t_o (°C)	RH_i (%)	THI (–)	t_e (°C)	RH_e (%)
A	**28.81 ± 0.37**	55.3 ± 3.2	**76.40 ± 0.73** ^{a}	28.86	52.7
B	**28.88 ± 1.27**	57.9 ± 3.0	**76.81 ± 1.05** ^{a}	29.57	54.8
C	20.20 ± 0.60	51.1 ± 4.5	65.05 ± 0.88 ^{b}	18.53	41.4

*The results that exceed allowable limits are highlighted in bold.
**Different letters (a, b) in the superscript refer to statistically significant difference at level $P = 0.05$ (*ANOVA* and *TUKEY HSD Test*).

The operational temperature in milking parlour A is corresponding with external temperature (*t–test*, $P = 0.83$) as well as the operational temperature in milking parlour B (*t–test*, $P = 0.19$). The maximum allowable temperature (26 °C) was exceeded in both of these milking parlours. The operational temperature in the milking parlour C is in the optimum range (14–22 °C) thanks to low external climatic condition during the measured period. According to the statistical evaluation (*t–test*, $P < 0.05$) the indoor operational temperature in milking parlour C does not correspond with external temperature. Internal relative humidity was higher than external relative humidity in all three milking parlours (*t–test*, $P < 0.05$), however, still below allowable maximum of 85%. THI values indicate stress condition for dairy cows (because of high external temperature) in milking parlours A and B and they could be considered as equal (*TUKEY HSD Test*, $P = 0.25$).

Improving of the internal conditions could be ensured by the installation of overpressure forced ventilation, which increases air velocity (Kic & Gurdil, 1999). According to Czech standard CSN 73 0543–2, the required mass flow rate of fresh air for heat removal in the summer period for cows is determined by the following equation:

$$\dot{M}_{v,max} = 0.95 \cdot y \cdot z \cdot Z \cdot m_z^{0,74} \cdot 10^{-3}, \tag{3}$$

where: $\dot{M}_{v,max}$ – required mass flow rate of fresh air (kg s^{-1}); y – coefficient, weight of the construction; z – coefficient, area of translucent structures; Z – average number of cows in milking parlour; m_z – average weight of one cow (kg).

According to equation (3) it is necessary to ensure mass flow of fresh air for milking parlours for 24 dairy cows in range of 3.43–3.91 kg s^{-1} (corresponding volume flow 10,284–11,732 m^3 h^{-1}), depending on 'y' and 'z'.

Winter period

The results of measurement of main microclimatic parameters and THI in winter period are shown in Table 2.

Table 2. Average values and standard deviation of operational temperature (t_o), relative humidity (RH_i) and THI in milking parlours A–C in the winter period, including external temperature (t_e) and relative humidity (RH_e)

Parlour	t_o (°C)	RH_i (%)	THI (–)	t_e (°C)	RH_e (%)
A	**12.07 ± 1.60**^{a}	68.9 ± 3.2 ^{a}	51.58 ± 1.71^{a}	–1.07	79.46
B	**11.82 ± 0.86** ^{a}	**94.0 ± 1.2** ^{b}	52.26 ± 1.03^{a,b}	–2.38	87.46
C	**12.26 ± 1.03** ^{a}	**89.2 ± 2.8** ^{c}	53.19 ± 1.65^{b}	–1.33	94.00

*The results that exceed (or do not reach) allowable limits are highlighted in bold.
**Different letters (a, b, c) in the superscript refer to statistically significant difference at level P = 0.05 (*ANOVA* and *TUKEY HSD Test*)

The operational temperature is below the optimum range of 14–16 °C in all three milking parlours (*t–test*, $P < 0.05$). It is also possible to consider the operational temperature in all three milking parlours as equal (*ANOVA*, $P = 0.31$). Internal relative humidity exceeds allowable limit of 85% in milking parlours B and C (*t–test*, $P < 0.05$). In milking parlour A, the relative humidity is below allowable limit of 85% (*t–test*, $P > 0.05$). THI values do not indicate stress condition for dairy cows in the winter period.

Higher relative humidity in the milking parlour is probably caused by inadequate ventilation in the milking parlour. The Czech standard CSN 73 0543–2 calculates the required mass flow rate of fresh air in the winter period separately for exhaust of water vapour and separately for exhaust of CO_2.

According to Czech standard CSN 73 0543–2, the mass flow rate of fresh air for exhaust of water vapour is determined by the following equation:

$$\dot{M}_{vd} = \frac{Z \cdot (\dot{m}_{do} + \Delta\dot{m}_{do}) \cdot 10^{-3}}{\Delta x_{ie}}, \tag{4}$$

where: $\dot{M}_{vd}$ – mass flow rate of fresh air for exhaust of water vapour (kg s^{-1}); $\dot{m}_{do}$ – total production of water vapour (mg s^{-1} pcs^{-1}) $\Delta\dot{m}_{do}$ – increased evaporation for underfloor heating (mg s^{-1} pcs^{-1}); Δx_{ie} – difference of specific humidity of internal and external air ($\text{g kg}^{-1}_{\text{d.a.}}$)

According to Czech standard CSN 73 0543–2, the mass flow rate of fresh air for exhaust of CO_2 is determined by the following equation:

$$\dot{M}_{vu} = \frac{Z \cdot \dot{m}_u}{K_{ui} - K_{ue}} \cdot \rho_i, \tag{5}$$

where: $\dot{M}_{vu}$ – mass flow rate of fresh air for exhaust of CO_2 (kg s^{-1}); $\dot{m}_u$ – CO_2 production of 1 dairy cow (mg s^{-1}); K_{ui}—design value of the concentration of CO_2 in the internal air (mg m^{-3}); K_{ue} – design value of the concentration of CO_2 in the external air (mg m^{-3}); ρ_i – internal air density (kg m^{-3}).

The required mass flow rate of fresh air in the winter period is determined by the following equation:

$$\dot{M}_v = \max(\dot{M}_{vd}; \dot{M}_{vu}), \tag{6}$$

According to equations (4) to (6), it is necessary to ensure in milking parlour A the mass flow rate 0.79 kg s^{-1} (volume flow rate 2,375 m^3 h^{-1}), in milking parlour B 0.81 kg s^{-1} (volume flow rate 2,439 m^3 h^{-1}) and in milking parlour C 0.89 kg s^{-1} (volume flow rate 2,696 m^3 h^{-1}). It is possible to achieve these mass flows by natural ventilation. According to various authors (Chysky et al., 1993; Novy et al., 2006) the calculation of required buoyancy for natural ventilation is determined by the following equation:

$$\Delta p = \Delta p_i + \Delta p_o = g \cdot (\rho_e - \rho_i) \cdot h, \tag{7}$$

where: Δp – total pressure difference (effective buoyancy) (Pa); Δp_i – the pressure required to overcome the resistance in inlet openings (Pa); Δp_o – the pressure required to overcome the resistance in outlet openings (Pa); g – gravitational constant (m s^{-2}); ρ_e – external air density (kg m^{-3}); ρ_i – internal air density (kg m^{-3}); h – height difference of axes of inlet and outlet openings (m)

In practice, the effective buoyancy is divided to the pressures required to overcome the resistance in inlet and outlet openings in the ratio 1:1. The required areas of inlet and outlet openings are determined by the following equations (Chysky et al., 1993; Novy et al., 2006):

$$S_i = \frac{\dot{M}_v}{\mu_i \cdot \sqrt{2 \cdot \rho_e \cdot \Delta p_i}}, \tag{8}$$

$$S_o = \frac{\dot{M}_v}{\mu_o \cdot \sqrt{2 \cdot \rho_i \cdot \Delta p_o}}, \tag{9}$$

where: S_i – required area of inlet openings (m^2); S_o – required area of outlet openings (m^2); μ_i a μ_o – coefficients of flows in inlet and outlet openings.

An overview of required and installed inlet and outlet openings according to the equations (7) to (9) is shown in Table 3.

Table 3. Overview of required and installed inlet and outlet openings for natural ventilation in milking parlours A–C in the winter period

Parlour	Required S_i (m^2)	Required S_o (m^2)	Installed S_i (m^2)	Installed S_o (m^2)
A	1.39	0.97	14.00	8.00
B	**0.84**	**2.23**	0.00	0.00
C	2.41	**1.16**	6.48	0.36

* Inadequate areas of inlet and outlet openings are highlighted in bold.

Adequate inlet and outlet openings are installed only in milking parlour A, so there is no problem with relative humidity. Other milking parlours have inadequate inlet and/or outlet openings and in these milking parlours the measured relative humidity was higher than allowed. To fix the problem with relative humidity in these milking parlours, it is necessary to make adequate inlet and outlet openings (or using forced ventilation installed in parlour B).

The lower temperature than the optimum during the measurement indicates inadequate heating in milking parlours. To set up adequate heating power, it is necessary to count the heat balance of a milking parlour (Kic et al., 2007; Zajicek & Kic, 2014). According to Czech standard CSN 73 0543–2, the heat balance is determined by following equation:

$$\dot{Q}_c + \dot{Q}_t - \dot{Q}_v - \dot{Q}_p = 0 \tag{10}$$

where: $\dot{Q}_c$ – apparent production of sensible heat (W); $\dot{Q}_t$ – adequate heating power (W); $\dot{Q}_v$ – ventilation heat loss (W); $\dot{Q}_p$ – building's heat loss (W).

Adequate heating power calculated according the equation (10) together with installed heating power is shown in Table 4.

Table 4. Adequate and installed heating power and adequate heating power using heat recovery system with 50% efficiency in milking parlours A–C in the winter period

Parlour	Adequate $\dot{Q}_t$ (W)	Installed $\dot{Q}_t$ (W)	Adequate $\dot{Q}_t$ using heat recovery system with 50% efficiency (W)
A	**11,246**	9,600	–748
B	9,954	24,000	–2,317
C	**8,931**	8,000	–4,704

* Inadequate heating power is highlighted in bold.

According to the equation (10) and results in Table 4, it is obvious that heating power in milking parlour A and C is inadequate (the heating power in milking parlour B is adequate, but not used). The problem with heating power could be solved using forced ventilation with heat recovery system. When using forced ventilation with heat recovery system with 50% efficiency, the heating power calculated according to equation (10) is more than sufficient (see table 4).

CONCLUSIONS

The results of measurement show that the indoor environment of milking parlours is influenced by thermal condition (operational temperature and relative humidity). From the results of measurements of selected milking parlours it is obvious that heating and ventilation is insufficient.

In the summer period, the operational temperature in the milking parlour corresponds to external temperature in days with high external temperature (around 30 °C). Internal relative humidity is below the critical limit of 85%; however, it is higher than external relative humidity. According to THI, combination of high temperature and relative humidity is stressful for dairy cows. Improving of the internal conditions could be ensured by installation of overpressure forced ventilation, which increases the air velocity in the milking parlour. The milking parlour for 24 dairy cows constructed from light-weight material (milking parlour B) needs a flow of fresh air with the volume of about 12,000 $m^3 h^{-1}$. The milking parlours constructed from medium-weight material (milking parlours A and C) need a flow of fresh air with the volume of about 10,500 $m^3 h^{-1}$.

Internal relative humidity over 85% indicates inadequate ventilation. In the winter period, natural ventilation is sufficient. Natural ventilation requires adequate inlet and outlet openings. Problem of low operational temperature is caused by inadequate installed heating power. One of the options for solving this problem is to increase the heating power by installation of additional radiant heating panels. Another solution can be using forced ventilation with heat recovery system instead of natural ventilation.

ACKNOWLEDGEMENTS. Supported by Internal grant agency of Faculty of Engineering, Czech University of Life Sciences in Prague no: 2015:31170/1312/3114.

REFERENCES

Armstrong, D.V. 1994. Heat stress interaction with shade and cooling. *Journal of Dairy science* **77**, 2044–2050.

CSN 73 0543–2. 1998. *Internal environment in buildings for animals. Part 2: Ventilation and heating*. CNI, Praha, 36 pp. (in Czech)

Chloupek, J. & Suchy, P. 2008. *Microclimatic measurements in animal houses*. VFU, Brno, 229 pp. (in Czech)

Chysky, J., Hemzal, K., Drkal, F., Kubicek, L. & Novy, R. 1993. *Ventilation and Air Conditioning*. BOLIT, Brno, 560 pp. (in Czech)

Kabele, K & Veverkova, Z. 2003. Modelling of operational temperature. *Heating Ventilation Installation*. **12**, 33–37. (in Czech)

Kic, P. & Broz, V. 1995. *Creation of Stable Environment*. IVV MZe CR, Praha, 47 pp. (in Czech)

Kic, P. & Gurdil, GAK. 1999. Trends in ventilation and air conditioning of animal houses. *Conference Proceedings - International Conference on Trends in Agricultural Engineering.* CZU, Praha, CZ, pp. 389–393

Kic, P., Kalvoda, T., & Zavadil, V. 2007. Energy savings by heat recovery in ventilation. *Conference Proceedings - 3rd International Conference on Trends in Agricultural Engineering.* CZU, Praha, CZ, pp. 215–218

Koznarova, V. & Klabzuba, J. 2008. *Microclimate of Stables*. CZU, Praha, 29 pp. (in Czech)

Kunc, P., Knizkova, I., Prikryl, M., Maloun, J. & Novak, P. 2007. *Technical, Animalistic and Humane Aspects of Milking*. CZU, Praha, 60 pp. (in Czech)

Novy, R., Broz, K., Drkal, F., Hemzal, J. & Hemerka, J. 2006. *Environmental Engineering*. CVUT, Praha, 267 pp. (in Czech)

Papez, J. & Kic, P. 2013. Wood Moisture of Rural Timber Constructions. *Agronomy Research* **11**, 505–512.

Pavelek, M. & Stetina, J. 2007. *Experimental Methods in Environmental Engineering*. CERM, Brno, 215 pp. (in Czech)

Zejdova, P., Chladek, G. & Falta, D. 2014. *Influence of stable environment on behaviour and milk production of dairy cows*. Mendel University, Brno, 26 pp. (in Czech)

Zajicek, M. & Kic, P. 2014. Heating of large agricultural and industrial buildings. *Agronomy Research* **12**, 237–244.