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Energy and Buildings 40 (2008) 1194–1201
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

Microclimate and ventilation in Estonian and Finnish dairy buildings

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Received 18 July 2007; received in revised form 15 October 2007; accepted 23 October 2007

Abstract

A series of ventilation, thermal and indoor air quality measurements were performed in 14 different dairy buildings in Estonia and Finland. The number of animals in the buildings varied from 30 to 600. Measurements were made all year round with ambient temperatures ranging between −40 °C and +30 °C. The results showed that microclimatic conditions in the dairy buildings were affected by the design of the building, outside temperature, wind, ventilation and manure handling method. The average inside air concentration of carbon dioxide was 950 ppm, ammonia 5 ppm, methane 48 ppm, relative humidity 70% and inside air velocity was 0.2 m/s. Although occasionally exceeded, the ventilation and average indoor air quality in the dairy buildings were mainly within the recommended limits.

Keywords: Microclimate; Thermal comfort; Indoor air; Ventilation; Cold; Warm; Uninsulated; Semi-insulated; Barns; Dairy buildings

1. Introduction

Due to the lower investment, capital and construction costs, cold uninsulated and semi-insulated dairy buildings have been of interest in recent times [1]. The building cost for the framework and walls are estimated to be about 15% lower in semi-insulated and 35% lower in uninsulated cubicles compared to fully insulated free stalls buildings [2]. Energy demands are also lower in uninsulated dairy buildings as there is no need for maintaining warm environment except for water troughs that are electrically heated. In the last 15 years about 310 semi-insulated buildings have been constructed in Finland consisting of about 15–40 animal units. In 2006, Estonia housed about 60 large semi-insulated dairy buildings, with between 300 and 1000 animal units each [3], and 90 uninsulated buildings [4].

Estonia and Finland experience weather conditions with temperature ranging from −40 °C to +30 °C, and relative humidity from 40% to 100% [5–7]. Typically cold winter conditions occur between December and January and warm summer weathers in July and August. These varying weather conditions make it difficult to ensure suitable microclimatic (thermal comfort and indoor air quality) conditions for the animals in dairy buildings.

Poor indoor air quality and high gaseous concentrations in animal buildings are known to increase the occurrence and severity of certain endemic diseases. At high concentrations ammonia can cause ulceration of the eyes and severe irritation to the respiratory tract. The main dangers of carbon dioxide and methane at high concentration are that they displace oxygen which can result in asphyxiation or suffocation [8]. Although there are research results [9] stating that temperatures of −13.8 °C to +28.7 °C and relative humidity of 26–99% do not affect lactating cows kept in uninsulated buildings, other publications have reported otherwise [10–12]. High gaseous concentrations and emissions from animal buildings have also been recorded by several authors [13–15].

The European Directive 2001/81/EC on National Emission Ceilings, sets upper limits for the total amount of emissions from each Member State for gases like sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs) and ammonia (NH_3). However, the directive leaves it largely to the Member States to decide which measures to take in order to comply. In Finland the building regulation of the Ministry of

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doi:10.1016/j.enbuild.2007.10.017

Table 1
Nationally recommended concentrations in dairy buildings in Finland [16], CIGR recommendations [21] and the exposure limits to humans in Finland [17]

Gases	Concentration limits in dairy buildings (ppm)		Exposure limits in office buildings (ppm)	
	MMM	CIGR	8 h	15 min
Carbon dioxide	3000	3000	5000	–
Ammonia	10	20	20	50
Hydrogen sulphide	0.5	0.5	10	15
Carbon monoxide	5	10	30	75

Agriculture and Forestry specifies some recommended microclimatic conditions in dairy buildings ([16], Table 1). In addition, the Ministry of Social Affairs and Health in Finland ([17], Table 1) and Labour Inspectorate in Estonia under the Ministry of Social Affairs have exposure limits for indoor air conditions for office workers. In Estonia, standards for indoor air quality and guidelines for cow protection in dairy buildings were found however, recommendations for animal buildings are not available [18–20]. Typically in Estonia, where recommendations are unavailable, animal building designers try to follow the recommendations given by the International Commission of Agricultural Engineering (CIGR) commission (Table 1). For relative humidity (RH) in animal buildings, CIGR recommends maximum and minimum values as a function of indoor temperature, for example, a RH of 50–90% at 0 °C followed by a steady decrease of RH to a tolerable range of 40–60% at 30 °C [21]. In Finland, the recommended optimum RH for dairy cows is from 50% to 80% and optimum temperature conditions is between 5 °C and 15 °C [16]. Lower and upper critical temperatures proposed by the Finnish recommendation are −15 °C to −25 °C and 23 °C to 27 °C, respectively [16].

The objective of this research paper was to find out the microclimate (thermal and indoor air quality) conditions in the different types of dairy buildings: fully insulated, semi-insulated and uninsulated dairy buildings in Finland and Estonia. Whole year measurements were performed under winter and summer conditions to assess whether prevailing microclimatic conditions meet national and international recommendations.

2. Materials and methods

A series of indoor air quality measurements were performed in five dairy buildings in Estonia and nine in Finland between

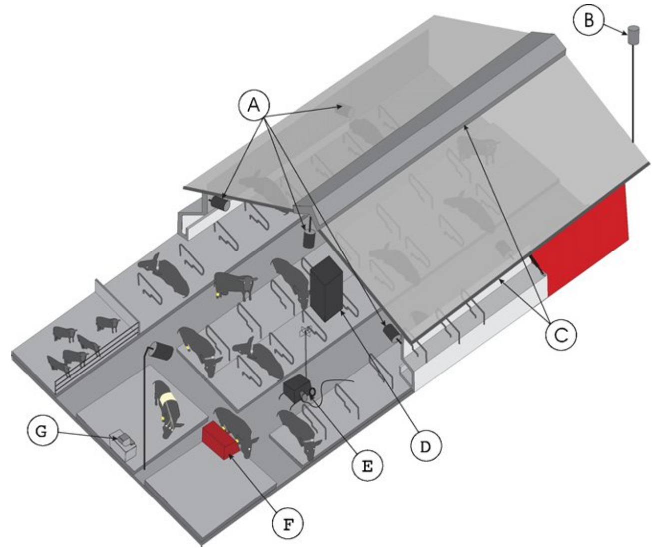

Fig. 2. Measurement set-up and location of sensors for dairy building microclimate studies. (A) Measuring sensors; (B) outdoor weather station; (C) ventilation opening; (D) stationary/wireless multiple-sensor measuring station; (E) mobile multiple-sensor measurement system; (F) milking station; (G) computer work-station and data logging system.

2005 and 2007. The number of animals in the buildings varied from 30 to 600 per dairy building. All year measurements were performed with ambient temperatures ranging from −40 °C to +30 °C. The measurements were grouped into three seasons. The winter measurements had outside temperature ranging between −40 °C and +4 °C, the spring/autumn measurements had temperatures between +5 °C and +15 °C, and the summer measurements between +16 °C and +35 °C. Three different types of dairy buildings; fully insulated dairy buildings, semi-insulated and uninsulated and buildings were considered in the measurements (Fig. 1).

Three different types of measurement systems were used. A stationary multi-sensor measuring station and wireless measurement system, both for long period measurements (1–5 months) and a mobile multi-sensor measurement system for one-day short period measurements (Fig. 2). The stationary measurement system was made of a 1 m × 1 m × 2.5 m (height) wire mesh protected cage located at the centre of the building. A set of sensors was placed in the cage at a height of 0.5 m, 1 m and 1.5 m, and the rest of the sensors were located at the inlet and outlet vents, and outside the dairy building (Fig. 2). Data were logged every 30 min in the stationary multiple-sensor system (Agilent HP 34970A) and in the wireless GSM measurement

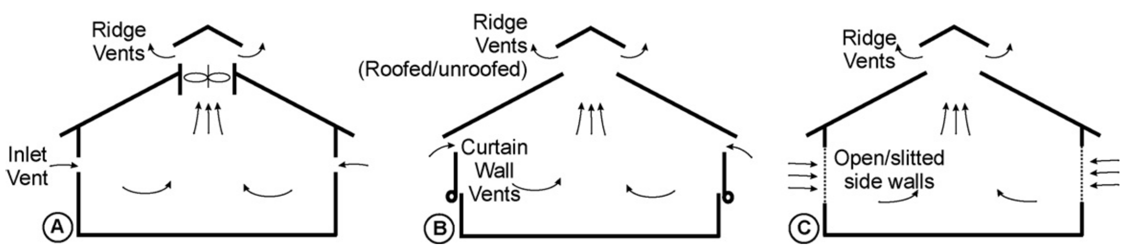

Fig. 1. Measured dairy buildings. (A) Fully insulated walls with mechanical ventilation; (B) semi-insulated roofs (15 cm insulation) with natural ventilation; (C) uninsulated building with open and free natural air ventilation.

system (A-Lab's model AWSC). T-type thermocouples were used to measure manure temperature, air temperature, and radiation temperature at heights of 0.5 m, 1 m, 1.5 m, 3 m and 7 m. Air velocity in the building was measured in two directions; across and along the building (with Elektronik GmbH Model EE66 and Envic Model AFT-1D) at 3 m height. Carbon dioxide concentration in the building was measured with IR gas sensors (SenseAir™ model K30 CO_2 infrared module). Ammonia concentration was measured with electrochemical sensor (Kimessa Model GSE 517). Relative humidity was measured with Honeywell HIH-3610 series sensor, and outdoor weather conditions with Vaisala's model WXT510 weather Station.

Short period measurements were performed in all the dairy buildings with the mobile multi-sensor measurement system where gas measurements were made from at least 10 spatial points all over the dairy building. Included in the mobile measuring system for detailed measurements was Gasmet™ model Dx-4000 portable Fourier Transform Infrared-FTIR Spectrometry multi gas analyzer and Young Model 8100 Ultrasonic three-dimensional anemometer. Extra samples were taken with the mobile system into Tedlar® sample bags and analyzed off-site with a gas chromatograph (Agilent Models 6890 and 5890) equipped with thermal conductivity detector (TCD), electron capture detector (ECD) and flame ionisation detector (FID).

Ideal mixing was assumed and carbon dioxide balances were employed in the estimation of ventilation in the dairy buildings. The calculations were made based on the conservation of mass under steady-state conditions in the building. The ventilation rate in the dairy building, q_v in m^3/h was estimated according to Eq. (1), where P is the production of CO_2 in m^3/h; C_{in} and C_{out} are the CO_2 concentrations in the indoor and outdoor air in parts per million by volume (ppm vol) as:

$$q_v = \frac{P}{C_{in} - C_{out}} \quad (1)$$

Carbon dioxide production varies by 15% depending on dairy cow's activity [12]. Pre-measurements during this research indicated that less than 10% of the total emission of CO_2 emerge from dairy building floors; confirming the assumption of cows being the main source of production to be fairly good [12]. If the production of CO_2 from other sources is assumed to be negligible, then the production of CO_2 per cow is 330 g/h [21].

3. Results and discussion

3.1. Ventilation rates

The intermittent and continuous measurements provided information about typical gas concentrations and microclimates in dairy buildings, under moderate to extreme winter and summer conditions (−40 °C to +30 °C). All the dairy buildings except F5 and F6 had natural ventilation (Table 2). The effect of the buildings' structural designs on ventilation was significant, and the frequency of manure removal affected the microclimate conditions in the respective dairy buildings. Instantaneous velocities varied a lot and multiple measurements with three-dimensional anemometer had to be performed in order to obtain a representative two-dimensional velocity profile as shown in

Table 2
Average microclimate and ventilation in the dairy buildings

Place (date)	Barn type	Cows no.	Vol × 10^3 (m^3)	T_{in} (°C)	T_{out} (°C)	v_{in} (m/s)	v_{out} (m/s)	RH_{in} (%)	RH_{out} (%)	$CO_{2\ in}$ (ppm)	$NH_{3\ in}$ (ppm)	$CH_{4\ in}$ (ppm)	V (m^3/h)
E1W (24 January)	U	480	22	−1	−2	0.2	2.3	91	74	672	3.1	21	629
E1S (21 June)	U	460	22	28	27	0.6	2.5	39	38	605	3.6	12	681
E2W (24 January)	S	500	33	1	−3	0.1	1.7	89	72	1125	3.6	38	248
E2S (21 June)	S	500	33	27	27	0.3	0.1	46	41	1051	11.7	43	284
E3W (25 January)	U	500	27	2	−1	0.1	0.4	87	91	1322	5.3	68	196
E3S (22 June)	U	500	27	29	29	0.3	0.4	45	37	525	5.0	13	1176[a]
E4W (24 January)	U	600	32	0	−4	0.1	4.2	86	85	1004	5.2	45	295
E4S (23 June)	U	600	32	28	28	0.6	2.5	47	48	562	19.0	18	634[a]
E5S (23 June)	U	500	26	30	32	0.7	1.0	38	30	547	4.6	15	1015[a]
F1W (3 February)	U	55	12	−17	−26	0.1	3.8	85	83	1006	2.2	43	284
F2W (16 January)	S	50	13	1	−1	0.3	3.2	82	68	1576	17.4	46	155
F3W (9 February)	S	95	5	4	−12	0.1	1.4	85	86	1979	9.0	120	114
F4W (3 February)	U	80	5	3	−12	0.1	1.6	85	85	1829	5.5	62	126
F5W (24 February)	F	70	3	8	−8	0.1	0.1	73	75	1673	5.4	114	143
F6W (3 April)	F	60	5	12	1	0.3	0.7	76	80	1595	10.0	90	154
F6S (31 May)	F	60	5	19	18	1.0	0.2	55	47	807	4.6	24	399
F7W (26 February)	U	50	3	6	3	0.1	2.9	92	86	700	3.3	21	586
F7S (5 July)	U	50	3	29	26	0.2	2.7	46	41	784	6.7	22	449
F8W (6 February)	S	110	7	10	−20	0.2	2.5	80	73	2925	9.4	201	72
F8S (23 June)	S	110	7	22	19	0.2	1.5	48	42	1003	3.8	20	288
F9W (4 March)	U	66	4	11	7	0.3	1.3	56	64	643	3.4	15	558
F9S (23 June)	U	66	4	22	19	0.2	1.5	48	42	545	3.4	13	774[a]

Notation: the measurement place—E: Estonia, F: Finland, 1–7: building number, W: winter and S: summer; barn types—U: uninsulated, S: semi-insulated and F: fully insulated; V: ventilation per cow calculated from CO_2 balance; Vol: volume of the dairy building.

[a] Differences between inside and outside CO_2 concentrations were too small to accurately estimate the ventilation rate in the dairy building.

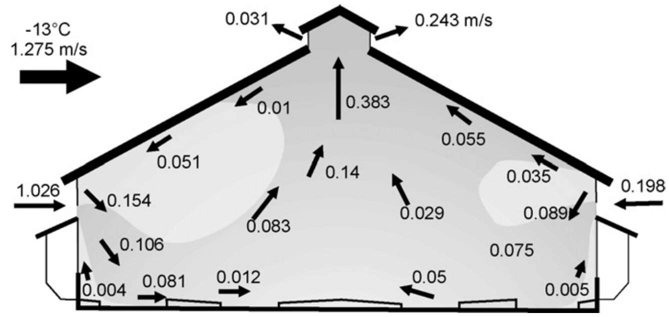

Fig. 3. Velocity profile in dairy building (building F3W).

Fig. 3. Large fluctuation in ventilation rates were observed in all the 14 dairy building and airflow velocities were between 0 m/s and 4 m/s, with an average of 0.2 m/s at the cows breathing level (1 m) (Table 2).

High spatial microclimate variability was observed in both Finnish and Estonian dairy buildings. Results from measurements show that the gases in the dairy building were not uniformly mixed as assumed in Eq. (1). Pockets of low and high concentrations were found usually at the corners of the dairy building compared to calculated averages (Fig. 4).

Estimated from Eq. (1), the minimum ventilation rate per cow to keep CO_2 concentrations below recommended harmful limits (3000 ppm, [21]) is 65 m^3/h. For a typical dairy building with 65 m^3 space per cow, the minimum exchange rate of air is about once an hour to keep CO_2 concentration below the recommended harmful limit.

Air ventilation in the uninsulated dairy buildings (Table 2) was adequate all year round according to the Finnish recommendations (ventilation rates of between 65 m^3/h and 360 m^3/h per cow) [16]. During the winter, manure froze; decomposition and bacterial activity decreased resulting in lower gas concentrations, therefore required less ventilation. In the summer, air temperatures increased, gas concentrations were higher and velocities in the building were also higher (Table 2). The semi-insulated and fully insulated dairy buildings had inadequate ventilation in the winter, because the ventilation inlets and outlets were adjusted to prevent freezing indoors; resulting in too low ventilation rates and higher indoor gas concentrations.

3.2. Thermal conditions

Minimum outdoor winter air temperatures of −40 °C and an average of −7 °C were recorded during the measurement period. The fully insulated buildings kept their inside temperatures above +10 °C. The semi-insulated kept temperatures above 0 °C in the winter to prevent manure from freezing. In the uninsulated buildings, winter indoor temperatures were a few degrees (3–7 °C) higher than the outside temperatures (Fig. 5). Indoor winter temperature varied depending on the respective buildings' structural design, the number of animal units and the method of ventilation (Table 2). At extreme winter conditions in the uninsulated buildings, the cows' body temperature dropped and lower cow activity was observed during our measurement visits (Fig. 6).

Summer average outdoor temperature was +18 °C and maximum outdoor temperature was +29 °C. There were high variations in diurnal indoor microclimates (Fig. 7). In the summer, all the building types had maximum ventilation. Semi-insulated buildings had all curtains and ridges open, and the mechanically ventilated buildings had full power and extra windows and doors usually open. For these reasons, the difference between inside and outside temperatures in the

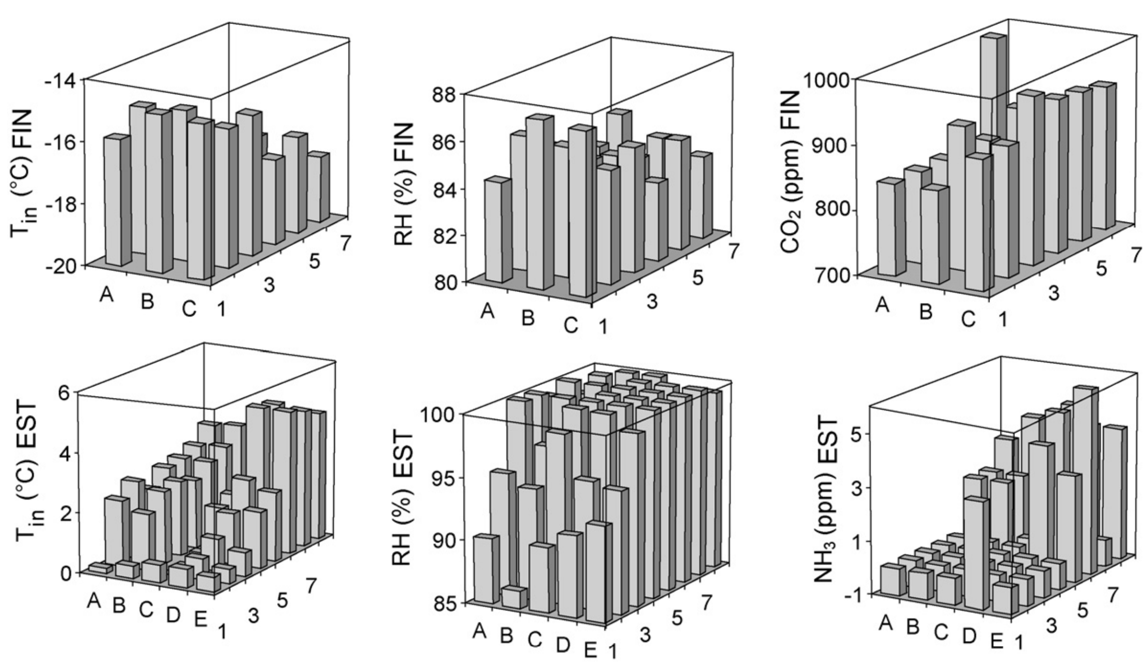

Fig. 4. Winter spatial microclimate variation in an uninsulated building in Finland and Estonia. Finland: outdoor temperature −27 °C and relative humidity 87% (building F1); Estonia: outdoor temperature −3 °C and relative humidity 90% (building E3).

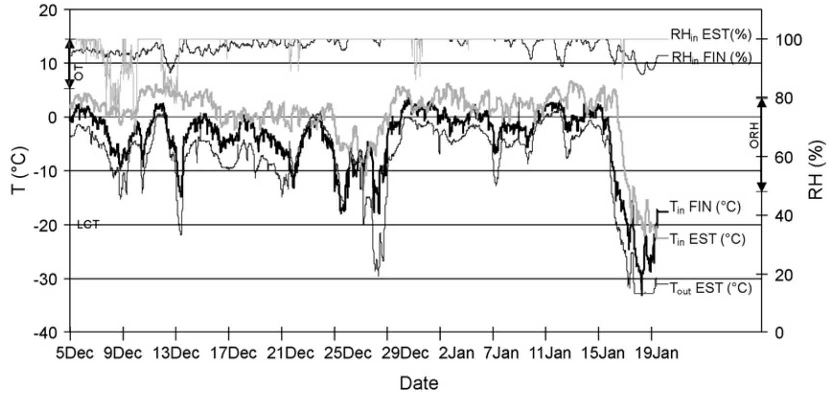

Fig. 5. Winter microclimatic conditions in a dairy building in Finland (building F1) and Estonia (building E4). OT: optimum temperature; ORH: optimum relative humidity; LCT: upper critical temperature.

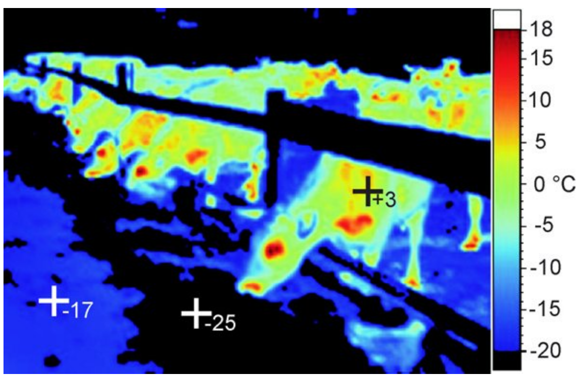

Fig. 6. Infrared picture of dairy cows feeding (building F1). Outdoor temperature: −30 °C, RH outside: 89%, indoor temperature: −25 °C, indoor relative humidity: 95%, milking parlour temperature: +5 °C, drinking water: +1 °C, cow hair temperature: +2 to +17 °C.

summer was about 3 °C in both the semi-insulated and the uninsulated buildings (Fig. 8).

3.3. Relative humidity

Relative humidity within the buildings varied according to the outside temperature and RH. However, in all the buildings, winter temperatures below −10 °C for long periods (one week and over) resulted in close to saturated RH conditions (100%) about 5–7 m above the cows (Fig. 5). Wood and metal surfaces were frosted at these saturated conditions and got wet when temperatures rose above 0 °C. Rusted metals, rotten and moulded wood were noticed in some of the dairy buildings. Spring, autumn and summer RH varied a lot; during the day it was below 50% and went above 70% in the night mainly due to changes in night and day temperatures (Fig. 7).

Relative humidity in the dairy buildings exceeded recommended values when the ventilation was inadequate with regards to the Finnish regulations (Table 2; Fig. 7). In some cases, temperatures in the uninsulated dairy buildings were below the lower critical temperatures (Fig. 7). The most eminent problems in the winter were related to high moisture content (RH) and freezing of moisture or water during cold weathers. Freezing indoor temperatures made manure removal difficult and resulted in uneven and slippery floors for the cows and workers.

3.4. Gases—carbon dioxide, ammonia and methane

A typical example of gas concentrations recorded in the dairy buildings during the measurement period is shown in Fig. 9. As shown in the figure, gas concentrations varied

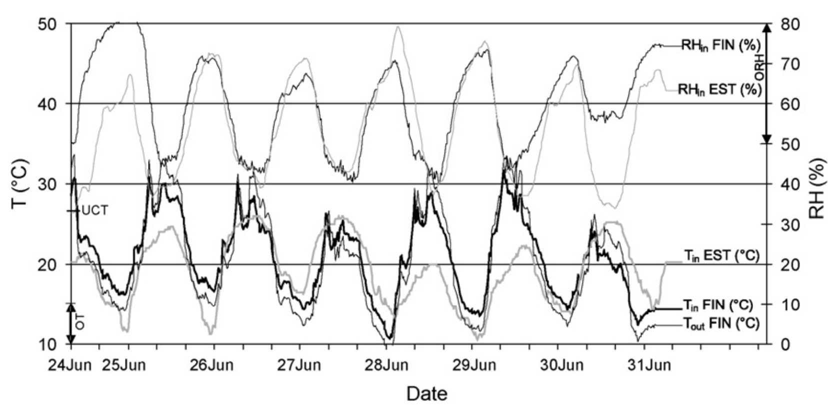

Fig. 7. Summer microclimatic conditions in a dairy building in Finland (building F1) and Estonia (building E4). OT: optimum temperature; ORH: optimum relative humidity; UCT: upper critical temperature.

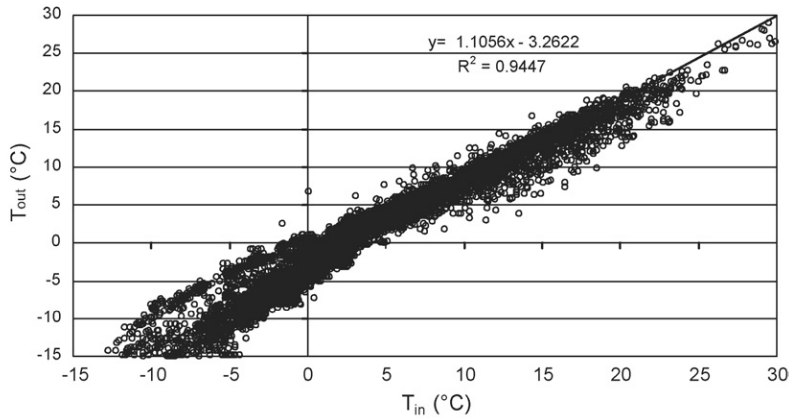

Fig. 8. Typical relationship between inside and outside temperatures in the uninsulated dairy buildings (buildings F1 and F9).

considerably during the measurement period. The lowest concentrations during a 24-h period usually occurred after midnight. The reasons were lower activity level of the cows and decreased gas emissions as a result of lower indoor air and floor temperatures. There were a few peak values during a 24-h period probably due to different management schedules such as feeding, manure removal and milking. Generally, a diurnal pattern was found in all the measurements and in most cases the highest concentrations occurred in the afternoon on typical summer days.

Carbon dioxide concentrations were in the range of the recommended levels in all the uninsulated dairy buildings. The concentration in the semi-insulated buildings sometimes increased beyond the recommended level of 3000 ppm (Fig. 9). Ammonia emissions were mostly below 10 ppm vol in both Finnish and Estonian dairy buildings. Increase in ammonia emissions was noticed during manure removal operations up to about 20 ppm. At low winter temperatures, ammonia and methane concentrations were lower in the uninsulated dairy buildings (Table 2). The overall average inside air concentration of carbon dioxide was 950 ppm, ammonia was 5 ppm and methane was 48 ppm for the 14 buildings. In some cases, however, methane concentrations were close to 200 ppm (Table 2). Higher concentrations of carbon dioxide, ammonia and methane were noted at 5–7 m above the cows attributed to the accumulation of gases as they escaped the ventilation openings at the ridge.

3.5. Recommendations as compared to measured microclimates

Research has shown that the working time spent in dairy buildings vary depending on the available technology and different work routines in milking, feeding and manure removal in the dairy building [22,23]. Working time spent in the dairy building with 45–55 milking cows varies between 130 and 354 person minutes per milking period, which is about 4.5–12 h for two milking periods per day. Considering these long working hours of dairy farmers indoors, the authors infer that the exposure limits in offices (also large buildings and factory) are comparable to those in dairy buildings since the main aim of the recommendations is to ensure good health, thermal comfort and good indoor air quality for workers in both dairy buildings and offices.

From literature research, however, it was not possible to clarify the basis of the recommendations for gas concentration levels imposed on the dairy buildings (Table 1). There were some differences in the requirements for dairy buildings as compared to normal offices, though dairy farmers spend several hours in the building per day. It was observed during the research that some working operations required the farmers to

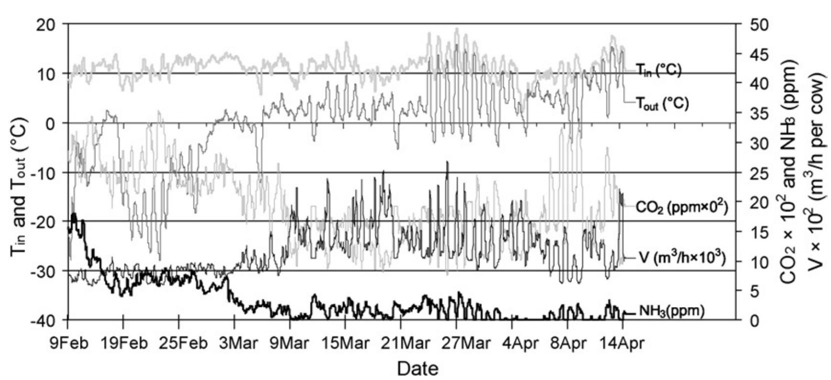

Fig. 9. Effect of ventilation on the concentration of gases in dairy building (building F8).

take off protective gloves or wear lighter clothing. To improve comfort, the farmers regulated the ventilations to suit them, which often led to higher gas concentrations or unsuitable microclimates for the dairy animals.

During the winter, temperatures were in most cases below the recommended optimum temperatures (5–15 °C) in the semi-insulated and all the uninsulated buildings. For the uninsulated buildings, indoor temperature was a few degrees lower or higher than outdoor temperatures, but sometimes went below the recommended critical temperature of −25 °C. During measurement visits to the buildings, temperatures below the critical recommendations were very harsh and difficult for performing routine measurements. In order to ensure thermal comfort for work (temperatures above +10 °C), it was observed that one of the farms had their ventilation openings (curtains) completely shut when outdoor temperature was below −10 °C, which resulted in gaseous concentrations, e.g. CO_2 and NH_3 exceeding the recommended national and international levels. Typical measured air-quality condition of the farm is presented in Fig. 9.

In the summer period, there were days when the recorded temperature went above the upper critical temperatures (+27 °C). Gaseous concentrations were mostly below the recommended upper limits, except on a few occasions when ammonia and methane exceeded the limits. There were no cooling systems in the dairy buildings for summer periods. For this reason the temperatures were high on hot summers, and were over 30 °C in buildings with transparent roofs.

During the measurement period, an average ventilation of 310 m^3/h per cow was recorded with respect to all the dairy buildings. Minimum and maximum ventilations were 72 m^3/h and 2025 m^3/h per cow, respectively. The maximum indoor velocity for the buildings was 3.9 m/s and the average was 0.2 m/s. The maximum allowed velocity for a dairy building in the winter according to Finnish regulation is 0.25 m/s [16]. A summary of observed maximum and minimum microclimates in the 14 dairy buildings in Finland and Estonia as compared to air-quality recommendations for dairy buildings is presented in Table 3.

Table 3
Comparison between air-quality recommendations for dairy buildings and observed microclimates in the 14 dairy buildings in Finland and Estonia

Parameters	Observed microclimate		Recommended microclimate	
	Maximum	Minimum	Maximum	Minimum
Carbon dioxide (ppm)	3150	321	3000[a]	–
Ammonia (ppm)	64	0	20[a]	–
Methane (ppm)	223	1.5	–	–
Relative humidity (%)	100	35	90[a]	40[a]
Temperature (°C)	31	−39	27[b]	−25[b]
Velocity (m/s)	4	0	0.25[c]	–
Ventilation (m^3/h)	2025[d]	72	360[e]	55[d]

[a] CIGR recommendations [21].
[b] MMM recommendations for critical temperatures [16].
[c] MMM recommendations for winter maximum [16].
[d] Differences between inside and outside CO_2 concentrations were too small to accurately estimate the ventilation rate in the dairy building.
[e] MMM recommendations for 400 and 700 kg dairy cows [16].

4. Conclusions

With adequate ventilation rates indoor air quality in dairy buildings can be kept within recommended levels. Extreme outdoor temperatures result in problems of manure freezing in the winter and indoor temperatures exceeding critical values in the summer.

There were only a few incidents of indoor gas concentrations exceeding the recommendations when the building ventilations were not obstructed. With respect to management of indoor air quality and ventilation rates, spring and autumn was found to be the most difficult periods of the year because of frequent significant diurnal changes in air temperature, relative humidity and air velocity.

Practical dairy building management should take the indoor air quality needs of housed animals into account. The building environment should, however, also reflect the requirements of the people working there.

References

[1] T. Kivinen, Visions for buildings and systems for dairy production in Finland in year 2010, NJF Seminar 337 (2002) 7–9.
[2] K. Jeppsson, G. Gustafsson, K. Sällvik, Semi-insulated freestall housing for dairy cows, JBT report no. 400, Swedish University of Agricultural Sciences, Department of Rural Buildings, 2006.
[3] T. Kivinen, K. Mattila, F. Teye, J. Heikkinen, I. Heimonen, Functionality of curtain wall ventilation in insulated barns in Finnish climate, working paper 119, Agrifood Research, Finland, 2006.
[4] A. Pajumägi, Uninsulated cowsheds: ventilation and aspects of building physics, Dissertation, Institute of Forestry and Rural Engineering, Estonia University of Life Sciences, 2007.
[5] A. Drebs, A. Nordlund, P. Karlsson, J. Helminen, P. Rissanen, Climatological Statistics of Finland 1971–2000, Finnish Meteorological Institute, Helsinki, Finland, 2002.
[6] T. Kalamees, J. Vinha, Estonian climate analysis for selecting moisture reference years for hygrothermal calculations, Journal of Thermal Envelope and Building Science 27 (2004) 199–220.
[7] S. Keevallik, P. Post, J. Tuulik, European circulation patterns and meteorological situation in Estonia, Theoretical and Applied Climatology 63 (1999) 117–127.
[8] ASAE, Manure Storage Safety. American Society of Agricultural Engineers, ASAE Standards, 39th ed., EP470, St. Joseph, Michigan, 1996.
[9] M. Zähner, L. Schrader, R. Hauser, M. Keck, W. Langhans, B. Wechsler, The influence of climatic conditions on physiological and behavioural parameters in dairy cows kept in open stables, Animal Science 78 (2004) 139–147.
[10] G.L. Hahn, Dynamic responses of cattle to thermal heat loads, Journal of Animal Science 77 (Suppl. 2) (1999) 10–20.
[11] J. Hassi, M. Rytkonen, J. Kotaniemi, H. Rintamaki, Impacts of cold climate on human heat balance, performance and health in circumpolar areas, International Journal of Circumpolar Health 64 (2005) 459–467.
[12] V.M. Tuure, Cold working environments on dairy farms in Finland, International Journal of Circumpolar Health 62 (2003) 190–203.
[13] B. Amon, T. Amon, J. Boxberger, C. Alt, Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall, Nutrient Cycling in Agroecosystems 60 (2001) 103–113.
[14] P.W.G. Groot Koerkamp, J.H.M. Metz, G.H. Uenk, V.R. Phillips, M.R. Holden, R.W. Sneath, et al., Concentrations and emissions of ammonia in livestock buildings in Northern Europe, Journal of Agricultural Engineering Research 70 (1998) 79–95.
[15] J. Seedorf, J. Hartung, M. Schröder, K.H. Linkert, S. Pedersen, H. Takai, et al., Temperature and moisture conditions in livestock buildings in

Northern Europe, Journal of Agricultural Engineering Research 70 (1998) 49–57.

[16] MMM, Heating and Ventilation of Agricultural Production Houses, Ministry of Agriculture and Forestry MMM-RMO C2.2, 2002.

[17] MSAH, Exposure Limits, Ministry of Social affairs and Health (MSAH), publication 2005:10, 2005.

[18] EVS, Building Ventilation Design, Estonian Centre for Standardization, EVS 845, 2004.

[19] EVS, Indoor Climate, Building Ventilation Design, Estonian Centre for Standardization, EVS 839, 2003.

[20] RTL, Animal Protection Law (under Council Directive 98/58/EC), RTL, 124, 179, Riga treaty, 2002.

[21] CIGR, Climatization of Animal Houses, Report of working group on climatisation of animal houses, Report of working group, Aberdeen, Scotland, 1984.

[22] K. Louhelainen, E. Rytkonen, O. Lankia, Noise exposure in cow houses-hazard to farmers and to animals? ASABE Meeting Presentation, paper number 065021, St. Joseph, Michigan, 2006.

[23] K. Radon, B. Danuser, M. Iversen, E. Monso, C. Weber, J. Hartung, et al., Air contaminants in different European farming environments, Annals of Agricultural and Environmental Medicine 9 (2002) 41–48.