Research of Microclimate in Dairy Cattle and Pig Buildings

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Abstract

The experimental investigations were carried out in industrial sheds of calves, meat pigs and cattle sheds of various design in different periods of the year. The correspondence of shed air temperatures and relative humidity to the regulations and the variation of air temperatures and relative humidity in respect of climate conditions outdoor were estimated. In winter the favourable temperatures were maintained in insulated sheds and during summer heat the temperatures were higher by a few degrees than the recommended level. The hottest temperature was in the cold cowshed (by about 10 °C higher than recommended) and the coldest temperature was as low as -14.2 °C during a short period with the outdoor temperatures below -20 °C. The main problem in all sheds was not unfavourable temperatures but high air humidity. In the insulated cattle sheds it was too humid even during the warm period of the year. In uninsulated sheds air humidity increased when outside temperature was below -10 °C and in insulated sheds air humidity already increases when outdoor temperature is below 6–14 °C. From all investigated sheds the air humidity met the regulations best in the pig shed, and in the insulated and semi-insulated cubicle cowsheds. The main reason for unfavourable microclimate is too low ventilation rates. In each shed it is recommended to prepare optimal algorithm for the management of temperature difference variation in sheds and outdoors and according to it to control ventilation rates in sheds.

Introduction

In the process of shed renovation frequently problems related to microclimate arise i.e. how to ventilate the shed intensively, what temperatures to maintain in it. During the last decade uninsulated (cold, outdoor climate) cattle sheds have become popular. Traditional insulated tied cowsheds are being reconstructed into deep bedding and cubicle cowsheds whose outer partitions are uninsulated or only the roof is insulated. The trend of such sheds development was influenced by positive evaluation of uninsulated cowsheds in many countries. Intensive construction of cold cowsheds in Western Europe started in 1985, in Scandinavian countries – in 1990, in Estonia – 1995, and in Lithuania – in 1998. Keeping cows and calves in cold sheds is also expanding in cold regions of the world. (Hilty et al., 2003; Lucenko and Salyga, 2006; Pajumagi et al., 2007). In order to lower construction costs of pig sheds, attempts are also made to insulate only bedding places. Many scientists, who have investigated microclimate in uninsulated sheds (Schneider, 1988; Zhao et al., 2007; Deuker, 1984), agree that methodological problems exist in analysing microclimate in open sheds, as it is difficult to identify ventilation rates accurately (Snell et al., 2003; Teye, 2008). Traditional methods are not suitable for the assessment of ventilation rates in sheds. The best way is to analyse dynamics of air parameters and according to it to assess ventilation effectiveness. From the most fluctuating air parameters (air temperature, relative humidity, air velocity), the temperature is the best index for ventilation assessment (Pajumagi et al., 2008). Properly installed ventilation systems in uninsulated sheds can ensure microclimate within the optimal range during all seasons of the year (Pajumagi et al., 2007). Other scientists (Frederick et al., 20080) observe that microclimate in such sheds is strongly affected by shed design, ambient temperatures, wind and manure removal method. In these sheds it is complicated to analyze air quality and ventilation rates in spring and autumn, as weather temperature, relative humidity and air velocity change rapidly. Problems also arise in these sheds in summer because temperatures are very often above the highest point of 27 °C. Although the air in cold cowsheds is cleaner and concentration of hard particles is lower if compared to pig and fowl sheds (Kaasik and Maasikments, 2013). Different microclimate factors in them fluctuate within wide range and have negative impact on animal bodies. Animal bodies can adapt to varied temperatures and other microclimate factors but only to certain limits. Very strong and unusual factors reduce body's resistance, causes deceases, animals become weaker and production decreases.

According to the data of scientific investigation (Sallvik, 1998; Neimann and Tribe, 1987), high temperatures are more hazardous for cattle than low temperatures. With the ambient temperatures as low as –15 °C, a cow milk yield decreases from 0.5 to 2.0 litres per day, whith the ambient temperatures as high as +30 °C, a cow milk yield decreases from 2.0 to 4.0 litres per day. Different opinions exist on optimal air temperatures for a cow. By summarising the results of investigations carried out by different scientists (Bartussek, 1984; Caenegem and Wechsler, 2000; Clark, 1992; Stolpe, 1985), it can be stated that the optimal temperatures for keeping productive cows are from –7 to + 23 °C. These temperatures are suitable for loose cattle. The recommended temperatures for insulated calf, cow, meat cattle sheds are 3–17 °C (Kavolėlis, 2006). The relative air humidity matching the highest temperature limit is 61%. When pigs are kept on deep bedding, the recommended air temperatures in sheds are 8–18 °C and when they are kept in sheds without bedding, the recommended air temperatures are 16–20 °C.

The best way to relate the highest allowed air relative humidity in an insulated shed φ_i %, to its temperature is to apply the following regression equation

$$\varphi_i = 95 - 1.5\, t_i,$$

t_i – air temperature in shed , $t_i \geq 0$ °C.

In order to have healthy and productive animals, optimal microclimate must be ensured in sheds all year round. It is essential to control the most important factors of microclimate air temperatures and humidity, which also influence other factors (ammonia, sulphur hydrogen gas concentrations, etc.). Effective natural or mechanical ventilation systems

in sheds must be installed which removes polluted air from sheds (also heat excess in summer) and supply clean outdoor air.

The objective of the investigation: to evaluate air temperatures and humidity in the pig shed and cattle sheds of different design and to foresee instruments for the controll ventilation rates under varions of climate conditions.

Objects and Methods

The experimental investigation was performed under industrial conditions in a calf shed, meat pig shed and in different cowsheds: a half-deep semi-insulated shed, a tied insulated shed, a cubicle cold shed and a cubicle semi-insulated shed (only the roof is insulated). Heifers are kept loose on half-deep bedding in an insulated, brick shed with eaves. A natural, channel type ventilation system was installed. A pig shed, where 80 pigs are kept on deep bedding, is brick and has insulated eaves. A combined ventilation system was installed in it.

The most popular cowshed types in Lithuania were selected for carrying out the investigation. A half-deep cowshed – such solutions are often applied in renovating old, tied, not very big cowsheds. 140 cows are kept in this cowshed whose walls are built from reinforced concrete blocs, its ceiling was insulated with a thick layer of straw. A shaft ventilation system is installed in the cowshed. Cows' bed places were covered with a straw. A tied cowshed is an old technology, and about half of cowsheds in Lithuania are still of this type. In the tied cowshed 200 cows were kept. Two feeding tracks are installed and cows are tied on both sides of them. The cowshed was insulated, had a ceiling on which straw was stored. In the cold cubicle cowshed 220 cows were kept, its walls and roof were uninsulated, it was covered with tin sheets. The cows are kept in shallow cubicles whose floors are covered with rubber mats. A non-channel, ridge – slit ventilation system is installed. Air enters the shed through wall openings which are covered with netting and it leaves the shed through ridge openings. Air flow is controlled by moving the curtains and changing the size of wall openings. In the semi-insulated cubicle cowshed 230 cows are kept, the average heat transmission coeffiecient of shed walls is 3.3 W/(m^2 K) and of roof is 0,45 W/(m^2 K). Fresh air enters through wall openings controlled by curtains and polluted air is removed through controlled ridge openings. In the cowshed no-bedding techology is applied, recreation cubicles were covered with rubber mats, and manure tracks are covered with grids.

The investigation was performed during different seasons of the year and the variation of basic microclimate indexes (air temperature, relative humidity) in sheds and outdoors was estimated. The air temperature and relative humidity were recorded hourly using the measuring device COX TRACER Almemo 2590-9, made by Ahlborn GmbH, Germany. The measured temperatures ranged from –30 °C to +40 °C. The accuracy of the measured temperatures was ±0.3 °C and the accuracy of the measured air humidity was ±3%. 7 sensors were used, 2 of them were placed outdoors on the northern side of the shed, 5 sensors were placed in the different locations of the shed.

The obtained data was analysed by applying the multinomial correlation and regression method. The data reliability was based on Stjudents criterion. The difference line of standard error and lowest reliability was calculated according to the level of statistical significance $p<0,05$.

Results and discussion

During the analysis of air temperatures and relative humidity in the sheds, the effectiveness of ventilation systems was assessed. At different periods of the year the measurements lasted from 124 days (in the tied cowshed) to 165 days (in the cold cubicle cowshed). The identified microclimate indexes during measurements are given in Table 1. Detailed analysis of air temperatures and humidity was performed in all investigated sheds. The data of three differently insulated sheds are given in Fig.1–3.

Table 1. **Microclimate parameters in different sheds**

Shed	Temperatures outdoor ^{0}C		Temperatures in shed ^{0}C		Air relative humidity in shed%		Maximum allowed air humidity in shed %	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Calves shed	14.5	-16.9–32.6	17.1	1.6–27.9	71.7	32.6–98.0	69.3	53.2–91.1
Meat pigs shed	13.3	-12.3–31.7	17.9	4.3–27.4	55.1	29.2–89.6	68.3	53.9–88.6
Half-deep insulated cowshed	9.94	-20.1–32.3	16.2	3.4–27.3	74.8	40.1–99.4	70.6	52.8–90.1
Insulated tied cowshed	3.9	-22.1–17.5	13.0	6.2–19.6	84.2	58.1–98.2	75.6	65.6–86.7
Cold cubicle cowshed	10.0	-21.2–32.1	14.1	-14.2–33.5	66.9	34.5–96.5	85.2	70.0–95.0
Semi-insulated cubicle cowshed	15.9	-16.1–32.6	17.6	0.9–29.0	62.0	32.5–99.5	68.6	51.6–94.7

During the investigation air temperatures outdoor fluctuated within the range from –21.2 °C to 32.1 °C. During the measurements average temperatures were within recommended limits in all sheds but in different sheds various temperature fluctuation patterns were observed. In the cold cowshed the temperatures fluctuated within big range from -4.2 °C to 33.5 °C, in the insulated sheds the fluctuation was smaller (maximal temperatures were lower only by a few degrees than in the cold cowshed and in the coldest periods the temperatures did not fall lower than 0 °C). It should be

emphasized that during heat periods temperatures were too high in all sheds, in the uninsulated cowshed they were higher by 10 °C than maximal recommended temperatures (24 °C), in the insulated cowsheds they were higher by 4–5 °C, too high temperatures were also measured in the pig shed. The variation of temperatures in sheds depends on shed design walls insulation , animal density and ventilation rate. The lowest temperature recorded in the cold cowshed was –14.2 °C, by 7 °C lower than recommended minimal temperature. At such temperature cows' productivity decreased and fodder costs increased. But it continued for a short period with outdoor temperatures lower than –20 °C (Fig. 2). In other sheds it was warm at cold periods. In all sheds a very strong correlation between air temperatures in a shed and outdoor was estimated (R^2>0.63), except the tied cowshed. It could have been caused by too low ventilation rate in the tied cowshed after closing ventilation channels.

The biggest problem in sheds is not unfavourable temperature but high air humidity. The highest humidity was in the insulated sheds. The relative air humidity varied from 33% to 98% (average 71.7%). During more than a half of measurement period the air in the shed was too humid i.e. more humid than maximally allowed rate. Having assessed temperatures the air humidity could not exceed 91%. The air relative humidity increases at night after closing the door. In summer the installed natural ventilation system is not effective enough, therefore, in warm periods windows and doors have to be opened. In the period of the whole investigation in the tied cowshed average relative humidity was 84.2%, it is not very high value but it is higher by 8.6% than the maximally allowed average air humidity. In this cowshed the air was more humid than recommended nearly through the whole period of investigation. (Fig.3). The air was dryer in less insulated sheds and in these sheds the average relative air humidity of the measurement period was lower than average maximal level (in the cold cubicle shed it was lower by 18.3%, in the semi-insulated cubicle shed – by 6.6%). In these sheds the humid air was observed only during short periods. During the whole period of investigation the air humidity was lower than maximum allowed level only in the pig shed. The air humidity in sheds mostly increased with the outdoor temperatures falling below 0 °C. The reason for this is too much closed ventilation channels in order to maintain higher temperatures in the shed.

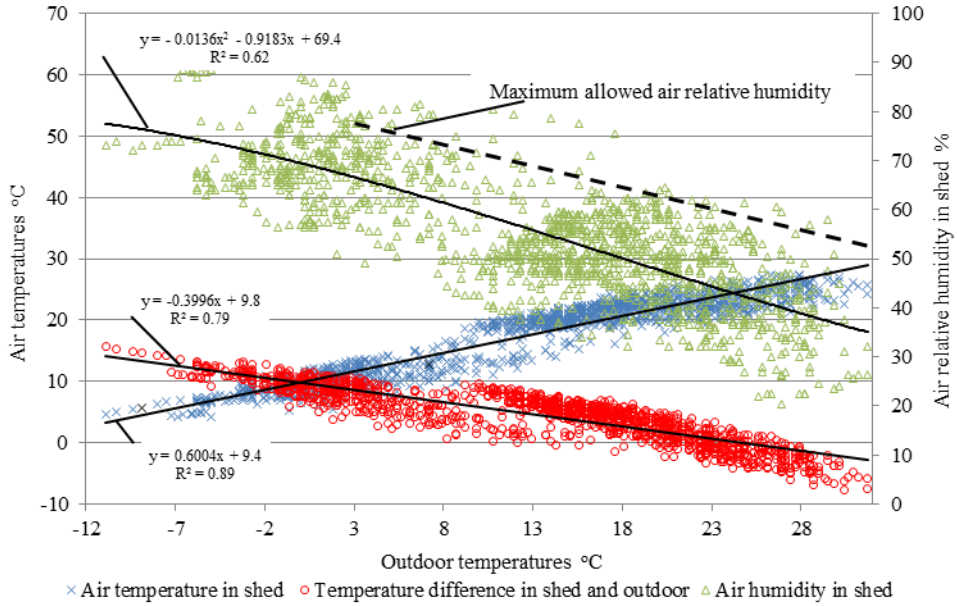

Figure 1. **Dynamics of air temperatures and relative humidity in pig shed as a function of outdoor temperatures**

After summarising the investigation results, the outdoor temperature intervals, which cause unfavourable microclimate in sheds, are given in Table 2. Most problems concerning unfavourable microclimate in all sheds is due to increases air humidity. Air humidity in sheds increases significantly when outdoor temperatures fall. It is possible to conclude that the less insulated the shed is and the lower temperature is in it, the dryer the air is in the shed. In the cold cubicle cowshed the humidity increases only when outdoor temperatures fall below –10 °C, and in the insulated tied shed – below –11 °C. Such results are conditioned by incorrect regulation of air supply channels and improperly maintained ventilation rate in the shed. The results of these measurements are confirmed by the investigations carried out by Kang and Lee (2008) and other scientists (Teye et al., 2008; Kaasik and Maasikmets, 2013; Zhao et al., 2007). Their results show that too low ventilation rate in a shed causes poor air quality indoors. It is not sufficient to install ventilation systems correctly, it is necessary to regulate them properly in respect of varied outdoor climate conditions.

The best way is to analyse dynamics of air parameters in a shed and according to the data to assess ventilation effectiveness. Of all mostly fluctuating air parameters (air temperatures, relative humidity), temperatures are the best index to assess ventilation. According to our investigation and the investigation performed by Pajumagi (2007), it is possible to ensure microclimate within optimal range in all sheds including the cold ones all year round provided that ventilation systems are properly installed and controlled. The temperatures in uninsulated sheds can be too low only during extremely cold periods. Under Lithuanian climate conditions such periods are short and they do not cause serious problems.

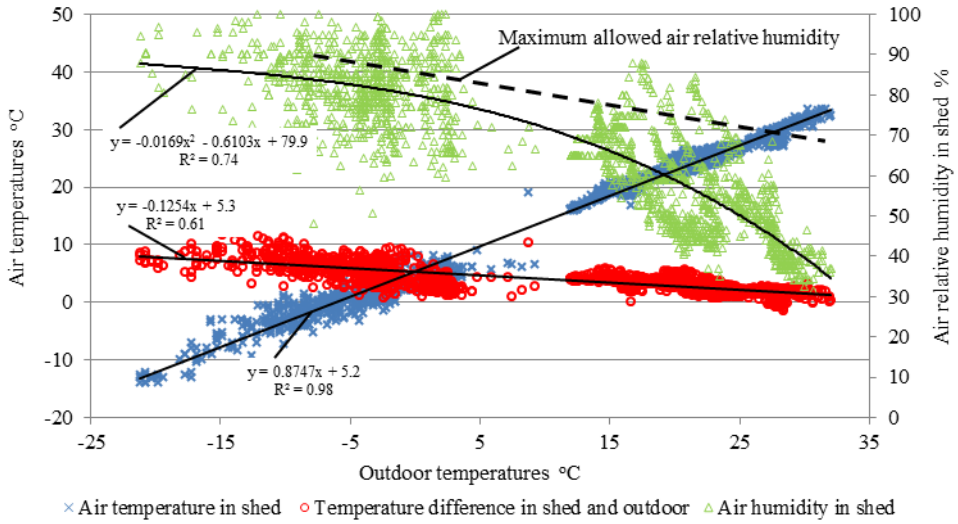

Figure 2. **Dynamics of air temperatures and relative humidity in cold cowshed as a function of outdoor temperatures**

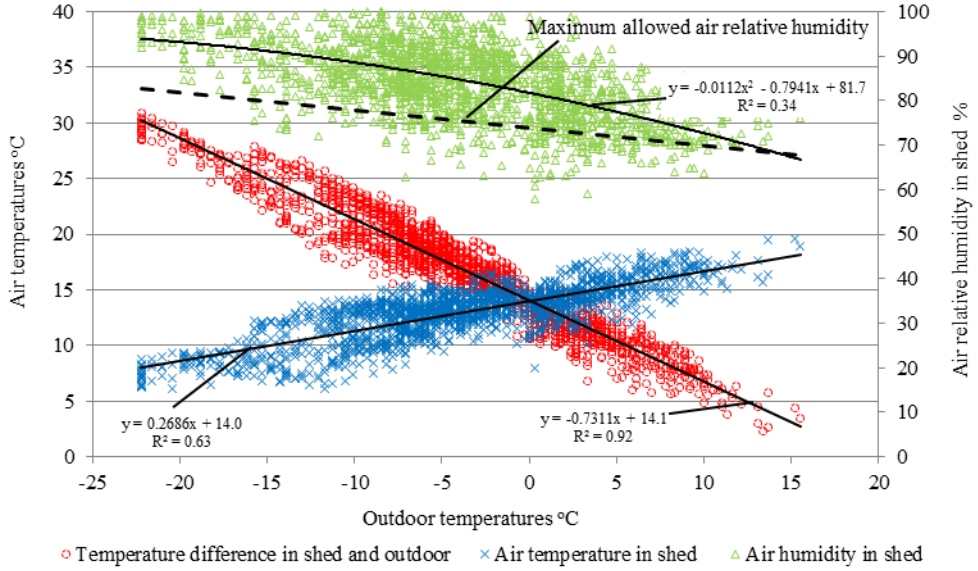

Figure 3. **Dynamics of air temperatures and relative humidity in insulated tied shed as a function of outdoor temperatures**

Table 2. **Outdoor climate conditions which cause unfavourable microclimate in sheds (P<0.04)**

Shed	When were air temperatures too low in shed?	When were air temperatures too high in shed?	When was air relative humidity too high in shed?
Calves shed	not observed	when t_u>26 °C	when t_u<14 °C, Δt>7 °C
Meat pigs shed	not observed	when t_u>23 °C	when t_u<-2 °C, Δt>12 °C
Half-deep insulated cowshed	not observed	when t_u>27 °C	when t_u<6 °C, Δt>13 °C
Insulated tied cowshed	not observed	not observed	when t_u<11°C, Δt>7 °C
Cold cubicle cowshed	when t_u<-13 °C	when t_u>24 °C	when t_u<-10 °C, Δt>6 °C
Semi-insulated cubicle cowshed	not observed	when t_u>25 °C	when t_u<1 °C, Δt>9 °C

t_u – air temperature outdoor °C; t_i – air temperature in shed °C; Δt – differences of air temperatures in shed and outdoor (t_i-t_u), °C.

Complex and expensive equipment, which is necessary for the analysis of air quality parameters, is not required for controlling ventilation systems in sheds. According to our investigation results it is recommended to change ventilation rate in respect to temperature differences outdoors and in a shed. Good correlation between air relative humidity in a shed and temperature differences outdoor and in a shed was estimated. The correlation was good in the tied, cold cubicle cowshed and calf shed (R^2>0.8), in other sheds it was weak (R^2<0.6). After assessing kept animals and thermal characteristics of shed construction, in each shed it is possible to prepare optimal algorithm for controlling ventilation rate according to temperature variation in a shed and outdoors.

Conclusions

In insulated sheds (pig shed, tied half-deep cow shed, heifer/calf shed) temperatures are maintained within limits in winter and in heat periods temperatures are higher by a few degrees than the recommended level. The highest temperatures were in the cold cowshed (10 °C higher than recommended). For a short period in this cowshed the lowest temperature was –14.2 °C, by 7 °C lower than the recommended minimal level (with outdoor temperatures lower than –20 °C).

The main problem in all sheds is not unfavourable temperatures but high air humidity. In the insulated sheds it was too humid even in warm periods of the year. In the cold sheds air humidity increased with outdoor temperatures were below –10 °C, and in the insulated shed - with outdoor temperatures below –11°C. From all measured sheds, the air humidity met the regulations best in the pig shed, cold cubicle cowshed and semi-insulated cubicle cowshed.

The main reason for unfavourable microclimate in sheds was not the improperly installed ventilation system but incorrect maintenance of ventilation systems and very frequently too low rate of ventilation.

After assessment of temperature variation in a shed and outdoors, it is recommended to prepare optimal algorithm for temperature control and to regulate ventilation rate according to it in each shed.

In order avoid too high temperatures in sheds with natural ventilation system during warm periods, it is necessary to use additional instruments for increasing ventilation rate.

References

1. Bartussek H. (1984). Report of Working Group on Climatization of Animal Houses. International Commission of Agricultural Engineering. Aberdeen, 72 p.
2. Caenegem L. V., Wechsler B. (2000). Stallklimawerte und ihre Berechnung. FAT,Tänikon TG, S. 89.
3. Clark J.A. (1992). Envirnmental Aspects of Housing from Animal Production, Butterwoths. London, 511 p.
4. Deuker R. (1984). Thermophysikalische Grundlagen und Untersuchungen wärmetechnischen Kriterien von perforierten Stallfußböden für Schweinehaltung. Dissertation, Justus-Liebig-Universität Gießen, Gießen, S. 177.
5. Frederick K. T., Hautala M., Pastell M., Praks J., Eerma I., Poikalainen V., Pajumagi A., Kivinen T., Ahokas J. (2008). Microclimate and ventilation in Estonian and Finnish dairy buildings. Energy and Buildings 40, pp. 1194–1201.
6. Hilty R., Kaufman R., Caenegem L. (2003). Building for cattle husbandry: Yearbook Agricultural Engineering. VDMA Landtechnik 14, pp. 163–170.
7. Kaasik A., Maasikmets M. (2013). Concentrations of airborne particulate matter, ammonia and carbon dioxide in large scale uninsulated loose housing cowsheds in Estonia. Biosystems engineering, 114, pp. 223–231.
8. Kavolėlis B. (2006). Galvijų fermų technologinio projektavimo taisyklės ir patarimai. Milga, Raudondvaris, 88 p.
9. Kavolėlis B. (2007). Kiaulių fermų technologinis projektavimas. Milga, Raudondvaris, 102 p.
10. Kang J.H., Lee S.J. (2008). Improvement of natural ventilation in a large factory building using a louver ventilator. Building and Environment, 43 (12), pp. 2132–2141.
11. Lucenko M., Salyga D.V. (2006). The estimation of functioning of new volumetric – planning and technological decisions of easily – sectional cowsheds in the conditions of Ukraine. „ New development of technologies and technical means in dairy“ – Proceedings of the 13th International Symposium, pp. 140–146, Gomel, Minsk, Belarus (In Rusian).
12. Neimann S.A., Tribe D.E. (1987). World Animal Science: Bioclimatology and the adaptation of livestock. Amsterdam – Oxford –NewYork – Tokyo, 278 p.
13. Pajumagi A., Veerma I., Praks J., Poikalainen V., Miljan J. (2007). Spatial microclimate patterns in reconstructed and new large uninsulated loose housing cowsheds. Building and Environment 42, pp. 113–121.
14. Pajumagi A., Poikalainen V., Veerma I., Praks J. (2008). Spatial distribution of air temperature as a measure of ventilation efficiency in large uninsulated cowshed. Building and Environment 43, pp. 1016–1022.
15. Sallvik K. (1998). Environment for Animals: Cigr Handbook Of Agricultural Engineering, Animal Production. Volume II. Publisher by: American Society of Agricultural Engineers, pp.32–54.
16. Schneider B. (1988). Computergestützte Kontinuierliche Erfassung der Wärme-, Wasserdampf- und Kohlendioxidproduktion in Nutztierställen. Dissertation, Universität Hohenheim, Hohenheim, S.163.
17. Snell H.G.J, Seipelt F., Van den Weghe H.F.A. (2003). Ventilation Rates and Gaseous Emissions from Naturally Ventilated Dairy Houses. Biosystems Engineering 86 (1), pp. 67–73.
18. Stolpe J. (1985). Stallklimagestaltung. Tierphysiologische Grundlagen und Normative. VEB Gustav Fischer Verlag, Jena, S.164.
19. Teye F.K. (2008). Microclimate and gas emissions in dairy buildings: Instrumentation, theory and measurements. Doctoral Thesis, University of Helsinki, Helsinki, p. 65.
20. Teye F.K., Hautala M., Pastell M., Praks J., Veermae I., Poikalainen V., Pajumagi A., Kivinen T., Ahokas J. (2008). Microclimate and ventilation in Estonian and Finnish dairy buildings. Energy Buildings 40, pp.1194–1201.
21. Zhao L.Y., Bruger M.F., Manuron R.B. (2007). Variations of air quality of New Ohio dairy facilities with natural ventilation systems. Aplied Engineering in Agriculture 23(3), pp. 339–346.

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