The effect of evaporative cooling on climatic parameters in a stable for sows

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Abstract

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The aim of this study was to find out the effect of indirect evaporative cooling on microclimatic parameters in a stable for sows. A high-pressure system was used for cooling, the nozzles sprayed water into the outside air before its entering into the building. Temperature-humidity index during cooling was higher by 0.9 than in the section without cooling ($P < 0.001$). Due to low indoor air flow velocity (below 0.18 m/s), a change in apparent temperature by the Comprehensive Climate Index (CCI) was only 1.94°C. It would be possible to provide markedly better cooling effectiveness by increasing the air velocity up to 2 m/s, which may improve the CCI by 19.8% and thus to achieve better environmental conditions for housed sows. The efficiency of evaluated evaporative cooling system was moderate because the nozzles were placed outdoors and only part of humidified and cooled air was drawn into the building through inlet openings, and also because the indoor air-flow velocity was low.

Keywords: cooling system; water evaporation; summer period; pigs

Current modern types of pigs are demanding as to conditions of stable environment. Pigs are relatively sensitive to high environmental temperatures when compared to other species of farm animals. A lot of research has been done on the factors affecting heat production in pigs (Brown-Brandl et al. 2001). Air temperature as cardinal environmental factor is influenced by relative humidity and air flow velocity. Optimum parameters of temperatures, relative humidity and air velocity for pigs in Slovakia were presented by Botto et al. (1995). Recommended optimum of the air temperature for pregnant sows is 12–20°C at relative humidity 50–75%. Max. air flow velocity at optimum temperature is 0.3 m/s and at temperature higher than optimum it is 2.0 m/s.

Heat waves during summer cause large losses in productivity in animal husbandry. Sows are exposed to heat stress when temperature exceeds the upper critical temperature of the thermoneutral zone of the sow (Black et al. 1993). Thermoneutral zone is the range of environmental temperatures within which the metabolic rate is minimum and independent of temperature. The temperatures that bound this zone are known as upper and lower critical temperatures (Webster 1991). Above the upper critical temperature of this zone the animal will reduce both production and reproduction to control body temperature. Sows begin to feel the negative effects of heat stress at a temperature of 20°C, and temperatures of 26°C and higher are

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considered a critical for pigs (Christianson et al. 1982; Quiniou et al. 2001). Heat stress is one of the major concerns in pork production during summer period because pigs do not have functional sweat glands like other livestock species to assist them in efficiently removing body heat (Souza 2009). Above the upper limit of the thermal neutral, feed consumption is reduced to limit the metabolic heat production (Le Dividich et al. 1998). Heat stress in pigs impairs the animals' welfare and environment (Huynh 2005; Mihina et al. 2011) and economics of pig industry (St-Pierre et al. 2003). The pigs would rid themselves of excess body heat by panting or surface wetting in water or their own excreta under the high ambient temperature and humidity (Aarnink et al. 1996; Huynh et al. 2006). High ambient temperatures cause heat stress and contribute to an increase in sow nonproductive days (St-Pierre et al. 2003). The more heat an animal produces internally by its metabolism, the smaller is its capacity for tolerating external heat (Brouček et al. 2009; Zhang et al. 2011). Environmental hot and humid weather conditions have a great impact on the performance, genetic components and hygienic conditions in pigs (Dong et al. 2001; Zumbach et al. 2008; Pogran et al. 2011). Exposing of sows to heat stress before mating and during early pregnancy may cause reduction in the conception rate and increase in the embryo mortality (Renaudeau et al. 2003), therefore negatively affecting subsequent reproductive performance (Suriyasomboon et al. 2006). Response to heat stress begins with increased respiration rate, continues with decreased feed intake, and leads to increased rectal temperature (Huynh 2005). Decreased feed intake and increased rectal temperature are good indicators of decreased performance of heat-stressed pigs (Huynh et al. 2005).

Utilization of enhanced air flow is one possible method of cooling during high ambient temperatures. In this system the sensational effect of temperature perception is applied. It means that at equal ambient temperature but higher air flow the ambient temperature is sensationally decreased. The cooling effect of air movement is typically expressed by effective temperature, the temperature that animals actually feel (Xin, McFadden 1995).

Barbari and Conti (2009) found out that the high velocity air stream combined with wet floor was preferred by sows during the hottest period. Floor cooling could increase the lying behaviour and improve the production together with reproductive performance of swine (Silva et al. 2006).

Evaporative cooling such as water dripping, showering system and evaporative pads are common and effective way in practice (Bull et al. 1997), but often limited to high relative humidity conditions with inducing additional water vapour into the animal occupied zone (Lucas et al. 2000). Water evaporation cause air-cooling in the building but at the same time, it causes an increase in humidity. This is usually acceptable in regions with hot-dry climates but in wet regions, in order to limit the adverse effects on indoor humidity, special attention must be paid to the accurate control of fogging and ventilation (Haeussermann et al. 2007).

One way how to eliminate heat stress of sows is indirect evaporative cooling, method that uses outside air humidification before its inlet into the building. Outdoor air cooled by evaporation of cold water from sprayed space under the roof at an angle of 45° to the outdoor environment is led to animals, while improving the quality of the indoor environment. This reduces the air temperature, it does not increase critically the relative humidity and temperature-humidity index (THI) (NOAA 1976; Hahn 1985; Mader et al. 2006; Nienaber, Hahn 2007) and improves the change of apparent temperature by Comprehensive Climate Index (CCI) (Mader et al. 2010). This study aims to test this hypothesis and to find out the effect of indirect evaporative cooling on microclimatic parameters in stable for sows in hot days during summer time.

MATERIAL AND METHODS

The experiment was conducted in relatively hot summer of 2012 (29–34°C) in the stable for mated and pregnant sows. Animals were housed in strawless gestation crates, which were arranged in 13 transverse rows with a total housing capacity of 120 sows. The housing also included 4 pens for boars, which were located in the alley next to the longitudinal peripheral wall oriented to the northwest. Feed was metered into a continuous trough, which also served for watering. Water level was maintained there by valve. Extract cross-ventilation was used in the house. Air was exhausted by 7 fans installed in the south-eastern outdoor wall with the total capacity of 4,000 m^3/h. Ten inlet flap-regulated openings, 2 × 600 × 200 mm each, were situated in the opposite wall of the building. Outside air cooled by sprayed water was drawn into the building, so indirect evaporative cooling process was used.

High-pressure water nozzles (11 units) provided spray. They were installed outside the building on a plastic pipe, located at the northwestern wall, at the end of the eaves, 650 mm above upper edge of the flap. Water jet sprayed out of nozzle by an angle of 45° downward.

During the experiment the air was cooled only in one half of the house (section A) and in the other one not modified air was exhausted (section N). Indirect evaporative cooling system was activated since noon to 6:00 p.m. Measurements were carried out from 1:00 to 6:00 p.m. Air temperature, relative humidity and air velocity were continuously recorded at 12 locations in each section in the zone of animals (500 mm above the floor) and at one place outdoor. Universal device ALMEMO 2290-4 (Ahlborn Mess und Regelungstechnik GmbH, Holzkirchen, Germany) and anemometer Testo 435-2 (Testo AG, Lenzkirch, Germany) were used for recording of measured parameters.

Corresponding temperature-humidity index (THI) was calculated according to the following equation recommended by NOAA (1976):

$$\text{THI} = 0.8\ T_a + (\text{RH}/100) \times (T_a - 14.3) + 46.4 \qquad (1)$$

where:
T_a – ambient air temperature (°C)
RH – relative humidity (%)

THI values were classified as a safe if THI ≤ 74, critical, if 74 < THI < 79, dangerous if 79 ≤ THI < 84 and emergency if THI ≥ 84.

Comprehensive Climate Index (CCI), which takes into account other relevant factors, was calculated according to Mader et al. (2010) equation as follows:

$$\text{CCI} = T_a + \text{RH}_{\text{cf}} + \text{WS}_{\text{cf}} + \text{RAD}_{\text{cf}} \qquad (2)$$

where:
T_a – ambient air temperature (°C)
RH_{cf} – correction factor of air humidity
WS_{cf} – correction factor of wind speed
RAD_{cf} – correction factor for radiation influence

Computed following equations:

Obtained climate parameters (temperature, relative humidity, air flow, THI and CCI) were statistically processed and compared among the cooled (A), not cooled (N) sections and outdoor environment (E). Basic statistic parameters (mean values and standard deviations) were calculated, data were analysed by One-Way AOV, and significant differences were tested by Tukey HSD All-Pairwise Comparisons by the STATISTIX, version 9.0 (Analytical Software, Tallahassee, USA).

RESULTS AND DISCUSSION

During the evaluated summer period, the outdoor air temperature ranged from 21.5°C to 34.8°C and relative air humidity ranged from 32.2% to 84.2%. Air temperature in the stable for mated and pregnant sows ranged from 23.4°C to 33.3°C and the relative humidity ranged from 35.7% to 76.4%. In the section without activated evaporative cooling the temperatures 32°C and higher were registered, which represented the proportion 21.53% of the whole observation time. Such values did not occur in the section with activated cooling.

When the outside air temperature was 31.54 ± 0.66°C, the indoor temperature in the section with inactive cooling (N) was the highest 32.88 ± 0.71°C, and in the section with active cooling (A) the lowest 29.96 ± 0.77°C (Table 1). Temperature in section A was lower by 2.92°C than in section N and lower by 1.58°C than ambient temperature. In section N, the temperature was higher by 1.34°C than the outdoor temperature. The differences in all cases were on a very highly significant level ($P < 0.001$; Table 2)

Relative air humidity in section A was higher by 18.52% than in section N and in comparison with the outdoor humidity it was higher by 21.85% (Table 1). Relative air humidity in section N was higher only by 2.80% compared with the outdoor air humidity. However, similar to the temperature also in relative air humidity very highly significant differences were recorded in all cases ($P < 0.001$; Table 2).

$$\text{RH}_{\text{cf}} = e^{[(0.00182 \times \text{RH}) + (1.8 \times 10^{-5} \times T_a \times \text{RH})} \times (0.000054 \times T_a^2 + 0.00192 \times T_a - 0.0246) \times (\text{RH} - 30) \qquad (3)$$

$$\text{WS}_{\text{cf}} = \left[\frac{-6.56}{e^{\left\{\left(\frac{1}{(2.26 \times \text{WS} + 0.23)^{0.45}}\right) \times (2.29 + 1.14 \times 10^{-6} \times \text{WS}2.5 - \log_{0.3}(2.26 \times \text{WS} + 0.33) - 2\right\}}}\right] - 0.00566 \times \text{WS}^2 + 3.33 \qquad (4)$$

$$\text{RAD}_{\text{cf}} = 0.0076 \times \text{RAD} - 0.00002 \times \text{RAD} \times T_a + 0.00005 \times T_a \times \sqrt{\text{RAD}} + 0.1 \times T_a - 2 \qquad (5)$$

Table 1. Mean values (± SD) of climate parameters at the period of cooling (n = 576)

Parameter of air	Outdoor environment	Section with non-active cooling	Section with active cooling
Temperature (°C)	31.54 ± 1.20	32.88 ± 0.71	29.96 ± 0.77
Relative humidity (%)	45.85 ± 10.85	48.65 ± 5.10	67.17 ± 3.00
Flow velocity (m/s)	1.226 ± 0.919	0.113 ± 0.066	0.175 ± 0.030
THI (–)	79.42 ± 0.73	81.75 ± 1.27	80.85 ± 1.21
CCI (°C)	41.03 ± 3.22	40.12 ± 0.99	38.18 ± 1.05

THI – temperature-humidity index; CCI – Comprehensive Climate Index; SD – standard deviation; n – number of measurements

The average air flow velocity in animal zone in section N was 0.113 ± 0.066 m/s, and in section A it was 0.175 ± 0.030 m/s (Table 1). The difference between the sections N and A was not significant (Table 2). The average outdoor wind speed (1.226 ± 0.919 m/s, $P < 0.001$) was significantly higher compared to air flow in both sections.

Outdoor temperature-humidity index had the lowest value of 79.42 ± 0.73 (Table 1). In both observed sections it was significantly higher ($P < 0.001$; Table 4), in section N by 2.33 and in section A by 1.43. These average values could be classified as dangerous (79 < THI < 84; NOAA 1976; Hahn 1985; Nienaber, Hahn 2007).

The average outdoor Comprehensive Climate Index was higher than both indoor sections (41.03 ± 3.22°C; Table 1). In section N (without cooling) CCI was 40.12 ± 0.99°C and in section A (with cooling) it was 38.18 ± 1.05°C. The differences in all cases were on a very highly significant level ($P < 0.001$; Table 2.)

According to Myer and Bucklin (2001), sows begin to feel the negative effects of heat stress at a temperature of 20°C, and temperatures 26°C and higher are critical for them (Christianson et al. 1982; Quiniou et al. 2001).

All indoor air temperatures exceeded 20°C, the upper value of the optimum. Average indoor relative humidity was in the optimum range recommended by Seedorf et al. (1998) and Haeussermann et al. (2007).

The combinations of two cooling systems (water bath and sprinkling) were evaluated by Huynh et al. (2006). The authors, who decided to test cooling systems in pens with or without an additional outdoor yards, found out that the bath and sprinkling reduced respiration rate of pigs by 4.2 and 5.2 min^{-1}, respectively ($P < 0.01$), and their surface body temperature by 0.3 and 0.4°C, respectively, ($P < 0.05$). Rectal temperature was not influenced by any treatment. An important finding in this study was that pigs in pens without an additional outdoor yard with sprinkling achieved greater weight gain. These pigs had limited space and had a high frequency of huddling. The pigs in pens with sprinkling not only benefited from sprinkling by showering but also by lying on the floor wetted by sprinklers. With 12 sprinkling periods at 30 min intervals, the floor stayed wet almost for the whole period between 10:00 a.m. and 4:00 p.m. In our experiment a wet floor was sporadically detected in windy climate and animals did not feel uncomfortably. A cooling system with sprinkling should avoid introducing surplus water into the air of barns. The main limitations of vapour cooling system is a heavy water use, increase of air humidity and the

Table 2. Differences of climate parameters among outdoor environment (E) and indoor sections (N) and section with active cooling (A) (n = 576)

Parameter of air	Section N–E	Section A–E	Sections N–A
Temperature (°C)	1.34*	–1.58*	2.92*
Relative humidity (%)	2.80*	21.32*	–18.52*
Flow velocity (m/s)	–1.113*	–1.051*	-0.062^{ns}
THI (–)	2.33*	1.43*	0.90*
CCI (°C)	–0.91*	–2.85*	1.94*

*significant at the level of $P < 0.001$; ^{ns}not significant ($P > 0.05$); CCI – Comprehensive Climate Index; n – number of measurements subsequent problems with slurry dilution if the water is collected in the slurry.

The analysis of period with frequent occurrence of both high temperature and low relative humidity during the heat stress periods is an indication that evaporative cooling systems may be a feasible and cost-effective solution for minimizing the effect caused by such high thermal stressors in pig production. A computer simulation of the psychrometric process predicted that most periods of heat stress can be eliminated by using an evaporative cooling pad system with an efficiency of 80% (Lucas et al. 2000). If we apply the Lucas theory to results of our measurements, it would be possible to decrease the dry bulb indoor temperature by 7.5°C. The described system of indirect evaporative cooling is easier from service and economy view points, but it is not possible to achieve adequate results at cooling without additional construction and technological arrangements.

In pig husbandry was developed a lot of technical solutions with direct and indirect elimination of heat stress of animal with different breeding effect and economy. Some cooling systems involve high investments and some can cause adverse effects like increased humidity. It is known that high relative humidity depresses pig production (Lucas et al. 2000).

Silva et al. (2006) found positive effects of sow cooling by using the floor cooling system. Although the results of this method of cooling are interesting in view of the breeding results, its implementation in existing pig husbandry is difficult.

In experiment carried by Pang et al. (2010) a significant decrease of respiration rate and surface body temperature of sows in individual boxes with water-cooled cover was demonstrable. This construction consisted of a steel frame (in ground floor plane 600 mm × 1,500 mm, height 1,000 mm), galvanized steel water pipes (total length 57 m), an aluminium canopy and the heat insulating layer. Significant differences were found between lying time in cooling and non-cooling boxes.

The indirect evaporation cooling, realized in our climatic conditions, decreased significantly the air indoor temperature, however, from the Comprehensive Climate Index (Mader et al. 2010) analysis follows that the change in apparent temperature was only 1.94°C. Increase of air moving in animal zone may play a big role during critical hot summer days. No suitable change of air speed was found in our study between activated and non-activated state of cooling. In our study the average air velocity in the animal zone during non-activated and activated process of cooling (0.113 and 0.175 m/s) at indoor air temperatures above 26°C was insufficient. Technological equipment and method of ventilation design should allow not only sufficient air exchange but an increased airflow in the zone of the animals as well.

From the analysis of the measured data we found out, by simulated mathematical calculations in the section with activated cooling (A), that if air velocity increased to 1 m/s, the value of CCI would be reduced by 10.2%. Upon reaching the max. permissible air velocity 2.0 m/s in the zone of animals, the CCI reduction would be up to 19.8%. The environmental conditions for housed sows markedly improved in this way.

Bieda et al. (2001) designed another method of cooling. They prepared an experimental prototype of air-earth exchanger tube system, usable in the winter and summer period for modification of indoor air in extreme climate conditions. According to the results of their studies the temperature of piped air was by 11–14°C cooler during hot summer period.

Although our findings were positive only partly when analysing the thermal-humidity mode in treated compartment (marginal decrease of air temperature and THI improvement) the used system of indirect cooling has still some reserves. Vegetation or non-vegetation shielding of space, from which the modified air will be applied into building, would be appropriate at careful building projection. It is possible to use a manual sprinkling of animal body or lying floors, to cool the animals by contacting a wet concrete in extremely hot summer days.

CONCLUSION

The indirect evaporative cooling was tested by analyses of climate parameters in the experimental stable for sows. That system uses a method of spraying water into the hot outdoor air, outside the building, where it is cooled by evaporative effect of water sprayed from the jets under the roof. The air, conditioned by that way, is drawn into the building and improves the quality of the indoor environment. The air temperature and comprehensive climate index decrease but the relative humidity does not increase critically; the temperature-humidity index decreases slightly. The resulting temperature difference with the application of cooling reached in our experiment cooling of the indoor air about 3°C. The system allows almost instantaneous declension of temperature curve from the risk of animals with a relatively low cost investment. A partial increase of internal relative humidity was within the range of recommended values. During the period with the higher relative humidity of ambient air, the air cooling system is not used. Running fans with higher output provided cooling at that time only by air flow. Due to low indoor air flow velocity (below 0.18 m/s), a change in apparent temperature by Comprehensive Climate Index was only 1.94°C. It would be possible to provide markedly better effectiveness of indirect cooling by increasing the air velocity up to 2 m/s in the zone of animals, which may improve the CCI by 19.8% and thus achieve better conditions for thermal comfort of housed sows. In capital-intensive cooling systems it is possible to achieve a greater impact; however, they cannot be usually installed additionally in full operation on farm. Efficiency of evaluated evaporative cooling system was moderate, because the nozzles were placed outdoors and only part of the humidified and cooled air was drawn into the building through inlet openings, and secondly because the indoor air flow velocity was low.

References

Aarnink A.J.A., van den Berg A.J., Keen A., Hoeksma P., Verstegen M.W.A., 1996. Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. Journal of Agricultural Engineering Research, *64*: 299–310.

Barbari M., Conti L., 2009. Use of different cooling systems by pregnant sows in experimental pen. Biosystems Engineering, *103*: 239–244.

Bieda W., Herbut E., Kozbial M., 2001. Preliminary results of studies on the heating of broiler house using aerial-earth tube heat exchanger. Annals of Animal Science, *1*: 195–202.

Black J.L., Mullan B.P., Lorschy M.L., Giles L.R., 1993. Lactation in the sow during heat stress. Livestock Production Science, *35*: 153–170.

Botto Ľ., Waldnerová S., Mihina Š., Brestenský V., Lendelová J., 1995. Podklady pre modernizáciu a rekonštrukciu objektov pre chov ošípaných. [Documentation for Modernization and Reconstruction of Stables for pig Rearing.] RIAP, Nitra: 61.

Brown-Brandl T.M., Eigenberg R.A., Nienaber J.A., Kachman S.D., 2001. Thermoregulatory profile of a newer genetic line of pigs. Livestock Production Science, *71*: 253–260.

Brouček J., Novák P., Vokřálová J., Šoch M., Kišac P., Uhrinčať M., 2009. Effect of high temperature on milk production of cows from free-stall housing with natural ventilation. Slovak Journal of Animal Science, *42*: 167–173.

Bull R.P., Harrison P.C., Riskowski G.L., Gonyou H.W., 1997. Preference among cooling systems by gilts under heat stress. Journal of Animal Science, *75*: 2078–2083.

Christianson L., Hahn G.L., Meador N., 1982. Swine performance model for summer conditions. International Journal of Biometeorology, *26*: 137–143.

Dong H., Tao X., Li Y., Xin H., 2001. Comparative evaluation of cooling systems for farrowing sows. American Society of Agricultural Engineers, *17*: 91–96.

Frančák, J., Mihina Š., Angelovič M., Gálik R., Korenko M., Simoník J., Botto Ľ., Jobbágy J., Žitňák M. 2012. Technika v Agrosektore. [Technic in Agrosector.] 1st Ed. Nitra, SUA in Nitra: 199.

Hahn G.L., 1985. Management and housing of farm animals in hot environmentals. In: Yousef M.K. (ed.), Stress Physiology in Livestock. Vol. II. Boca Raton, CRC Press: 151–174.

Haeussermann A., Hartung E., Jungbluth T., Vranken E., Aerts J.-M., Berckmans D., 2007. Cooling effects and evaporation characteristics of fogging systems in an experimental piggery. Biosystems Engineering, *97*: 395–405.

Huynh T.T.T., 2005. Heat stress in growing pigs. [Ph.D. Thesis.] Wageningen, Wageningen University: 167.

Huynh, T.T.T., Aarnink A.J.A., Verstegen M.W.A., Gerrits W.J.J., Heetkamp M.J.W., Kemps B., Canh T.T., 2005. Effects of increasing temperatures on physiological changes in pigs at different relative humidities. Journal of Animal Science, *83*: 1385–1396.

Huynh T.T.T., Aarnink A.J.A., Truong C.T., Kemp B., Verstegen, M.W.A., 2006. Effects of tropical climate and water cooling methods on growing pigs' responses. Livestock Science, *104*: 278–291.

Le Dividich J., Noblet J., Herpin P., Van Milgen J., Quiniou N., 1998. Thermoregulation. In: Wiseman J., Varley M.A., Chadwick J.P. (eds), Progress in Pig Science. Nottingham, Nottingham University Press: 229–263.

Lucas E.M., Randall J.M., Meneses J.F., 2000. Potential for evaporative cooling during heat stress periods in pig production in Portugal (Alentejo). Journal of Agricultural Engineering Research, *76*: 363–371.

Mader T.L., Davis M.S., Brown-Brandl T., 2006. Environmental factors influencing heat stress in feedlot cattle. Journal of Animal Science, *84*: 712–719.

Mader T.L., Johnson L.J., Gaughan J.B., 2010. A comprehensive index for assessing environmental stress in animals. Journal of Animal Science, *88*: 2153–65.

Mihina Š., Cicka A., Brouček J., 2011. Animal welfare as an important factor of food quality. Potravinarstvo, *5* (Special Issue): 156–163.

Myer R., Bucklin R., 2001. Influence of hot-humid environment on growth performance and reproduction of swine. Document AN107, Extension, Institute of Food and Agricultural Sciences, University of Florida. Available at http://edis.ifas.ufl.edu/an107

Nienaber J.A., Hahn G.L., 2007. Livestock production system management response to thermal challenges. International Journal of Biometeorology, *52*: 149–157.

NOAA, 1976. Livestock Hot Weather Stress. Operations Manual Letter C-31-76. Kansas City, National Oceanic and Atmospheric Administration.

Pang Z., Li B., Xin H., Lee I.B., Xi L., Cao W., Bitog J.P., Wang Ch., Li W., 2010. Effect of a water-cooled cover on the thermal comfort of pregnant sows in hot and humid climate. In: CIGR XVIIth World Congress, June 13–17, 2010, Québec City: 11.

Pogran Š., Bieda W., Gálik R., Lendelová J. Švenková J., 2011. Kvalita vnútorného prostredia ustajňovacích objektov. [Quality of Internal Environment in Animal Housing.] 1st Ed. Nitra, SUA in Nitra: 242.

Quiniou N.J., Renaudeau D., Milgen J., Dubois S., 2001. Modelling heat production and energy balance in group-housed growing pigs exposed to cold or hot ambient temperatures. British Journal of Nutrition, *85*: 97–106.

Renaudeau D., Noblet J., Dourmad J.Y., 2003. Effect of ambient temperature on mammary gland metabolism in lactating sows. Journal of Animal Science, *81*: 217–231.

Seedorf J., Schröder M., Linkert K.-H., Wathes C.M., 1998. Concentrations and emissions of airborne dust in livestock buildings in Northern Europe. Journal of Agricultural Engineering Research, *70*: 59–77.

Silva B.A.N., Oliveira R.F.M., Donzele J.L., Fernandes H.C., Abreu M.L.T., Noblet J., Nunes C.G.V., 2006. Effect of floor cooling on performance of lactating sows during summer. Livestock Science, *105*: 176–184.

Souza L., 2009. How Can Heat Stress Affect your Production? The Pig Site (the website for the global pig industry). Available at http://www.thepigsite.com

Suriyasomboon A., Lundeheim N., Kunavongkrit A., Einarsson S., 2006. Effect of temperature and humidity on reproductive performance of crossbred sows in Thailand. Theriogenology, *65*: 606–628.

St-Pierre N.R., Cobanov B., Schnitkey G., 2003. Economic losses from heat stress by US livestock industries. Journal of Dairy Science, *86* (E. Suppl.): E52–E77.

Xin H., Mcfadden V.J., 1995. Tunnel ventilation to alleviate animal heat stress. In: Livestock Industry Facilities & Environment, Pm-1606, Ames, Iowa State University. Available at http://www.extension.iastate.edu

Webster A.J.F., 1991. Metabolic Responses of Farm Animals to High Temperature. EAAP Publication, No. 55: 15–22.

Zhang H., Wang Z., Liu G., He J., Su Ch., 2011. Effect of dietary fat supplementation on milk components and blood parameters of early-lactating cows under heat stress. Slovak Journal of Animal Science, *44*: 52–58.

Zumbach B., Misztal I., Tsuruta S., Sanchez J.P., Azain M., Herring W., Holl J., Long T., Culbertson M., 2008. Genetic components of heat stress in finishing pigs: Development of a heat load function. Journal of Animal Science, *86*: 2082–2088.

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