HEAT STRESS IN GROWING PIGS

Promotoren:	Prof. dr. ir. M. W. A. Verstegen Hoogleraar in de Diervoeding, Wageningen Universiteit
	Prof. Dr. Ir. B. Kemp Hoogleraar in de Adaptatiefysiologie, Wageningen Universiteit
Co – promotor:	Dr. ir. A. J. A. Aarnink Group of Livestock Environment van Wageningen UR

Promotiecommissie:

Prof. dr. G. H. Visser	Rijksuniversiteit Groningen
Prof. dr. D. van der Heide	Wageningen Universiteit
Prof. dr. L. A. den Hartog	Wageningen Universiteit
Dr. Truong Thanh Canh	University of Natural Science of Ho Chi Minh city, Vietnam

Dit onderzoek is uitgevoerd binnen de onderzoekschool Wageningen Institute of Animal Sciences.

HUYNH THI THANH THUY

HEAT STRESS IN GROWING PIGS

PROEFSCHRIFT

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Prof. Dr. Ir. L. Speelman,
in het openbaar te verdedigen
op maandag 14 maart 2005
des namiddags te vier uur in de Aula.

Huynh, T.T.T., 2005. Heat Stress in Growing Pigs.
PhD. Thesis, Wageningen Institute of Animal Science, Wageningen University, Wageningen, The Netherlands.

With summaries in Vietnamese, Dutch and English

ISBN 90-8504-156-2

ABSTRACT

HEAT STRESS IN GROWING PIGS

Compared to other species of farm animals, pigs are more sensitive to high environmental temperatures, because they cannot sweat and do not pant so well. Furthermore, fast-growing lean pigs generate more heat than their congeners living in the wild. This, in combination with confined housing, makes it difficult for these pigs to regulate their heat balance. Heat stressed pigs have low performance, poor welfare, and, by pen fouling, they give higher emissions of odour and ammonia.

Above certain critical temperatures (inflection point temperatures) pigs start to adapt their mechanisms of balancing heat loss and heat production. The inflection point temperatures above which the responses change may well differ depending on which animal parameter is studied. Within this thesis, firstly, these critical temperatures were determined for different physiological, behavioral and production parameters. Secondly, the effect of different cooling systems on these parameters was studied.

In order of appearance we found inflection point temperatures for respiration rate, evaporative water, ratio of water to feed intake, total heat production, activity heat production, lying on slatted floor, voluntary feed intake and rectal temperature. These inflection point temperatures were different for the different parameters and show the subsequent strategies the pig follows at increasing temperatures. Relative humidity had minor effects on physiological parameters. However, a combination of high relative humidity and high temperature showed a detrimental effect on daily gain. The availability of cooling systems, e.g. floor cooling, water bath or sprinklers, had beneficial effects on pigs' performance.

It is concluded that high ambient temperatures strongly affect physiology, behaviour and performance of growing pigs. The inflection point temperatures found in this study are good indicators of heat stress. These can be used as set points for cooling systems. Cooling systems improve animal performance and welfare under high temperature conditions.

TÓM TẮT

STRESS NHIỆT TRÊN HEO THỊT

Khi so sánh với các loài gia súc nuôi khác, heo kém chịu đựng trong môi trường nhiệt độ cao. Heo không có khả năng thoát nhiệt bằng toát mồ hôi và cũng không thể tăng tối đa tần số hô hấp. Heo có sức tăng trưởng nhanh tiêu thụ nhiều thức ăn hơn và sản xuất nhiều nhiệt hơn heo chậm phát triển. Ngoài ra, heo công nghiệp thường được nuôi giam và do đó khả năng tự điều chỉnh nhiệt của chúng thấp hơn heo nuôi trong điều kiện tự nhiên. Heo thịt trong tình trạng stress nhiệt chậm phát triển, an sinh kém, và gây ô nhiểm môi trường như tăng thải mùi và ammonia. Mục tiêu quan trọng của luận văn này là xác định tại những điểm nào của nhiệt độ môi trường khiến heo bộc lộ ảnh hưởng của stress nhiệt. Tùy theo từng thông số khać nhau về sinh lý, hành vi và khả năng sản xuất mà heo sẽ bộc lộ stress ở những điểm khác nhau của nhiệt độ môi trường. Sau khi xác định được nhiệt độ môi trường tại đó heo bộc lộ stress, những biện pháp làm mát cho heo được tuần tự áp dụng. Những biện pháp này gồm có sàn lạnh cho heo nuôi trong trại công nghiệp hiện đại tại Hà Lan và bễ tắm và vòi phun mát cho heo trong điều kiện chăn nuôi đơn giản tại Việt Nam.

Theo thứ tự mà heo bộc lộ sự stress nhiệt, chúng tôi xác định các điểm stress nhiệt khác nhau cho các thông số khác nhau của heo như sau: tăng hô hấp, thoát hơi nước tổng số, tỉ số giữa thức ăn và nước uống, tổng số nhiệt sản xuất, hoạt động của heo tuỳ thuộc mức độ sản xuất nhiệt, số heo nằm trên sàn lưới, thực phẩm ăn vào, và thân nhiệt. Nhiệt độ môi trường ảnh hưởng nặng nề đến việc heo phải điều chỉnh các hoạt động sinh lý và hành vi và sức sản xuất. Ẩm độ có ảnh hưởng chỉ khi kết hợp với nhiệt độ cao. Khi các biện pháp làm mát đựoc sử dụng, hậu quả của stress nhiệt trên heo đựoc giảm nhẹ rất có ý nghĩa. Tóm lại, các thông số tìm thấy thông qua đề tài đóng góp rất lớn cho việc hiểu biết về ảnh hưởng của nhiệt độ cao trên chăn nuôi heo thịt tại vùng nhiệt đới cũng như vào giai đoạn nóng bức tại vùng ôn đới. Những thông số chính xác về điểm stress nhiệt cho heo thịt có thể trước mắt được sử dụng cho việc xác định nhiệt độ giới hạn cho các hệ thống làm mát tự động. Hiệu quả của bễ tắm và vòi phun có thể được áp dụng trong thực tế chăn nuôi heo trong vùng nhiệt đới.

UITTREKSEL

HITTESTRESS BIJ VLEESVARKENS

Vergeleken met andere landbouwhuisdieren zijn varkens zeer gevoelig voor hoge omgevingstemperaturen. Zij kunnen namelijk niet actief zweten en de waterverdamping via de longen is ook beperkt. Daarnaast produceren snel groeiende vleesvarkens meer warmte dan hun soortgenoten in het wild. Het voorgaande, gecombineerd met de geringe mogelijkheden die ze in stallen hebben, maakt het voor deze varkens extra moeilijk om hun warmtebalans te reguleren. Varkens met hittestress hebben een slechtere productie, verminderd welzijn en, door hokbevuiling, geven ze meer emissies van geur en ammoniak.

Boven bepaalde kritieke temperaturen (breekpunt temperaturen) veranderen varkens hun mechanismen van warmteregulatie. De breekpunttemperaturen kunnen verschillend zijn voor de verschillende parameters die gemeten worden. In dit proefschrift zijn deze breekpunttemperaturen voor verschillende fysiologische, gedrags- en productieparameters bepaald. Daarnaast is het effect van verschillende koelsystemen op deze parameters onderzocht.

Bij toenemende temperatuur, werden achtereenvolgens breekpunten gevonden voor ademhalingsfrequentie, waterverdamping, water/voer verhouding, totale warmteproductie, warmteproductie als gevolg van activiteit, liggen op de roostervloer, voeropname en lichaamstemperatuur. Deze achtereenvolgende breekpunten laten de opeenvolgende strategieën van het varken zien als reactie op toenemende omgevingstemperaturen. Relatieve luchtvochtigheid had slechts een gering effect op de fysiologische parameters. Een combinatie van een hoge relatieve luchtvochtigheid en een hoge temperatuur gaf echter een lagere groei bij de dieren. Koelsystemen, zoals vloerkoeling, een waterbad of sproeiers, verbeterden de productieresultaten bij de dieren. De conclusie is dat hoge omgevingstemperaturen een sterke invloed hebben op de fysiologie, het gedrag en de productie van vleesvarkens. De breekpunttemperaturen zoals gevonden in dit onderzoek zijn goede indicatoren van hittestress. Ze kunnen gebruikt worden als setpoints voor koelsystemen. Koelsystemen verbeteren de productie en het welzijn van vleesvarkens bij hoge omgevingstemperaturen.

Contents

GENERAL INTRODUCTION

INTRODUCTION

Compared to other species of farm animals, pigs are more sensitive to high environmental temperatures because they cannot sweat and do not pant so well. They respond to heat stress by invoking a complex of physiological, behavioural and anatomical mechanisms aimed at facilitating heat loss to, or minimizing heat gain from, the environment. In nature, wild pigs can wallow in mud or water when necessary, shelter during hot periods of the day and shift their activity from day to night (Mount, 1979). Since the nineteenth century, pigs have been bred for high lean meat content and fast growth and have been kept in confined systems (Mount, 1979). Fast-growing lean pigs generate more heat from their feed intake. This, in combination with confined housing, makes it difficult for the pigs in intensive systems to regulate their heat balance. Whereas outdoor pigs can choose their own environment (e.g. shadow, mud pool, staying away from other pigs), indoor pigs have to cope with the confined environment. The opportunity to lose heat is especially important in the indoor climate. In a normal climatic environment, pigs have a variety of mechanisms for eliminating heat. Radiation, conduction, convection and evaporation can transfer heat through the body surface to the environment (Mount, 1979). This heat loss pathway is efficient when ambient temperature is lower than body temperature; it can be physically changed by increasing or decreasing respiration rate, skin temperature, and body temperature.

Figure 1 illustrates the general concept of thermo-regulation of pigs as formulated by Mount (1979). Within the temperature zone A - D pigs can keep their body temperature constant. Ambient temperatures below A cause body temperature to fall, while above D the body temperature rises. The zone A - D can be divided into zones A - B and B - D. Within zone A – B, body temperature is kept constant by regulation of heat production. Heat production within this zone can be increased by shivering (shivering thermogenesis) or by producing extra heat without shivering (non-shivering thermogenesis). In zone B - D body temperature is kept constant by regulation of heat loss.

Heat loss in zone B – D is regulated by changing the thermal resistance of the skin and by water evaporating via skin and the lungs. In this zone, heat production is minimal at a given feed intake. Known as the thermo-neutral zone, this is the zone in which optimal production can be achieved, while the energy required for maintenance is minimal. Point B is called the lower critical temperature, while point D is called the upper critical temperature.

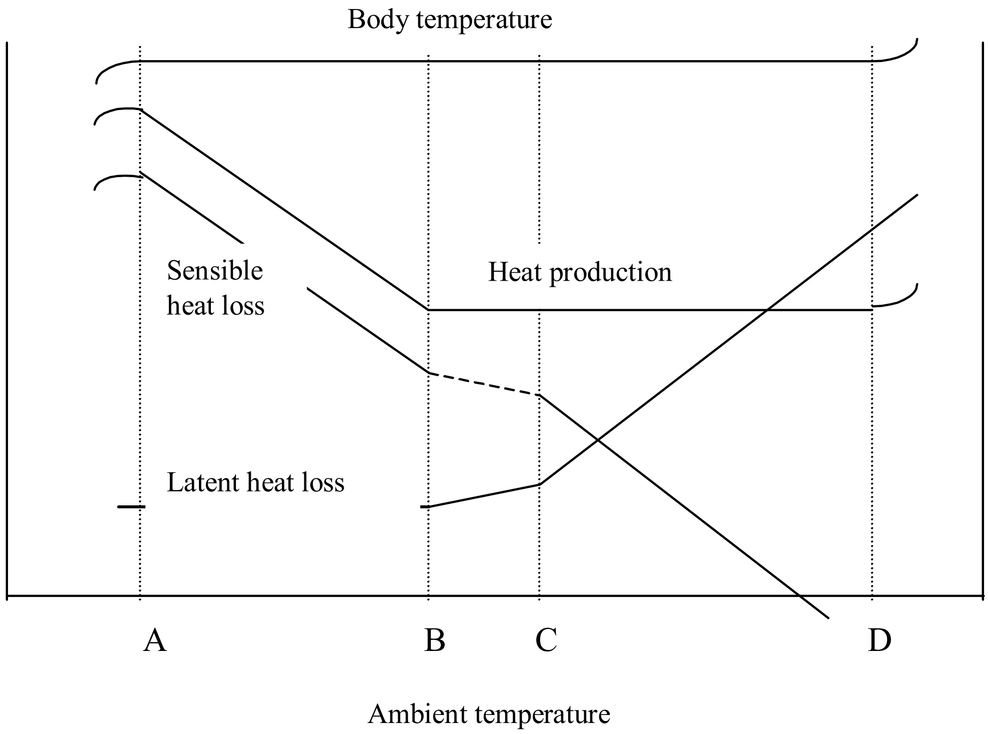

Figure 1. Pattern of heat production and its balance with heat loss as affected by the external effective environmental temperature (Mount, 1979)

Above the thermo-neutral zone heat production increases because extra energy is needed to lose heat. The upper critical temperature mainly depends on feeding level, animal weight, air movement and relative humidity (RH) (Esmay, 1969; Curtis, 1985). Zone B-C, called the comfort zone, is defined as the zone in which pigs can regulate their heat loss by physical means (Curtis, 1983). This means that they do not need to pant to lose heat. The lower temperature of the comfort zone equals the lower critical temperature (point B, figure 1). The upper temperature of the comfort zone is lower than the upper critical temperature (point C, figure 1).

A lot of research has been done on the factors affecting heat production in pigs (e.g. Verstegen et al., 1974; 1978; Nienaber et al. 1991; 1996; Brown - Brandl et al., 1998; 2000; 2001). The negative effects of upper critical temperatures in animal production have also been discussed (Curtis, 1985; Hahn et al., 1987; Christon et al., 1988). The primary consequence of heat stress is that animals reduce feed intake progressively with increased temperature (Kemp and Verstegen, 1987). This loss in feed intake will reduce the performance of the pig. During heat stress pigs will not only lower feed intake to reduce heat production, but will also alter their behaviour in order to lose more heat. Mount (1979) reported that the pigs could modify their postures in relation to ambient conditions, to either increase or decrease heat loss. Steinbach (1978) correlated the use pigs made of cooling facilities in hot conditions, showing the relationship between the thermoregulation of pigs and their environments. Hahn (1985) reported that the behavioural patterns of farm animals, including pigs, were altered by hot environments, as animals attempted to maintain homeostasis by postural adjustment. When lying, pigs will avoid contact with other pigs and will seek out cool places in the pen. The excreting area is often the coolest place. Aarnink et al. (1996; 1997; 2001) reported that fattening pigs preferred to lie on slatted floor at high ambient temperature. They commented that pigs also shifted their excreting area to the solid floor and daubed themselves with manure and urine to cool themselves by evaporative cooling. However, from the hygienic and environmental pollution point of view this is undesirable.

To date, the effects on pig performance of a climatic environment in which temperatures are constant or fluctuate diurnally or from day to day have not been investigated in detail. A fluctuating ambient temperature seems to have a smaller effect on pig productivity than a constant temperature at the same mean (Nienaber, 1989). This is because a lower ambient temperature at night enables pigs to compensate for the lower feed intake in the day and improves the comfort stage of the pig. As both cases may occur in practice, it is important to understand how the pigs react to each situation. The problems described above might be more serious in combination with high humidity. In the literature it has even been stated that humidity contributes importantly in the thermoregulation of finishing pigs (Heitman and Hughes, 1949; Mount, 1972; Curtis, 1985; Nienaber, 1999), but quantitative evidence of this has been lacking. When ambient temperature is above a certain threshold, evaporation may be the only means by which pigs can lose heat; therefore, evaporative heat loss becomes a major avenue in the heat balance in pigs. Evaporative heat loss might occur either via respiratory evaporation or by evaporation from the wet body surface. In non-sweating animals these two ways are not equal. For pigs, evaporation via the skin surface is only possible when the skin is wet. In confined housing, the pigs eliminate their heat load mainly by respiratory evaporation. In short-term studies (less than a week), Heitman and Hughes (1949) found that at ambient temperature of 32^0 C and with a rise in relative humidity from 30 % to 95 % the respiration rate increased.

Ideally, we should know the heat regulation of pigs in relation to the effective temperature, i.e. the temperature experienced by the pig. The effective temperature depends not only on the temperature effect but also on the relative humidity (and air velocity). In this project, we approached these questions as described in the thesis outline below.

Thesis outline

Little information is available about the ambient temperatures above which group-housed pigs start to adapt their mechanisms of balancing heat loss and heat production. The temperature above which an adaptive response occurs (also called the critical temperature or inflection point temperature) may well differ depending on which physiological parameter is studied. We considered the following four physiological parameters: respiration rate, rectal temperature, skin temperature and heat production. In addition, we considered one performance parameter: voluntary feed intake. There is little published information on the effect of relative humidity (RH) on these parameters too. The present study was therefore designed to quantify the short-term responses of growing-finishing pigs to different ambient temperatures and at different relative humidities. We measured heat production and heat dissipation mechanisms as indicated by the pigs themselves. Changes were observed in the temperature range of 16 to 32^0 C and relative humidity range of 50 % to 80 %. These ambient temperature and RH combinations were chosen to cover the same values as in a tropical climate. The results of this experiment are presented in chapter 2.

Chapter 3 describes how, in the same experiment as described in chapter 2, the behavioural responses of group-housed, ad libitum fed, growing-finishing pigs at different ambient temperatures and different relative humidities was evaluated. The aim was to derive the inflection point temperatures above which growing-finishing pigs change their lying and excretion behaviour. We hypothesised that high ambient temperatures and high humidity will affect lying and excreting behavioural patterns, and that the relationship between this behaviour and temperature and humidity can be used to derive upper critical temperatures for the climate in pig houses.

Chapter 4 demonstrates the effect of a floor cooling system on the responses of fattening pigs during a hot summer period in Western commercial pig production. Since a slatted floor is a popular design in terms of hygiene and lower labour cost for cleaning, about 40% of the floor in the pens in Dutch pig farms is slatted. Pigs prefer to lie on an insulated solid floor and not on the slatted floor. Therefore the number of pigs lying on the slatted floor is an important indicator that temperatures in the pig house are undesirably high. In addition to causing thermoregulatory and behavioural problems, high ambient temperatures also have a detrimental effect on pig production. The objective of the experiment described in this chapter was to determine how floor cooling in partially solid floor systems changed the behaviour of the animals. It was also aimed to improve the performance of growing-finishing pigs at high ambient temperatures. More specifically, this study looked at the effects of floor cooling on lying behaviour, pen fouling, feed intake, and average daily gain.

Given the importance of pig production in Viet Nam in particular, and in the humid tropics in general, there is a need to ascertain the impact of this climate on physiology and behaviour and how this is related to animal performance. We therefore carried out an experiment to determine the influence of tropical climate conditions on the physiological, behavioural responses in pigs as raised on small-scale farms in Viet Nam. We also applied different cooling facilities, e.g. sprinklers, water bath, and an extra outdoor yard to investigate the effects of cooling and housing systems on these responses. The results of this experiment are presented in chapter 5.

In chapter 6 the results from all the experiments are reviewed and evaluated. The discussion is based on how we bridged the gaps between the existing literature and our findings on heat stress in finishing pigs. The bridges were inflection point temperatures for reactions in the physiology, behaviour, and performance of ad-lib, fast growing, and group-housed finishing pigs. Also discussed is the agreement between results from controlled experiments and field experiments.

LITERATURE CITED

Aarnink, A. J. A., van den Berg A. J., Keen A., Hoeksma P., and 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.

Aarnink, A. J. A., D. Swierstra, A. J. van den Berg, and L. Speelman. 1997. Effect of type of slatted floor and degree of fouling of solid floor on ammonia emission rates from fattening piggeries. Journal of Agricultural Engineering Research 66: 93-102.

Aarnink, A. J. A., J. W. Schrama, R. J. E. Verheijen, and J. Stefanowska. 2001. Pen fouling in pig houses affected by temperature. In: Livestock Environment VI, Galt House Hotel Louisville, Kentucky. p 180 - 186.

Brown-Brandl, T. M., J. A. Nienaber, and L. W. Turner. 1998. Acute heat stress effects on heat production and respiration rate in swine. Transactions of the ASAE 41: 789-793.

Brown-Brandl, T. M., J. A. Nienaber, L. W. Turner, and J. T. Yen. 2000. Manual and thermal induced feed intake restriction on finishing barrows. In: Effects on heat production, activity, and organ weights. Transactions of the ASAE 43: 993-997.

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

Christon, R. 1988. The effect of tropical ambient temperature on growth and metabolism in pigs. Journal of Animal Science 66: 3112-3123.

Curtis, S. E. 1983. Environmental managements in animal agriculture. Iowa State University. Press, Ames.

Curtis, S. E. 1985. Physiological responses and adaptations of swine. In: M. K. Yousef (ed.) Stress physiology in livestock No. II. p 62 - 63. CRC Press, Las Vegas, Nevada.

Esmay, M. L. 1969. Principles of animal environment. The Avi Publishing Company, Inc., Westport, Connecticut.

Hahn, G. L. 1985. Management and housing of farm animals in hot environments. In: M. K. Yousef (ed.) Stress physiology in livestock No. II. p 152 - 171. CRC Press.

Hahn, G. L., J.A. Nienaber, and J. A. DeShazer. 1987. Air temperature influences on swine performance and behavior. Appl-Eng-Agric. St. Joseph, Mich.: American Society of Agricultural Engineers 3: 295-302.

Heitman, H. J., and E. H. Hughes. 1949. The effects of air temperature and relative humidity on the physiological well being of swine. Journal of Animal Science 8: 171 - 181.

Kemp, B., and M. W. A. Verstegen. 1987. The influence of climatic environment on sows. In: M.W.A.Verstegen and A.M. Henken (eds.) Energy metabolism in farm animals effects of housing, stress and disease. p 115. Martinus Nijhoff, Dortrecht.

Mount, L. E. 1979. Adaptation to thermal environment: Man and his productive animals. Edward Arnold Limited, Thomson Litho Ltd, East Kilbride, Scotland.

Nienaber, J. A., G. L. Hahn, H. G. Klemcke, B. A. Becker, and F. Blecha. 1989. Cyclic temperature effects on growing - finishing swine. J. therm. BioL 14: 233 - 237.

Nienaber, J. A., G. L. Hahn, and T. McDonald. 1991. Thermal environment effect on feeding patterns and swine performance. Paper presented at the "1991 International Summer Meeting sponsored by the American Society of Agricultural Engineers", Albuquerque, New Mexico: 14.

Nienaber, J. A., G. L. Hahn, T. P. McDonald, and R. L. Korthals. 1996. Feeding patterns and swine performance in hot environments. Transactions of the ASAE 39: 195-202.

Nienaber, J. A., G. L. Hahn, and R. A. Eigenberg. 1999. Quantifying livestock responses for heat stress management: A review. International Journal of Biometeorology. Publisher: Springer-Verlag Heidelberg 42: 183 - 188.

Steinbach, J. 1978. Diurnal behaviour patterns of pigs in a tropical environment. In: 1st World Congress Ethol. Appl. Zootech., Madrid. p. 157.

Verstegen, M. W. A., and W. v. D. Hel. 1974. The effects of temperature and type of floor on metabolic rate and effective critical temperature in groups of growing pigs. Animal Production. 18: 1 - 11.

Verstegen, M. W. A., E. W. Brascamp, and W. v. d. Hel. 1978. Growing and fattening of pigs in relation to temperature of housing and feeding level. Canadian Journal of Animal Science. 58: 1 - 13.

Effects of increasing temperatures on pigs' physiological changes at different relative humidities

T.T.T. Huynh [1,2], A.J.A. Aarnink [2], M.W.A. Verstegen [3], W.J.J. Gerrits [3], M.J.W. Heetkamp [4], B. Kemp [4], C.T.Truong [5]

[1] Department of Animal Health, Ministry of Agriculture and Rural Development, Viet Nam.
[2] Livestock Environment, Wageningen University and Research Center, The Netherlands.
[3] Animal Nutrition, Wageningen University and Research Center, The Netherlands.
[4] Adaptation Physiology, Wageningen University and Research Center, The Netherlands.
[5] Ho Chi Minh City Natural Science University, Viet Nam.

Accepted for publication in Journal of Animal Science. Jan. 2005

ABSTRACT

The effects of relative humidity and high temperature on physiological responses and animal performance were studied using twelve groups (ten gilts per group) in pens inside respiration chambers. The microclimate in the chamber was programmed so that ambient temperature (T) remained constant within a day. Each day, the temperature was increased by 2^0 C from low (16^0 C) to high (32^0 C). Relative humidity (RH) was kept constant at 50 %, 65 % or 80 %. The pigs' average initial BW was 61.7 kg (58.0 to 65.5 kg). Their average BW was 70.2 kg (65.9 to 74.7 kg). Respiration rate (RR), evaporative water (EW), rectal temperature (RT), skin temperature (ST), voluntary feed intake (VFI), ratio water to feed (rW:F), heat production (HP) and animal gain were analyzed. The animals had free access to feed and water. We determined the ambient temperature above, which certain animal variables started to change: the so-called inflection point temperature (IPt) or "upper critical temperature". We found an IPt for RR, EW, RT, rW:F, VFI, HP. The first indicator of reaction, respiration rate, was in the range from 21.3 to 23.4^0 C. Rectal temperature was a delayed indicator of heat stress tolerance, with IPt values ranging from 24.6 to 27.1^0 C. For both these indicators the IPt was lowest at 80 %RH ($p < 0.05$). Heat production and feed intake were reduced above IPt of 22.9 and 25.5^0 C, respectively ($p < 0.001$). For each degree Celsius above IPt, numerically, the VFI was reduced by 81, 99, and 106 g $pig^{-1}d^{-1}$ in treatments 50, 65, and 80 %RH respectively. Average daily gain was highest at 50 %RH ($p < 0.05$).

The ambient temperature strongly affects the pigs' physiological changes and performance; relative humidity has a relatively minor effect on heat stress in growing pigs. However, the combination of high temperatures and high humidities lowered the daily gain in pigs. The upper critical temperature can be considered to be the inflection point temperatures above which voluntary feed intake declined and rectal temperature then increased. Temperatures of the magnitude of both these IPt are regularly measured in commercial pig houses. We conclude that the upper critical temperatures for 60 kg group-housed pigs fed ad libitum are between 21.3 and 22.4^0 C for respiration rate, between 22.9 and 25.5^0 C for heat production and feed intake, and between 24.6 and 27.1^0 C for rectal temperature. It is clear that different physiological and productive parameters of group-housed growing finishing pigs have different critical temperatures.

INTRODUCTION

An environmental temperature range of 18 to 21^0 C has generally been found to support optimal productive performance of growing - finishing pigs. Pigs have a limited capacity to lose heat by water evaporation from the skin (Ingram, 1965). At higher ambient temperatures (upper part of the mentioned range) the pig may already show increased respiration rate, body temperature, and a decreased feed intake (Nienaber and Hahn, 1996 and Quiniou et al., 2000). And in order to increase heat loss, the pigs increase the exposure of their body to cool air or cool and wet floors (Aarnink et al., 1996; 2001). Furthermore, the effects of high ambient temperatures on pigs are expected to be more pronounced at high humidities.

If the temperature exceeds the point above which the balance between heat production and heat loss can be maintained, evaporative heat loss is at its maximum and respiratory evaporation will be inadequate for sufficient heat loss to keep the body temperature constant. Under such conditions the animals are supposed to be above the thermoneutral zone. As a consequence, body temperatures rise and then there is an adaptive depression of the heat production (Quiniou et al., 2001). Thus, the reduction in the associated thermal effect of feeding is an efficient mechanism to reduce heat load (Verstegen et al., 1987).

Little information is available about the ambient temperatures above which group-housed pigs start to adapt their mechanisms for balancing heat loss (evaporative heat loss, behavioral and physiological adaptation) and heat production. The temperature above which the responses change (also called critical temperature or inflection point temperature) may well differ, depending on the parameter studied. In addition, the effect of relative humidity on these parameters is unknown. This study was designed to quantify the short-term responses of growing-finishing pigs to increased ambient temperatures at different relative humidities.

MATERIALS AND METHODS

Experimental design

For this study, 12 groups of 10 growing pigs were used (i.e. 4 replicates of each RH treatment). Each group (i.e. replicate) was subjected to a 14-day adaptation period and a subsequent 13-day experimental period. The experiment consisted of 6 consecutive trials. During each trial, 2 replicates were measured. After the 14-day adaptation period, the group was put in one of two identical climate respiration chambers for 13 days, including four days for adaptation to the experimental conditions and nine days for the experiment. For all groups, the ambient temperature set for days 1 through 4 were 20, 18, 16, and 16^0 C. Subsequently, temperature was gradually increased by two degrees daily, from 16^0 C to 32^0 C within a 9-day period. The experimental treatments comprised three relative humidities: 50, 65 and 80 %. Depending on the treatment, relative humidity was maintained constant during the 13-day experimental period, at 50, 65, or 80 %. One replicate of 50 %RH and one of 65 %RH had to be discarded from the analysis due to technical failure of the equipment. Feed and water were available ad libitum.

Housing and climatic control

Respiration room

In this study, two identical 80 m^3 climate respiration rooms were used (Verstegen, 1987). Each chamber had an inner room of 6 m x 4 m x 2.2 m (length x width x height). Air was drawn from the chamber by means of a centrifugal fan. Air velocity at animal level was approximately 0.2 m sec^{-1}. The volume of air exhausted from the chamber was replaced by the same amount of outside air. This was equivalent to 3 % capacity of chamber volume per minute. The outside air was added to the air conditioning circuit through motorized valves to maintain a constant flow under pressure. The amount of recirculated air was 158m^3 min^{-1}, equalled to an air exchange rate of twice per minute. Condensate in the heat exchanger was collected and measured.

Pen

Groups of ten gilts were assigned randomly to one of the two respiration rooms. Pen size inside the room was 2.50 x 4.50 m. Of the pen floor 60 % was solid (2.50 x 2.80 m) with 4 % slope, and 40 % was metal slatted floor (2.50 x 1.70 m). The thickness of the insulated concrete solid floor was 10cm. Under the slatted floor was a slurry tank in which urine, feces and spilt water collected. The slurry tank was emptied on day 13 of each trial. The slats had tribar metal bars of 15 mm width with intervening spaces of 15 mm. A dry feeder and a bowl drinker were installed to provide the pigs with ad libitum feed and water.

Climate control

The air temperature was kept constant within a day, but during a 9-day period it was increased stepwise in the morning by two degrees per day from 16 to 32^0 C. Due to the data collection procedures carried out by the researchers, there was a 30-min time lag between room 1 and room 2 in temperature increase and the switching on or off of the lights. In room 1, temperature was increased daily at 0900. Daylight was provided from 0600 to 1800 using 9 fluorescent tubes, which produced 400 – 450 lx at floor level. Two light bulbs of 25 W, which was 4 – 5 lx, were left on during the night (1800 – 0600). Throughout the 13 d the relative humidity was fixed at one of three levels (50, 65 or 80 %). It was kept constant by a humidifier per chamber. The circulating air was heated or cooled depending on the deviation from the set point temperatures. Temperature and humidity were well controlled; their fluctuation was less than 0.5^0 C and 5 %, respectively.

Animals

One hundred and twenty crossbred young female pigs at 90 d of age were used for the trials. For each trial, 20 gilts were purchased at about 25 kg of BW and assigned to one of two groups based on weight. The composition of the groups was not changed. Prior to the experiment, the pigs had spent 40 d in growing pens that were similar to the pens used during the experimental period. At 130 d of age, the group of 10 pigs was moved into a chamber. At this moment, the average initial BW was 61.7 kg (range 58.0 kg – 65.5 kg). Starting 14 d before the experimental period, the pigs were offered the experimental pelleted diet; containing 157 g kg^{-1} crude protein, and 16.13 MJ. kg^{-1} gross energy. For data collection, three of the ten pigs in each room were randomly chosen and each assigned a unique identifying number, which was painted on their backs. Twice daily (at 0900 and 1400 and at 0930 and 1430 for rooms 1 and 2, respectively) the physiological parameters of these three pigs were measured during the 9-d trial, as described below. Finally weights were taken in the morning of d 13.

Measurements

The relative humidity and temperature of the incoming and outgoing air were continuously recorded automatically. Feed intake was recorded twice daily by weighing the dry feeder. Water intake was measured by reading the water meter twice a day. All physiological measurements on the animals were done twice a day, for 30 min per chamber before feeding time from 0800 – 0900 in the morning and from 1400 – 1500 in the afternoon. During collection of these individual daily data, the pigs were not restrained. Rectal temperature was taken with a digital thermometer (BARCHEN YS-723, Switzerland), which was inserted into the rectum of the marked pigs. Respiration rate was observed by means of a stopwatch and by counting the flank movements of the marked pigs. Skin temperature was measured by using a radiant thermometer (CHINO IR-AH, Japan). The emission factor of the radiant thermometer was set as instructed from the manual. The radiant thermometer was calibrated regularly by means of a black hole apparatus. During calibration the calibration room temperature was set at different levels within the range of the chamber temperatures. A linear regression model was applied to adjust the measured skin temperatures to the calibrated temperatures. Four fixed points on the skin surface were measured (on each of the three marked pigs): the point on the area behind the ear, three points on the lateral side of the pig (two in the loin area and one in the ham area).

Heat Production

Throughout the 9-d experimental period, O_2 consumption, CO_2 and CH_4 production were measured at 6-min intervals as described by Verstegen et al (1987). From these data, heat production (HP) was calculated as described by Brouwer (1965).

Evaporative water and evaporative heat loss

Water evaporation mostly by panting is a vital route of heat loss in pigs at high ambient temperatures. In order to quantify the evaporative heat loss of the pigs during the experimental period, complete air water balance measurements were performed, as described below. Calculations were done daily and for each replicate:

$$\text{Evaporative water loss (kg. d}^{-1}\text{)} = (A + B) - (C + D + E + F) \qquad (2)$$

Where:

A is the volume of water in outgoing air, calculated daily after measuring the volume and humidity of the outgoing air. The relative humidity and temperature of the outgoing air were measured every minute (HMT320, Vaisala, Finland) and the volume of air was measured continuously by dry gas meters (G65, Actaris - Schlumberger, the Netherlands) (see also Verstegen, 1987)

B is the amount of water that condensed on the heat exchangers. Water was collected in a tank outside the chamber, which was positioned on top of a weighing device and was recorded daily. To prevent evaporation from this tank, a layer of soy oil was poured onto the water.

C is the volume of water in incoming air calculated daily after measuring the volume and humidity of the incoming air. The relative humidity and temperature of incoming air were measured every minute with the same devices as mentioned in (A) and the volume of air leaving the chambers was set equal to the volume entering the chamber (Verstegen et al., 1987).

D is the volume of water evaporated from wet solid floor. The wet area on the solid floor was determined using video images taken at hourly intervals to estimate the proportion of the solid floor wetted with urine. The mean surface of solid wet floor then was calculated and multiplied by the evaporation per square meter as calculated in (E)

E: evaporation of water was measured daily as the weight loss of a tray with water with a known surface area (about 0.20 m^2). As this contributes to the air water balance, it should be accounted for in equation (2). The evaporated water was then divided by the area of the trays to calculate evaporation in $kg.m^{-2}$ to use in the parameter (D).

F: to maintain a specific humidity in the climate respiration chambers additional water had to be added to the air, especially at the higher temperature and humidity set points. The volume of water sprayed into the air by a humidifier was measured daily. Evaporation heat is 2260 kJ/kg at 373K = 100^0 C. In our case the body temperature of finishing pig is on average of 39^0 C. Specific heat of water is 4.18 kJ/(kg.K), between 293 and 373 = (boiling point) so from 20 to 100^0 C. From 39^0 C body temperature to 100^0 C = (100 - 39) * 4.18 = 254.98 kJ/kg.

So the energy of evaporative water from pig (kJ/(pig.d)) = (2260 kJ/kg + 254.98 kJ/kg) * evaporative water (in kJ/(pig.d)) (3)

Statistics

For determining the effect of temperature and relative humidity on physiological data (respiration rate, rectal temperature and skin temperature) the mean of individual data per pig per day (3 pigs in each chamber) were used. Data analysis of feed intake and growth rate were based on means per group per day. Data were initially subjected to a broken line model (Aarnink et al., 2001; Huynh et al., unpublished data) to validate whether an inflection point temperature could be determined. If the model failed to converge, a linear regression model was used. This residual maximum likelihood technique (REML, Genstat 5, release 6.1, 6th Edition) was used for analyzing effects of temperature, relative humidity and their interaction on skin temperature as well as for establishing the relationship between respiration rate and water intake, respiration rate and evaporative water. The Chi-square test was used to test the significance of the model and the Student t-test was used to test differences between treatments.

Broken line model

The broken line analysis was performed to calculate the inflection point temperatures for different relative humidities above which response variables changed. The broken line analysis proved to be a suitable model for respiration rate, evaporative water, rectal temperature, ratio of water to feed, feed intake, and heat production. The model can be described as follows:

$$Y = C_{RH\%} + Z_{RH\%} * (T - IPt_{RH\%}) \qquad \text{when } T \geq IPt_{RH\%}$$
$$Y = C \qquad \text{when } T < IPt_{RH\%}$$

Where:
Y is the response variable, e.g. respiration rate, evaporative water, rectal temperature, ratio of water to feed, feed intake, and heat production
C is a constant over a range of T at each level of humidity (50, 65 and 80 %)
Z is a regression coefficient at each level of humidity (50, 65 and 80 %)
T is the chamber temperature in ^{0} C (16 to 32^0 C)
IPt is the inflection point temperature in ^{0} C at each level of humidity

An F - test was used to test the significance of the broken line model. A Student t-test was used to test the differences within parameters.

Linear regression model

$$Y_{ijk} = \mu + \alpha T_i + RH_j + \beta (T*RH)_{ij} + \varepsilon_{ijk}$$

Where:
μ, α, β are regression coefficients
T_i: is room temperature, (16 to 32^0 C)
RH_j: is the effect of relative humidity (50, 65 and 80 %)

$(T*RH)_{ij}$: is the interaction between room temperature and humidity. This component was excluded from the model when it was not significant.
ε_{ijk}: residual error

All analyses were performed with Genstat software (Genstat 5, release 6.1, 6th Edition)

RESULTS

Table 1 shows that the broken line model fits for respiration rate (RR), evaporative water (EW), rectal temperature (RT), voluntary feed intake (VFI), the ratio of water to feed (rW:F), and heat production (HP). Treatment effects on respiration rate are presented in figure 1.

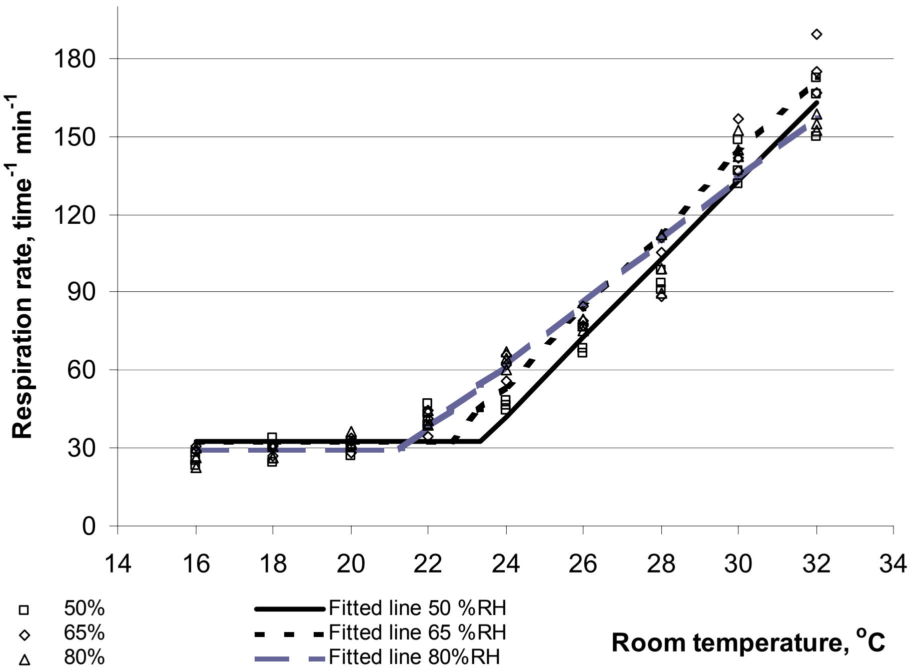

Figure 1. Broken line relationship between ambient temperature and respiration rate; □ ◇ Δ are means of measured data of three marked pigs.

With increasing ambient temperature, respiration rate remained constant at on average 32 min^{-1} until the inflection point (on average 22^0 C), after which it increased by on average 13 $C^{0\ -1}$min^{-1}. Relative humidity affected both the IPt (23.1, 22.6, 21.3^0 C for 50, 65 and 80 %RH, respectively, $p < 0.05$) as well as the increase (regression coefficient) above IPt (15.1 min^{-1}, 14.8 min^{-1}, and 12.0 min^{-1}, for 50, 65 and 80 %RH, respectively, $p < 0.05$).

Table 1 shows the effects of treatments on evaporative water. Above an average of 20.4^0 C the evaporative water increased. Below that inflection point, there were differences in volume of water evaporated at different humidity (1.26, 1.12, 0.89 g pig^{-1} min^{-1}, respectively, $p < 0.05$). For each degree Celsius above the IPt, evaporative water increased by approximately 0.08 g pig^{-1} min^{-1} or about 115.2 g pig^{-1} d^{-1}. Humidity had no effect on IPt and the increase of evaporative water after the IPt had been exceeded. Rectal temperature was affected by increasing temperature (table 1, figure 2).

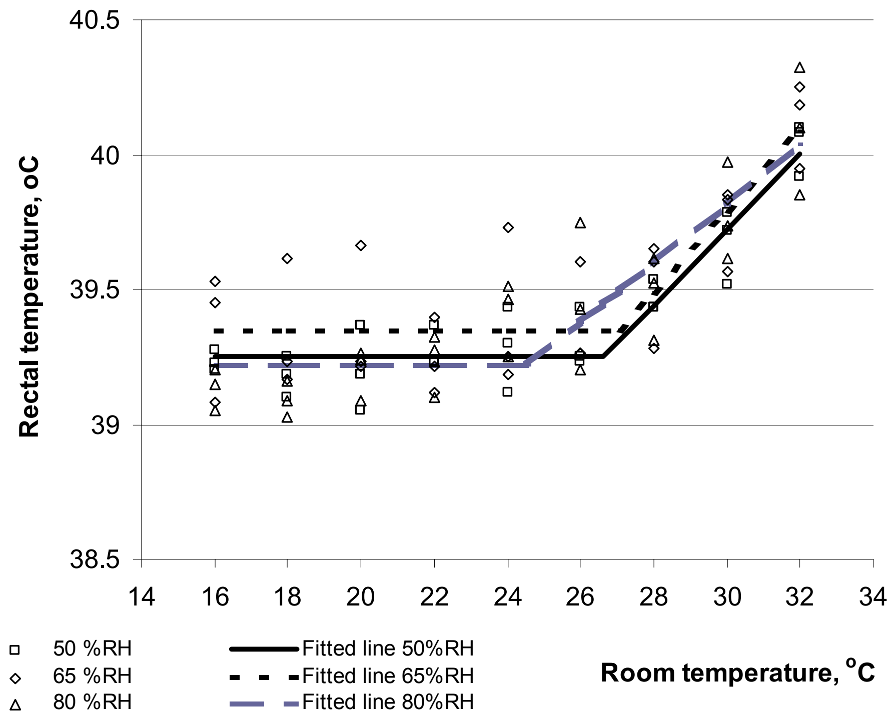

Figure 2. Broken line relationship between ambient temperature and rectal temperature; □ ◇ Δ are means of measured data of three marked pigs

Until the ambient temperature reached 26.1^0 C, the rectal temperature of pigs was constant at an average of 39.3^0 C. Above that IPt, it increased 0.13^0 C per degree Celsius. Relative humidity affected the IPt (26.6, 27.1, 24.6^0 C, respectively, $p < 0.05$).

Treatment effects on voluntary feed intake are presented in table 1 and figure 3. As the ambient temperature increased, the voluntary feed intake remained constant until an average of 25.5^0 C.

After that IPt, per degree Celsius there was a decrease of an average of 95.5 g pig^{-1} d^{-1}. Relative humidity had no statistically significant effect on either the IPt or the decrease. Because water intake is closely related to feed intake we calculated the ratio of water to feed intake.

Table 1. Non-linear regression analysis of different variables on temperatures using broken line model

Dependent variables	Adjusted -R^2	Nonlinear regression model components	Humidity, %		
			50	65	80
Respiration rate, time min^{-1}			N = 9	N = 9	N = 12
	0.874	Ipt	23.36^{a} (± 0.41)	22.57^{a} (± 0.45)	21.32^{b} (± 0.44)
		Constant	32.66 (± 3.18)	32.71 (± 3.05)	29.41 (± 3.18)
		Z	15.07^{a} (± 0.96)	14.80^{a} (± 0.96)	12.00^{b} (± 0.63)
Evaporative water, g pig^{-1} min^{-1}			N = 9	N = 9	N = 12
	0.786	Ipt	18.95 (± 1.63)	20.98 (± 1.51)	21.15 (± 1.04)
		Constant	1.26^{a} (± 0.10)	1.12^{a} (± 0.07)	0.89^{b} (± 0.07)
		Z	0.08 (± 0.01)	0.08 (± 0.01)	0.11 (± 0.01)
Rectal temperature, ^{0}C			N = 9	N = 9	N = 12
	0.479	Ipt	26.63^{a} (± 0.93)	27.08^{a} (± 0.08)	24.57^{b} (± 0.09)
		Constant	39.25^{a} (± 0.04)	39.35^{b} (± 0.04)	39.22^{a} (± 0.04)
		Z	0.14 (± 0.03)	0.15 (± 0.03)	0.11 (± 0.02)
Voluntary feed intake, g $pig^{-1}d^{-1}$			N = 3	N = 3	N = 4
	0.689	Ipt	25.38 (± 1.16)	25.61 (± 0.91)	25.58 (± 0.74)
		Constant	2121.7^{a} (± 41.2)	1978.1^{b} (± 39.8)	2001.2^{b} (± 35.3)
		Z	-81.20 (± 19.9)	-99.30 (± 19.9)	-106.10 (± 17.2)
Ratio water to feed intake			N = 3	N = 3	N = 4
	0.841	Ipt	24.54 (± 1.36)	25.85 (± 0.65)	25.81 (± 0.36)
		Constant	2.45 (± 0.11)	2.40 (± 0.11)	2.31 (± 0.10)
		Z	0.22^{a} (± 0.05)	0.37^{b} (± 0.06)	0.58^{c} (± 0.05)
Heat production, kJ $W^{-0.75}d^{-1}$			N = 3	N = 3	N = 4
	0.499	Ipt	23.94 (± 1.99)	22.08 (± 2.11)	22.54 (± 2.06)
		Constant	725.84 (± 8.24)	721.37 (± 8.57)	714.06 (± 7.10)
		Z	-8.98 (± 2.87)	-8.90 (± 2.43)	-7.33 (± 2.17)

^{a,b,c} values within a row with different superscripts are different at $p < 0.05$

Abbreviations: IPt = inflection point temperature; Z = regression coefficient

N: number of observations

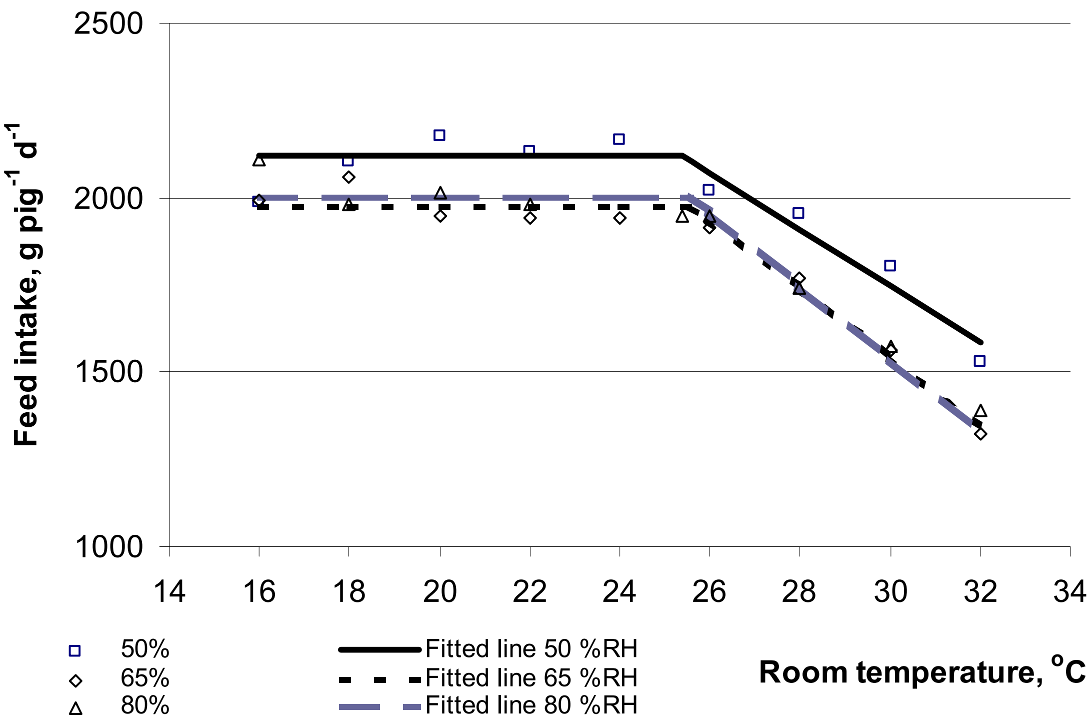

Figure 3. Broken line relationship between ambient temperature and voluntary feed intake; □ ◇ Δ are means of measured data.

With increasing ambient temperature, the ratio remained constant at an average of 2.4 until an average of 25.4^0 C (table 1 and figure 4). Relative humidity had no effect on the water to feed intake ratio; however, the increase was affected by relative humidity (0.22, 0.37 and 0.58 at 50, 65 and 80 %RH, respectively, $p < 0.05$).

Heat production remained constant below 22.9^0 C ambient temperature (table 1). Above this IPt, each degree Celsius increase brought about a decrease in HP of 8.40 kJ. $W^{-0.75}$. d^{-1}. No significant effect of humidity on heat production was found. Table 2 shows that skin temperature clearly increased with room temperature ($p < 0.001$; figure 5). On average, skin temperature increased by 0.25^0 C for every degree Celsius increase in ambient temperature. Average skin temperature was lower in the 80 %RH group than in the 50 and 65 %RH groups ($p < 0.05$; table 2). There was no interaction effect on ST.

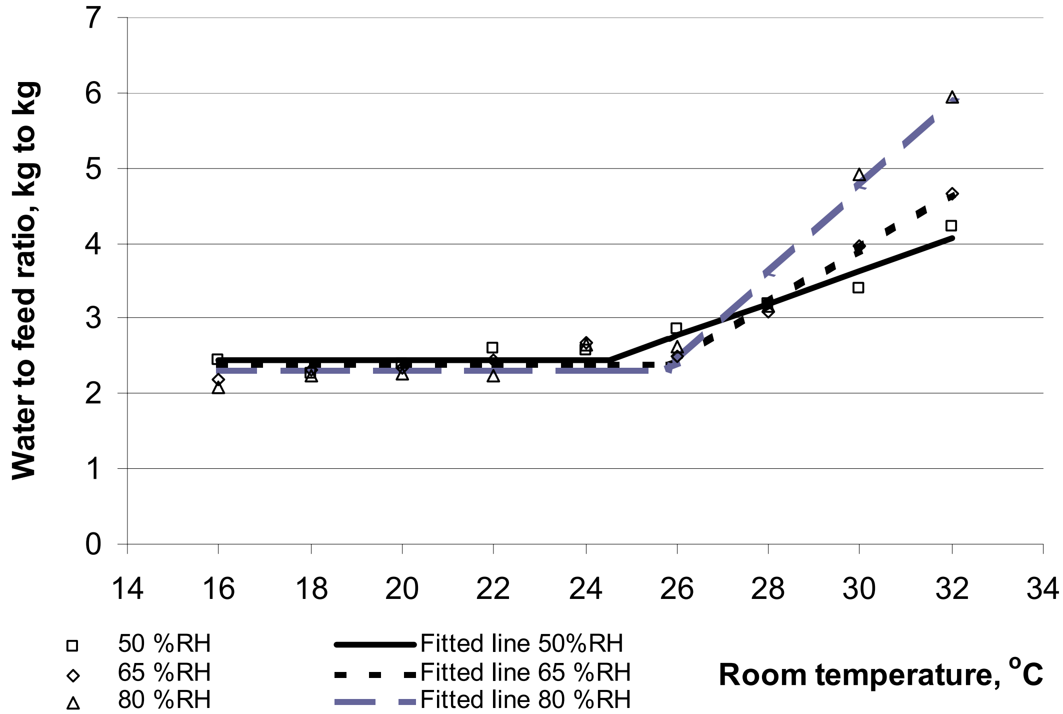

Figure 4. Broken line relationship between ambient temperature and water to feed ratio; □ ◇ Δ are means of measured data.

The relationship between respiration rate and water intake is shown in table 2. With each extra respiration stroke per minute the water intake increased by 12.7 g pig^{-1} per day ($p < 0.001$). Water intake was lower at 80 %RH than at 50 and 65 %RH ($p < 0.05$). A similar relationship was found between evaporative water and respiration rate (table 2): evaporative water increased by 10 mg $pig^{-1}min^{-1}$ per extra respiration stroke per minute (or 14.4 g pig^{-1} d^{-1}) ($p < 0.001$). In this study, at 32^{0} C and at 180 min^{-1} of respiration rate the evaporative water reached a maximum value of 2.1 g pig^{-1} min^{-1}. There were no effects of interaction on these relationships.

We found that pigs kept at 50 % RH grew faster than pigs at 65 and 80 %RH (721 vs. 644 and 630 g pig^{-1} d^{-1}, respectively, $p < 0.05$).

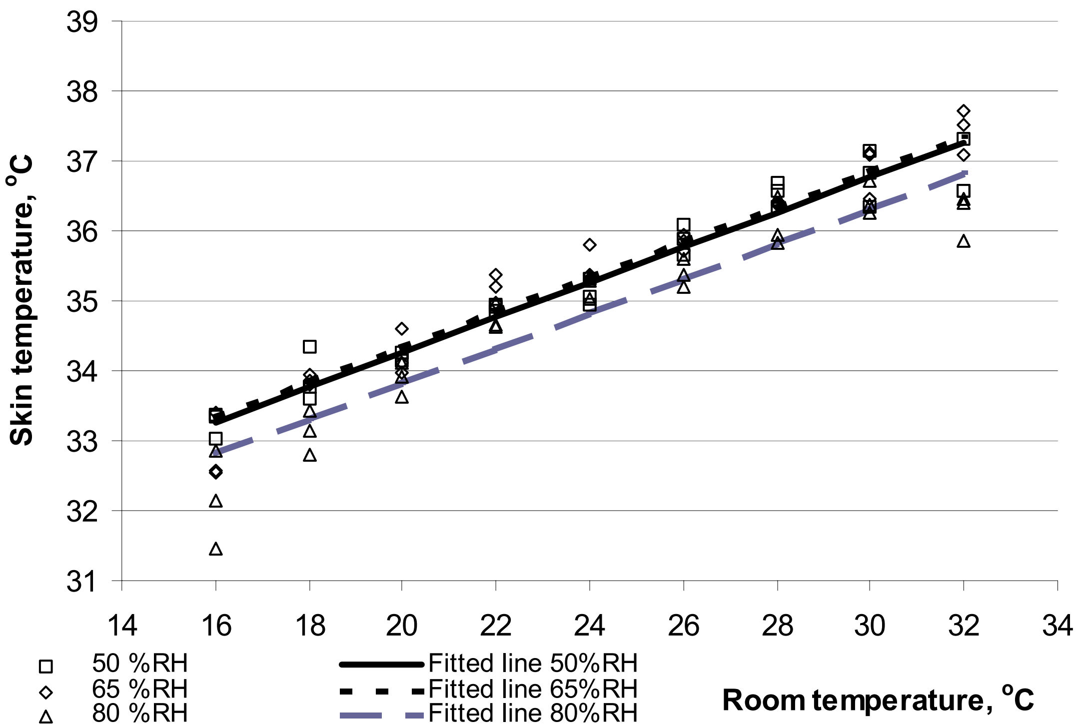

Figure 5. Linear relationship between ambient temperature and skin temperature; □ ◇ Δ are means of three marked pigs.

Table 2. Linear regression analysis of skin temperature on ambient temperature and relationship between water intake and respiration rate and evaporative water and respiration rate

Dependent variable	Adjusted - R^2	Model	Humidity, %		
			50	65	80
Skin temperature, ^{0}C			N = 9	N = 9	N = 12
	0.784	Average	35.3^a (±0.08)	35.4^a (±0.11)	34.8^b (±0.10)
		r.c. of Temperature		0.25*** (±0.00)	
Water intake, g pig^{-1} d^{-1}			N = 3	N = 3	N = 4
	0.268	Average	4918^a (±232)	4769^a (±254)	3894^b (±239)
		r.c. of Respiration		12.7*** (±1.97)	
Evaporative water, g min^{-1}			N = 9	N = 9	N = 12
	0.246	Average	1.2^a (±0.05)	0.9^b (±0.06)	0.8^c (±0.06)
		r.c. of Respiration		0.01*** (±0.00)	

^{a,b,c} values within a row with different superscripts are different at $p< 0.05$

r.c. is regression coefficient

N: number of observations

DISCUSSION

In the present study clear inflection point temperatures (IPt's) were found for respiration rate, evaporative water, rectal temperature, voluntary feed intake, ratio water to feed intake, and total heat production. Below the IPt's the responses of these variables were relatively constant, while above these IPt's the response variables clearly changed at increasing room temperature. The effects of relative humidity on IPt were less pronounced and only significantly different for respiration rate (RR) and rectal temperature (RT). No significant effects of humidity were found on the IPt of other parameters e.g. evaporative water, voluntary feed intake (VFI), ratio water to feed intake, and total heat production (HP).

According to Mount (1979), the thermal neutral zone of pigs can be defined as the range of environmental temperature within which metabolic rate is minimum, constant and independent of temperature. The thermal neutral zone can be divided into two distinct parts, based on the evaporative activity of the pig. One part is the comfort zone, which covers the range from the lower border of the thermal neutral zone to the point where pigs activate their evaporative function. The second is the zone from the upper border of the comfort zone to the upper border of the thermal neutral zone. Within this zone, evaporative heat loss increases considerably. With regard to the thermal neutral zone of finishing pigs, Verstegen and Henken (1987) stated that the lower border of the thermal neutral zone for 40 kg pigs housed in groups was in the range of 19 – 20^0 C. Little information is available on the upper border of the thermal neutral zone of pigs, especially for finishing pigs. Quiniou et al. (2000) found that pigs of 30 to 90 kg had a depressed VFI in the temperature range from 23 to 25^0 C. In this study there were no differences between humidities in inflection point temperature for VFI. So the upper border of thermal neutral zone as measured by VFI did not depend greatly on RH. For pig production, and thus for economic reasons, it is important to assess heat stress on the basis of depression of VFI and heat production. However, for reasons of animal welfare, increasing respiration rate (panting), followed by increasing rectal temperature may be more important. When room temperature increases, sensible heat loss (radiation, convection, conduction) decreases rapidly, and evaporative heat loss becomes a vital route for pigs to eliminate heat load. As they do not sweat, pigs have to pant. Above an IPt of approximately 22.4^0 C the pigs increased RR with increasing ambient temperatures. As expected, the IPt was somewhat lower at higher relative humidity. Christon (1988) mentioned an RR in tropical finishing pigs of 120 min^{-1} at an average temperature of 29^0 C in a RH range of 69 to 91%. Brown-Brandl (2000) found the RR's of pigs exposed for 22 h to temperatures of 18 and 32^0 C were 56.7 and 100.7 min^{-1}, respectively. At high temperature, the RR we measured was higher than the results of these authors. It should be noted that our pigs had higher feed intake below IPt, which caused more heat to be produced. Another reason for these different results could be unreported differences in radiant temperature between the studies. In our study, the temperature of floor surface, wall, and ceiling was similar to the ambient temperature. So radiant temperature was the same as air temperature. There are two other possible reasons for the higher RR values in our pigs: 1. Group housing. Our pigs were housed in groups, and therefore they may have been more active, furthermore, group-housed pigs are less able to lose heat by radiation, because they are surrounded by the warm bodies of other pigs; 2. Different treatment protocols: Our pigs experienced a constant heat stress throughout the whole day, while in the other studies mentioned the pigs were exposed to cyclic temperatures. Because pigs can influence heat production within a day by the feed intake pattern, they can dissipate more heat during cooler periods.

When evaporation is reduced by high humidity (80 compared to 65 and 50 %), the respiration rate and rectal temperature increase at lower temperatures (table 1). Figure 6 demonstrates that the increase in respiration rate occurred at a lower temperature than the increase in rectal temperature. Panting allows pigs to maintain a constant rectal temperature for an increase in temperature of approximately 3 to 4^0 C after respiration rate increases. Above IPt, rectal temperature increases linearly with room temperature. Some authors have suggested that rectal temperature is an important indicator of heat-stressed animals (Close, 1971; Holmes, 1973; Kadzere et al., 2002; Ricalde and Lean, 2002; Silanikove, 2000). These authors reported that cattle and sheep showed increased rectal temperatures above ambient temperatures of 24 to 26^0 C. In Mount's (1979) diagram, the thermal neutral zone is defined as the temperature zone with minimal heat production at constant body temperature. Above this zone, core temperature increases and pigs really become heat stressed. This has a direct effect on pig productivity (McDowell et al., 1976). Our results show that at 80 %RH the IPt's for rectal temperature and for respiration rate were approximately 2.0 degree Celsius lower than at 50 %RH (table 1). Earlier, it was suggested by Curtis (1983) that at 30^0 C an increase of 18 % in RH is equivalent to an increase in air temperature of one degree Celsius. This is supported by our results.

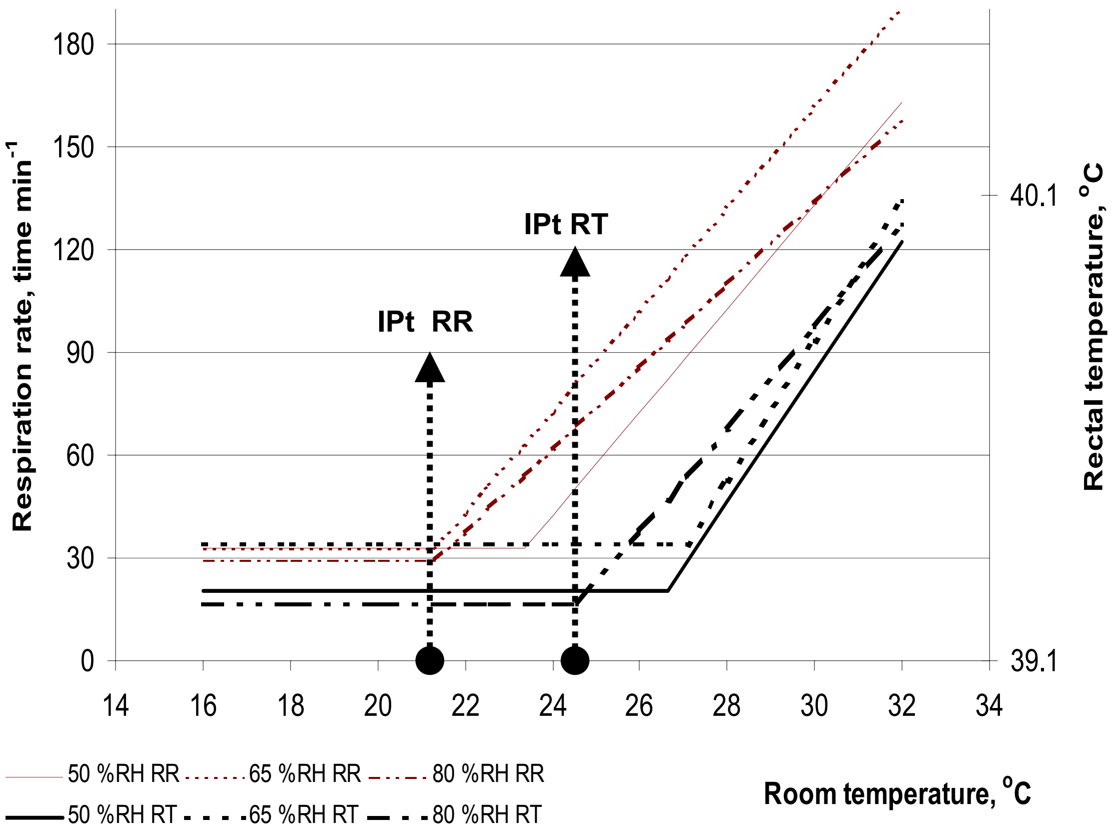

Figure 6. A sample of broken line responses to ambient temperatures of respiration rate and rectal temperature. IPt RR = inflection point temperature for respiration rate (80 % relative humidity); IPt RT = inflection point temperature for rectal temperature (80 % relative humidity).

The current study illustrates that heat production declined with increasing room temperature above IPt. Concurrently, respiration rate and rectal temperature increased. According to Mount (1979) above IPt for body temperature, heat production will rise. Brown-Brandl et al. (1998) reported that in an 85 kg pig kept individually in a respiration room, HP decreased above 28^0 C, but then increased above 32^0 C.

However, Close (1971), Holmes (1973), Nienaber et al. (1987), and Ricalde et al. (2002) reported that at high temperatures a decrease in HP was found in relation to an increasing rectal temperature. The differences between the different studies can be explained by many factors. First of all, one should distinguish between studies with restricted and ad libitum intake: our animals were fed ad libitum, so when ambient temperature rose above the thermal neutral zone, causing increased RT, voluntary feed intake was largely reduced, with the consequence that HP declined as well. Secondly, a distinction must be made between studies with group-housed animals and studies with individually housed animals. Thirdly, because total heat production is connected to muscle activity, at high temperature heat production changes markedly, especially for heavy pigs (van Milgen et al. 1998). Heavy pigs will lie more and reduce activity. A final factor confounding the comparison is that the experimental protocols differed between the studies. In the other studies, animals had often been subjected to constant thermal conditions for longer than in our study.

In this study, for each degree Celsius ambient temperature increase above IPt, voluntary feed intake declined steadily by an average of 95.5 g. Nienaber et al. (1983) reported that for 45 and 85 kg pigs an increasing ambient temperature from 20 to 30^0 C reduced VFI from 65 to 74 g d^{-1} per degree Celsius. For the same temperature range the average decrease in our study was 43 g d^{-1}, which was lower the reduction in feed intake found by Nienaber et al. (1983). An effective result of panting was that the pigs could maintain a constant VFI until a few degrees above the IPt for RR (+ 2.0^0 C at RH 50 %, + 3.0^0 C at RH 65 % and + 4.3^0 C at RH 80 %). In other words, the pigs were able to maintain their level of VFI by increasing RR and exploiting evaporative heat loss. RR was the first physiological adaptational reaction to heat stress in our study. Back in 1965, Ingram had reported that panting pigs increased their total oxygen consumption at maintenance or constant feed intake and therefore an increase in physical activity was accompanied by an increase in total HP. In our study, feed intake fell so much that although panting activity increased, total HP decreased.

Little information is available on the changes of the skin temperature of finishing pigs at high ambient temperatures. According to the thermal concept, at high temperature, animals may take up heat from the environment if the ambient temperature is above the surface skin temperature (Robertshaw, 1985). It is interesting that in our study the pigs' ST changed already at moderate temperatures. Black et al. (1993) reported that skin temperature rose promptly to 36.8^0 C in sows exposed to 28^0 C air temperature. Geers et al., (1987) (cited from Fanger, 1972) reported that the comfort skin temperature of homeothermic animals ranges from 32 to 35^0 C. This is confirmed by our results, with ST ranging from 33 to 35^0 C at ambient temperatures ranging from 16 to 22^0 C (figure 2).

The water to feed ratio in our study increased differently with higher ambient temperature at the three RHs. For each degree Celsius increase, pigs at 80 %RH had the largest increase in ratio; the smallest increase was at 50 %RH. The ratio increase at 80 %RH was more than double that at 50 %RH. This means that at high relative humidity and high temperature the pigs reduced feed intake and increased water intake more than at low humidity. For these two reasons it can be expected that at high relative humidity and high temperature, water consumption will be more independent from VFI than at low temperature and humidity. It should be noted that drinking water temperature was lower than room temperature. The water tank was located outside the respiration chamber, in a temperature of about 16^0 C. So, some direct cooling was also obtained by drinking the relatively cool water.

A general picture of the total heat production, respiration rate and heat loss can be seen in figure 7. This figure illustrates the theory of Mount (1979), but based on our measured data. Taking into account the heat production, respiration and evaporation response of the pigs, ranges of thermal zone could be illustrated. The increased respiration frequency could be interpreted as a sign of discomfort. The range between respiration increase and heat production decrease was narrow: only 1.2^0 C at 80 %RH. It can also be concluded that evaporative water increased with enhanced respiration rate. However, a poorer relationship between evaporation and respiration can be seen at 80 %RH (table 2), presumably because at this high humidity less respiratory evaporative water could be added to the humid air by the pig. At high humidity pigs seem to find other means to get rid of the heat. One possibility is by means of behavioral changes (Huynh et al., 2004), e.g. wallowing, defined as the behavior of rolling from side to side in urine and feces. Wallowing already occurred at low temperatures and increased with increasing temperatures.

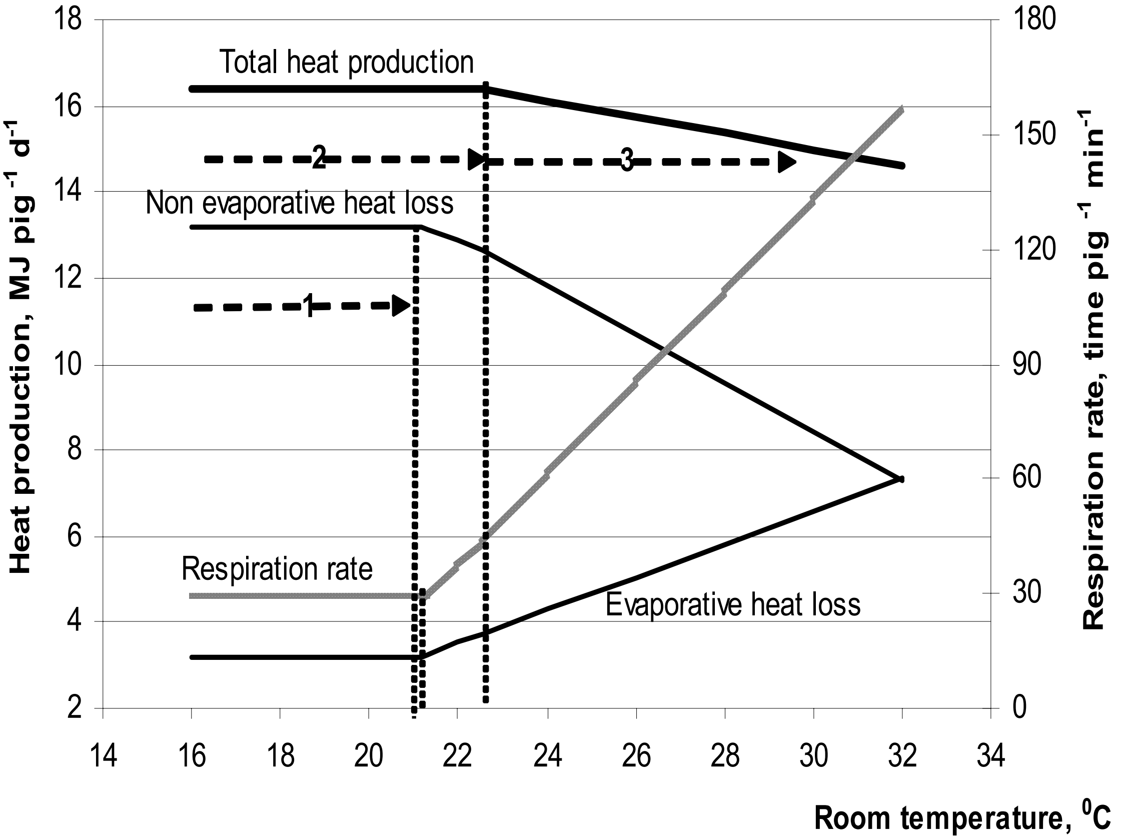

Figure 7. A sample of broken line relationship (80 % relative humidity) between temperatures and total heat production, evaporative heat loss, non-evaporative heat loss, and respiration rate: 1, within thermal comfort range; 2, within thermal neutral range; 3, above thermal neutral zone

In this study, the lowest daily weight gain was at 80 %RH and the highest at 50 %RH. Previous studies on short-term heat stress showed that at each degree Celsius above a daily mean temperature of 21^0 C, pigs gained 36 - 60 g d^{-1} less body weight (Steinbach, 1987). Mount (1979) mentioned a decrease of 30 g d^{-1} in pigs' daily gain for each 1^0 C above the optimum temperature. Serres (1992) found that in the temperature range from 21 to 32^0 C, the growth rate of 70 kg pigs was reduced by 46 %. Our results are consistent with these results. The decrease in daily gain of the pigs seemed to be mainly caused by the drop in VFI during heat stress.

From this study it can be concluded that in modern Western pigs, physiological signs of heat stress already occur at temperatures above 22^0 C. The modern Western pig has a high metabolic activity and thereby a high heat production. Pig farmers should take account of this when designing and controlling indoor climate.

CONCLUSIONS

From our study we can conclude the following:

- Above certain inflection point temperatures, clear physiological changes occur in high lean growth group-housed finishing pigs.
- The first physiological indicator that the pig is reacting to high ambient temperatures is respiration rate. For 60 kg high lean growth group-housed finishing pigs this reaction occurs on average at 22.4^0 C. At higher relative humidities the pigs respond at lower temperatures (2.0^0 C lower when RH increases from 50 to 80 %).
- For 60 kg high lean growth group-housed finishing pigs, rectal temperature increased when ambient temperature was on average above 26.1^0 C. An increase in RT and a reduction in feed intake are indicators that room temperature is above the upper limit of the thermal neutral zone.
- Generally, we found that humidity had minor effects on physiological parameters. However, we did find a significant difference in animal gain at the three levels of humidity. A combination of high humidity and high temperature clearly has a detrimental effect on daily gain.
- The best indicators to access heat stress of finishing pigs are, in order of usefulness: increased respiration rate and water to feed ratio, then reduced heat production and feed intake, and finally increased rectal temperature. Decreased feed intake and increased rectal temperature are good indicators of reduced performance of heat-stressed pig.

LITERATURE CITED

Aarnink, A. J. A., J. W. Schrama, R. J. E. Verheijen, and J. Stefanowska. 2001. Pen fouling in pig houses affected by temperature. In: Livestock Environment VI, Galt House Hotel Louisville, Kentucky. p 180 - 186.

Aarnink, A. J. A., van den Berg A. J., Keen A., Hoeksma P., and 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.

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

Brower, E. 1965. Report of the sub-committee on constants and factors. In: EAAP. Energy Metabolism. p 441-443.

Brown-Brandl, T. M., J. A. Nienaber, and L. W. Turner. 1998. Acute heat stress effects on heat production and respiration rate in swine. Transactions of the Asae 41: 789-793.

Brown-Brandl, T. M., J. A. Nienaber, L. W. Turner, and J. T. Yen. 2000. Manual and thermal induced feed intake restriction on finishing barrows. Ii: Effects on heat production, activity, and organ weights. Transactions of the Asae 43: 993-997.

Christon, R. 1988. The effect of tropical ambient temperature on growth and metabolism in pigs. Journal Animal Science 66: 3112-3123.

Curtis, S. E. 1983. Environmental managements in animal agriculture. Iowa State University. Press, Ames.

Geers, R. et al. 1987. Surface temperatures of growing pigs in relation to the duration of acclimation to air temperature or draught. Journal of Thermal Biology 12: 249-255.

Nichols, D. A., D. R. Ames, and R. H. Hines. 1982. Effect of temperature on performance and efficiency of finishing swine. In: the 2nd International Livestock Environment Symposium, April 20 - 23, 1982, Urbana, Illinois. p 376-379.

Nienaber, J. A., G. L. Hahn, and T. McDonald. 1991. Thermal environment effect on feeding patterns and swine performance. Paper presented at the "1991 International Summer Meeting sponsored by the American Society of Agricultural Engineers", Albuquerque, New Mexico: 14.

Nienaber, J. A., G. L. Hahn, T. P. McDonald, and R. L. Korthals. 1996. Feeding patterns and swine performance in hot environments. Trans-ASAE. St. Joseph, Mich.: American Society of Agricultural Engineers 39: 195-202.

Quiniou, N., D. Renaudeau, A. Collin, and J. Noblet. 2000. Influence of high ambient temperatures and physiological stage on feeding behaviour of pigs. Productions Animales 13: 233-245.

Quiniou, N., J. Noblet, J. v. Milgen, and S. Dubois. 2000. Modelling heat production and energy balance in group-housed growing pigs exposed to low or high ambient temperatures. British Journal of Nutrition 85: 97-106.

Randall, J. M., A. W. Armsby, and J. R. Sharp. 1983. Cooling gradients across pens in a finishing piggery: II. Effects on excretory behaviour. Journal of Agricultural Engineering Research 28: 247-259.

Robertshaw, D. 1985. Sweat and heat-exchange in man and other mammals. Journal of Human Evolution 14: 63-73.

Serres, H. 1992. Manual of pig production in the tropics. 2 ed. CAB International, Cedex, France.

Steinbach, J. 1987. Swine. Effects of the tropical climate on the physiology and productivity of the pig. Elsevier: 181:199.

vanMilgen, J., J. F. Bernier, Y. Lecozler, S. Dubois, and J. Noblet. 1998. Major determinants of fasting heat production and energy cost of activity in growing pigs of different body weight and breed, castration combination. British Journal of Nutrition 79: 509-517.

Verstegen, M. W. A., and A. M. Henken. 1987. The Wageningen respiration unit for animal production research: A description of the equipment and its possibilites. In: V. M. W. A. and Henken (eds.) Energy metabolism in farm animals. p 478. Martinus Nijhoff, Dordrecht.

Verstegen, M. W. A., A. M. Henken, and W. vanderHel. 1987. Influence of some environmental, animal and feeding factors on energy metabolism in growing pigs. In: M. W. A. Verstegen and A.M.Henken (eds.) Energy metabolism in farm animals. p 478. Martinus Nijhoff, Dordrecht.

Yousef, M. K. 1985. Stress physiology: Definition and terminology. In: M. K. Yousef (ed.) Stress physiology in livestock No. 1. p 205. CRC Press.

Software

Genstat. Copyright 2002. Genstat release 6.1 (PC/windows 2000). Lawes Agricultural Trust (Rothamsted Experimental Station).

Thermal Behaviour of Growing Pigs in Response to High Temperature and Humidity

T.T.T. Huynh[1,2], A.J.A. Aarnink[2], W.J.J. Gerrits[3], M.J.H. Heetkamp[4], C.T.Truong[5], H.A.M. Spoolder[6], B. Kemp[4] and M.W.A. Verstegen[3]

[1] Department of Animal Health, Ministry of Agriculture and Rural Development of Viet Nam.
[2] Livestock Environment, Wageningen University and Research Center, The Netherlands;
[3] Animal Nutrition, Wageningen University and Research Center, The Netherlands;
[4] Adaptation Physiology, Wageningen University and Research Center, The Netherlands;
[5] Natural Science University Viet Nam
[6] Animal Science, Wageningen University and Research Center, The Netherlands

Published in Appl. Anim. Behav. Sci. 91 (1 – 2): 1 - 16. Reproduction from permission of Journal of Applied Animal Behaviour Science

ABSTRACT

The effects of high ambient temperatures and humidities on thermal behavioural adaptation and pen fouling of group-housed growing pigs were assessed. Twelve groups of ten gilts of an average initial body weight of 61.7 kg were used. During nine experimental days, ambient temperatures were increased by two degrees per day from 16^0 C on day 1 to 32^0 C on day 9 and fixed at one of three levels of relative humidity 50, 65, and 80 %. Space allowance per pig was 1 m^2. The floor was 60 % solid and 40 % slatted. Lying, excreting and fouling behaviour were studied using video recordings. During the nine trial days a radar activity meter was used to record the physical activity of each group of 10 pigs every six minutes. A regression model was used to calculate the heat produced by activity from total heat production. The lying position of the pigs was classified e.g. Lateral, Sternal, Half lateral lying. Excreting behaviour was determined in terms of e.g. urination and defecation. Furthermore, thermoregulatory lying behaviour (huddling and wallowing) were recorded. All behaviours were determined in terms of frequency and location. Temperature affected lying and excretion behaviours. The number of pigs lying on slatted floor increased with increasing temperature ($p < 0.001$). The inflection point temperature (IPt) for the pigs to lie on slatted floor was on average 18.8^0 C; below this IPt the pigs remained lying on the solid floor. The heat produced by activity was relatively constant below 24.2^0 C, but once this IPt had been exceeded it down turned. Temperature was inversely related to huddling ($p < 0.001$) and positively related to wallowing ($p < 0.001$). The total excretions on solid floor increased with temperature ($p < 0.05$). The number of urinations was inversely related to temperature ($p = 0.13$). However, the relative number of urinations on the solid floor increased concomitantly with temperature ($p < 0.05$). It can be concluded that high temperatures greatly affect lying and excreting behaviour. At a relatively low temperature, pigs preferred to lie on the slatted floor. At high temperature, there was a clear increase in fouling of the solid floor. At high humidity, changes in behaviours occurred at lower temperatures.

INTRODUCTION

Previous research has demonstrated conclusively that behavioural elements such as lying posture and excretion are affected by ambient temperature (Hacker, 1994; Blackshaw, 1994; Beattie, 1996; Aarnink, 2001; Peishi, 2001). Ekkel et al. (2003) reported that in thermoneutral conditions fattening pigs spent 90% of the day lying. Furthermore, they found that lying laterally was the most dominant position (> 60% of observations). Under experimental conditions, Geers (1986) observed that on hot days pigs changed their lying position from sternal to lateral and avoided physical contact with other pen mates. Aarnink et al. (2001) found that the relative number of pigs lying laterally increased by 1.8 % for each degree Celsius rise in temperature. Furthermore, they found that the number of pigs lying in physical contact with each other fell by 3.7% for each degree Celsius increase (16 to 32^0 C).

Pigs are known to separate their lying and dunging areas. Stolba and Wood-Gush (1989) found that none of the defecation sites in their Edinburgh 'Pig Park' were closer than 5 m to a nest site, and none were further than 15 m from the nest. Under optimal housing conditions pigs will rest and sleep in a defined lying area and dung consistently in the dunging area (Hacker et al., 1994; Aarnink et al., 1997; 2001). Aarnink et al. (2001) reported a strong relationship between the percentage of the slatted floor used by pigs to lie on, and the relative number of excretions on the solid floor, postulating that the pigs fouled the solid floor because the space remaining on the slatted floor was limited.

Despite the many advances made in recent decades in the technological control of indoor climate in animal buildings, ambient temperatures will not always be within the thermal comfort zone of the pig. Though results are available on the effects of temperature on behavioural changes, quantitative relationships between temperature and thermoregulatory behaviour of pigs are lacking. Neither is information available on the effects of humidity at different temperatures on fattening pigs' behaviour.

To evaluate how pigs regulate their thermal regulatory behaviour under hot conditions we therefore designed an experiment with temperatures varying from low to high at three humidities. The aim was to derive the upper limit of thermal neutral zone with respect to lying and excretion behaviour in growing pigs. We hypothesized that high ambient temperatures and high humidity will affect lying and excreting behavioural patterns, and that the relationship between this behaviour and temperature and humidity can be used to calculate upper critical temperatures.

MATERIALS AND METHODS

Experimental design

In this study 12 groups of 10 growing pigs (experimental unit) were each housed in a pen in one of two large respiration chambers. Before being housed in the chamber, the pigs were kept in similar growing pens for a preliminary period of two-weeks to adjust to the experimental conditions. They were then placed in the respiration chambers for 13 days: four of these days were for habituation. During the four-day habituation period the ambient temperature was gradually reduced: the respective day temperatures were 20^0 C, 18^0 C, 16^0 C, and 16^0 C. During the 9-d experimental period, air temperature was gradually increased by two degrees daily, from 16^0 C on day 1 to 32^0 C on day 9. In the two parallel chambers, relative humidity (RH) was fixed pair wise at 50, 65, or 80 % during the whole period of 9 days. Each group of pigs was assigned to one of the three levels of RH.

Animals

For each of the six rounds, 10 crossbred gilts originating from a cross between a synthetic boar (New-Dalland synthetic x 25 % Pietrain) and F1 sow (Finnish Landrace x Large White). At 90 d of age the pigs were put in one of the pens in the two large respiration chambers and kept there for 13 days. The pigs were weighed on day 0 and also on day 13. Both weightings were done in the morning (09.00 h). At the beginning of the habituation period, average initial body weight (BW) was 61.7 kg (range: 58.0 kg – 65.5 kg). The pigs were offered a standard pelleted diet ad libitum, which contained 157 g kg^{-1} crude protein, and 16.1 MJ kg^{-1} gross energy. The pigs had free access to water.

Respiration chamber

Two respiration chambers as described by Verstegen et al. (1987) were used. Each had an inner capacity of 80 m^3 air. Air was drawn from the chamber by means of a centrifugal fan with airflow of 2.3 m^3 min^{-1}. Air velocity at animal level was approximately 0.2 m sec^{-1}. The air removed from the chamber was replaced by outside air at a constant rate of 2.3 m^3 min^{-1}, which was equivalent to 3 % capacity of chamber volume every minute. The amount of recirculated air was 158.4 m^3 min^{-1}, equivalent to an air exchange rate of twice per minute.

In order to allow the animals to adapt to the respiration chamber, the initial temperature on the arrival of the animals was the same as in the habituation pens and then was gradually decreased to 16^0 C at the start of the nine-day experimental period. An additional humidifier was used in each chamber to maintain the desired relative humidity. In each treatment, humidity remained constant (< 5% fluctuation) throughout the 9-d experiment. The circulating air was heated or cooled, depending on the deviation from the set point temperatures.

As a result of the data collection procedures, in room 1 the temperature increase and the switching on and off of the lights was 30 minutes earlier than in room 2. In room 1, temperature was increased daily at 0900. Daylight was provided from 0600 to 1800, using nine fluorescent tubes that produced 400 – 450 lx at floor level. During the night (1800 h – 0600) the illumination was from two light bulbs produced 4 – 5 lx each.

Pen

One pen was built within each of the two respiration chambers. Pen size was 2.5 m x 4.0 m. The pen floor was 60 % solid (2.5 m x 2.4 m) with 4% slope, and 40 % tribar metal slatted (2.5 m x 1.6 m): see figure 1. Space allowance was approximately 1.0 m^2 pig^{-1}. A slurry tank underneath the slatted floor stored urine and faeces. The slurry tank was emptied at the end of each trial. The slats had tribar metal bars of 15-mm width; the slots were 15 mm wide. A dry feeder at the front of the pen on lying area provided the pigs with ad libitum feed. A bowl drinker was installed at the back of the pen on the slatted floor area; the pigs had free access to the drinker. The design of the drinker was the same as in commercial pens and ensured that water did not spill on the floor. The floor surface area of the pen was divided into six sectors: sectors 1 to 4 were on the solid floor and the remaining two sectors were on the slatted floor. In practice, the two main sections (i.e. the solid floor and the slatted floor) were generally used. The division into six sectors enabled the location of fouling to be specified more precisely.

Measurements

Two video cameras (Panasonic wv-bl 200 with 2.8 mm fish eye lens) were used to record the temporal patterns of lying, excretion and fouling behaviour of pigs. The cameras were installed inside each chamber and covered the whole pen area. Pictures from the cameras were transferred to time-lapse video tape recorders (Panasonic AG-6024-e). From these videotapes, scan samples were taken at 30 min intervals, resulting in 48 observations per pen per day. The lying and excreting behaviours that occurred on each of the six sectors (figure 1) were recorded. Frequencies and percentages of behaviours were calculated per group.

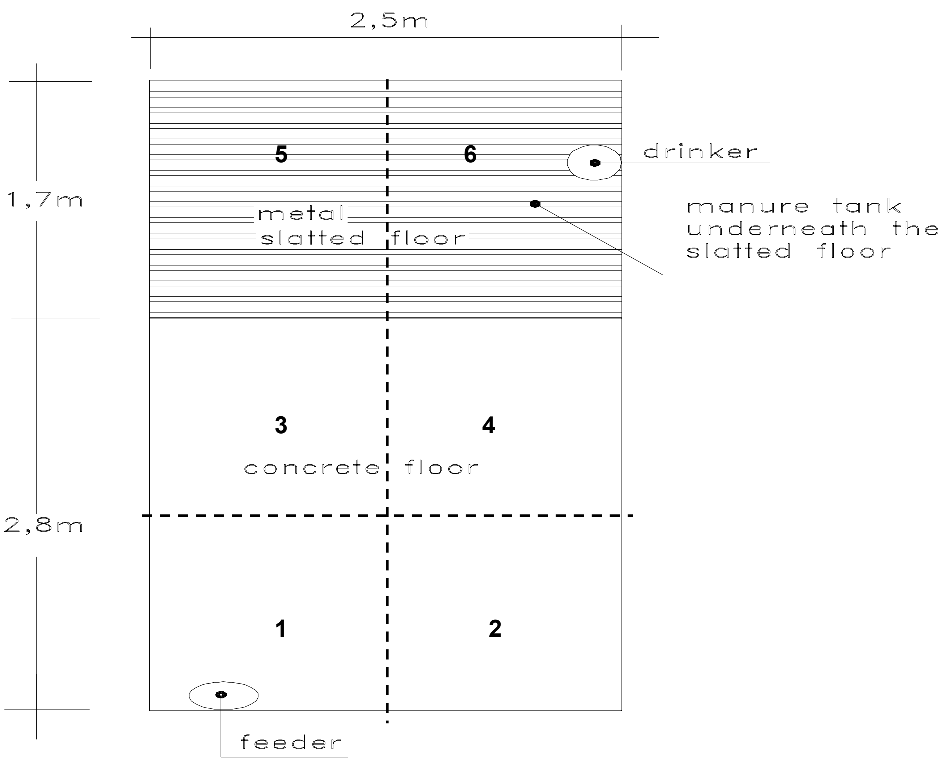

Figure 1. Pen layout, 60 % solid and 40 % slatted floor.
Sectors 1, 2, 3, 4, 5, 6 were used to determine lying and excreting locations of the pigs

Lying position

The ethogram of lying postures consisted of the following mutually exclusive behavioural elements:

Lateral lying: the pig lies flat on one side of its body, not supported by legs.

Sternal lying: the pig lies on its belly and has 3 or 4 legs supporting its body.

Half lateral lying: the pig reclines, with its body supported by 1 or 2 legs. This lying posture is intermediate between sternal and lateral lying.

Thermoregulatory lying

Huddling: pigs lying with over 50 % of their lying side in contact with another pig.

Wallowing: this behaviour was scored from the tapes. Wallowing was defined as rolling or rubbing the body in a mixture of faeces and urine. The frequency of wallowing was determined the same way as excretion

Excretion

The method of recording and analysing this behaviour is similar to work done by Aarnink et al. (2001) and Huynh et al. (2004). Excretion was scored using the behaviour sampling technique from continuous video recordings; any occurrence of this behaviour was recorded, and the frequency of the events was analysed. Two behavioural elements were identified: defecation and urination. Finally, analysing videotapes estimated the area of fouled solid floor as well. Scan samples were taken at 60 min intervals, resulting in 24 pictures per sector per pen per day. Fouled areas in each sector were counted as percentage of the area covered with urine and faeces. When analysing the frequency of excretions on solid floor, only sectors 1 and 2 were taken into account. This was because faulty construction of the floor resulted in sectors 3 and 4 often being already fouled at the start of each experimental period by urine produced in those sectors that could not run off the solid floor.

Heat Production

Heat production (HP) was calculated using indirect calorimetric methods (Verstegen et al., 1987). Energy expenditure was obtained from data on the volume of incoming and outgoing air and the percentage of CH_4, O_2 and CO_2. Heat production was expressed in kJ $d^{-1} * W^{-0.75}$. The rate of O_2 consumption and CO_2 production and energy expenditure were computed as proposed by Brouwer (1965), Yousef (1985) and Verstegen et al. (1987). Gas samples of air entering and leaving the chamber were collected and analysed every 6 min during the 9-d experiment. Physical activity was recorded using radar activity meters. The principle of this method is based on the Doppler effect: the frequency of reflected radar waves emitted by the meters changes when the animals move, and the change of frequency is converted to a signal (electrical pulses), recorded continuously by the data acquisition system. To convert the number of pulses to energy expenditure, the energy expenditure per pulse should be known. Within the day, variation within physical activity causes variation in heat production. By recording activity and heat production in distinct time periods and regressing heat production on activity counts, the heat production per activity count can be calculated. For this purpose, a regression analysis was performed on heat production as a function of activity counts each experimental day. The slope of the regression line (= β) then represents the heat production per activity count. Average activity heat production per day then can be calculated as average amount of activity pulses * β.

Statistics

The daily means of the groups of ten pigs were used for data analysis. For determining the effects of temperature and relative humidity on behavioural changes of growing pigs, the percentage (relative value) or number (absolute value) of each variable was used. Data from the first round was excluded due to a technical problem. The effects of temperature and humidity were determined by using two models: a linear model and a broken stick model. First, the broken stick model was applied to the data. If the model failed to converge (indicating no inflection point in the data) the linear model was used. Room temperature was included as a continuous variable, and humidity as a factor. The linear model was run with the REML procedure (residual maximum likelihood technique). A Chi - square test was used to test differences between treatments. The model can be described as follows:

$$Y_{ijk} = \mu + \beta T_i + RH_j + (\beta T*RH)_{ij} + e_{ijk} \quad (1)$$

Where: Y is dependent variable e.g. lying pigs, urinations, defecations on solid floor, and excretions on solid floor

μ: is the overall mean

β: is the regression coefficient of room temperature

T_i: is room temperature, (16 to 32^0 C)

RH_j: is the effect of relative humidity, (50, 65, and 80 %)

$(\beta T*RH)_{ij}$: is the interaction between variable room temperature and factor humidity

e_{ijk}: residual error

Where there was no significant effect of the interaction, this element was excluded from the model.

A broken stick analysis was done (Aarnink et al., 2001; Huynh et al., 2004) in order to estimate quantitatively the upper limit of behavioural thermoneutral zone of the pig. The model calculated the inflection point temperatures (IPt) above which there were clear changes in the pigs' behaviour. The model can be described as:

$$Y = c + z * (T - IPt_{RH}) \quad \text{when } T >= IPt_{RH} \quad (2)$$
$$Y = c \quad \text{when } T < IPt\ RH$$

Where: Y is the dependent variable, e.g. relative frequency of lying pigs on slatted floor, activity heat production.

c is a constant
z is a regression coefficient
T is the room temperature
IPt is the inflection point temperature at 50, 65, or 80 %RH

All analyses were performed with the Genstat software (Genstat 5, release 6.1, 7th Edition)

RESULTS

Due to technical problems data from the first series had to be excluded. Tables 1 and 2 give data on the effects of room temperature on the lying and excretion variables.

As table 1 and figure 2 show, there was a tendency for room temperature to be related to percentage of lying pigs ($p < 0.1$): for each degree Celsius increase in room temperature, this percentage increased by 0.2 %. At 80 % humidity there were significantly more pigs lying than at 50 % humidity ($p < 0.05$; table 1). Room temperature also significantly affected the lying posture of the animals (table 1).

Table 1. Effects of room temperatures and humidity on lying behaviour and thermoregulatory behaviours

Dependent variables	Adjusted R^2	Parameters of model[1]	Factors		
			50 %RH	65 %RH	80 %RH
Lying pigs, %	0.17	Average	87.3^a (± 0.6)	87.8^{ab} (± 0.8)	88.8^b (± 0.7)
		Regression coefficient	0.2^{**} (± 0.1)		
Sternal lying, %	0.87	Average	12.5 (± 0.9)	12.8 (± 1.4)	11.9 (± 1.3)
		Regression coefficient	$-0.3^{n.s}$ (± 0.2)		
Half lateral lying, %	0.04	Average	15.8 (± 1.02)	14.8 (± 1.5)	15.6 (± 1.4)
		Regression coefficient	-0.4^{*} (± 0.2)		
Lateral lying, %	0.19	Average	71.66 (± 1.3)	72.3 (± 1.8)	72.1 (± 1.8)
		Regression coefficient	0.8^{***} (± 0.3)		
Huddling, %	0.87	Average	36.3 (± 1.9)	37.3 (± 2.7)	38.4 (± 2.5)
		Regression coefficient	-4.9^{***} (± 0.40)		
Wallowing, %	0.49	Average	16.6^a (± 1.4)	16.7^a (± 2.1)	22.5^b (± 1.9)
		Regression coefficient	1.2^{***} (± 0.16)		

[1] Simple regression analysis with room temperature as a variable and relative humidity as a factor

*, **, ***, n.s Levels of significant difference from 0: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, n.s. non-significance

a,b within a row, means without a common superscript letter differ $p < 0.05$

Relative humidity had no effect on these variables ($p > 0.05$). On average, 12.4 % of pigs lay sternally, 15.4 % lay half laterally, and 72.0 % lay laterally. For each degree Celsius increase, the percentage of pigs lying sternally decreased by 0.3 % (n.s), but the pigs lying half laterally decreased significantly (by 0.4 %) and the pigs lying laterally increased significantly (0.8 %) (in both cases, $p < 0.001$).

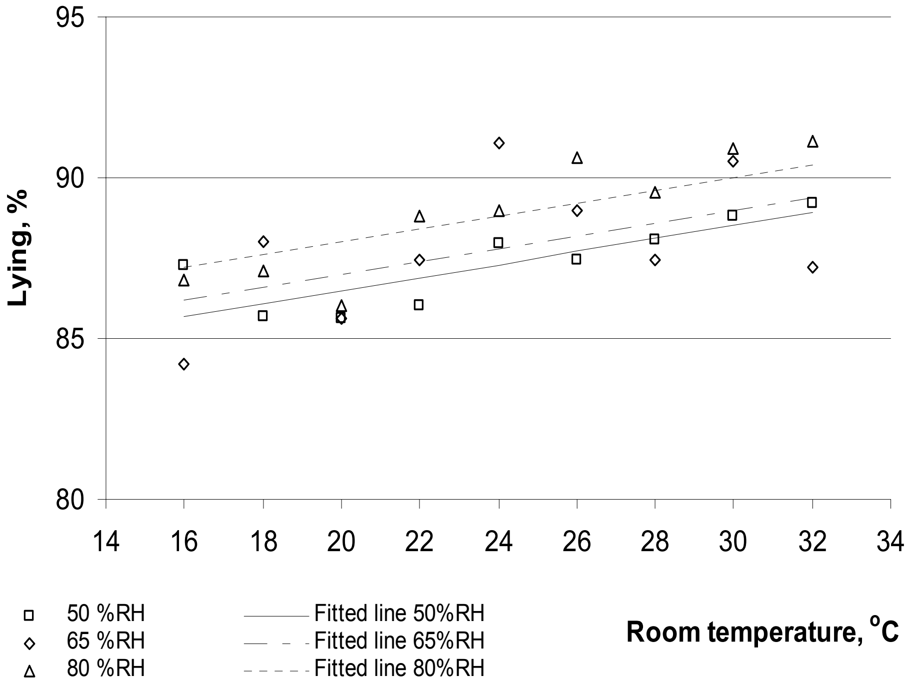

Figure 2. Relationship between lying pigs (%) and room temperature.
□ ◇ Δ were means of measured data.

Huddling was negatively affected by temperature ($p < 0.001$) (table 1 and figure 3): for each degree Celsius increase there was a 4.9 % decrease in number of huddling pigs. The pigs started to decrease huddling at a relatively low ambient temperature (figure 3).

Table 1 and figure 4 show that the relative frequency of wallowing increased with increasing temperature ($p < 0.001$). For each degree Celsius increase in ambient temperature, wallowing increased by 1.2 %.

Table 2 gives the results for excreting behaviour. Per day, on average, a pig urinated 3.5 times and defecated 2.3 times. Urinations differed significantly between humidities (table 2). On average, frequency of urination decreased by 0.03 times for each degree Celsius increase. However, across humidities the number of urinations on the solid floor rose by 0.6 % per degree Celsius increase ($p < 0.01$; table 2).

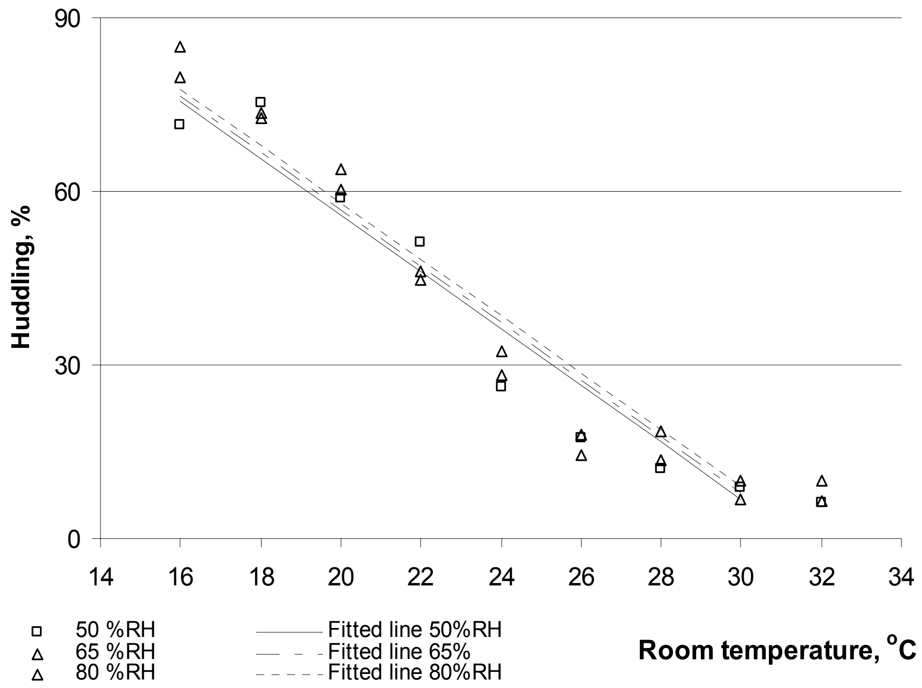

Figure 3. Relationship between huddling (%) and room temperature.
□ ◇ Δ were means of measured data.

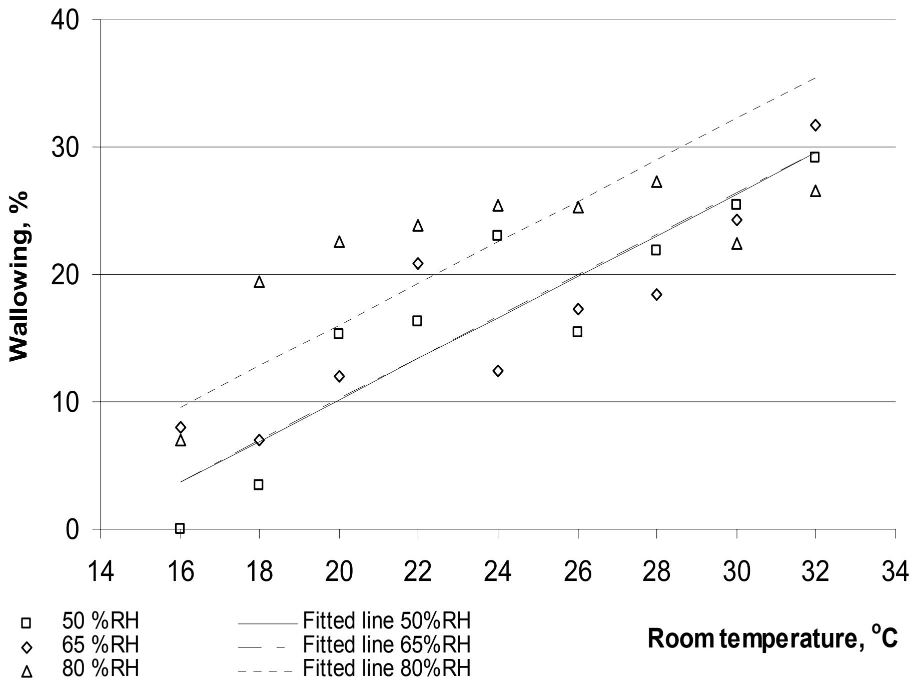

Figure 4. Relationship between wallowing (%) and room temperature.
□ ◇ Δ were means of measured data.

No significant effect of humidity on this parameter was found. Room temperature was also found to be inversely related to defecation (table 2): defecations decreased by 0.07 for each degree Celsius increase ($p < 0.01$). On average, defecations on the solid floor increased by 0.11 % for each degree Celsius rise in ambient temperature (n.s). The frequency of excretions on the solid floor was positively related to temperature (figure 5): it rose by 0.5 per degree Celsius increase (table 2). To ascertain how increasing temperature would affect floor hygiene, the percentage area of solid floor fouled with excrement was estimated (table 2).

Table 2. Effects of room temperature and humidity on excreting behaviour.

Dependent variables	Adjusted R^2	Parameters of model [1]	Factors		
			50 %RH	65 %RH	80 %RH
Urination, time pig^{-1} d^{-1}	0.41	Average	3.4^a (± 0.1)	4.0^b (± 0.2)	3.0^c (± 0.16)
		Regression coefficient	$-0.03^{n.s}$ (± 0.02)		
Defecation, time pig^{-1} d^{-1}	0.45	Average	2.0^a (± 0.1)	2.3^a (± 0.2)	2.6^b (± 0.2)
		Regression coefficient	- 0.07** (± 0.02)		
Urination on solid floor, %	0.22	Average	3.3 (± 1.1)	6.1 (± 1.7)	5.5 (± 1.5)
		Regression coefficient	0.60** (± 0.21)		
Defecation on solid floor, %	0.04	Average	1.1 (± 0.5)	2.7 (± 0.7)	1.1 (± 0.6)
		Regression coefficient	$0.11^{n.s}$ (± 0.09)		
Total excretions on solid floor, %	0.24	Average	3.2^a (± 0.8)	5.4^b (± 1.2)	4^a (± 1.1)
		Regression coefficient	0.49** (± 0.15)		
Fouling solid floor, %	0.06	Average	16.3 (± 1.9)	14.4 (± 2.8)	16.8 (± 2.4)
		Regression coefficient	0.69* (± 0.34)		

[1] Simple regression analysis with room temperature as a variable and relative humidity as a factor

[*, **, ***, n.s] Levels of significance difference from 0: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, n.s. non-significance

[a,b] within a row, means without a common superscript letter differ $p < 0.05$

For each degree Celsius increase in room temperature, the solid floor area became 0.7 % more fouled with urine and faeces ($p < 0.05$; table 2). There were no interactive effects of temperature and humidity on excreting behaviour. Two variables clearly showed a broken stick relationship with room temperature (see table 3).

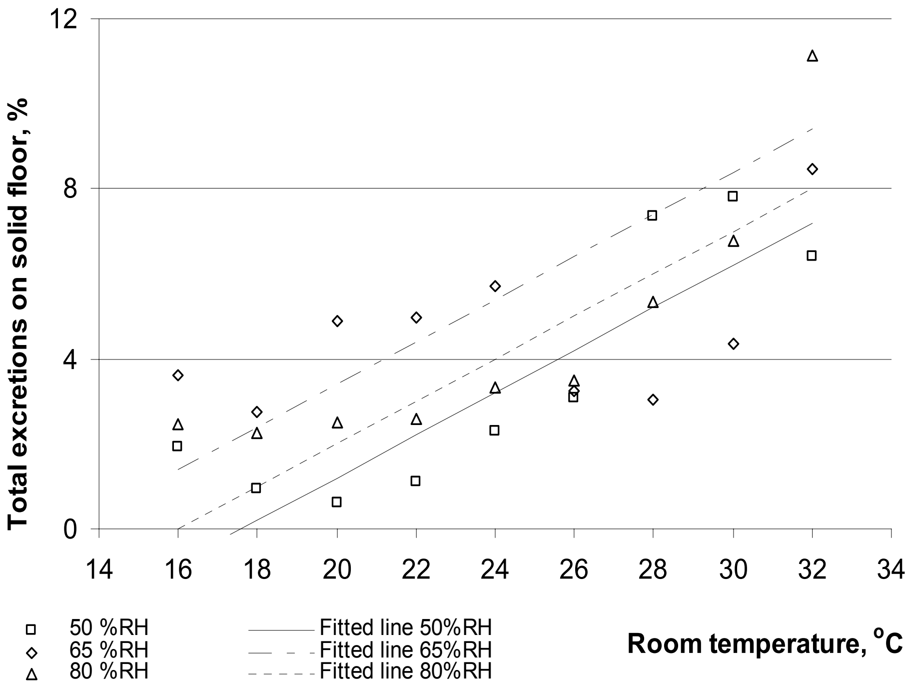

Figure 5. Relationship between excretions on solid floor (%) and room temperature. □ ◇ Δ were means of measured data.

Table 3. Inflection point temperatures at which pigs changed their behaviours

Dependent variables	Percentage variance account[1]	Parameters of model[2]	Humidity		
			50 %RH	65 %RH	80 %RH
Lying on slatted floor (%)	88	IPt	17.6 (± 1.6)	19.8 (± 0.9)	18.9 (± 0.8)
		Constant	0.1 (± 3.2)	0.7 (± 1.8)	0.9 (± 1.7)
		Regression coefficient	2.2[a] (± 0.2)	2.9[b] (± 0.2)	2.9[b] (± 0.2)
Activity Heat Production (kJ $W^{-0.75}d^{-1}$)	52	IPt	24.3 (± 1.8)	22.5 (± 2.2)	25.8 (± 1.4)
		Constant	610.7[a] (± 9.0)	580.27[b] (± 9.8)	596.4[a] (± 7.8)
		Regression coefficient	-13.5 (± 4.4)	- 9.8 (± 3.1)	- 11.8 (± 3.8)

[1] For validity of the nonlinear model, %

[2] Nonlinear regression model analysed with room temperature is variable and humidity is factor

[a,b] within a row, means without a common superscript letter differ $p < 0.05$

The IPt above, which the relative frequency of pigs lying on slatted floor started to rise, was, on average, 18.8^0 C (table 3 and figure 6). Humidity had no effect on this inflection point. When room temperature exceeded IPt the relative frequency of pigs lying on the slatted floor increased. Humidity affected this response: table 3 shows that at 50 %, the increase was less than at 65 and 80 %RH ($p < 0.05$). On average, activity heat production of the pigs decreased above 24.2^0 C (table 3 and figure 7). It fell approximately 11.7 kJ $W^{-0.75}d^{-1}$ per degree Celsius rise. Table 3 shows that when ambient temperature was below inflection point temperature, the activity heat production within the three levels of humidity was different ($p < 0.05$): at 65 % RH it was lower than at 50 and 80 %RH.

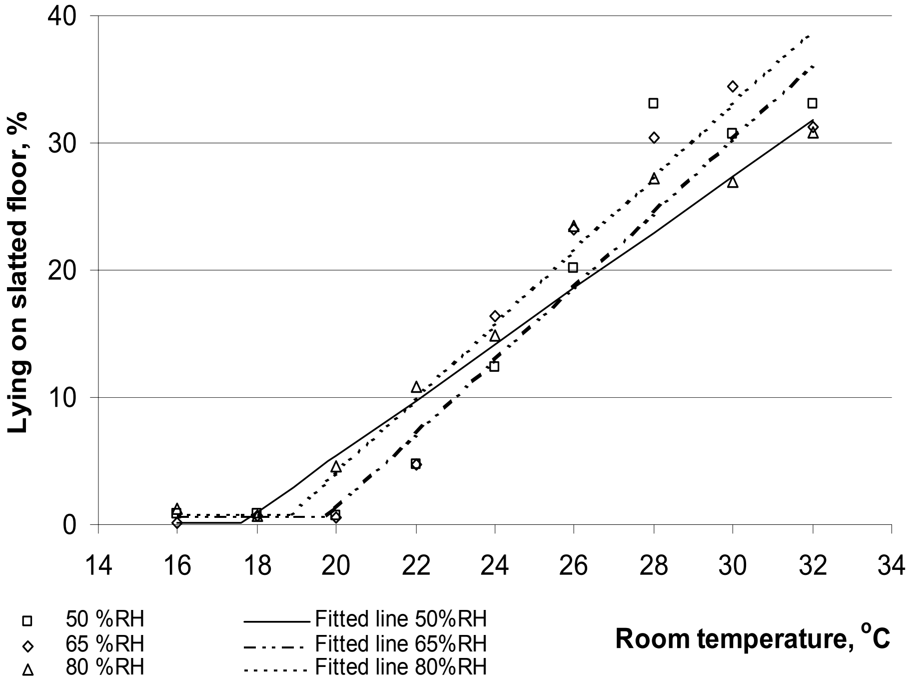

Figure 6. Broken stick relationship between lying on slatted floor (%) and room temperature. □ ◇ Δ were means of measured data.

DISCUSSION

This study investigated the behavioural adaptation of confined finishing pigs to increasing temperatures at different humidities. The pigs responded to increasing temperatures by modifying their lying, excretion and wallowing behaviour. High humidity accentuated the effects of temperature on the pigs' behaviour. The upper critical temperatures of some variables could not be estimated, due to large variations. As a result, for some variables the broken stick model failed to estimate the different parameters of the model, yet in a previous study (Aarnink et al., 2001), the broken stick model had proved to be the best model to fit data on pen fouling at increasing temperatures.

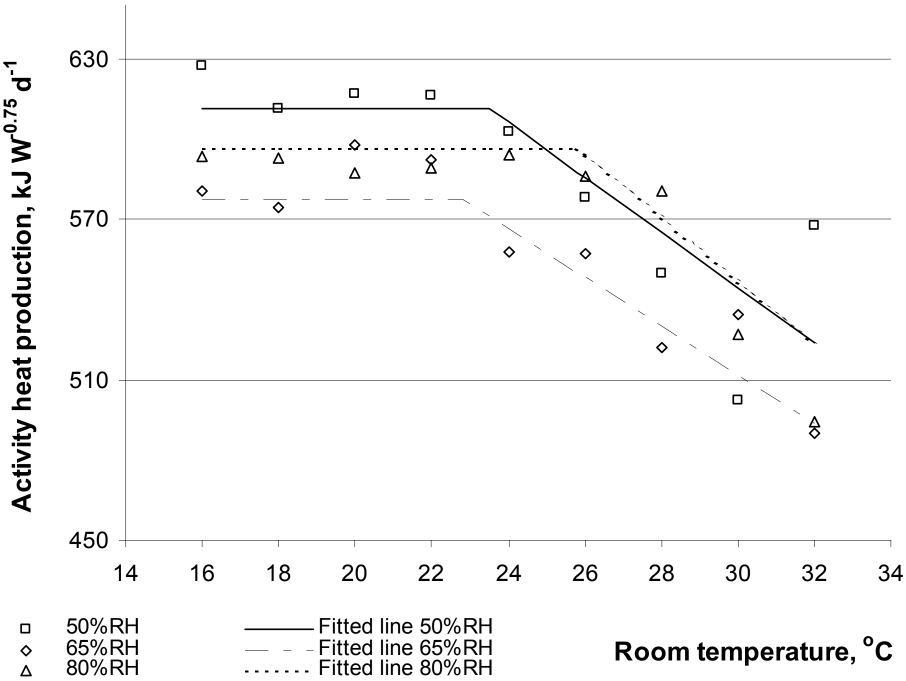

Figure 7. Broken stick relationship between activity heat production and room temperature. □ ◇ Δ were means of measured data.

There are two possible reasons for this difference: 1) in the present study, the groups of pigs were larger than in the Aarnink et al. (2001) study (10 versus 5 pigs per pen); 2) often, part of the solid floor (sectors 3 and 4) was already fouled at the start of observations. This might have contributed to the greater variation in the fouling of sectors 1 and 2, as well. When no broken stick model could be applied a linear regression model was chosen to provide a general view of pigs' behaviours at increasing temperatures and at different humidities.

Our finding that on average the pigs lay for 88.0 % of the day (24 hours) agrees with Ekkel et al. (2003), who found that finishing pigs rested for 90 % of their time. Blackshaw et al. (1994) reported 67.6 % of growers lay in the shade (at 15 - 20^0 C), but that above 35^0 C this figure rose to 93.9 %. We found that pigs spent slightly more time lying when humidity increased from 50 to 80 %.

Surprisingly, we found that activity heat production fell with increasing room temperature. Below 24.2^0 C activity heat production remained constant; at higher temperatures it declined – probably because of increased lying behaviour. Furthermore, even though we could not identify an IPt for lying in general, it is likely that activity heat production did have an IPt, due to an influence of the lying factor.

On average there was 72% of lying pigs lay on their lateral side. In contrast, Petherick (1983) presumed that the average floor area occupied by resting pigs under thermoneutral conditions could be estimated assuming on a half lateral lying posture of the pigs. In our study, at room temperatures between 16 and 18^0 C (so-called thermoneutral range as defined by Petherick (1983)), only 22.6 % of pigs lay half laterally, and sternal and half lateral lying gradually declined with increasing room temperature. The pigs reduced the percentage of lying in this position by 0.4 % for each degree Celsius increase. This switch from half lateral to lateral lying was gradual: within the temperature range we investigated there was no clear inflection point. The relative number of pigs lying on their lateral side increased with increasing room temperature. In a previous study with the same group of animals and experimental design, Huynh et al. (2004a) reported that pigs' skin temperature rose by 0.25^0 C for each degree Celsius increase in ambient temperature. It is likely that the pigs in the present study lay laterally to increase their body surface in contact with the cooler floor in order to disseminate the increased body heat brought about by the rise in ambient temperature. This agrees with Close et al. (1981), who reported that pigs housed at high temperatures will spend more time lying on their side in order to transfer as much of their excess body heat to the environment as possible.

Lying location changed with increasing temperature. When room temperature was below 18.8^0 C, the pigs chose to lie on the solid floor only. As temperature increased, they changed their preferred lying location to the slatted floor, because in partially slatted pens such floors are about 3.6^0 C cooler than solid floors (Huynh et al. 2004b). When room temperature was above 30^0 C, the percentage of lying pigs on this area peaked (30 – 35 %). This percentage is less than could be expected. Petherick and Baxter (1981), Petherick et al. (1983) and Ekkel et al. (2003) introduced an equation to estimate the area occupied by a lying pig, assuming a 60 kg growing pig and pigs lying fully on their side: 0.7 m^2. Based on this, approximately 50 % of the lying pigs could share the slatted floor area, but we observed only a maximum of three to four pigs (30 – 35 %) on the slatted floor per time. There are three likely explanations for this: 1) at high temperatures, 90 % of pigs prefer to lie, effectively obstructing access to the slatted floor; 2) At high room temperatures, pigs avoid lying in close contact with each other, to maximise heat loss through radiation. Our study did indeed show a negative linear relationship between percentage of huddling pigs and room temperature. This is in agreement with Geers

(1986); Riskowski et al. (1990) and Olsen et al. (2001), who found that as temperature rose, pigs tried increasingly to avoid body contact with other pigs. This means that the estimates of space required made by Petherick et al. (1983) and Ekkel et al. (2003) are too low for pigs are kept at higher temperatures. 3) The third possible reason is that pigs stay on the solid floor because the floor is soiled and they can lose heat there. As described earlier, in our study the solid floor was fouled at an early stage and the pigs used this foul area as a dunging area. At high ambient temperature they used this area to cool themselves by wallowing in excrement.

Several previous studies have reported that at high ambient temperatures pigs housed indoors on partially slatted flooring will shift their lying behaviour towards the slatted dunging area, and will dung on the solid floor (Randall et al., 1983; Hacker et al., 1994; Aarnink et al., 1996; 2001). Some authors have also added that this behaviour is most obvious when pigs are heavy (Hacker et al., 1994; Ni, 1999; Aarnink et al, 2001). Aarnink et al. (2001) reported that above a certain temperature, which ranged from 25.9 to 21.7^0 C for pigs weighing 25 to 105 kg, the percentage of excretions on the solid floor increased. Ni et al. (1999) reported that floor contamination could be seen already at 17.5^0 C room temperature. When studying the effects of floor cooling in commercial housing for fattening pigs at an average ambient temperature above 25^0 C, Huynh et al. (2004b) saw an increase of lying on slatted floor and also of dunging on the solid floor. Our results confirm those of the studies mentioned, but in addition we observed that with increasing temperature, pigs become uncomfortable and inactive, extending their bodily contact with the floor while lying, and avoiding physical contact with other pigs. These stretched-out pigs restricted access to the dunging area even though space allowance was acceptable. We therefore suggest that future space allowance studies should take account of thermoregulatory behavioural changes when determining the physical space pigs require. This means that physical space should increase with increasing temperature, as when they are hot, pigs show less space sharing and lie more laterally. In addition, the number of pigs lying on slatted floor could be an indicator that pig welfare suffers when pigs are exposed to high ambient temperatures. As shown in the Results section, humidity had no effect on the IPt for lying on slatted floor, but did affect the increase (regression coefficient) of this response at ambient temperature above IPt. At low humidity the increase was slightly less than at 65 and 80 %RH. This meant that at high humidity the temperature effect was more pronounced.

In our study we observed a distinctive form of pig behaviour: wallowing in a mixture of urine and faeces. Wallowing by wild pigs serves two purposes: coating the body with a layer of mud to protect against external parasites, and increasing evaporative heat loss when temperature is high (Schein et al., 1969). However, pigs will avoid lying or wallowing in their own excrement. In our study, at 80 % relative humidity the pigs wallowed at relatively low ambient temperature; wallowing increased gradually with increasing room temperature. In the groups subjected to 50 and 65 %RH, the change in wallowing activity seemed to occur later (data not shown). The temperature at which wallowing was induced was higher than the temperature at which outdoor pigs start to wallow in mud. We found that at 80 % humidity the pigs wallowed very early at the start of temperature increase. This showed that at high humidity the pigs felt the need to cool down earlier than at low humidity, and that the immediate options for relieving heat load were wallowing in excrement and lying on the slatted floor. This suggests a conflict between the motivation to stay clear of excrement and the need to increase evaporative heat loss by getting wet. For the pig to start wallowing in its own urine and faeces, the natural desire to avoid contact with excrement had to be abandoned.

The cause of the decrease in frequency of urinating might be that at high temperatures pigs increased their evaporative heat loss (Huynh et al., 2004a). By increasing respiratory frequency, much water containing body heat could be dissipated. In addition, an increase in urination on the solid floor was observed when room temperature increased. At lower humidity, the urinations of pigs on solid floor were lower. As discussed earlier, at high humidity the pigs experienced heat stress stronger and sooner. The main reason for urinating on the solid floor at high temperature might be the lack of space due to changes in lying behaviour: the increased number of pigs lying on the slatted floor when temperature increased would have hampered other pigs from reaching the slatted floor and finding an unoccupied quiet place to urinate. Finally, although not recorded in detail nor mentioned in the Results section, when temperature rose there was a dramatic increase in the incidences of pigs being showered with urine from other pigs and in urinating while lying. These behaviours again demonstrate the overriding desire of the pigs to cool themselves at these temperatures.

CONCLUSION

From this study we conclude that:

- Temperature has a strong effect on the lying and excreting behaviour of growing pigs. Humidity has a minor effect.
- Growing pigs at 60 kg body weight regulated their thermal behaviour at an early stage when exposed to high temperatures. There are ranges of critical temperatures for growing pigs.
- We found that from 16.6^0 C huddling was reduced; above 18.8^0 C lying on slatted floor was increased, from 20^0 C the excretions on solid floor increased, and above 24.2^0 C the activity heat production was reduced.
- On the basis of our findings on thermoregulation we recommend that when determining the physical space required by fattening pigs the behavioural changes at increasing temperatures should be taken into account.
- The current study demonstrates clearly that the changes in pigs' behaviour induced by heat should be taken into account when assessing pen design and indoor climate conditions.
- Finally, the number of pigs lying on slatted floor could be an indicator for assessing the welfare of pigs exposed to high ambient temperatures.

LITERATURE CITED

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.

Aarnink, A. J. A., Swierstra, D., van den Berg, A. J. and Speelman, L., 1997. Effect of Type of Slatted Floor and Degree of Fouling of Solid Floor on Ammonia Emission Rates from Fattening Piggeries. Journal of Agricultural Engineering Research, 66, 93-102.

Aarnink, A. J. A., Schrama, J. W., Verheijen, R. J. E. and Stefanowska, J., 2001. Pen Fouling in Pig Houses Affected by Temperature. In: Livestock Environment VI (Ed. by R.R, S., R, B. and R.W, B.). Galt House Hotel Louisville, Kentucky: The Society for engineering in agricultural, food, and biological systems. pp. 180 – 186.

Beattie, V. E., Walker, N. and Sneddon, I. A., 1996. An investigation of the effect of environmental enrichment and space allowance on the behaviour and production of growing pigs. Appl. Anim. Behav. Sci., 48, 151-158.

Blackshaw, J. K. and Blackshaw, A. W., 1994. Shade-seeking and lying behaviour in pigs of mixed sex and age, with access to outside pens. Appl. Anim. Behav. Sci., 39, 249-257.

Brouwer, E., 1965. Report of sub committee on constants and factors. In: 3rd Symposium on Energy Metabolism, Troon Scotland: EAAP. pp. 441 - 443.

Close, W. H., Heavens, R. P. and Brown, D., 1981. The Effects of Ambient-Temperature and Air Movement on Heat-Loss from the Pig. Animal Production. 32, 75-84.

Ekkel, E. D., Spoolder, H. A. M., Hulsegge, I. and Hopster, H., 2003. Lying characteristics as determinants for space requirements in pigs. Appl. Anim. Behav. Sci., 80, 19-30.

Geers, R., Goedseels, V., Parduyns, G. and Vercruysse, G., 1986. The group postural behaviour of growing pigs in relation to air velocity, air and floor temperature. Appl. Anim. Behav. Sci., 16, 353-362.

Hacker, R. R., Ogilvie, J. R., W.D.Morrison and F.Kains., 1994. Factors Affecting Excretory Behaviour of Pigs. Journal Animal Science, 72, 1455-1460.

Huynh, T. T. T., A. J. A. Aarnink, M. W. A. Verstegen, W. J. J. Gerrits, and M. J. H. Heetkamp. 2004a. Pigs' Physiological Responses at Different Relative Humidities and Increasing Temperatures. In: 2004 ASAE/CSAE Annual International Meeting, Fairmont Chateau Laurier, The Westin, Government Centre - Ottawa, Ontario, Canada. 16 pages, paper number 044033.

Huynh, T. T. T., A. J. A. Aarnink, H. A. M. Spoolder, M. W. A. Verstegen, and B. Kemp. 2004b. Effects of floor cooling during high ambient temperatures on the lying behavior and productivity of growing finishing pigs. Transactions of the Asae 47: 1773-1782.

Ni, J. Q., Vinckier, C., Coenegrachts, J. and Hendriks, J., 1999. Effect of manure on ammonia emission from a fattening pig house with partly slatted floor. Livestock Production Science, 59, 25-31.

Olsen, A. W., Dybker, L. and Simonsen, H. B., 2001. Behaviour of growing pigs kept in pens with outdoor runs II. Temperature regulatory behaviour, comfort behaviour and dunging preferences. Livestock Production Science, 69, 265-278.

Peishi, Y. and Toshio, I., 2001. Variation of resting position of miniature pigs by environmental temperature and food intake. Animal Science Journal, 72, J62-J68.

Petherick, J. C. and Baxter, S. H., 1981. Modelling the static spatial requirements of livestock. In: Proceedings of the CIGR Section II Seminar on Modelling, Design and Evaluation of Agricultural Buildings (Ed. by MacCormack, J. A. D.). Scottish Farm Buildings Investigation Unit, Bucksburn, Aberdeen, UK. pp. 75–82.

Petherick, J. C., 1983. A biological basis for the design of space in livestock housing. In: Farm Animal Housing and Welfare (Ed. by Baxter, S. H., Baxter, M. R. and MacCormack, J. A. C.), pp. 103-120.

Randall, J. M., Armsby, A. W. and Sharp, J. R., 1983. Cooling gradients across pens in a finishing piggery : II. Effects on excretory behaviour. Journal of Agricultural Engineering Research, 28, 247-259.

Riskowski, G. L., Bundy, D. S. and Matthews, J. A., 1990. Huddling Behaviour and Hematology of Weanling Pigs as Affected by Air Velocity and Temperature. Transactions of the Asae, 33, 1677-1685.

Schein, M. W. and Hafez, E. S. E., 1969. The behaviour of domestic animasl. London: the Williams and Wilkins Company, Baltimore.

Stolba, A. and Wood-Gush, D. G. M., 1989. The Behaviour of Pigs in a Semi-Natural Environment. Animal Production, 48, 419-425.

Verstegen, M. W. A., Hel van der, W., Brandsma, H. A., Henken, A. M. and Bransen, A. M., 1987. The Wageningen Respiration Unit for Animal Production research: a description of the equipment and its possibilities. In: Energy Metabolism In Farm Animals Effects of Housing, Stress and Disease (Ed. by Verstegen, M. W. A. and Henken, A. M.) Dordrecht: Martinus Nijhoff. pp. 478.

Yousef, M. K., 1985. Stress Physiology: Definition and Terminology. In: Stress Physiology in Livestock (Ed. by Yousef, M. K.): CRC Press. pp. 205.

Effects of Floor Cooling during High Ambient Temperatures on the Lying Behavior and Productivity of Growing Finishing Pigs

T.T.T.Huynh[12], A.J.A. Aarnink[2], H.A.M. Spoolder[3], B. Kemp[4] and M.W.A. Verstegen[5]

[1] Department of Animal Health, Ministry of Agriculture and Rural Development of Viet Nam.
[2] Livestock Environment, Wageningen University and Research Center, The Netherlands;
[3] Animal Science, Wageningen University and Research Center, The Netherlands;
[4] Animal Nutrition, Wageningen University and Research Center, The Netherlands;
[5] Adaptation Physiology, Wageningen University and Research Center, The Netherlands;

Published in Transactions of ASAE 47 (5): 1773 – 1782. Reproduction from permission of ASAE.

ABSTRACT

Given that exposing rapidly growing finishing pigs to high ambient temperatures can induce heat stress which reduces their welfare and production, this study looked at the influence of floor cooling at high ambient temperatures with two different floor designs on pigs' lying behaviour and performance. The pigs were offered a cool floor to lie during periods of high ambient temperatures. Their behaviour and performance were compared with control pigs without floor cooling. The experiment was carried out under field conditions in two types of commercial pens commonly used in Dutch pig production. Pens in room 1 had a solid floor in the front (accounting for 60% of the pen's floor area) and a metal slatted floor at the back (40% of the area). The pens in room 2 had a concrete slatted floor at the front (15% of the pen area), then a convex solid floor (45% of the area), and finally a metal slatted floor at the back (40% of the area). Each room was stocked with 144 pigs with a starting weight of around 23 kg; room 1 had six pens, each 25.0 m^2 and containing 24 pigs. Room 2 had 12 pens, each of 13.0 m^2 and containing 12 pigs. The net area per pig was approximately 1.0 m^2. In half of the pens in each room the floor could be cooled by cold groundwater flowing through plates in room 1 or through pipes embedded in the solid concrete floor in room 2. The floor cooling was activated automatically at ambient room temperatures above 25^0 C in week 3 and above 20^0 C from week 7 onwards. Feed and water were accessible ad libitum. Lying behavior was monitored by video recording once every 15 minutes. The video frames were used for analysis. Fouling of the solid floor was recorded by direct observations. Feed intake was determined at bi-weekly intervals, and growth rate was calculated from weight measurements at the start and the end of the experiment. Cooling lowered the surface temperature of the solid floor (25.0^0 C vs. 26.8^0 C, $P < 0.001$), reduced the percentage of pigs lying on the slatted floor (15.0% vs. 22.2%; $P < 0.001$) and increased feed intake (2.04 vs. 1.95 kg d^{-1} pig^{-1}, $P < 0.01$) and growth rate (753.2 vs. 720.4 g d^{-1}; $P = 0.017$). Cooling and pen design also affected fouling of the solid floor. The cooled pens were cleaner than the uncooled pens, and the pens in room 2 were cleaner than those in room 1. These results show that floor cooling can improve the thermal comfort and performance of intensively reared growing and finishing pigs during hot weather.

INTRODUCTION

Petherick (1983) described how the space pigs require for minimal welfare depends on the position they adopt while resting. According to Curtis (1983), pigs spend about 79% of the day (19 h) resting. This means that most of the time, a large part of their body is in contact with the floor. Thus, the thermal comfort provided by the floor is very important. When ambient temperature is high, pigs will change their position to increase their effective surface area for conductive and convective heat exchange (Steinbach, 1987). To be able to lie down fully to cool off, pigs need sufficient and comfortable floor space. Generally, there is not enough solid floor space in modern pig houses to enable all the pigs to lie down at the same time, so some pigs have to lie in the dunging area.

The European Union (such as Council Directive 91/630/EEC) and the Dutch government (Welfare Regulations) have legislated improvements to the welfare of pigs in intensive production systems. Under the Dutch regulations, since 1998; there has been a phasing out of fully slatted floors for growing-finishing pigs.

Since a slatted floor is a cooler for pigs to lie on than an insulated solid floor, the number of pigs lying on the slatted floor is an important indicator that temperatures in the pig house are undesirably high. The surface temperature of a slatted floor is generally about 3^0 C to 5^0 C cooler than an insulated solid floor (Randall et al., 1983). On insulated solid floors, pigs are less able to dissipate their excess heat: this is particularly important at high ambient temperature. Aarnink et al. (2001) have shown that at increasing temperatures more pigs will lay on the slatted floor than on the solid floor. They also concluded that if many pigs lie on the slatted floor, the fouling of the solid floor will increase. This confirmed previous work from Hesse and Jackisch (1995). In addition to causing thermo-regulatory and behavioral problems, high ambient temperature also has a detrimental economic effect. During the hottest months, average daily gain (ADG) and voluntary feed intake are lower, negatively affecting pig production. Generally, an ambient temperature range of 18^0 C to 21^0 C has been found to support optimal productive performance of growing finishing pigs. For each degree Celsius above a daily mean temperature of 21^0 C, pigs gained 36 to 60 g d^{-1} less body weight (Heitman and Hughes, 1949; Curtis, 1985). Quiniou et al., (1999) have also shown that high ambient temperatures have a marked negative effect on voluntary feed intake in finishing pigs. Rinaldo et al., (2000) have indicated that in the tropics, growth performance varies with the season and that during the warm season feed intake is a major factor limiting growth rate.

Large daily fluctuations between extremes of hot and cold can also reduce performance (Nienaber et al., 1987).

The objective of this study was to determine how floor cooling in partially solid floor systems could change the behavior and improve the performance of growing-finishing pigs at high temperatures. This study looked at effects of floor cooling on lying behavior, pen fouling, feed intake, average daily gain, and animal health.

MATERIAL AND METHODS

Animals

A total of 288 crossbred pigs (Dutch Landrace boar × (Duroc boar × Great Yorkshire) sow) was used. The experiment started in May and lasted until September. Animals were allocated to one of two rooms that differed in pen design (figs. 1 and 2). Mean initial live weight in room 1 at the start of the experiment (May 22) was 30.1 kg (±3.2 kg). In room 2, mean initial live weight at the start of the experiment (June 1) was 28.5 kg (±4.9 kg). At the end of the experiment, average live weight in room 1 was 116.2 kg (±15.3 kg) on September 18, and in room 2 it was 109.2 kg (±12.3 kg) on September 25.

Housing

Within each room, groups of animals were randomly assigned to the pens. Room 1 contained six pens with 24 pigs in each. As the pigs grew, the pens were enlarged, from an initial size of 3 × 5 m to a maximum of 5 × 5 m by the time the pigs weighed approximately 85 kg. Sixty percent of the pen floor was solid (5 × 3 m) and had a 6% slope. At the back of the pen was a slatted floor of 5 × 2 m (fig. 1). The slats were tribar metal bars 15 mm wide with 15 mm gaps. Room 2 contained 12 pens, each for 12 pigs. The pen size remained 2.5 × 5.0 m (fig. 2) throughout the fattening period. The first 10% of the floor at the front of the pen (2.5 × 0.50 m) was slatted concrete; the slats were 65 mm wide with 20 mm gaps. The next 60% of the floor area was a solid convex floor with a 6% slope to both sides. The remaining 30% of floor space, at the back of the pen (2.5 × 1.5 m), was metal slats similar to that in room 1.

Feeding

The animals were fed ad libitum with a normal commercial fattening diet. They received a two-phase feeding. At the start of the experiment, the diet contained

9.5 MJ NE (CVB, 2000) and 180 g kg^{-1} crude protein (CP). From day 77 of the experiment onward, the diet contained 9.8 MJ NE and 142 g kg^{-1} CP. The pigs had free access to water from a nipple water drinker.

Floor Cooling

In both rooms, heat exchange systems were embedded in the solid floor to heat or cool it. In room 1, a polyethylene plate heat exchanger system (figs. 3 and 6) was used. The plates were 140 mm wide, 15 mm high (fig. 4), and 100 mm apart. In room 2, a polyethylene piping heat exchanger system was used (figs. 5 and 7).

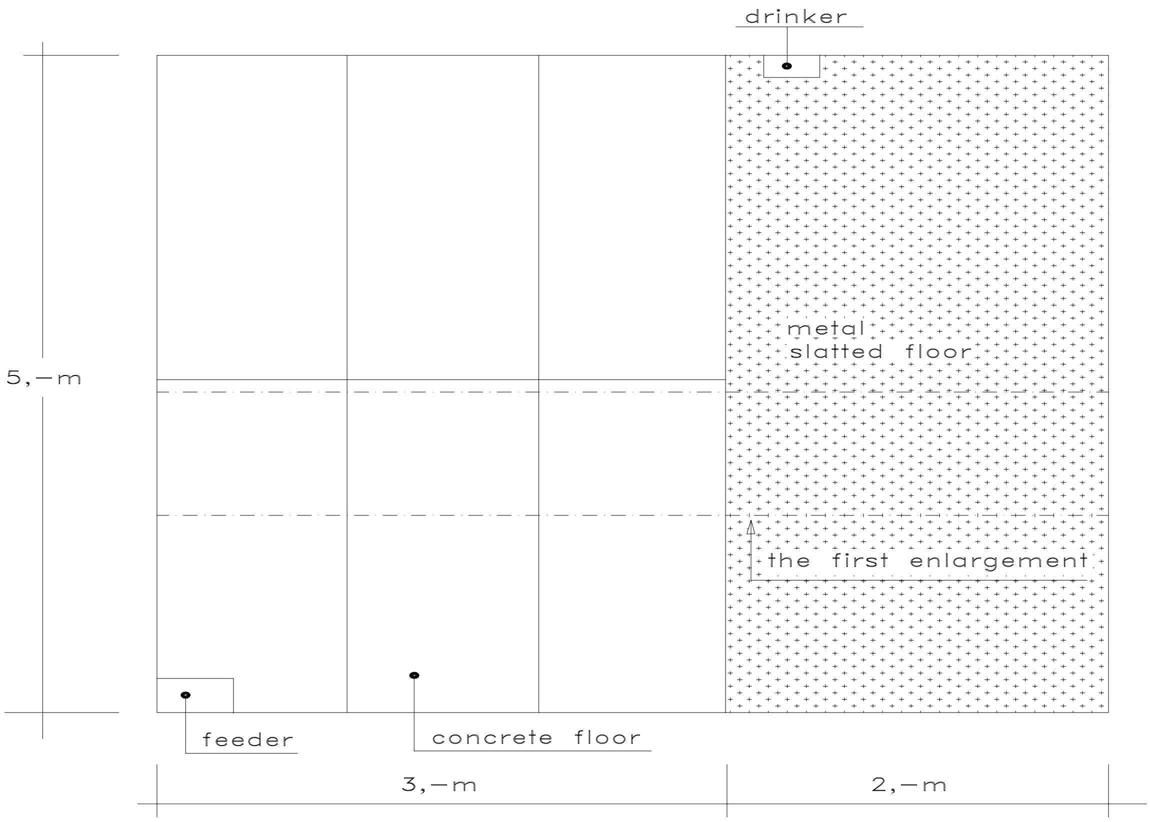

Figure 1. Layout of a pen in room 1. When the pigs reached 50 and 85 kg of weight, the pens were widened by removing a partition. The floor areas per pig were 0.6, 0.85, and 1.0 m^2, respectively.

The pipes had an internal diameter of 18 mm and were spaced 170 mm apart. An insulation layer underneath restricted heat exchange from the heat exchanger system to the ground. The water circulating within the floor was cooled within a water-water heat exchanger by groundwater of approximately 10^0 C.

Control of the Cooling System

In both rooms, the heat exchange system was used to cool the floor in pens on one side of the room. The pens on the other side of the room had no floor cooling. During the first two weeks of the fattening period, the floor cooling was off but the floor heating was on. During these weeks, the temperature of the water flowing into the floor fell linearly from 30^0 C to 25^0 C. From week 3 onwards, the floor cooling system was automatically controlled as follows:

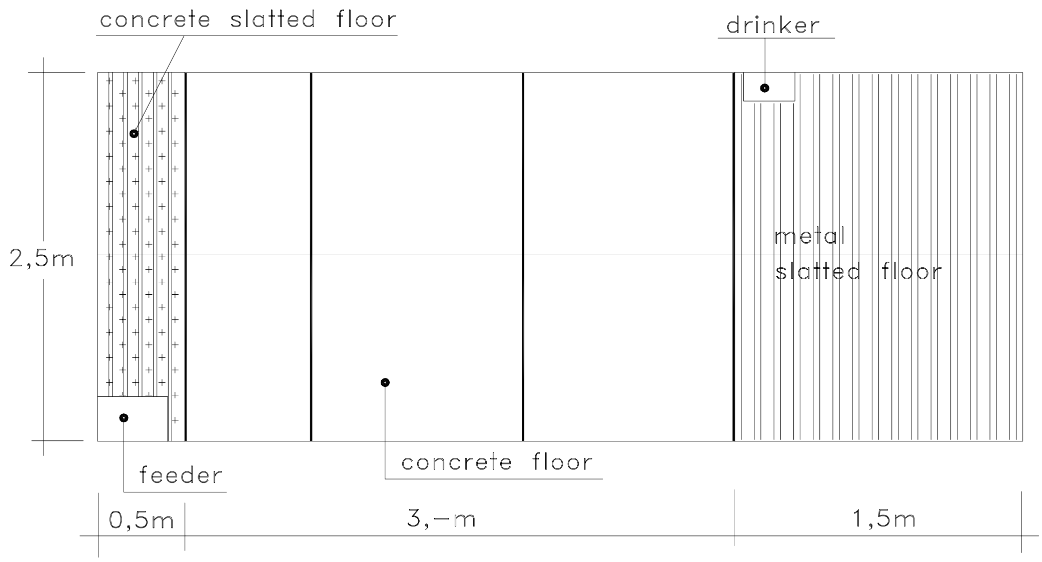

Figure 2. Layout of a pen in room 2.

The cooling setpoint (= the room temperature, measured at 1.5 m above floor level, at which cooling was turned on automatically) was decreased linearly from 25^0 C to 20^0 C between week 3 and week 7. From week 7 until the end of the fattening period, the cooling setpoint was kept at 20^0 C.

The water temperature was initially set at 23^0 C. It was lowered by 1^0 C for every 2^0 C that the room temperature exceeded the cooling setpoint. The minimum water temperature was 18^0 C. From 24 July onwards, the water temperature was set 2^0 C lower, to increase the floor's cooling capacity, and the minimum water temperature was lowered to 16^0 C as well. The temperature of the water was measured by PT 100 temperature sensors connected to a data logging system (Yokogawa, Japan) just before the water flowed into the floor.

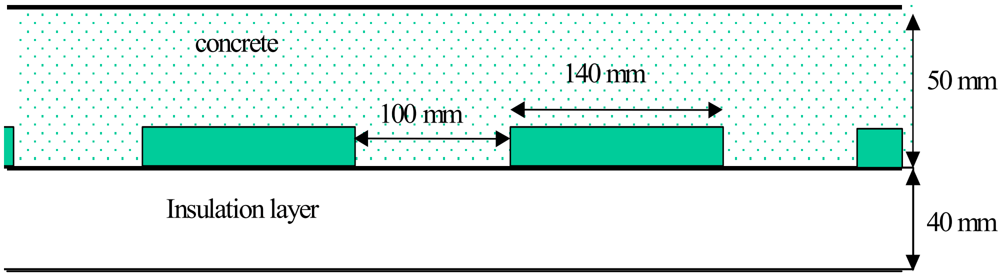

Figure 3. Cross-section of floor cooling with heat exchange plates in room 1.

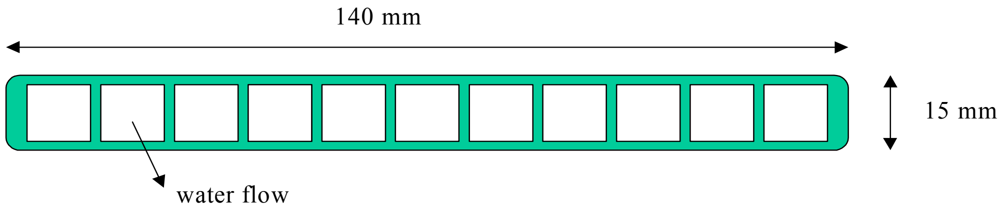

Figure 4. Cross-section of a heat exchange plate in room 1.

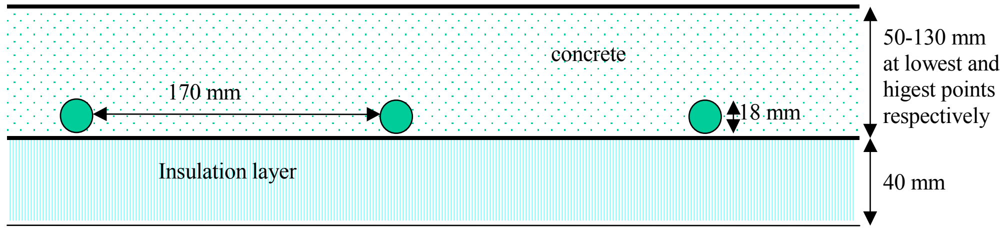

Figure 5. Cross-section of floor cooling with heat exchange pipes in room 2.

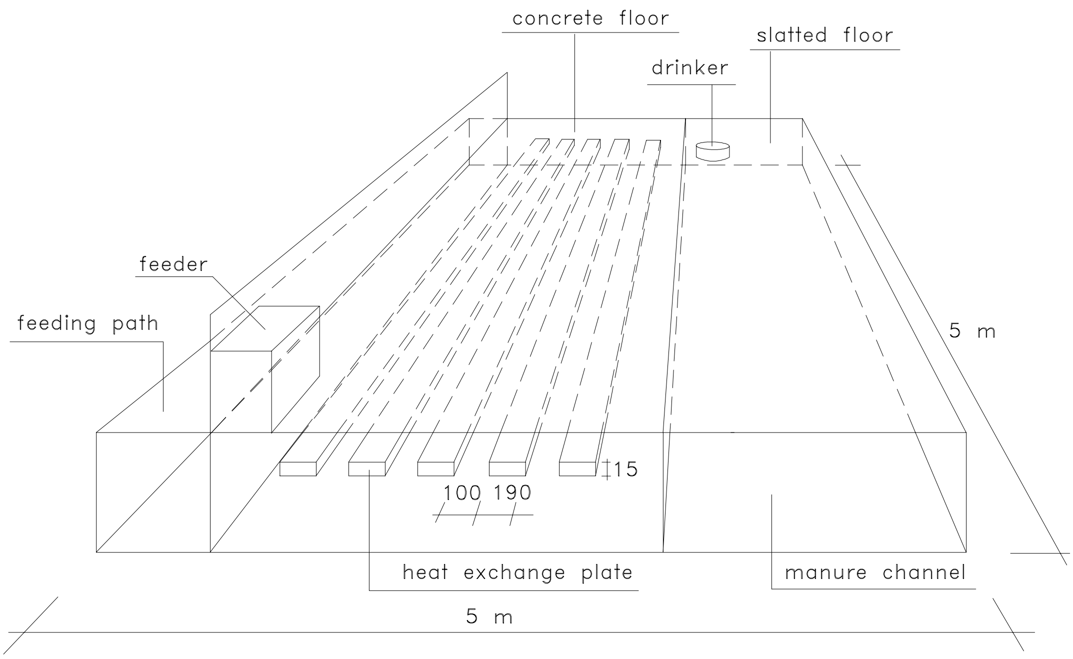

Figure 6. Layout of a pen in room 1, showing water plates.

Ventilation Control

An Ecovent (Fancom, Panningen, The Netherlands) ventilation system was used, with a central frequency controller that controlled all fans. Each room had two exhaust shafts with measuring fans. The ventilation rate was automatically controlled, depending on the number of days after the start of the fattening period (table 1). The airflow within rooms 1 and 2 is illustrated in figures 8 and 9, respectively.

Table 1. The various ranges of ventilation control.

No. of days after start of fattening period	Temperature (^{0} C)		Ventilation rate (m^3 h^{-1})	
	During Min. Ventilation	During Max. Ventilation	Min.	Max.
1	26.0	30.0	8.6	30.0
3	25.0	29.0	8.6	30.0
7	24.0	28.0	10.9	35.0
14	22.0	27.0	12.7	40.0
50	21.5	26.5	16.8	60.0
100	21.0	26.5	24.0	70.0

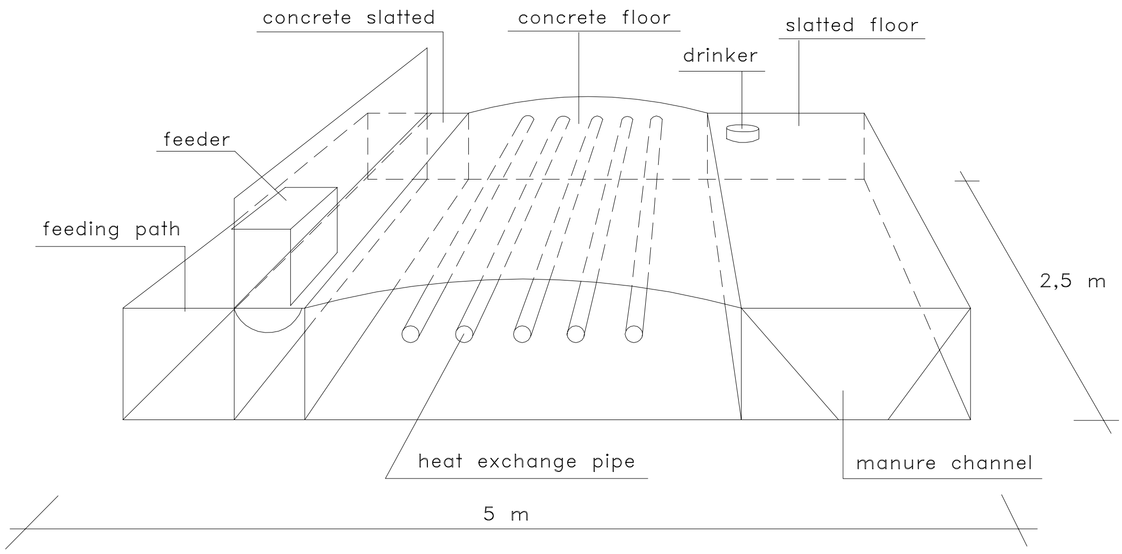

Figure 7. Layout of a pen in room 2, showing water pipes.

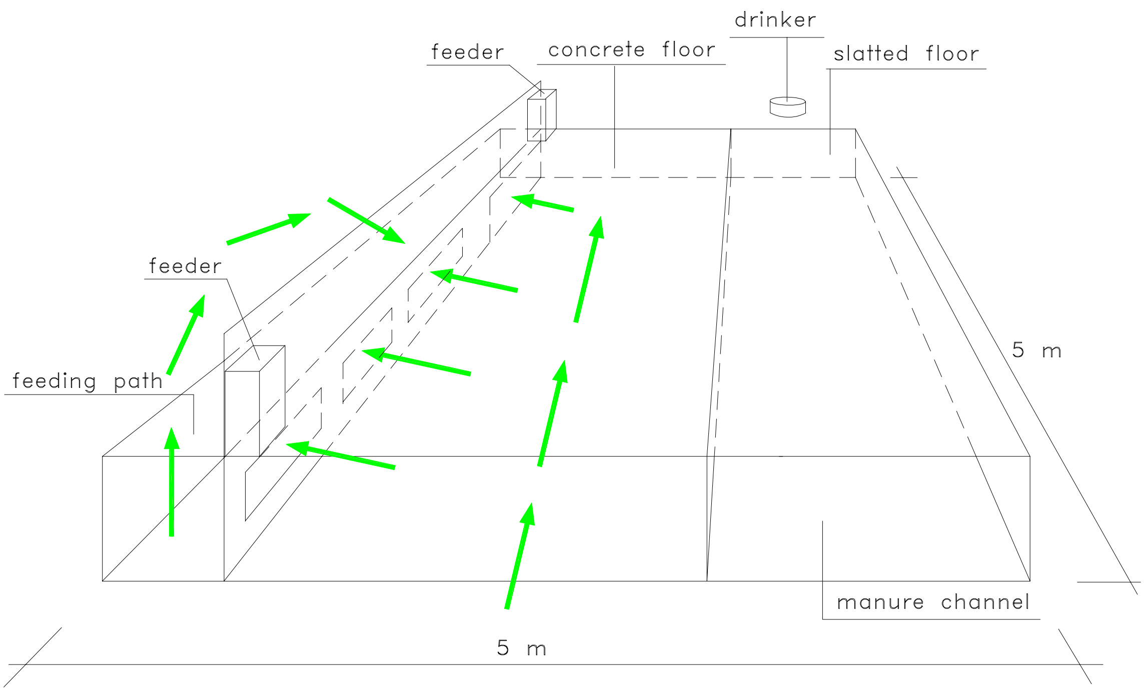

Figure 8. Layout of the pen in room 1, showing airflow.

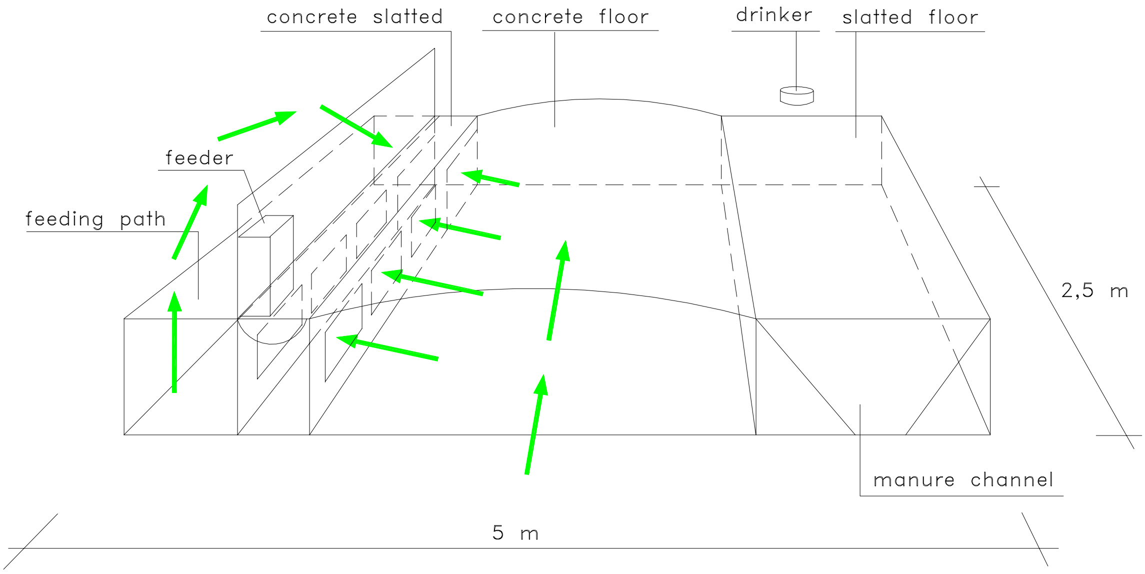

Figure 9. Layout of the pen in room 2, showing airflow.

Measurements

Outside temperature and relative humidity and inside temperature and relative humidity (measured at 1 m above both the cooled and uncooled solid floors) were measured every 10 min in both rooms. Temperature and humidity were measured by the same combined instrument (Hygromer I100, Rotronic, Switzerland).

Temperature of the water flowing into and out of the floor was measured by PT 100 temperature sensors connected to a data logging system (Yokogawa, Japan). The energy uptake by the cooling system was determined by means of an energy-flow measuring instrument (Q 2.5E, Raabkärcher, Viterra Energy Service, Germany). This instrument measured the flow rate and temperature difference between the entering and leaving water.

Twice a week, the surface temperature of the floor was determined randomly between 08:00 and 15:00 h. On six sections of the solid floor and on two sections of the slatted floor (figs. 1 and 2), the floor surface temperature was measured by infrared thermography (Quicktemp 850-1, Testo B.V., The Netherlands).

Feed was weighed and delivered to each pen automatically. Total feed intake per pen was recorded for each two-week period. The average daily gain of pigs was determined by weighing the pigs at the start of the fattening period and when they went to the slaughterhouse.

Pig Behavior

Lying Behavior

The lying behavior was recorded by round-the-clock video observations. The pigs were recorded with four cameras, two in room 1 and two in room 2, from June through August. Each camera observed one pen. The cameras were switched between pens approximately once every two days. One digital picture (frame) was stored every 15 min.

The observations were done pairwise in each room, and simultaneously in two pens: one pen with floor cooling and the opposite pen in the same room without floor cooling. To determine the effects of floor cooling on the pigs' lying behavior during hot periods, we analyzed data for days on which the average inside temperature between 09:30 and 21:30 h exceeded 25^0 C. From the pictures taken at 15 min intervals, we determined the number of pigs lying in the different sections of the pen (figs. 1 and 2) and the lying position of the animals, which we classified as follows:

Side: pigs lying flat on one side of the body.

Sternal belly: pigs lying on their belly, with their legs folded under them.

In between: in between the above two positions, with only one or two legs folded under the belly.

For analysis, the data were split into two periods per day: 09:30 to 21:30 h (the period with high ambient temperature) and 21:30 to 09:30 h (the cool period).

Pen Fouling

Daily, except for the weekends, the fouled areas were drawn on a plan of the pen layout, on which a grid had been superimposed. The grid squares were used to calculate the percentage of area fouled with urine and feces. At the end of the fattening period, the grid was used to determine the extent of the manure crust (the dried mixture of feces and urine) on the different sections of the solid floor. The crust, which was classed as thin (<1 mm), medium (1 to 10 mm), or thick (>10 mm), was qualitatively assessed by the same person for each section of all pens.

Health Records

Health records were kept. They included any application of drugs, other veterinary treatments, and the reasons for removing animals from the experiment.

Statistical Analysis

The data collected were analyzed in a linear mixed model using the residual maximum likelihood method (REML) of Genstat 5, release 4.2, 5e edition. The fixed effects in the model were cooling (d.f. = 1, no or yes) room (d.f. = 1, room 1 or 2), the cool/warm period of the day, and the two-way interactions between these factors. These were tested against the random pen within room variation. The surface temperatures of the floor were analyzed with the same statistical model, but without the effect of period of the day. To ascertain the effect of cooling on the lying behavior of the pigs, the inside temperature was included in the fixed model to correct for temperature differences between rooms. Interaction effects were excluded from the model when not significant. The experimental units for lying behavior were the 24 h observation periods per pen; the experimental units for pen fouling were the manure crust, feed intake, and growth rate.

RESULTS

Cooling System and Floor Temperature

The floor cooling systems were controlled separately for each room. The mean floor surface temperatures were 26.8^0 C for the cooled pens and 24.9^0 C for the uncooled pens (s.e. 0.14; $p < 0.001$). The difference between the cooled and uncooled pens was 2.4^0 C for room 1 and 1.3^0 C for room 2 (s.e. 0.14; $p < 0.001$). In room 1, the difference between the surface temperature of the solid floor and the slatted floor was $+3.6^0$ C in the uncooled pens and $+ 2.3^0$ C in the cooled pens. In room 2, these values were $+ 2.7^0$ C and $+ 1.9^0$ C, respectively. The temperature of the solid floor in the uncooled pens was 1.6^0 C higher in room 1 than in room 2. The equivalent value for the cooled pens was 0.5^0 C (table 2).

Figure 10 shows the two-weekly averages of outside temperature, ambient temperature, and energy uptake by the cooled floor. It can be seen that the temperature in room 1 was slightly higher than the temperature in room 2. The energy uptake of the floor was clearly higher in room 1 than in room 2.

Table 2. The mean floor surface temperatures of solid and slatted floor with and without floor cooling.

				Effect		
		Temperature (°C)		Room	Cooling	Room × Cooling
Floor Type	Cooling[a]	Room 1	Room 2	s.e	s.e	s.e
Solid	0	27.6	26.0	0.1	0.1	0.2
	1	25.2	24.7	($p < 0.001$)	($p < 0.001$)	($p < 0.001$)
Slatted	0	23.9	23.3	0.1	0.1	0.1
	1	22.9	22.8	($p = 0.003$)	($p < 0.001$)	($p < 0.001$)

[a] 0 = without cooling; 1 = with cooling.

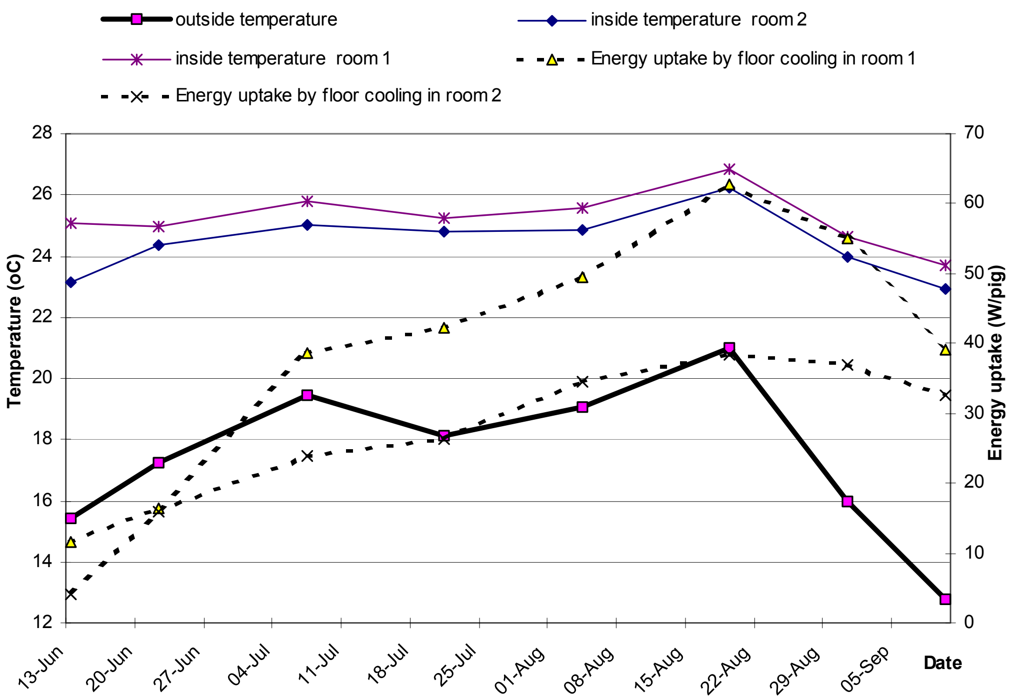

Figure 10. Variation in outside and room temperatures, and energy uptake by the cooled floors.

Room Climate and Number of Observation Days

The floor cooling system was used from June 12 until September 18 in room 1 and from June 12 until September 25 in room 2. Table 3 gives the numbers of observations per pen. The reason that the number of observations per pen is not the same is that we excluded observation days on which the mean temperature during the warm part of the day was below 25^0 C. The average temperature of the cool period (21:30 to 09:30 h) of the observation days was 24.1^0 C in room 1 and 24.7^0 C in room 2. During the warm period of the day (from 09:30 to 21:30 h), the average temperature was 26.6^0 C in room 1 and 26.5^0 C in room 2. During the cool period of the day, the average relative humidity was 59.9% in room 1 and 54.0% in room 2. During the warm period, it was 54% in room 1 and 48% in room 2.

Table 3. Number of observation days (n) with mean indoor temperatures above 25^0 C during the warm part of the day (from 09:30 to 21:30 h).

Room	Pen	n
1	1	13
	2	16
	3	8
		37 total
2	1	3
	2	6
	3	6
	4	4
	5	3
	6	5
		27 total

The energy absorbed by the cooled floors during the cool period of the observation days was 38.3 W per pig in room 1 and 28.3 W per pig in room 2. The comparable figures during the warm period were 45.0 W per pig in room 1 and 28.7 W per pig in room 2. Table 4 shows the average inside temperature above the uncooled and cooled pens for the observation days on which the average temperature from 09:30 to 21:30 h exceeded 25^0 C.

Table 4. Average indoor temperatures on observation days.

	Indoor Temperature above Uncooled Pen (°C)[a]		Indoor Temperature above Cooled Pen (°C)[a]			
Room	Average	Range	Average	Range	Mean	SD
1	25.3	21.0 - 31.6	25.6	21.3 - 32.2	25.5	0.2
2	25.9	22.8 - 31.7	25.7	21.7 - 31.3	25.6	0.1

[a] Temperature sensors hung at 1.5m above the floor.

Pig Behavior

Lying Behavior

Table 5 presents the percentage of pigs lying on the slatted floor during the cool period (from 21:30 to 09:30 h) and warm period (from 09:30 to 21:30 h) of the day for uncooled and cooled pens in both rooms. In the uncooled pens, more pigs lay on the slatted floor than in the cooled pens (22.16% vs. 15.03%; s.e. 0.67; $P < 0.001$). More pigs lay on the slatted floor during the warm period of the day than during the cold period (19.55% vs. 17.63%; s.e. 0.67; $P < 0.01$). In room 1, more pigs lay on the slatted floor than in room 2 (24.36% vs. 12.83%; s.e. 1.8; P <

0.001). No interactive effects were found between cooling and room, period and room, and cooling and period of the day.

Table 5. Effects of period of the day, cooling, and room on percentage of pigs (relative to total number of lying pigs) that were lying on the slatted floor and were lying on their side during the cool (from 21:30 to 09:30 h) and warm (from 09:30 to 21:30 h) periods of the day.

Behavior	Period	Cooling[a]	Room		Effect		
			1	2	Period s.e.	Cooling s.e.	Room s.e.
Lying on slatted floor	Cool[b]	0	26.8	15.1	0.7 (p < 0.005)	0.7 (p < 0.001)	1.8 (p < 0.001)
		1	20.4	8.2			
	Warm[c]	0	29.0	17.8			
		1	21.2	10.2			
Lying on side	Cool	0	50.1	52.4	1.2 (p < 0.05)	1.2 (n.s.)	2.5 (n.s.)
		1	47.5	50.9			
	Warm	0	54.3	53.5			
		1	52.7	52.9			

[a] 0 = without cooling; 1 = with cooling.
[b] From 21:30 to 09:30 h.
[c] From 09:30 to 21:30 h.

There were no differences ($P > 0.05$) in the lying positions of pigs between rooms or between floor cooling treatments. However, during the warm period of the day, more pigs lay on their side than during the cool period of the day (5.17% more for room 1, and 2.00% more for room 2; $P < 0.05$) (table 5).

Pen Fouling

The areas fouled with urine, feces, and with a mixture of urine and feces were determined. The areas fouled with urine were larger in room 1 than in room 2 ($P < 0.001$). There were no statistical differences between uncooled and cooled floors for the three types of fouling. However, there were differences between cooled pens and uncooled pens; in the cooled pens, the percentage of floor fouled was less than in the uncooled pens (table 6).

Table 6. Effects of cooling and room on fouling of solid floor area (in % of total floor area) fouled with urine, feces or with a mixture.

Fouling	Cooling[a]	Effect			
		Room		Cooling	Room
		1	2	s.e.	s.e.
Urine	0	3.2	0.9	0.2	0.2
	1	3.0	0.7	(p = 0.2)	(p < 0.001)
Feces	0	0.6	0.8	0.1	0.2
	1	0.6	0.7	(p = 0.7)	(p = 0.4)
Mixture	0	2.1	3.6	1.5	1.9
	1	1.8	0.8	(p = 0.3)	(p = 0.9)
Total fouled	0	6.1	5.1	1.8 (p = 0.2)	1.9 (p = 0.9)

[a] 0 = without cooling; 1 = with cooling.

Crust formation on the solid floor was assigned to three classes: light, medium, and heavy. The data, shown in table 7, reveal an effect of cooling on the crust classed as "heavy" (P < 0.05). There was more crust formation on the solid floor in room 1 than in room 2. This can be seen from table 7; room 1 had a significantly larger area in the "medium" category and a significantly smaller area in the "light" category.

Table 7. Effects of cooling on degree of crusting on solid floor (as % of total floor area).

Crusting	Cooling[a]	Effect			
		Room		Cooling	Room
		1	2	s.e.	s.e.
Light	0	3.0	65.8	11.6	17.8
	1	12.7	92.0	(p =.0.08)	(p < 0.001)
Medium	0	73.7	10.8	6.7	7.1
	1	82.7	0.0	(p = 0.5)	(p < 0.001)
Heavy	0	23.3	23.3	6.7 (p < 0.05)	14.6 (p = 0.9)

[a] 0 = without cooling; 1 = with cooling.

Health Records

Seven pigs were removed from the experiment (2.43% of all pigs), all from room 1. Six were from uncooled pens; one was culled from a cooled pen. The pigs from the uncooled pens were culled because of respiration problems and slow daily gain. The reason for culling the pig in the cooled pen was rectal prolapse. Overall incidences were too low to differentiate between treatments.

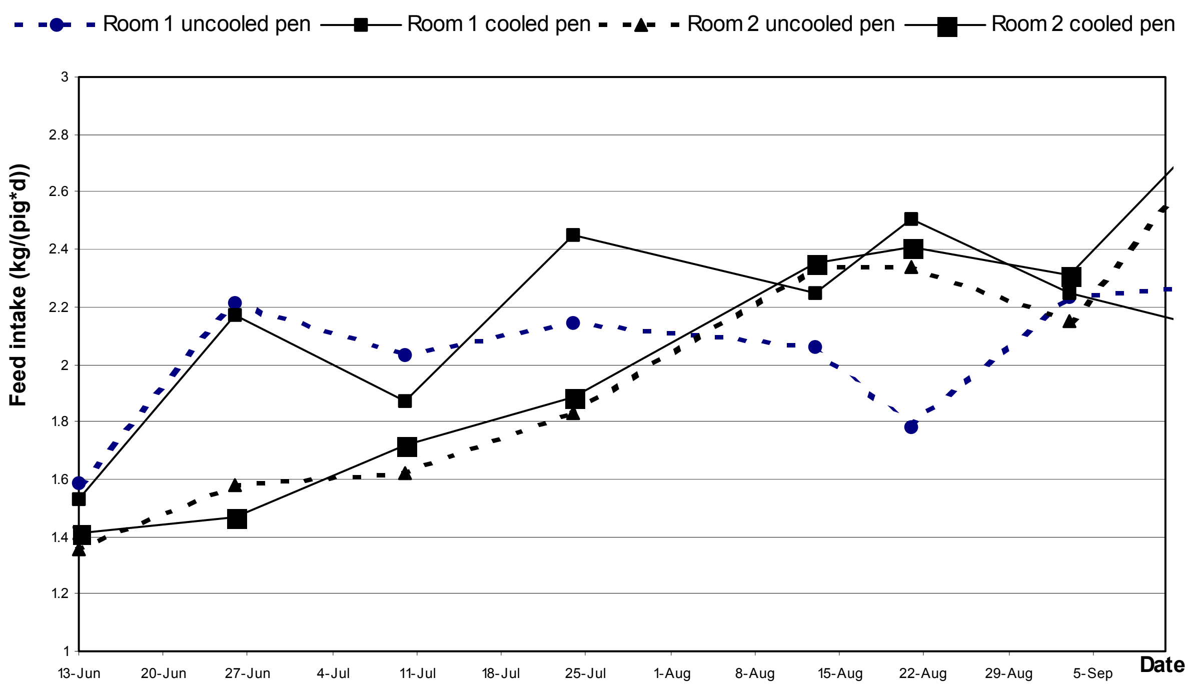

Figure 11. Comparison of voluntary feed intake.

Voluntary Feed Intake

There were significant differences in feed intake between the cooled and uncooled pens. The pigs in the cooled pens consumed more feed than those in the uncooled pens ($P < 0.01$). No difference in feed intake was observed during the first part of the fattening period (fig. 11). There was also a higher voluntary feed intake in room 1 than in room 2 ($P < 0.05$; table 8).

Average Daily Gain

Weight gain was somewhat higher (32.8 g d^{-1} pig^{-1}) for pigs in the cooled pens than for pigs in the uncooled pens (table 8). There were no differences in daily gain between the two rooms. A tendency was found ($P = 0.056$) for a room and cooling to interact with regard to pig weight gain. The difference in growth performance between cooled and uncooled pens was more pronounced in room 1.

Table 8. Effects of cooling on voluntary feed intake (kg/pig) and average daily gain (g d^{-1} per pig) during the entire fattening period.

		Effect			
		Room		Room	Cooling
	Cooling[a]	1	2	s.e.	s.e.
Feed intake[b]	0	220.4	213.2	6.9	5.0
	1	242.0	221.2	($p < 0.05$)	($p < 0.01$)
Average daily gain[c]	0	717.5	723.4	14.7	11.3
	1	771.9	734.4	($p = 0.28$)	($p = 0.017$)

[a] 0 = without cooling; 1 = with cooling.
[b] kg/pig.
[c] g d^{-1} per pig.

DISCUSSION

Housing systems confine animals in a particular environment and restrict their opportunity to find an area with maximal thermal comfort. This is a major constraint to production, especially when ambient temperatures are high. Our results demonstrate that cooling the solid pen floor in pig houses affects the lying and excreting behavior and performance of growing finishing pigs. Lying on the slatted floor, or more generally in the excretion area, indicates that pigs are suffering thermal discomfort, especially when the temperature inside the room is high (Aarnink et al., 2001; Hesse and Jackisch, 1995; Randall et al., 1983). Our results show that floor cooling reduces the number of pigs lying on the slatted floor at high ambient temperatures. These cooling-induced changes in the pigs' lying behavior might have improved their thermal comfort and welfare conditions during hot weather.

The area of the solid floor fouled with urine or feces did not differ much between the uncooled and cooled floors. We had expected a larger difference, given an earlier finding (Aarnink et al., 2001) that pen fouling increased as more pigs lay on the slatted floor. One factor that might explain the difference in the results could be the very strictly controlled indoor climate in the current experiment, in which for nine consecutive days the temperature was increased by 2^0 C every day, from an initial temperature of 16^0 C to 28^0 C. In addition, the short duration of the heat stress scheme might have caused the changes in excreting behavior to be larger than in our long duration exposure. It seems likely that there will be differences between short-term and long-term effects. Another reason for the discrepancy with the earlier experiment (Aarnink et al., 2001) is that in that experiment the air was introduced through a perforated ceiling, while in the current experiment the fresh air came from the feeding passage and flowed down directly into the lying area.

The main reason for the greater pen fouling in room 1 than in room 2 could be that during the hot periods of the experiment the pigs in room 1 were heavier than those in room 2. Various researchers (e.g., Hacker et al., 1994; Aarnink et al., 1996) have shown that heavier pigs foul their pens more. Furthermore, in room 1 the group size was larger than in room 2 (24 vs. 12 pigs per pen), and the shape of the pens was different, especially the shape of the floor. On the convex floor in room 2, the urine probably drained to the manure pit much faster than on the sloping floor in room 1. Buré (1986) demonstrated experimentally that long, narrow pens like those in room 2, in which the lying and excreting areas adjoin along the narrow side, had less fouling than pens in which these areas adjoined along the wide side. This may have been a contributory factor in our study.

Although the solid floor was cooled, its surface temperature was always higher than that of the slatted floor. However, the difference decreased at higher cooling capacity (cooler inflowing water). To keep the pigs lying on the solid floor at high ambient temperatures, the temperature of the solid floor should be the same as or lower than that of the slatted floor. Some of the factors limiting the cooling system were the system's capacity and the fact that the water warmed up somewhat as it flowed from the heat exchanger to the room floor. The temperature of the inflowing water in room 2 was higher than in room 1 because room 2 was farther from the cooling water unit (25 m vs. 10 m). This implies that one way to improve the results would be to increase the capacity of the cooling system.

During the warm period of the day, from 09:30 to 21:30 h, the pigs lay somewhat more on the slatted floor than during the cool period of the day. The differences in mean inside room temperature between the cool and warm periods of the day were small: 2.5^0 C for room 1 and 1.8^0 C for room 2. When differences are larger, e.g., in spring and fall, it might be worth cooling the floor during the warm period of the day only and turning off the cooling during the night. According to Curtis (1983) and Steinbach (1987), at higher ambient temperatures pigs lie on their sides more in order to maximize their body contact with the floor and thus maximize heat loss. Our findings confirm this: the pigs lay more on their sides during the warm period of the day than during the cool part of the day. We found no effect of cooling on the lying position. A possible reason is that, regardless of whether or not the floor is cooled, pigs generally prefer to lie on their side rather than on their belly. It seems likely that as the floor temperature falls, a point will be reached at which the pigs will lie less on their sides in order to reduce their heat loss to the floor.

The effect of cooling on feed intake became visible after approximately 6 weeks of the fattening period. This confirms Verstegen's (1971) contention that the critical temperature decreases with increasing live weight. In pigs weighing 50 to 90 kg, this decrease in temperature with increasing weight is slightly faster than in younger pigs weighing 20 to 50 kg. When no cooling is applied, apart from adapting their behavior, the only way pigs can limit their stress at temperatures above the comfort zone or above their upper critical temperature is by eating less. In this experiment this was clearly shown: the pigs in the uncooled pens ate less than pigs in the cooled pens, and consequently, the growth rate in the uncooled pens was lower. This effect on pig growth rate can be an economic justification for installing a cooling system in houses for growing finishing pigs. Thus, cooling pig pens during hot summer weather not only improves the pigs' welfare, but may benefit the farmer economically as well.

CONCLUSION

In this study, we have demonstrated that:

- Cooling a solid pen floor improves the lying behavior of growing and finishing pigs at high ambient temperatures: more pigs chose to lie on the cool solid floor instead of on the slatted floor.
- We have also demonstrated that floor cooling significantly increased the pigs' feed intake and growth rate under summer conditions.
- The system might be further refined if more were known about how the cooling requirements of the pigs varies with ambient temperature and animal weight.

LITERATURE CITED

Aarnink, A. J. A., A. J. van den Berg, A. Keen, P. Hoeksma, and M. W. A. Verstegen. 1996. Effect of slatted floor area on ammonia emission and on the excretory and lying behavior of growing pigs. J. Agric. Eng. Res. 64: 299-310.

Aarnink, A. J. A., J. W. Schrama, R. J. E. Verheijen, and J. Stefanowska. 2001. Pen fouling in pig houses affected by temperature. In Proceeding of the Sixth International Symposium, pp180 - 186. Galt House Hotel Louisville, Kentucky. ASAE: The society for engineering in agricultural, food, and biological systems.

Buré, R. G. 1986. Die Auswirkung der Buchtenstruktur auf das Liege- und Ausscheidungsverhalten von Schweinen. Aktuelle Abeiten zur artgemässen Tierhaltung: 83-91. KTBL-Schrift 319. Darmstadt, Germany: Kuratorium für Technik und Bauwesen in der Landwirtschaft.

Curtis, S. E. 1983. Environmental Management in Agriculture. Ames, Iowa: Iowa State University Press.

Curtis, S. E. 1985. Physiological responses and adaptations of swine. In: M. K. Yousef (ed.) Stress physiology in livestock. No. II. p 62 - 63. CRC Press, Las Vegas, Nevada.

CVB. 2000. Veevoedertabel. Centraal Veevoederbureau, Lelystad, The Netherlands.

Hacker, R. R., J. R. Ogilvie, W. D. Morrison, and F. Kains. 1994. Factors affecting excretory behavior of pigs. J. Animal Sci. 72: 1455-1460.

HeitMan, H., Jr., and E. H. Hughes. 1949. The effects of air temperature and relative humidity on the physiological well being of swine. J. Animal Sci. 8: 171-181.

Hesse, D., and T. Jackisch. 1995. The sloped floor system - an accomodating pen design. Pig Progress No. June - July. p 29 - 31.

Nienaber, J. A., G. L. Hahn, H. G. Klemcke, B. A. Becker, and F. Blecha. 1989. Cyclic temperature effects on growing - finishing swine. J. therm. BioL. 14: 233 - 237.

Petherick, J. C. 1983. A biological basis for the design of space in livestock housing. In Current Topics in Veterinary Medicine and Animal Science, pp 103 - 120. The Hague, The Netherlands: Martinus Nijhoff Publishers.

Quiniou, N., S. Dubois, and J. Noblet. 1999. Voluntary feed intake and feeding behavior of group-housed growing pigs are affected by ambient temperature and body weight. Livestock Prod. Sci. 63: 245-253.

Randall, J. M., A. W. Armsby, and J. R. Sharp. 1983. Cooling gradients across pens in a finishing piggery: II. Effects on excretory behavior. J. Agric. Eng. Res. 28: 247-259.

Rinaldo, D., J. Le Dividich, and J. Noblet. 2000. Adverse effects of tropical climate on voluntary feed intake and performance of growing pigs. Livestock Prod. Sci. 66(3): 223-234.

Steinbach, J. 1987. Effects of the tropical climate on the physiology and productivity of the pig. World Animal Sci. B5: 181-199.

Verstegen, M. W. A. 1971. Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups. PhD diss. Wageningen,The Netherlands: Agricultural University Wageningen.

Effects of Cooling Methods on Growing Pigs in a Tropical Climate

T.T.T. Huynh[1,2], A.J.A. Aarnink[2], C.T. Truong[3], H.A.M. Spoolder[4], B. Kemp[5] and M.W.A. Verstegen[6]

[1] Department of Animal Health, Ministry of Agriculture and Rural Development, Viet Nam.
[2] Livestock Environment, Wageningen University and Research Center, The Netherlands.
[3] Ho Chi Minh City Natural Science University, Viet Nam.
[4] Animal Science, Wageningen University and Research Center, The Netherlands
[5] Adaptation Physiology, Wageningen University and Research Center, The Netherlands
[6] Animal Nutrition, Wageningen University and Research Center, The Netherlands

Submitted to Journal of Animal Science (Dec. 2004)

ABSTRACT

In order to determine the effects of cooling methods on physiology, behavior, and productivity of growing pigs under the humid tropical climate of Viet Nam, an experiment with a 2 x 3 factorial design was carried out using 120 growing pigs. The factors were cooling system and pen design. The effects of two cooling systems (water bath (WB) and sprinkling (S)) were evaluated and compared with a control (no cooling (CON)). Cooling systems were tested within each of two pen types (with (yard) or without an additional outdoor yard (no)). The pens were similar to those used in small-scale pig keeping in Viet Nam. Inside pen size was 2.5 x 3 m, outdoor yard size was 2.5 x 2 m. Within two blocks the same experimental design was used, one block was in the wet season (temperature 24.3 to 29.7^0 C, humidity 65 to 86.7 %) and the other block was in the dry season (temperature 25.9 to 32. 8^0 C, humidity 43.8 to 82.6 %). Per block a batch of 60 cross - bred pigs each was reared in 12 groups of five pigs each. Pigs had free access to feed and water. Results showed that cooling method and type of pen had a significant effect on most parameters. Water bath and sprinklers reduced respiration rate by 4.2 and 5.2 min^{-1}, respectively ($p < 0.01$), and skin temperature by 0.3 and 0.4^0 C, respectively, ($p < 0.05$). Rectal temperature was not influenced by any treatment. The water bath significantly reduced number of defecations and urinations in the resting area in pens without outdoor yard ($p < 0.001$). An outdoor yard reduced the number of excretions in resting area ($p < 0.01$). There were significant interaction effects of cooling and type of pen on lying, laterally lying and huddling ($p < 0.01$; $p < 0.001$; $p < 0.01$, respectively). Daily weight gain increased by 6 g d^{-1} by cooling with water bath and with 50 g d^{-1} by sprinkler cooling ($p < 0.05$). The highest daily weight gain for pigs was obtained when sprinkling was combined with pen without an outdoor yard ($p < 0.01$).

From this study we conclude that the physiological and behavioral response of group-housed growing pigs raised under tropical climate conditions were affected both by cooling and by the presence of an outdoor yard. The pigs experienced heat stress by maintaining a high respiration rate. This was why the physiological, behavioral and productive responses of growing pigs in small-scale farming under tropical climate condition were affected positively by cooling facilities like a water bath or sprinkler.

INTRODUCTION

Viet Nam's pig population has grown yearly by 5.5 % since 1994 (FAO, 2004). Seventy percent of the pigs are kept on small-scale farms and 30 % on medium and large-scale farms. Situated in Southeast Asia, Viet Nam has a humid tropical climate, which lies between 23 ½ ^{0} North and 23 ½ ^{0} South of the equator with an average of 80 % relative humidity. Pigs kept under this climate are generally exposed to daytime ambient temperatures that exceed their thermoneutral zone (Christon, 1988; Serres, 1992). Exposure to high ambient temperatures has been shown affected daily feed intake (McGlone et al., 1988; Black et al., 1993), which finally results in lower body weights (Brown-Brandl et al., 1998).

In a study in the temperate climate of the Netherlands, Huynh et al., (2004c) found that a floor cooling system significantly affected pig behavior and performance during hot period in summer time. The floor cooling reduced number of lying pigs on slatted floor and increased voluntary feed intake. However, floor cooling is too expensive for small-scale pig farmers in Viet Nam, but a suitable alternative might be to offer the pigs a cooling system with sprinklers or a water bath.

Few studies have been done on the effects of hot humid climate on pigs' physiological and behavioral responses in a tropical environment. In a controlled climatic experiment, Huynh et al., (2004a;b) found that at constant high temperature and humidity within a day, performance and physiological and behavioural responses of finishing pigs were detrimentally affected. The authors found different inflection point temperatures (critical temperatures) for respiration rate, rectal temperature, feed intake, ratio of water to feed intake and heat production. It is not known whether these critical temperatures exist in practical situations for pig in the tropics. Furthermore, the effect of actual hot humid conditions with variations between days on responses of growing pigs is still undetermined. Given the importance of pig production in the humid tropics, there is a need to ascertain the impact of this climate on physiology and behaviour and how this is related to animal performance. This knowledge could be used to develop practical management tools to prevent heat stress. The aim of this experiment was determine the influence of two types of cooling systems (water bath versus sprinklers) with a control group on the physiological, behavioural and performance responses of pigs housed on small scale farms either with or without an outside area in a tropical climate.

MATERIALS AND METHOD

A total of 120 growing to finishing cross-bred pigs ((Duroc x Pietrain) x Large White) were used in two batches of 60 each. The animals were considered to have a free health status from list A and B diseases that states by OIE (World Organization of Animal Health). The study was conducted in 12 pens for 5 pigs each at the experimental farm in Ho Chi Minh city, Viet Nam, which situated in an area with hot humid climate. Prior to the start of data collection in each trial there was a 10-day period, in which the pigs could habituate to their new accommodation. The main testing period was 47 days for trial 1 and 48 days for trial 2.

The temperature and relative humidity ranged from 24.3 to 29.7^0 C with humidity from 65 to 86.7% in the trial 1 and range of 25.9 to 32. 8^0 C with humidity from 43.8 to 82.6% in the trial 2. During day time, wind direction was from East to South with air velocity varied from 0 (at noon time normally) to 0.4 m s^{-1}.

Table 1 shows composition of dry feed which were fed for the pigs in the whole finishing period. The composition is based on Viet Nam standard for finishing pig feed composition.

Table 1. Feed composition from the start of the experiment to the date of finishing the experiment.
(TCVN – Viet Nam Animal Feed Standard - 1547-1994)

DE (MJ/kg)	12.5
Crude protein (%)	11.6
Crude fibre (%)	4.8
Crude fat (%)	4.6
Lysine / DE (g/MJ)	0.65
Calcium : (%)	0.86
Phosphor: (%)	0.39

Pen

The 12 pens were designed to be similar to those used in small-scale pig keeping in the rural areas of Viet Nam. The indoor pen was 2.5 x 3 m, the outdoor yard was 2.5 x 2 m. Density in indoor pen was 1.5 m^2 per pig, the pig in the pen with an outdoor yard had an extra of 1 m^2 per pig. The facilities had a V – shape, fibrocement sheet roof, on the top most of the V – shape had an open space which its' function was natural roof ventilator. From floor level to the roof was 4.5 m height and to the eaves was 2.5 m height. There were cement outer walls of 1.0 m height. At the back of the pen, a curtain made from feed sacks protected the animals from direct sunshine and rain. The pen floor was 100 % solid concrete, which was 4% slope (see figure 1).

The outdoor yard was separated from the indoor area by a 1m high concrete wall to protect the pigs from outdoor weather conditions. The outdoor yard also ended at a 1m high concrete wall. The pigs in this type of pen had free access to the outdoor yard through an opening 0.8m wide, located in the defecation area (see figure 1).

Manually, the pen was dry cleaned twice a day before feeding time. Manure was removed from the pen and transported to a composted station while urine was let to run off into a channel, which was outside the protected wall.

Sprinkler

In four of the 12 pens a simple sprinkler system was installed at the back of the pen (see figure 1). The water tank supplying water to the sprinklers was placed inside the animal house at 3m above floor level and connected to the sprinklers by pipes (21 mm diameter x 10 m long). A water pump was used to increase the water pressure to the six showers in each sprinkling system. The sprinklers were fixed at 1.2m above floor level. A timer was used to control the sprinkling schedule; following the diagram of Ingram (1965a; cited by Mount, 1979) which performed an evaporative water loss from the skin of pig was approximately 30min, the sprinklers were activated for 2min every 30min during the hottest period of the day only, i.e. from 1000 in the morning until 1600 in the afternoon (see figure 2). Each time before the sprinklers were activated, a bell was rung for 1min to alert the pigs. Underground water was approximately 22^0 C at the source, when water was pumped to the sprinklers; its temperature became approximately 25^0 C.

Water bath

A water bath (0.3 x 0.8 x 1.5m) was placed at the back of the indoor area in four of the 12 pens (see figure 1). With the WB size there were two pigs bathing at the same time. During 10-d adaptation, dirtiness of WB that occurred after using by the pigs was noticed. Thus, in the main experimental period the bath was filled with clean water twice a day, once at 0800 in the morning and once at 1400 in the afternoon. The bath was filled up to 0.20 cm of its' height. On hot days, the pigs emptied the water more often and so the bath was refilled late in the afternoon, as well, normally at 1600. The bath was cleaned twice a week during the experimental period.

Measurements

Climatic conditions

Temperatures and relative humidities were measured at 1.5 m above floor level in the feeding path using a combined instrument HygroLog (Rotronic HygromerTM C94, sensors Pt100 RTD (1/3 DIN), Switzerland). Temperature and relative humidity were stored every 30 min.

Physiology

Physiological data was collected twice a day at 0630 in the morning and at 1630 in the afternoon. This time schedule was aimed to collect animal data at the periods that ambient temperatures were relative at the lowest and highest figures (see figure 2). In each pen during each observation period, three randomly chosen pigs were marked for measurement of skin temperature (ST), respiration frequency, and rectal temperature. Skin temperature was measured using a radiant thermometer (CHINO IR-AH, Japan). Measurements of ST and RR as well as RT were taken similar to as described in Huynh et al., (2004a). Skin temperatures were measured at three marked positions (shoulder, loin and ham) (Huynh et al., 2004a). The ST was taken on dry skin, when this was not possible because of wetness and dirtiness; the measurement was repeated on an extra time, which was about 1 h after. During bathing and sprinkling the marks on pigs' skin were washed out and therefore the marking was repeated frequently. Respiration rate was determined by counting flank movements using a stopwatch. After these two measurements, RT was taken using a thermometer (BARCHEN YS-723, Switzerland).

Behaviour

Behavioral data were collected by four cameras (Panasonic wv-bl 200 with a 2.8 mm fisheye lens), each mounted above the indoor area of each pen and with a range of view covering both the indoor and outdoor areas of the pen. Video observations were made in random order for 24 hours on three consecutive days. This set-up was similar to the work done by Huynh et al. (2004b;c). This meant that after each 3-d period, all four cameras were moved to four other pens. Each pen was monitored for 16 d in trial 1 and for 33 d in trial 2. The images recorded by the cameras were stored digitally in a computer for behavioral analysis (Huynh et al., 2004b;c).

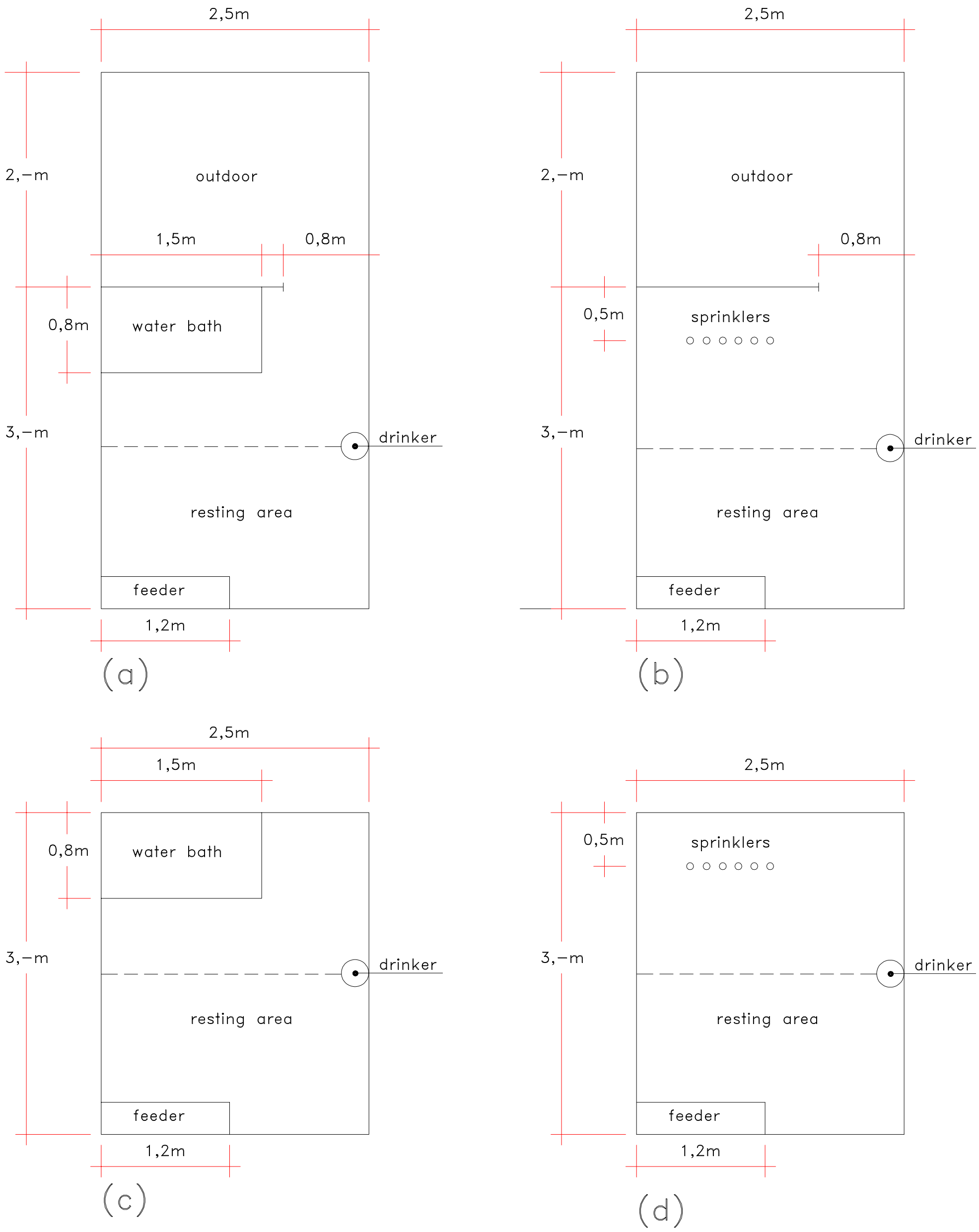

Figure 1. Pen layout with and without outdoor yard, and cooling system. (a) pen with outdoor yard and water bath; (b) pen with outdoor yard and sprinklers; (c) pen with water bath without outdoor yard; (d) pen with water bath without outdoor yard

Absolute and relative frequencies of the behaviors were analyzed at group level. As a result of power cuts, some data were lost and could therefore not be statistically analyzed.

In this study, use of pen locations and behaviors were defined as follows:

(a) The indoor area consisted of feeding, resting and excreting areas. Feeding and resting areas were contiguous and were located at the front of the pen. The excreting area was located at the back of the pen, furthest away from the feeding area. The outdoor yard remained empty for free activity of the pigs.

(b) Lying and excreting behavior were determined in each area. Lying behaviour was determined by scan sampling at 60 min intervals, resulting in 24 observations per pen per day. Excreting behaviour was determined by continuous observations. The ethogram of lying postures, excretions and thermoregulatory behaviors consisted of behavioral elements described in detail elsewhere (Huynh et al., 2004a).

Lateral lying: the pig was lying flat on one side, not supported by the legs.

Huddling: pigs lying in contact with more than 50 % of their flanks touching.

Defecation: relative frequency of defecation in resting area. This area at the front of the pen was half the size of the indoor pen and included the feeding area.

Urination: relative frequency of urination in resting area.

Excretions in bath: frequency of defecation and urination in the water bath

Furthermore, thermoregulatory behaviour was determined by analyzing the frequency at which the pigs used the WB and S.

Performance

Each pen had a concrete feed trough (1.20 x 0.40 x 0.30 m) and one drinking nipple. The feed troughs, which were fixed at the front of the resting area (see figure 1), were similar to those used in small-scale pig housing in Viet Nam. The feeding semi ad libitum method was the same as that used in small-scale pig keeping in Viet Nam. Feed was weighed and given four times per day at 0730, 1130, 1530, and 1930. Before new feed was added to the trough, any left - over feed was collected, weighed and recorded. Pigs had free access to water via the drinking nipple installed at the back of the resting area on the wall that connected indoor and outdoor area as illustrated in figure 1. Water intake was recorded twice a day by reading a scale marked on the water container.

Assuming that the dry matter content of the leftover was similar to that of the added feed, the voluntary feed intake was calculated. Rate of daily gain was calculated from live weights recorded at the start and end of each experiment. In each trial, a batch of 60 pigs of average starting weight of 57.1 ± 5.4 kg in trial 1 and 58.6 kg ± 5.4 kg in trial 2 were randomly assigned to one of the 12 experimental pens (two pens per treatment combination). The pigs were weighed at the start and at the end of the experiment when the pigs reached slaughter weight (end weights of 93.0 kg ± 8.7 kg and 94.2 kg ± 8.9 kg, for trial 1 and 2, respectively). In the first trial, one pig died on day 38. The cause of death could not be determined.

Statistical Analysis

This experiment was a randomized 3 x 2 factorial design in which the treatments were tested in a randomized design in two blocks. The treatments were cooling systems with control (CON), water bath (WB), and sprinklers (S); and type of pens with pen with outdoor yard (yard), and pen without outdoor yard (no). The effects of treatments were determined by submitting data to ANOVA (GenStat, Release 7.1, 2002). Standard errors of differences of means between treatments were tested by using Fishers' test. Means of RR per minute, RT and ST of the three individual pigs per pen in each trial were used for physiological data analysis. Means of behavioral and performance per pen over the whole period in each trial were used for data analysis. The frequencies like lateral lying relative to total lying pigs, defecation in resting area relative to total number of defecations, urination in resting area relative to total number of urination and the frequency at which the pigs used the water bath and sprinklers were used in the analysis. Fixed factors of the model included pen with outdoor yard, pen without outdoor yard, water bath, sprinkler, control and the interaction effects of cooling and type of pen. Trial was used as a block factor in the statistical model; therefore the differences between treatment factors (cooling and type of pen) were corrected for trial influences. Effects of cooling and pen design were similar in both blocks so three way interactions were excluded from the model. The model was:

$$Y_{ijk} = \mu + \text{Block}_i + \text{Cooling}_j + \text{Type of pen}_k + [\text{Cooling} * \text{Type of pen}]_{jk} + \varepsilon_{ijk}$$

In which Block is: Trial / (Cooling + Type of pen); ε is: residual error

RESULTS

Ambient conditions

Air temperature and humidity fluctuated throughout the experimental period and within a day. Air temperature was on average 27.5^0 C (range 24.3 to 29.7^0 C) in trial 1, and on average 28.7^0 C (range 25.9 to 32.8^0 C) in trial 2. The relative humidity varied between 65.0 and 86.7 % (on average 74.7%) in trial 1, and between 43.8 and 82.6 % (on average 62.8%) in trial 2. Throughout the two trials the highest temperature was recorded on average at 1300 (32.6^0 C), and the lowest at 0500 (23.8^0 C); the highest relative humidity was at 0600 (89.3 %), and the lowest at 1300 (52.7 %) (see figure 2).

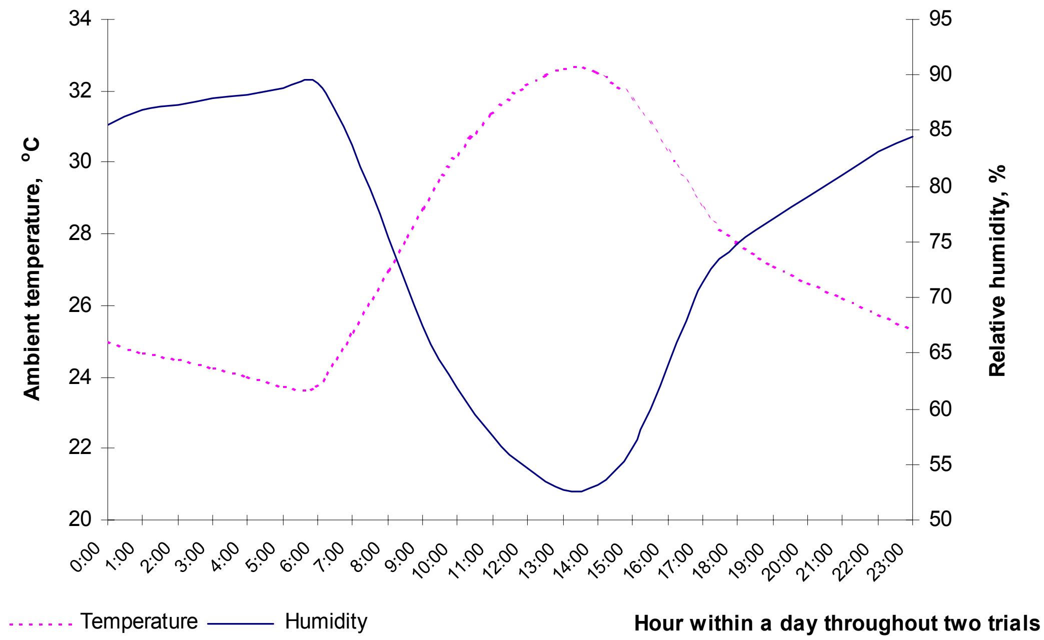

Figure 2. Diurnal temperature and humidity per hour, derived from hourly means throughout the experimental period.

Physiological responses

In this study the pigs had an average respiration rate (RR) of 50.9 min^{-1}. Mean RR was higher in the afternoon than in the morning (64.8 vs. 36.9 min^{-1}, respectively, table 2). In the morning differences between cooling and control no cooling (CON) were relatively small when compared to the differences in the afternoon. In the afternoon, RR was high with large effects of cooling, markedly in pens with outdoor yard. In the pens with outdoor yard sprinklers (S) showed more effect, while water bath (WB) showed more effects in pens without outdoor yard ($p < 0.05$).

Table 2. Mean and effect of type of pen, and cooling method on physiological and performance parameter of ad lib, fast growing group-housed finishing pigs

Response variables	Cooling[†]	Type of pen[‡]		Effects of factors with S.E.M[a] and F. prob[b]		
		Yard	No	Cooling N[c] = 9	Type of pen N = 6	Cooling*Type pen N = 54
Respiration rate, min^{-1}	CON	56.2	51.9	1.02	3.82	2.11
	WB	51.3	48.2	**	n.s	*
	S	46.6	51.0			
Respiration rate morning, min^{-1}	CON	37.9	38.6	0.91	1.11	1.41
	WB	37.8	33.6	**	n.s	**
	S	34.9	38.6			
Respiration rate afternoon, min^{-1}	CON	74.5	65.3	1.42	7.42	3.23
	WB	64.7	62.7	**	n.s	*
	S	58.5	63.3			
Rectal temperature, ^0C	CON	39.2	39.2	0.13	0.40	0.14
	WB	39.2	39.1	0.09	n.s	n.s
	S	39.2	39.3			
Rectal temperature morning, ^0C	CON	39.0	39.0	0.20	0.88	0.28
	WB	39.1	39.1	n.s	n.s	n.s
	S	39.0	39.1			
Rectal temperature afternoon, ^0C	CON	39.5	39.4	0.31	0.06	0.24
	WB	39.2	39.1	n.s	*	n.s
	S	39.5	39.4			
Skin temperature, ^0C	CON	35.8	35.8	0.28	0.86	0.28
	WB	35.6	35.5	*	n.s	n.s
	S	35.3	35.6			
Skin temperature morning, ^0C	CON	34.1	34.5	0.68	0.21	0.53
	WB	34.1	34.4	n.s	*	n.s
	S	34.2	34.7			
Skin temperature afternoon, ^0C	CON	37.5	37.1	0.47	1.41	0.48
	WB	36.9	36.7	*	n.s	n.s
	S	36.3	36.5			

[†] Cooling = CON: pen with no cooling; WB: pen with water bath; S: pen with sprinklers

[‡] Type of pen = Yard: with outdoor yard; No: without outdoor yard

[a] S.E.M = Standard Errors of Differences of Means

[b] F. prob. = Fisher test probability; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

[c] N = number of observations

The rectal temperature (RT) of pigs in this study was on average 39.2^0 C. No effect of pen type was found. In the afternoon, however, type of pen affected the RT of pigs (see table 2); in pens with an outdoor yard, pigs had a higher RT than those in pens without an outdoor yard ($p < 0.05$). There was no significant interaction effect on RT between treatments.

On average, the skin temperature (ST) of pigs in this study was 35.6^0 C. Water bath and sprinklers reduced ST by 0.3 and 0.4^0 C, respectively ($p < 0.05$). Note that cooling strongly affected ST in the afternoon but had no effect in the morning (table 2). In the morning, pigs in pens with an outdoor yard had a lower ST than those in pens without an outdoor yard ($P < 0.05$), while this effect was not found in the afternoon. There were no significant interaction effects on ST.

Behaviour

Lying

Table 3 shows the lying behaviors of the pigs. On average, at any one time in the experimental period, 85.8 % of pigs were lying. Significant interaction effects were found between cooling and type of pen for a few variables (table 3). The interaction showed that effects of water bath on number of pigs lying depended on the presence of an outdoor yard. The number of lying pigs was highest in the control pen (no cooling) with an outdoor yard ($p < 0.05$). For the pens with a water bath, those with an outdoor yard had the lowest number of lying pigs. By contrast, the highest number of lying pigs in the resting area was found in pens with water bath. The number of pigs lying on their sides (i.e. laterally) was higher in the control pens than in the pens with cooling ($p < 0.05$). The fewest pigs lying on their sides were recorded in pens with water bath plus outdoor yard ($p < 0.001$). The most huddling was recorded in the pens with sprinklers and without an outdoor yard ($p < 0.01$). The least huddling was in control pens without an outdoor yard. The number of pigs lying in outdoor yard was lowest in control pens, and highest in pens with water bath. The number of pigs lying on their sides in outdoor yard was higher in control pens than in cooled pens.

Excretion

Table 4 shows frequencies of defecation and urination in the resting area. There was a clear interaction effect between cooling and type of pen on defecation and urination ($p < 0.001$, for both variables). Pigs defecated and urinated in the resting area much more often in pens without outdoor yard than in pens with outdoor yard, except for pens with water bath. All pens with water bath had low (p < excretions in the resting area (table 4).

Table 3. Mean and effect of type of pen and cooling method on lying behavior of ad lib, group-housed finishing pigs

Response variables	Cooling[†]	Type of pen[‡]		Effects of factors with S.E.M [a] and F. prob [b]		
		Yard	No	Cooling N[c] = 3	Type of pen N = 2	Cooling*Type pen N = 6
Lying, %	CON	92.7	84.1	1.38	5.08	5.36
	WB	79.1	82.5	*	n.s	**
	S	88.7	87.8			
Lying pigs in resting area, %	CON	40.8	38.7	7.17	2.94	7.81
	WB	75.2	66.4	0.09	n.s	n.s
	S	52.2	45.4			
Lateral lying, %	CON	78.5	76.0	2.20	1.63	2.97
	WB	56.2	67.9	*	n.s	***
	S	69.3	62.0			
Huddling, %	CON	19.2	16.2	0.47	2.05	2.26
	WB	16.8	22.3	*	n.s	***
	S	17.5	23.8			
Lying pigs in outdoor yard, %	CON	19.6		9.91		
	WB	37.4		n.s		
	S	25.0				
Lateral lying pigs in outdoor yard, %	CON	99.6		5.51		
	WB	93.5		n.s		
	S	93.2				

[†] Cooling = CON: pen with no cooling; WB: pen with water bath; S: pen with sprinklers

[‡] Type of pen = Yard: with outdoor yard; No: without outdoor yard

[a] S.E.M = Standard Errors of Differences of Means

[b] F. prob. = Fisher test probability; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

[c] N = number of observations

In pens with an outdoor yard, differences between cooling systems were small. In pens with an outdoor yard, a lot of excretions were done in that yard (table 4). The data in table 4 show that if a water bath was present, pigs often defecated and urinated in it, especially if the pen had no outdoor yard. Defecations in the water bath were 64.5 % when there was no outdoor yard and 15.9 % when there was an outdoor yard ($p < 0.01$). The difference of pen types on urination in water bath was not significant.

Use of cooling facilities

Table 4 shows the frequencies with which the pigs used the cooling facilities. On average, each pig used sprinklers 4.7 times of the 12 sprinkling periods daily between 1000 and 1600.

Table 4. Mean and effect of type of pen and cooling method on excretion behaviors of ad lib, fast growing group-housed finishing pigs

Response variables	Cooling†	Type of pen‡		Effects of factors with S.E.M[a] and F. prob[b]		
		Yard	No	Cooling $N^c = 3$	Type of pen N = 2	Cooling*Type pen N = 6
Defecation in resting	CON	7.7	62.3	0.4	0.3	1.8
area,%	WB	3.5	5.4	***	**	***
	S	3.0	58.8			
Urination in resting	CON	4.9	62.6	1.7	1.2	2.8
area,%	WB	2.8	7.7	**	*	***
	S	1.2	62.4			
Defecation in outdoor	CON	50.5		0.5		
yard, %	WB	40.0		**		
	S	48.0				
Urination in outdoor	CON	45.0		5.2		
yard, %	WB	40.9		n.s		
	S	48.8				
Defecation in water	CON				5.9	
bath, %	WB	15.9	64.5		**	
	S					
Urination in water	CON				17.7	
bath, %	WB	18.4	60.4		n.s	
	S					
Sprinklers used	CON					
frequency, time pig^{-1} d^{-1}	WB				4.70	
	S	4.8	4.6		n.s	
Bathing frequency,	CON				2.68	
time pig^{-1} d^{-1}	WB	7.2	7.7		n.s	
	S					

† Cooling = CON: pen with no cooling; WB: pen with water bath; S: pen with sprinklers

‡ Type of pen = Yard: with outdoor yard; No: without outdoor yard

[a] S.E.M = Standard Errors of Differences of Means

[b] F. prob. = Fisher test probability; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

[c] N = number of observations

The minimum was 1 sprinkling per day and the maximum was 11 sprinklings per day per pig. This variation did not differ between pens or between pigs. The pigs used the water bath on average 7.4 times per day. The intensive bathing time was between 1400 and 1700. The minimum duration that the pig stayed in a water bath was 1min and the longest duration was 9min. The water bath could contain maximum two pigs at the same time. The minimum use was once per day and the maximum was 15 times per day. This variation did not differ between pens or between pigs. Type of pen had no effect on the use of sprinkler or water bath.

Performance

Table 5 shows the performance data. Cooling had no effect on voluntary feed intake, but pigs in pens without cooling drank more, especially when compared with pigs in pens with water bath ($p < 0.001$). Pen type also affected water intake; pigs in pens without an outdoor yard drank more ($p < 0.001$). Pigs in pens with cooling had higher daily gain than pigs in pens without cooling ($p < 0.05$). However, there was a significant interaction effect between cooling system and type of pen. The pigs in pens with sprinklers and without an outdoor yard had the highest daily gain ($p < 0.01$).

Table 5. Effects of cooling and type of pen on performance of fast growing group-housed finishing pigs

Response variables	Cooling[†]	Type of pen[‡]		Effects of factors with S.E.M[a] and F. prob[b]		
		Yard	No	Cooling $N^c = 3$	Type of pen N = 2	Cooling*Type pen N = 6
Voluntary feed intake,	CON	2,074	2,063	0.11	0.09	0.16
g pig^{-1} d^{-1}	WB	2,068	1,991	*	n.s	n.s
	S	2,147	2,198			
Drinking water,	CON	10.160	11.150	0.04	0.02	0.40
liter pig^{-1} d^{-1}	WB	5.830	8.800	***	***	**
	S	8.620	11.290			
Daily gain, kg^{-1} d^{-1}	CON	0.562	0.507	0.05	0.04	0.07
	WB	0.560	0.512	0.06	n.s	0.09
	S	0.566	0.606			

[†] Cooling = CON: pen with no cooling; WB: pen with water bath; S: pen with sprinklers

[‡] Type of pen = Yard: with outdoor yard; No: without outdoor yard

[a] S.E.M = Standard Errors of Differences of Means

[b] F. prob. = Fisher test probability; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

[c] N = number of observations

DISCUSSION

Fundamental information on heat stress prevention is available in the literature, but producers require the means to recognize stress responses and take appropriate action. The means is not always available. Furthermore, the narrow range of ambient temperatures in which optimal performance is possible may not make it easy to optimize the profitability of an operation (Nienaber, 1989). Recently, Huynh et al., (2004a;b) reported physiological and behavioral changes when ambient temperature gradually increased above certain critical ambient temperatures. These changes occurred in growing-finishing pigs in response to excessive heat loads. In that study, Huynh et al. also estimated the upper critical temperature for reduced performance. Under controlled experimental conditions, above certain critical temperatures, pigs raised their respiration rate and finally their rectal temperature. Generally, the climatic conditions in the present study were far above the inflection point temperatures (critical temperatures) recorded in the previous study. It should be emphasized that in the present study pigs experienced natural fluctuation within a day whereas in the previous study (Huynh et al., 2004a) the pigs were exposed to a constant daily temperature and humidity. In the present study, the pigs showed consistently high respiration rates and skin temperatures. It may be explained that these pigs reacted to tropical conditions by having a high respiration rate and skin temperature. This aspect is more important in high lean fast-growing pigs and in the fattening period (Mount, 1979). These statements will be discussed point to point in the following paragraph.

Physiological benefits

On average, a normal respiration rate in growing pigs ranges from 29.1 to 32.7 min^{-1} (Huynh et al., 2004); which are very close to RR in the morning measurements in the present study. However, on average the mean rate in the present study was 51.2 min^{-1}. Christon (1988) found that in tropical conditions, 25 to 50 kg pigs increased their respiration rate by 366 % when air temperatures were consistently above the thermo neutral zone. In previous controlled climate studies, Huynh et al., (2004) had shown that the respiration rates of ad lib fed, group-housed finishing pigs started to increase when the temperature was in the range from 21.3 to 23.4^0 C. In this field study when measurements were done in the morning the temperature was at the lowest point (23.8^0 C) and close to these IPts. However, in the afternoon when ambient temperature was high, the RR increased significantly and the pigs could experience heat stress. Brown-Brandl et al., (2001; cited from Brody, 1945) defined that when the pigs must employ their thermoregulatory devices e.g. increase respiration rate they are out of their thermo neutrality and in stressful temperature. The temperature and humidity in this field study fluctuated at a high level. A clear diurnal pattern was observed with high RR in the afternoon and moderate RR in the morning. At this state the cooling system had the effect of lowering the RR.

Importantly, the high respiration rate enabled the pigs to maintain a rectal temperature in the normal range. Heitman and Hughes (1949) reported that in 90 kg pigs kept under controlled conditions with air temperatures in the range from 5 to 39 °C, an elevated respiration rate was immediately followed by a rise in rectal temperature. This was not seen in the present study, not even in the afternoon when the pigs' RR was much higher than in the morning. In a study with a highly controlled climate, Huynh et al., (2004) reported that the rectal temperature of growing pigs increased in response to a critical temperature in the range of 24.6 to 27.1^0 C. It was concluded that increased rectal temperature is an important indicator of heat stress in fattening pigs. Bull et al., (1997) showed that when gilts were exposed to one of three cooling facilities, their rectal temperature did not differ from that of control pigs without cooling. It is clear that by responding with a high respiration rate, the pigs in our study maintained a constant rectal temperature throughout changes in ambient temperature. This sheds light on whether the pigs in our study were coping with heat stress. Though they responded to high ambient temperature in the afternoon by increasing their RR, the pigs did not exhibit the same response for RT.

Despite their constant rectal temperatures, the skin temperatures of pigs in the control pens were significantly higher than those of pigs in the other treatments with cooling facilities. Furthermore, at constant high ambient temperatures like those in our field study, pigs had a consistently high skin temperature (average of 35.6^0 C). Normal skin temperature of finishing pig was reported in several studies e.g. Geers et al., (1987, cited from Fanger, 1972) reported that the comfort skin temperature of homeothermic animals ranges from 32 to 35^0 C. This is similar to the finding reported by Huynh et al., (2004) that within an ambient temperature range from 16 to 22^0 C, the skin temperature of 60 kg ad lib fed, group-housed pigs ranged from 33 to 35^0 C. In the current study, the ambient temperature in the morning when the skin temperature was measured was comparable and the response of the pigs' skin temperature was markedly similar. However, in the afternoon, skin temperature was higher than in the morning. It is interesting to see that when temperature varied within a day, the change of skin temperature distinctly harmonized with the findings of Huynh et al., (2004). The high skin temperature of pigs in the present study shows that pigs raised under tropical conditions not only reacted by maintaining a high respiration rate but also by maintaining high skin temperature. This is logical, because vasodilatation of epidermal blood vessels allows deep body heat load to be dissipated more easily to the cooler environment (Yousef, 1985).

Behavioral benefits

Aarnink et al., (2001) reported that when ambient temperatures increased above 20 to 25^0 C for animals in the weight range of 25 to 105 kg, pigs increased the number of excretions in the resting area. Huynh et al., (2004) found that the number of instances of huddling of pigs decreased with increasing ambient temperature. They found that above 18.8^0 C, lying on a slatted floor increased, above 20^0 C excretions on solid floor increased, and above 24.2^0 C the activity-related heat production was reduced. As shown in table 2, at constant high temperature above 25^0 C, in pens without an outdoor yard the pigs altered their excretion behavior. The effects of outdoor yards on excretion and lying behavior emphasize the importance of allocating sufficient space to fattening pigs in a hot tropical climate. With an extra outdoor yard, pigs would benefit significantly with regard to cleanliness and comfort. According to Huynh et al., (2004), increasing lying behavior indicates heat stress, because lying animals avoid expending energy on movement and therefore reduce their total heat load.

As the pigs excreted in the water bath, especially in pens without an outdoor yard, in this treatment we recorded fewer excretions in the resting area. In a previous study, Huynh et al., (2004b;c) showed that a 60 kg pig provided with 1 m^2 floor space (with 40 % slatted floor) in hot conditions did not discriminate between its resting and defecation areas at all. In addition, Hacker et al., (1994) reported that the pig's basic instinct is to excrete in a wet, cool place. These findings might explain the high frequency of excretion in the water bath. This is undesirable with respect to hygiene and health. In practice, the problem could be solved by locating the water bath away from the excretion area, e.g. in the outdoor yard.

Performance effects

In this field study feed intake was not significantly different between treatments. However, the differences seemed to have resulted in different gain rate of pigs. In our study, though the dry matter content of the leftover feed and the newly added feed was probably not the same, the difference was minor, as the feed remained dry always. In a study of Huynh et al., (2004a) ratio of water to feed intake was lower than in the present study (2.4 vs. 4.4). An increase by 40 % of drinking water by effect of warming up the hypothalamus and skin temperature of pig was reported (Ingram and Stephens, 1979) Thus, if the pigs were in heat stress because of evaporative heat regulation; they probably needed a large surplus of water, independent from feed intake.

Rinaldo et al., (2000) reported a 13 % diminution in growth rate of 35 to 90 kg pigs raised in the humid tropics, in which average temperature was 27.3^0 C and average humidity was 82 %. Huynh et al., (2004a) reported that pigs gained faster in conditions of low humidity (50% compared to 80%) at similar high temperatures. McGlone et al., (1994) reported that space allowance influenced growth rates in finishing pigs. Regarding pen design, in our study a density of 2.5 vs. 1.5 m^2 per pig (pen with an outdoor yard and without an outdoor yard, respectively) caused a slight difference in daily gain. In the absence of cooling facilities, pigs in pens with outdoor yard had a higher gain rate than pigs in pens without such a yard. In this field study, an area of 1.5 m^2 per pig without direct sunshine and with a sprinkling system seems to be the best treatment in term of productivity.

Summary effects of cooling and housing facilities

Cooling systems in pig housing are beneficial for reducing animal heat stress in warm climates. According to Kunavongkrit et al., (2000), pig producers in South East Asia try to reduce the detrimental effects of high ambient temperatures in animal houses in many ways e.g. air conditioning and evaporative cooling for boar houses; water dripping and fogging systems in sow houses. All can help to solve the problem but they involve high investments and some can cause adverse effects like increased humidity. It is known that high humidity depresses pig production (Lucas et al., 2000). A cooling system should avoid introducing surplus water into the air of animal houses. Following this principle, the cooling systems we used in our study did not increase the humidity of the air to a great extent. In addition, our pigs were free to choose whether to use the cooling system.

A water bath contributed to reduce heat stress, as can be seen from the lower skin temperature, respiration rate, and a tendency for pigs in pens with water bath to have a lower body temperature compared with pigs in control pens. Bull et al., (1997) reported that rectal temperature could be used as thermoregulatory assessment. If body temperature is taken as a crucial indicator of animal comfort, a water bath clearly contributes importantly to this comfort under tropical conditions. Direct observation on bathing of pigs in this study showed that a pig stayed in a water bath on average 3min (the shortest was 1min and the longest 9min). With this duration of bathing, the resulting lower rectal temperature was logical. However, it should be noted that maintaining a water bath is costly in terms of labor for cleaning and refilling the bath. Since the pigs excreted at a high frequency in water bath and consumed water from the water bath, low rate in daily gain can be expected as a negative effect of poor hygiene. In Viet Nam, it is possible to recommend farmers to clean the water bath more often than twice a week but for Western intensive production system it will be an impractical recommendation. Therefore, the best location of the water bath, pen size and cleaning frequency should be studied further to improve the use of this cooling system.

An outdoor yard significantly increased the rectal temperature of pigs during the afternoon. As reported, in this study the diurnal temperature fluctuation was about 8.8^0 C. In the afternoon, ambient temperature (32.6^0 C) was very close to the controlled temperature (32^0 C) in a previous study by Huynh et al., (2004a), in which experimental pigs had increased their rectal temperatures up to 40^0 C. Furthermore, pigs exposed to sunshine in outdoor yards could gain heat from radiation. Indeed, Heitman and Hughes (1949) reported that the body temperature of pigs increased due to the direct rays of the sun. According to report of Blackshaw et al., (1994), when ambient temperature was above 25^0 C, more than 80 % of pigs lay in the shade when they were in outdoor yard. In the current study no shade was available. A shade in the outdoor yard probably reduces heat stress and might contribute to the effects of cooling on pigs' productivity.

An important finding in our study was that pigs in pens with a sprinkler and without an outdoor yard gained weight fastest. This is an interesting finding because these pigs were limited in space, but for social contact they could lie next to their pen mates (high frequency of huddling). The pigs in this field study did not only benefit from sprinkling by directly showering but also by lying on the floor wetted by sprinkling. With 12 sprinkling periods at 30min interval, the floor stayed wet almost for the whole period between 1000 and 1600. Mount (1979) presented evaporative water loss from the skin of pigs. The author found that evaporation could last up to 30min (by water) and from 90min to 120min (by mud). Thus, in tropical conditions, pens with a freely accessible area (or more space per pig) can facilitate alleviation of heat stress by increasing the opportunity for eliminating heat loss, and thus giving many more benefits for the pigs in terms of behavioral comfort and environment (a cleaner pen). In a limited area, however, a sprinkling system could increase pig productivity.

CONCLUSIONS

From this study we conclude that ad libitum, fast growing, group-housed pigs raised in a tropical climate clearly showed physiological and behavioral responses to this climate. Cooling systems and also an outdoor yard had positive effects on the physiological responses, behavior and productivity of the pigs in a small-scale farming situation.

- The pigs seem to have responded to tropical conditions by maintaining a high respiration rate. In this condition, a high respiration rate is not a sign of heat stress but of adaptation.
- Even though these pigs were able to adapt to tropical conditions by having an average high respiration rate and skin temperature but the environment in which this experiment was conducted apparently exceeded the threshold of these pigs' tolerance to heat stress. The evidence was the respiration rate of the pigs was low when ambient temperature was low (in the morning) and high when ambient temperature was high (in the afternoon).
- The availability of cooling systems e.g. a water bath or sprinklers had beneficial effects on the pigs' performance compared to control groups with no cooling.
- With the presence of an outdoor yard, the resting area was less fouling.
- Interaction effects between cooling systems and type of pen were present. The combination of sprinkling and provision of an outdoor yard gave the lowest respiration rate in these pigs, while the combination of sprinkling and a pen without an outdoor yard gave the highest daily gain.

LITERATURE CITED

Aarnink, A. J. A., J. W. Schrama, R. J. E. Verheijen, and J. Stefanowska. 2001. Pen fouling in pig houses affected by temperature. In: Livestock Environment VI, Galt House Hotel Louisville, Kentucky. ASAE, St. Joseph, MI. p 180 - 186.

Black, J. L., B. P. Mullan, M. L. Lorschy, and L. R. Giles. 1993. Lactation in the sow during heat stress. Livest. Prod. Sci. 35: 153-170.

Blackshaw, J. K., and A. W. Blackshaw. 1994. Shade-seeking and lying behaviour in pigs of mixed sex and age, with access to outside pens. Applied Animal Behaviour Science 39: 249-257.

Brown-Brandl, T. M., J. A. Nienaber, and L. W. Turner. 1998. Acute heat stress effects on heat production and respiration rate in swine. Transactions of the ASAE 41: 789-793.

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

Bull, R. P., H. P.C., R. G.L., and G. H.W. 1997. Preference among cooling systems by gilts under heat stress. J. Anim. Sci. 75: 2078 - 2083.

Christon, R. 1988. The effect of tropical ambient temperature on growth and metabolism in pigs. J. Anim. Sci. 66: 3112 - 3123.

Curtis, S. E. 1985. Physiological responses and adaptations of swine. In: M. K. Yousef (ed.) Stress physiology: Definition and terminology No. 2. p 129 - 139. CRC Press, Boca Raton, Fla.

Geers, R. et al. 1987. Surface temperatures of growing pigs in relation to the duration of acclimation to air temperature or draught. Journal of Thermal Biology 12: 249-255.

Hacker, R. R., J. R. Ogilviei, W. D. Morrison, and F. Kainst. 1994. Factors affecting excretory behavior of pigs. J. Anim. Sci. 72: 1455-1460.

Heitman, H., and E. H. Hughes. 1949. The effects of air temperature and relative humidity on the physiological well being of swine. Journal of Animal Science 8: 171-181.

Huynh, T. T. T., A. J. A. Aarnink, M. W. A. Verstegen, W. J. J. Gerrits, and M. J. H. Heetkamp. 2004a. Pigs' Physiological Responses at Different Relative Humidities and Increasing Temperatures. In: 2004 ASAE/CSAE Annual International Meeting, Fairmont Chateau Laurier, The Westin, Government Centre - Ottawa, Ontario, Canada. 16 pages, paper number 044033.

Huynh, T. T. T. et al. 2004b. Thermal behavioral adaptation of growing pigs as affected by temperature and humidity. Accepted for publication in Applied. Anim. Behav. Nov. 2004.

Huynh, T. T. T., A. J. A. Aarnink, H. A. M. Spoolder, M. W. A. Verstegen, and B. Kemp. 2004c. Effects of floor cooling during high ambient temperatures on the lying behavior and productivity of growing finishing pigs. Transactions of the ASAE 47 (5): 1773-1782.

Ingram, D. L., and D. B. Stephens. 1979. The relative importance of thermal, osmotic and hypovolaemic factors in the control of drinking in the pig. The Journal of Physiology 293: 501-512.

Kunavongkrit, A., and T. W. Heard. 2000. Pig production in South East Asia. Animal Reproduction Science 60 - 61: 527 - 533.

Lopez, J., G. W. Jesse, B. A. Becker, and M. R. Ellersieck. 1991. Effects of temperature on the performance of finishing swine. 1. Effects of a hot, diurnal temperature on average daily gain, feed-intake, and feed-efficiency. Journal of Animal Science 69: 1843-1849.

Lucas, E. M., J. M. Randall, and J. F. Meneses. 2000. Potential for evaporative cooling during heat stress periods in pig production in Portugal (Alentejo). J. Agric. Engng Res. 76: 363 - 371.

McGlone, J. J., W. F. Stansbury, L. F. Tribble, and J. L. Morrow. 1988. Photoperiod and heat-stress influence on lactating sow performance and photoperiod effects on nursery pig performance. Journal of Animal Science 66: 1915-1919.

McGlone, J. J., and B.E.Newby. 1994. Space requirements for finishing pigs in confinement: Behaviour and performance while group size and space vary. Applied Animal Behaviour Science 39: 331-338.

Morrison, S. R., H. Heitman, and R. L. Givens. 1975. Effect of diurnal air temperature cycles on growth and food conversion in pigs. Animal Production 20: 287-291.

Mount, L. E. 1979. Adaptation to thermal environment: Man and his productive animals. Edward Arnold Limited, Thomson Litho Ltd, East Kilbride, Scotland.

Myer, R., and R. Bucklin. 2001. Influence of hot-humid environment on growth performance and reproduction of swine. AN 107. EDIS Web Site at http://edis.ifas.ufl.edu . Animal Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural, Marianna, FL 32446.

Nienanber, J. A., G. L. Hahn, H. G. Klemcke, B. A. Becker, and F. Blecha. 1989. Cyclic temperature effects on growing - finishing swine. Journal Therm. Biol. 14: 233 - 237.

Nienaber, J. A., G. L. Hahn, and R. A. Eigenberg. 1999. Quantifying livestock responses for heat stress management: A review. International Journal of Biometeorology Publisher: Springer-Verlag Heidelberg 42: 183 - 188.

Petherick, J. C. 1983. A biological basis for the design of space in livestock housing. In: Current Topics in Veterinary Medicine and Animal Science - Farm animal housing and welfare, Aberdeen. p 103 - 120.

Rinaldo, D., J. Le Dividich, and J. Noblet. 2000. Adverse effects of tropical climate on voluntary feed intake and performance of growing pigs. Livest. Prod. Sci. 66: 223-234.

Serres, H. 1992. Manual of pig production in the tropics. 2 ed. CAB International, Cedex, France.

Verstegen, M. W. A., E. W. Brascamp, and W. v. d. Hel. 1978. Growing and fattening of pigs in relation to temperature of housing and feeding level. Can. J. Anim. Sci 58: 1 - 13.

Genstat. 2002. Genstat release 6.1 (pc/windows 2000). Lawes Agricultural Trust (Rothamsted Experimental Station).

FAO, 2004 http://faostat.fao.org/faostat/form?collection=Production.Livestock.Stocks&Domain=Production&servlet=1&hasbulk=&version=ext&language=EN

GENERAL DISCUSSION

INTRODUCTION

The context of the study

Before discussing the experimental findings, the boundary conditions of the research will be given.

Compared with the different environmental conditions to which wild pigs are exposed, the indoor environment in which domesticated pigs are often kept is unpleasant (Holmes, 1973; Mount, 1979; Close, 1981; Silanikove, 2000). The domesticated pig has a high percentage of lean meat, is fast growing, produces a lot of heat and is kept in confined systems (Curtis, 1983). Farmed pigs may experience heat stress throughout the world: in temperate areas during summer months and in tropical areas during the whole year. Heat stressed pigs have low performance, poor welfare, and pollute the environment (Verstegen et al., 1971; Ingram, 1981; Curtis, 1983; Hahn et al., 1987; Christon et al., 1988; Nienaber et al. 1991; 1996; Aarnink et al., 1996; 1997; 2001). Thermal stress of pigs can be short term or long term and may occur in constant or fluctuating conditions. By measuring the responses of pigs in both situations, effective temperatures can be determined.

The experiments

Within this thesis we followed three approaches with regard to animal parameters. First of all, some physiological traits and metabolism of fast growing, ad libitum fed group-housed finishing pigs were measured under controlled thermal stress conditions. In this approach, pigs were exposed to constant temperature within a day and approximately 2^0 C change between days. This condition was to identify the responses of the pigs under short-term and constant heat stress at different humidities. As described in chapters 2 and 3, upper critical temperatures for respiration rate, rectal temperature, total heat production, activity heat production and number of pigs lying on the slatted floor could be derived.

Secondly, we studied whether pigs kept under the conditions prevailing on commercial farms responded the same as pigs in controlled conditions. It should be noted that parameters such as the mean temperatures and humidity in the farm situation were relatively constant between days and mainly fluctuated within a day. An interesting finding, reported in chapter 5, was that the pigs' responses in physiology, behaviour, and performance were consistent with the results reported in chapters 2 and 3. The pigs' responses were consistent not only after adapting to a short exposure to heat stress within a day, but also when adapting in the longer term (days).

Finally, we applied some cooling methods in order to determine if heat stressed pigs could benefit from these systems. Under controlled and practical conditions, the basic responses of the pigs to heat stress were quantified, such as skin temperature, respiration rate and also behavioural and performance parameters. The responses were compared with the responses of the pigs to cooling equipment and to pen design. It can be derived that the application of cooling system and an extra area as outdoor yard translate into a change in the effective temperature for the pigs compared to standard conditions. With floor cooling, there was a measurable positive effect on the performance and "welfare" of the pigs. We provided the pigs with some cooling facilities, e.g. water bath, sprinklers, and an extra yard, so they could cope with the conditions of high temperature and humidity in the practical situation, as well.

THEORETICAL CONSIDERATIONS

The four most important findings from our study are as follows.

1. Firstly, upper critical temperatures could be derived for different animal parameters. Such temperatures allow us to assess in which sequence the behavioural and physiological adaptations to heat stress appear. The sequence is presented in figure 1: wallowing, lying on cool floor, increase evaporative water, increase respiration rate, decrease feed intake and heat production, and increase rectal temperature. It clearly shows that at the end of the chain of reactions to rising ambient temperatures, heat stress in pigs caused a reduced heat production and feed intake. Finally, in the last reaction, when heat loss cannot totally balance out heat production, the rectal temperature will increase.

   The first visible sign of how the pig reacts to increasing ambient temperature is a change in behaviour. Wallowing was observed as the first of all behavioural changes. It occurs at relatively low ambient temperature: from 16 to 17^0 C. The first physiological indicator that the pigs are reacting to high ambient temperatures is an increase in respiration rate; on average this occurs at 22.4^0 C. The second step is for rectal temperature to rise; this happened when ambient temperature was on average above 26.1^0 C. This implies that pigs can avoid increasing their rectal temperature for a temperature range of about 3.7^0 C. An increase in rectal temperature and an extra reduction in feed intake are indicators that room temperature is clearly above the upper limit of the thermal neutral zone (figure 1).

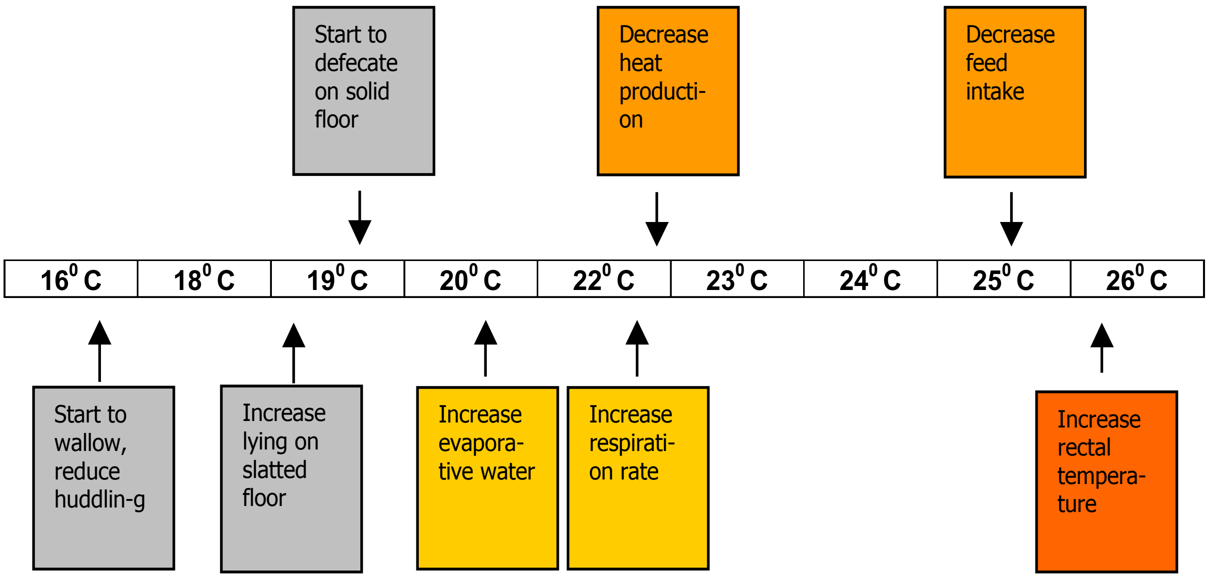

Figure 1. Adaptation of pigs to increasing temperatures; (the temperature scale should be read from left to right)

2. Secondly, heat stressed pigs have reduced performance. It should be noted that performance is the culmination of all effects over a long period. The physiological response measurements presented in chapter 2 show that the respiration rate and rectal temperature of pigs exposed briefly (4 h) to high ambient temperature were similar to the reactions after 24 h exposure: 111 min^{-1} vs. 106 min^{-1} and 39.7^0 C vs. 39.6^0 C, respectively (data not shown). In chapter 5, during the hottest part of the day the pigs kept in commercial conditions responded similar to those in controlled conditions. The respiration rate of the pigs in the afternoon (high ambient temperature) was significantly higher than the respiration rate in the morning measurement (low ambient temperature): 64.8 min^{-1} vs. 36.9 min^{-1}. The pigs' reaction revealed that since the physiological response was much less during the cooler periods of the day, they could maintain feed intake at stable level (on average, 2164 g $pig^{-1}d^{-1}$) and body temperature (on average, 39.2^0 C).
3. Thirdly, relative humidity influences the performance of the animal at high ambient temperatures. When ambient temperature increased, the pigs in this study deployed their evaporative heat loss by panting and wallowing. At high relative humidity, the inflection point temperature for increased respiration rate (chapter 2) was lower than

it was at lower relative humidity (21.3^0 C at 80% RH, 22.6^0 C at 65% RH, and 23.4^0 C at 50% RH). The daily weight gain per pig was also lower at high relative humidity (at the same ambient temperature) than at low relative humidity (chapter 2). These findings show that at high relative humidity the effects of high temperatures on the pigs are more pronounced.

4. Finally, heat stressed pigs responded positively to cooling systems. Cooling a solid floor during hot periods in the summer improves the feed intake and daily gain. The cool floor also improves the lying behaviour: more pigs chose to lie on the cool solid floor instead of the slatted floor (chapter 4). In the experiments in practical conditions, cooling systems like a water bath and sprinklers, in combination with an extra yard had positive effects on the physiological responses, behaviour (chapter5).

Inflection point temperatures

Thermo neutrality was defined as the ambient temperature at which an animal does not employ any thermoregulatory mechanism or body energy reserve to maintain its body temperature (Brody, 1945). Heitman and Hughes (1949) suggested that the upper critical temperature is the point above which there is a rise in core temperature or frequency of respiration. From the concept of thermoneutral zone (Mount, 1974), the upper critical temperature, which is called the inflection point temperature in the present study, is that level of ambient temperature at which a change in heat production is first detectable. In addition, Holmes and Close (1977) described the upper critical temperature as that temperature point at which a pig with a dry skin can maintain its maximal rate of heat loss. Nienaber et al. (1993) defined upper critical temperature as the temperature above which there is a strong decrease in voluntary feed intake. The authors observed that fast-growing lean pigs were very sensitive to elevated temperatures. Brown-Brandl et al. (2001) reported breakpoint temperatures (similar to upper critical temperature) for total heat production, respiration rate and rectal temperature. They exposed the animals to one of four elevated temperatures for 20 hours and found breakpoint temperatures in a range from 18 to 19.8^0 C for respiration rate and 18 to 22.3^0 C for rectal temperature. In the present study we showed that inflection point temperatures (upper critical temperatures) could be derived for various animal responses. The inflection point temperature derived differed, depending on the variable. These critical temperatures show the temperature threshold between thermal comfort and stress for the animal. The early increase in respiration rate seems to show that pigs may not yet be severely stressed, but it may be an indicator of a survival reaction triggered by exposure to high ambient temperature. Christon (1988) mentioned that finishing pigs in the tropics had a respiration rate of 120 min^{-1} at an average temperature of 29^0 C in a RH range of 69 to 91%. Brown-Brandl (2000) found the respiration rates of pigs exposed for 22 h to temperatures of 18 and 32^0 C were 56.7 and 100.7 min^{-1}, respectively. On that basis Brown-Brandl et al. (2001) suggested that respiration rate could be an early indicator of heat stress, which is in agreement with our finding.

Figure 2 (derived from chapter 2) demonstrates that the increase in respiration rate occurred at a similar inflection point temperature to that for the decrease in heat production. It was not possible to identify a clear effect of relative humidity on inflection point temperature for voluntary feed intake. This suggests that the upper border of thermal neutral zone as measured by voluntary feed intake does not depend greatly on relative humidity (see later in this chapter). For pig production however, and thus for economic reasons, it is important to assess heat stress on the basis of depression of voluntary feed intake and heat production. In our study, for each degree Celsius ambient temperature increase above the inflection point temperature the voluntary feed intake declined steadily by an average of 95.5 g. With respect to the inflection point, figure 3 illustrates a difference in temperatures between the decrease of heat production and the decrease of voluntary feed intake.

In chapter 2 this difference was discussed and it was suggested that the decrease in heat production comes from reducing activity-related heat production. The energy saved by reduced activity might be shifted to energy for gain.

Figure 2 and its’ connected figure 3 show that in addition to a slowed down activity, the panting allows the pigs to maintain a similar voluntary feed intake at a temperature about 3 to 4^0 C higher than the temperature at which respiration rate increases. Within the range of ambient temperatures from inflection point temperature for decreasing total heat production to decreasing voluntary feed intake, the pigs might use the saved energy for growth. However, this point should be further investigated. Important in this respect is the consideration between animal welfare and productivity.

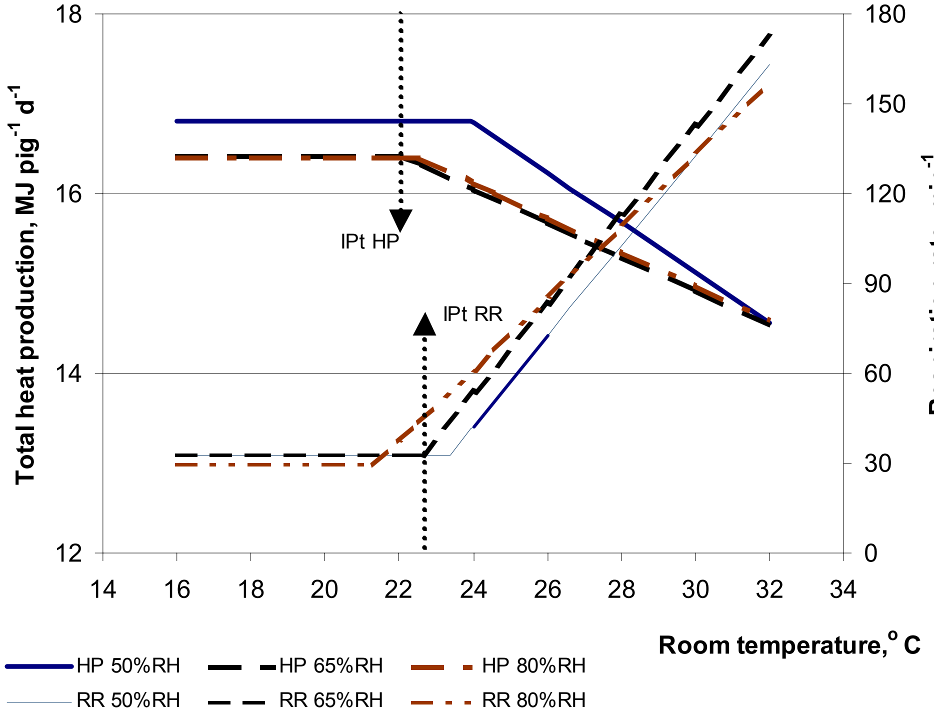

Figure 2. Broken line responses of total heat production and respiration rate to increasing temperatures.
IPt HP= inflection point temperature for a sample of total heat production at 65 % relative humidity;
IPt RR= inflection point temperature for a sample of respiration rate at 65 % relative humidity

In Mount's (1979) diagram, the thermo neutral zone is defined as the temperature zone with a "minimal" heat production at constant body temperature. Above this zone, core temperature increases and pigs become heat stressed. This is in agreement with the finding in the present study that below the inflection point temperature there is a zone of ambient temperature in which both heat production and rectal temperature are constant. However, in practical terms there are some differences between Mount's definition of thermo neutrality and the findings reported in this thesis.

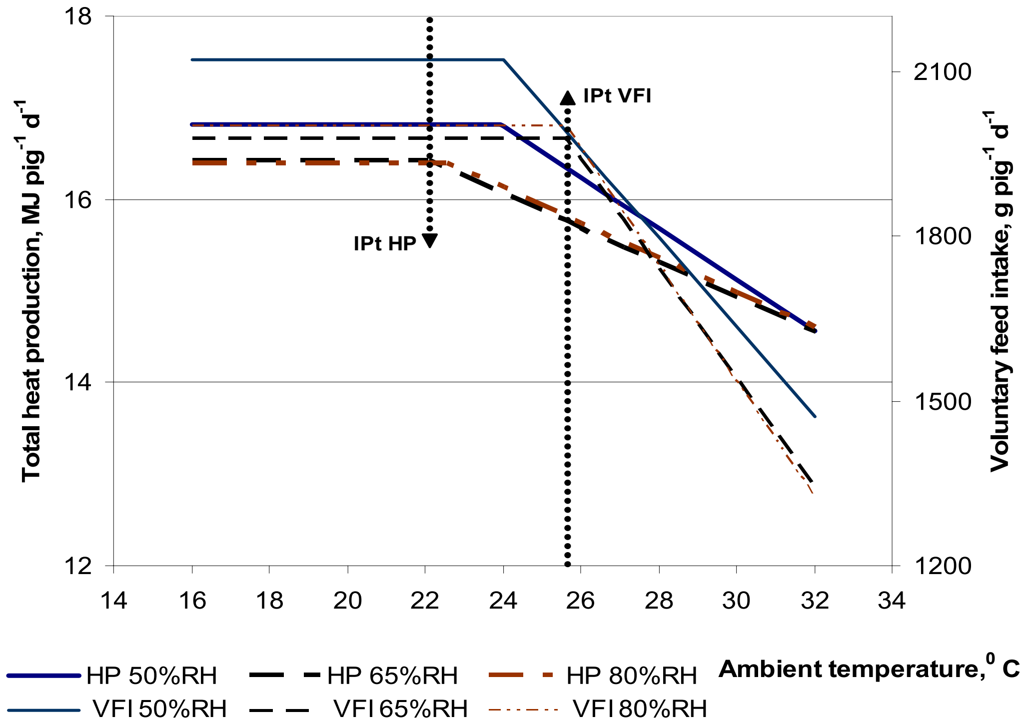

Figure 3. Broken line responses to temperatures of feed intake and total heat production. IPt VFI, inflection point temperature for voluntary feed intake at 65 % relative humidity; IPt HP; inflection point temperature for total heat production at 65 % relative humidity

First of all, the area of decreasing HP at low temperature areas in which RT was constant was not found. In the controlled experiment the ambient temperature treatment started at 16^0 C. This was already below what was reported for the lower critical temperatures for finishing pigs single housed at low feed intake (Verstegen and Henken, 1987). In figures 1, 2 and 3, total heat production was presented constant until the occurrence of inflection point temperature. This means that 16^0 C for ad lib fed pigs is within the thermal neutral zone. Then from above the inflection point temperature onwards total heat production decreases despite that the increase in temperature will increase respiration rate and rectal temperature. This is in agreement with the results reported by Brown-Brandl (2001), who found that within thermo neutral zone ambient temperature did not affect total heat production, respiration rate and rectal temperature.

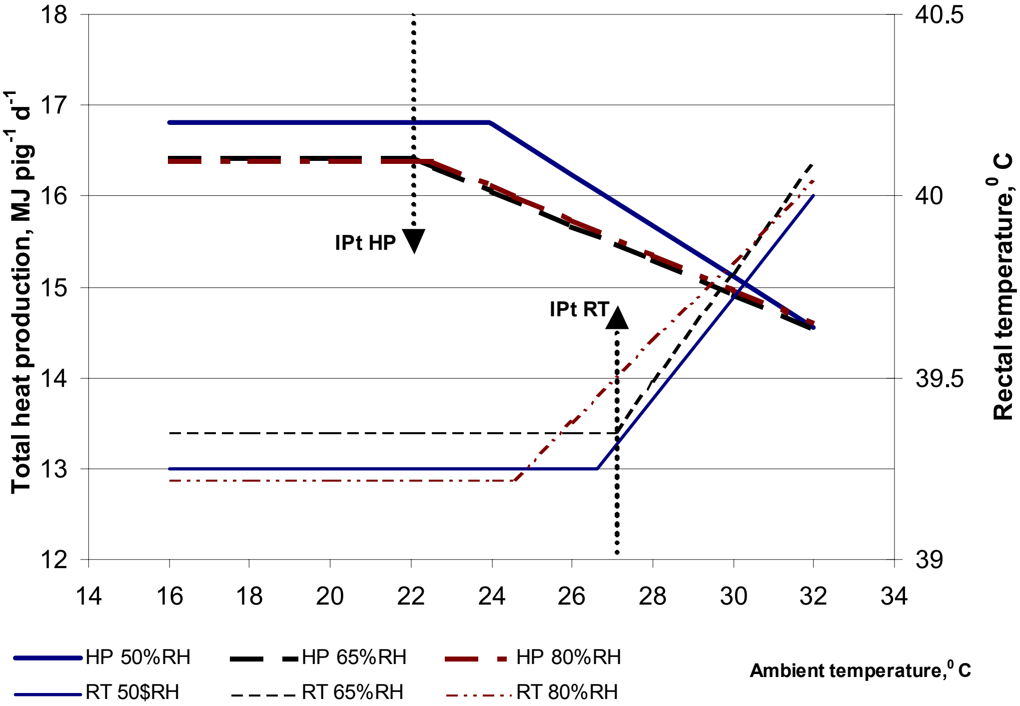

Figure 4. Broken line responses to temperatures of total heat production and rectal temperature. IPt HP; inflection point temperature for a sample of total heat production at 65 % relative humidity; IPt RR, inflection point temperature for a sample of rectal temperature at 65 % relative humidity. (for data see chapter 2)

In fact, to maintain such constant heat production and rectal temperature over that temperature range, the pigs have to increase their respiration rate to compensate for the reduction of sensible heat loss due to the ambient temperature increase.

Various authors have suggested that rectal temperature is an important indicator of heat-stressed animals (Close, 1971; Holmes, 1973; Kadzere et al., 2002; Ricalde and Lean, 2002; Silanikove, 2000). Our study confirmed that rectal temperature is a very important indicator that the pigs might have exhausted their thermoregulation capacity. This is especially true for pigs subjected to constant high ambient temperature for a long time. After all efforts of the pigs with regard to e.g. increasing respiration rate, decreasing total heat production by lower activity, changing posture, decreasing voluntary feed intake, have not enough effect to balance heat loss of the pigs. A higher rectal temperature is a tangible sign that the pig is experiencing thermal discomfort. When figure 4 is viewed in relation to figures 2 and 3, it is clear that the inflection point temperature for rectal temperature is higher than the inflection point temperatures for respiration rate, heat production and voluntary feed intake. It can be seen that inflection point temperature for rectal temperature is the end of the chain of reactions of the heat-stressed pig coping with its environment.

The effects of high temperatures in the practical situation

Upper critical temperatures for pigs derived from a well-controlled constant environment may be inappropriate for varying conditions, as there are various studies have confirmed that the pig is capable of maintaining productivity when temperature varies to some extends (Bond et al., 1967; Morrision et al., 1975; Nienaber et al., 1989). Pigs have additional properties: Morrison and Mount (1971) reported that heat-stressed pigs reduce feed intake, but compensate for this when the stressful temperature disappears. When ambient temperature fell below 30^0 C, pigs were able to fully compensate for the weight they had lost during a 17-d period exposed to temperatures of 30 – 33^0 C (Hahn et al., 1975). In the short term, temperature and humidity fluctuate within a day and challenge the homeostasis and thermo regulation of the pigs (Nienaber et al., 1989). A study by Verstegen et al. (1986) has indicated that diurnal temperature variations resulted in different patterns of heat production at certain periods within a day.

In the present study (chapter 5), a difference between the afternoon and morning temperature altered the pigs' respiration rates. A clear diurnal pattern was observed, with a high RR in the afternoon and moderate RR in the morning (64.8 vs. 36.9 min^{-1}). It is clear that by increasing their respiration rate, the pigs in our study were able to maintain a constant rectal temperature throughout changes in ambient temperature (chapter 5).

At the constant high ambient temperatures in our field study in Viet Nam, pigs had a consistently high skin temperature (average of 35.6^0 C). The normal skin temperature of a finishing pig has been reported by various authors; Geers et al. (1987, cited from Fanger, 1972), for example, noted that the comfort skin temperature ranges from 32 to 35^0 C. The change of skin temperature we found in our study with variable temperatures within a day (chapter 5) agreed well with the findings from our controlled climatic experiments (chapters 2 and 3). And the high skin temperature of pigs recorded in the field study (chapter 5) shows that pigs raised under tropical conditions reacted not only by maintaining a high respiration rate but also by maintaining a high skin temperature. This is expected, because vasodilatation of epidermal blood vessels allows deep body heat load to be dissipated more easily to the cooler environment (Yousef, 1985). Clearly, the skin temperature directly reflects the pig's ambient temperature and the animal's responses to that temperature. The use of the skin temperature figure will be discussed later in this chapter.

In general, under diurnal tropical climate condition pigs responded by maintaining a high respiration rate, especially during the hot part of the day. However, in the field study, the maximum respiration rate in the afternoon was still much lower than the maximum value in the controlled climate study: at similar ambient temperature (approximately 32^0 C), the average respiration rate of pigs in the field study was 65 min^{-1}, compared with 170 min^{-1} for the pigs in the experiment described in chapter 2. The fluctuating temperatures between day and night might explain the lower respiration rate in the field study. This gives pigs the opportunity to shift feed intake to the lower temperature periods of the day. Lower feed intake in the afternoon, the hot part of the day, reduces heat production and the necessary heat loss. Therefore respiration rate can be lower than in the situation of a constant high temperature as in the controlled climate experiment.

Given the definition of the thermo neutral zone of Brody (1945) pigs with high respiration rates are heat stressed. However, the respiration rate during the hot parts of the day in the field study are still a lot lower than the highest values measured in the controlled climate study. Like feed intake, pigs can also shift activity from the hot parts to the cooler parts of the day. Thus fluctuating temperatures give pigs more possibilities to escape from heat stress caused by high temperatures.

Humidity and evaporative heat loss

In the high temperatures and humidity of the tropics, productive pigs have difficulty losing their metabolic heat. This is because the pig is a homeothermic animal, i.e. its heat production and heat loss must be in equilibrium. Heat loss depends on the climatic conditions. In temperate climatic conditions, i.e. when the ambient temperature is cooler than the skin temperature, pigs can use a variety of mechanisms to eliminate heat from the body into the environment: radiation, conduction, and convection (Mount, 1979). But when ambient temperature approaches skin temperature, evaporation becomes important. At high temperatures, humidity affects the rate of heat loss from animals (Esmay, 1969). When the environment is hot their main way of losing heat is via respiratory and skin evaporation. Bond et al. (1959) reported that at an ambient temperature of 32^0 C, 54.7 % of the heat loss in pigs was from evaporation. A study on skin and lung moisture loss from swine by Morrison et al. (1967) showed that 35 to 67 % of total evaporative heat loss is through skin evaporation. Another study on heat and moisture loss in swine by Ingram (1974) showed that at 29.4^0 C a 40 kg pig disseminated 45% heat by evaporation. The calculated moisture loss from skin evaporation and respiration can be used to derive an effective temperature (Bull, 1997; Johnston, 1999).

Figure 5 shows the distribution of evaporative water from respiration and from evaporation from the skin, calculated with data from chapter 2.

The calculations were done for a room temperature of 32^0 C and a relative humidity of 80%. Under these conditions, the water content in the chamber air is 27.01 g m^{-3} (ANIPRO, 2000). Assuming that air exhaled by the pigs has a temperature of 37.7^0 C and an RH of 90 % (Brody, 1945; Morrison, 1967; Ingram, 1974), the exhaled air contains 40.90 g water m^{-3} (ANIPRO, 2000). This means there is scope for the animal to add 13.89 g water per m^{-3} of exhaled air. Data from Morrison (1967); Ingram (1969; 1974) show that a 60 kg pig breathes approximately 0.5 litres per breathing stroke. Given an average respiration frequency of 169 min^{-1}, these figures lead to an estimate that on average, each of our pigs exhaled 84.5 litres of air per minute, equalling a volume of 121.7 m^3 per day to the chamber.
Thus, the estimated amount of moisture added to the air by breathing when the pig is exposed to an ambient temperature of 32^0 C with 80 %RH is 1.69 litres d^{-1}. However, under these conditions, the evaporative water actually measured from the chamber, corrected for evaporation from the floor, was 2.8 litres. The difference of 1.11 litres is assumed to come from skin evaporation. From our results, at 32^0 C with 80 %RH, most (67%) of the total evaporative heat loss from our pigs was achieved as heat loss by respiration. In addition, there were significant differences in regression coefficients, which are presented in figure 5, of evaporative water by respiration: 0.15 v.s. 0.11 v.s. 0.08 for 50, 65, and 80 % relative humidity, respectively. This comparison shows that at high relative humidity the increase of evaporative water from breathing is much less than the increase at low relative humidity. These findings show that at high relative humidity the pigs had less possibility of eliminating heat load by breathing. They depended much more on wetting their skin and therefore lost heat by evaporation from the skin. They wetted their skin by wallowing.

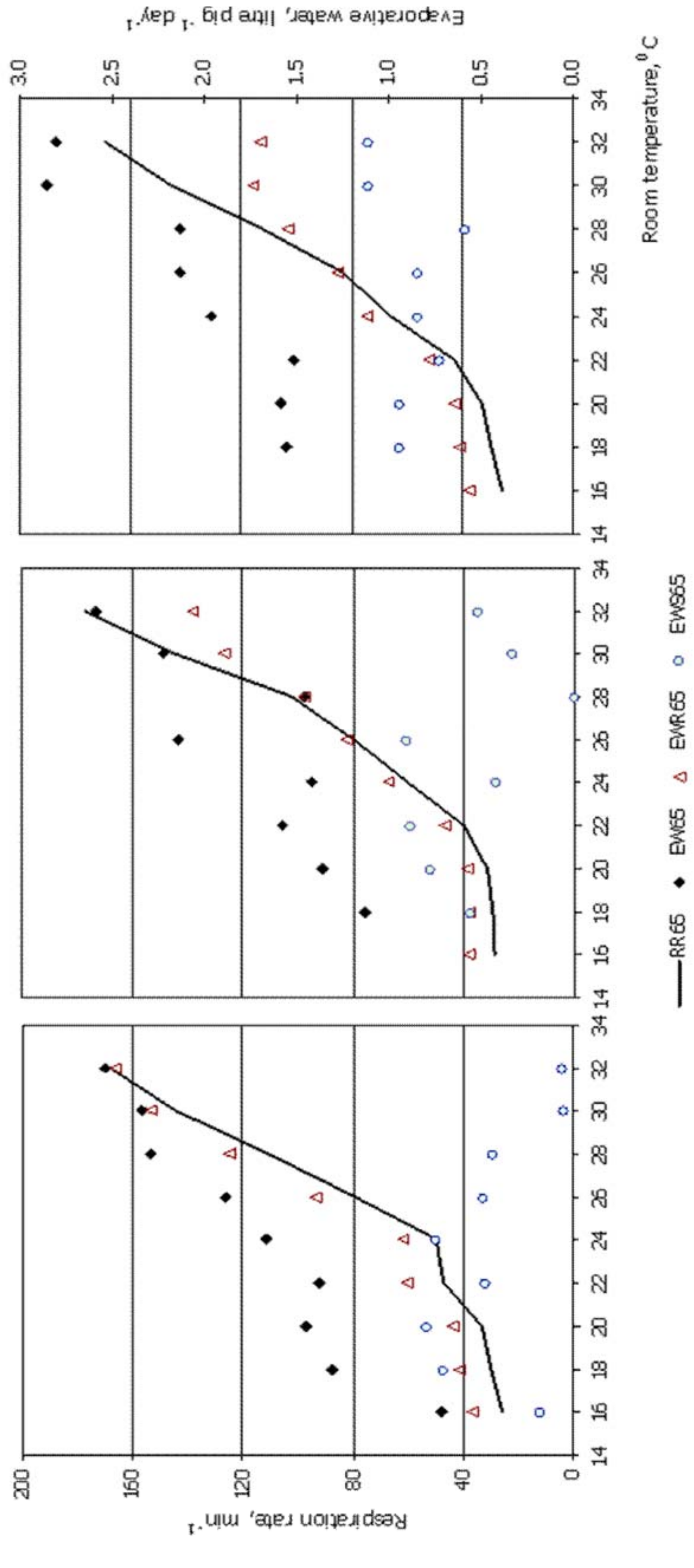

Figure 5. Effect of temperature and relative humidity on evaporative heat loss,
RR = respiration rate (measured values were corrected); EW = Total evaporative water;
EWR = Evaporative water from respiration; EWS = evaporative water from the skin

For the whole range of ambient temperature after wallowing started to occur (>= 18^0 C), the means of evaporative water from the skin were 0.51, 0.64 and 0.96 kg pig^{-1} d^{-1} for 50, 65 and 80 %RH pig, respectively (figure 5, data see chapter 2). In chapter 3, this finding was discussed and we reported that wallowing was observed earlier in the 80 %RH group than in the 50 and 65 %RH groups. It can be argued that the ways the pigs employed their skin evaporation strongly influenced the determination of the inflection point for that parameter. Summing up: a lower skin temperature was observed for pigs at 80 %RH than for pigs at 50 %RH (chapter 2). The lower skin temperature is probably caused by the higher skin evaporation of pigs at 80 %RH. In addition, chapter 5 demonstrated that pigs kept in a hot humid climate used the water bath and sprinklers intensively. On average, each pig used sprinklers 4.7 times of the 12 sprinkling periods daily between 10.00 and 16.00. The pigs used the water bath on average 7.4 times per day. The intensive bathing time was between 1400 and 1700. In addition, the pigs made use of the wet floor under the sprinklers to wet themselves when the sprinklers were not working.

It may be concluded that under constant high ambient temperature and humidity, in the present study the pigs clearly employed skin moisture evaporation to lose heat (as discussed in detail in chapters 3, 4 and 5). This shows the importance of evaporative cooling from the skin. The implication is that pigs at high ambient temperatures, especially in combination with a high humidity, should be able to wet themselves. For animal welfare and environmental reasons it is important that the pigs do not have to do so with their own excreta. Water should be available for the pigs, in a water bath or from sprinklers.

IMPLICATIONS OF THE FINDINGS

Yousef (1985) defined stress physiology as a study of the animal's physiological, biochemical, and behavioural responses to the various factors of the physical, chemical, and biological environment. According to this definition and in the light of this study, the pig's responses can be respiration rate, rectal temperature, skin temperature, postural behaviour and performance; the environmental factors can be temperature and relative humidity. When pigs experience thermal conditions above the thermo neutral zone as defined by Mount (1974), the pigs' ambient temperature is at above the inflection point temperature in this study. When this happened, we concluded that the animals were in heat stress. Heat stress can be measured (Yousef, 1985), as the animals respond by trying to maintain their conditions at constant state as in the thermo neutral environment. Heat stress has implications for the animals' welfare and environment, as discussed below.

Welfare

The definition of welfare in an individual animal is its state with regard to attempts to cope with its environment (Broom, 1986). Recent public debate on sustainable animal production has focused on the concept of animals' needs (Broom, 1992; Bartussek, 1999). The needs of the farm animals include all management and environmental factors e.g. quality of microclimate (temperature, humidity, air velocity, ventilation), quality of housing (flooring, wall, fence, indoor, outdoor), method of management (feeding, confinement, free or confined range). Welfare indicators associated with physiology, performance, and behaviour are often used (Dawkins, 1980). In general, it is not simple to quantify the welfare state of an animal; Dantzer and Mormede, (1979) therefore suggested that to assess welfare, its opposite should be evaluated. This entails looking for signals that indicate impaired welfare. The impairment in welfare is a sequence of changes in physiology, behaviour, and performance in such a negative way that it can be considered harmful for the animal. Silanikov (2000) stated that welfare could be measured and scaled from poor to good, and suggested that an animal has poor welfare when it has difficulties coping with its environment. When pigs are heat stressed, an impaired performance can be good evidence of poor welfare. If the heat-stressed pigs can use their postural behaviour repertoire, this can be used as a signal of all the internal and external environmental factors at work, and the pig's welfare status can be inferred. In other words, when pigs show a change in postural behaviour, an upset in their homeostasis may have occurred. In the previous chapters we presented responses of finishing pigs to thermal stress. These included physiological and behavioural changes.

When temperature rose, the pigs we studied displayed signs of discomfort: they became inactive, extended their body contact with the floor while lying, and avoided physical contact with other pigs. So, when they are hot, pigs show less space sharing and lie more on their sides compared to low temperatures. This means that with increasing temperature, the need for physical surface space increases.

The heat-stressed pigs in the current study could only choose between lying on the slatted floor or on the solid concrete floor (chapters 3 and 4). With high ambient temperatures, more pigs lay on the slatted floor (chapters 3 and 4) or in the excretion part of the resting area (chapter 5). They increased this shift until there was no longer enough space to do so (Aarnink et al., 2001). We concluded that they preferred the slatted floor because they experienced it as cooler than the solid floor. The difference between the slatted floor and solid floor temperatures was approximately 2 to 3^0 C (chapter 4). The inflection point temperature for this change in lying behaviour was relatively low (22^0 C). We consider this low inflection point temperature as an indicator that welfare is impaired. In chapter 5, the experimental pigs were offered only a solid floor system, and in pens without cooling facilities under humid tropical conditions they lay in manure and urine. Lying on the slatted floor or excreting area is not the natural motivation of the pigs (Aarnink et al., 2001; Hesse and Jackisch, 1995; Randall et al., 1983). Thus, pigs had to lie on slatted floor or in their own urine and faeces to reduce heat stress; to do the latter, they had to abandon the natural desire to avoid contact with excrement. In hot conditions this behaviour can be interpreted as a decline in welfare.

An important adjustment of the pigs with regard to thermoregulation is wallowing. Wallowing of the pigs greatly increases their heat dissipation (Mount, 1971) and heat tolerance may be increased as well. In chapter 3 we reported a distinctive behaviour: the pigs wallowed in a mixture of urine and faeces. Wild pigs also wallow when temperature is high (Schein et al., 1969). With regard to wallowing, Roller and Goldman (1969) noted that the pig evolved in warm, wet swampy areas. So, evolution favoured their behavioural adaptation of wallowing instead of the physiological adaptation of sweating as the evaporative heat loss mechanism. Mount (1971) remarked that a clean, dry pen for pigs may therefore force pigs to pant in order to dissipate excess heat.

Environment

When the animals wallowed in their own manure and urine to increase evaporative heat loss, the emission of environmentally damaging gases such as NH_3 increased. Hacker et al., (1994) reported that pen dirtiness is an important factor for ammonia emission. A study on ammonia emission by Aarnink et al., (1996) showed that urine-fouled floor area and urine-fouled animal body related positively with ammonia emission. This was an average of 40% of the total emission from the pen floor (25% of the pen floor was slatted). In other study, Aarnink et al., (1997) observed that pen fouling was higher in summer than in winter, and that pen fouling increased towards the end of growing period.

From the research reported in this thesis, it is clear that on exposure to heat stress the animals immediately changed their lying and excretion behaviour (chapters 3, 4, 5). Those changes could cause a large increase in ammonia and odour emissions. The implication of this finding is that it is important to offer the animals cooling systems like water bath or sprinklers. During hot periods, this could prevent the animals from fouling their pen with manure and urine and thus from increasing emission of environmental pollutants.

Prevention of heat stress

The present study has demonstrated the benefits of floor and spray cooling systems under normal commercial conditions in the Netherlands and small-scale pig production in Viet Nam. Growth rates and feed intake were significantly improved in pigs provided with floor and spray cooling. Compared to the expensive and complex system of floor cooling, spray cooling is one of the cheapest and simplest ways of reducing the negative effects of hot weather. This system can be used to improve the production efficiency and welfare of pigs not only in Viet Nam, but also in intensive production systems outside the tropics.

In the commercial conditions with partly solid and slatted floor pens we studied, even though the solid floor was cooled, its surface temperature was always higher than that of the slatted floor. However, cooling the solid floor decreased the difference in temperature between the solid and slatted floor. For reasons of welfare and hygiene (Hacker, 1994; Aarnink, 1996; 1997; 2001), in order to keep the pigs lying on the solid floor at high ambient temperature, the temperature of that floor should be the same or lower than that of the slatted floor. Some of the factors limiting the cooling system were the system’s capacity and the fact that the water warmed up somewhat as it flowed from the heat exchanger to the room floor.

Spray cooling is also believed to have a positive effect on dunging patterns, which can improve pen hygiene (Banhazi et al. 2000). Of course, spray cooling has to be managed according to the actual air temperatures and diurnal temperature variations. Most modern spraying systems are designed to allow this. When using spray-cooling equipment it is important to use spray heads capable of producing large droplet sizes. In addition, the water should be sprayed just directly above animal level. In this way it is possible to avoid producing high humidity conditions, which can actually increase rather than decrease heat stress (Bolla, 1986). A combination of sprinkling with a high airflow can also cause too much heat loss, especially in young pigs, even at high air temperatures (Hahn et al. 1987; Riskowski and Bundy 1995). It is therefore essential to have a well-controlled sprinkling system. It is also important that the animal can choose whether or not to use the cooling system, as the animal itself is the best sensor of heat stress.

Further research

The research described in this thesis has revealed some remaining gaps in our understanding of animals' reactions to heat stress. Further research is necessary to bridge the gaps, as described below.

The literature contains reports that inflection point temperatures differ for different animal live weights. Aarnink et al. (2001) derived inflection point temperatures for lying and excreting behavioural change in different ranges of ambient temperatures and animal weights. They reported that the inflection point temperatures for excretion on the solid floor decreased with increasing pig weight: from approximately 25^0 C at 25 kg to 20^0 C at 100 kg live weight. A study on acute heat stress on 84 kg high lean barrows by Brown-Brandl et al. (1998) showed that at 18^0 C ambient temperature the respiration rate increased, and at 28^0 C a decrease in feed intake occurred. In light of these findings and the results from the present study, it would be useful for future research to be done to determinate inflection point temperatures for different animal live weights, feeding methods, and housing conditions.

From this current study it is obvious that animals are able to deploy many different mechanisms to cope with hot conditions. But we still need to elucidate the physiological reaction underlying the sequence of the animal's responses like increased wallowing, increased lying on cool floor, increased moisture and respiration rate and then increased rectal temperature.

Our research has also clearly shown that cooling is very important for pigs during hot weather. The optimal set-up for the cooling systems needs to be determined. From chapter 4, it is clear that improvement is necessary in the efficient temperature for the incoming water to the cooling floor, whereas from chapter 5, it is clear that the optimal location of the water bath, and also the efficient water pressure for sprinklers need to be investigated.

CONCLUSIONS

This study on ad libitum, fast-growing, group-housed pigs leads to the following conclusions:

- Upper critical temperatures (inflection point temperatures) could be derived not only for the change of heat production but also for many other animal parameters. In order of appearance, these include lying on slatted floor, evaporative water, respiration rate, total heat production, ratio of water to feed intake, activity heat production, voluntary feed intake and rectal temperature. These inflection point temperatures are different for the different parameters and explain the subsequent strategies an animal follows as ambient temperature rises.
- The best indicators for assessing heat stress of finishing pigs are: increased respiration rate and water to feed ratio, followed by reduced heat production and feed intake, and, finally, increased rectal temperature. Decreased feed intake and increased rectal temperature are good indicators of reduced performance of heat-stressed pigs. An increase in rectal temperature and a reduction in feed intake are indicators that room temperature is above the upper limit of the thermo neutral zone, as defined by Mount (1979).
- Observations of lying and excreting behavioural changes of the pigs may be useful to assess their very first reactions in thermal regulation. There are ranges of critical temperatures for behavioural responses of growing pigs. We found that huddling already decreased above 16^0 C; wallowing occurred above 16 to 17^0 C; lying on the slatted floor gradually increased above 19^0 C, and as a result of the changed lying behaviour the excretions on the solid floor increased when temperature rose above 20 to 22^0 C. Above those temperatures, activity and activity-related heat production also declined.
- On the basis of our findings on thermoregulation we recommend that when determining the physical space required by fattening pigs the behavioural changes at increasing temperatures should be taken into account. The number of pigs lying on slatted floor could be the first indicator for assessing the welfare of pigs exposed to high ambient temperatures.
- Ad libitum, fast-growing, group-housed pigs raised under tropical climate conditions clearly show physiological and behavioural responses to this climate similar to those of pigs kept under controlled environmental conditions. The

pigs adapt to adverse tropical conditions by maintaining a high respiration rate in order to maintain homeostasis and performance.

- The availability of cooling systems e.g. floor cooling, water bath or sprinklers has beneficial effects on pig performance compared to control groups without cooling.
- Floor cooling significantly increases pigs' feed intake and growth rate under summer conditions. The system might be further refined if more were known about how the cooling requirements of the pigs vary with ambient temperature and animal weight. In terms of cost, a water bath and sprinkler system are more suitable for animal production in a developing country like Viet Nam. A water bath contributes to a clean pen, while sprinklers increase pigs' feed intake and gain. In hot humid tropical conditions these two systems contribute only little extra humidity to the air.
- Generally, we found that humidity had minor effects on physiological parameters. However, we did find a significant difference in animal gain at the three levels of humidity we investigated. A combination of high humidity and high temperature clearly has a detrimental effect on daily gain.
- The indicators of heat stress found in this study could be used as set points for cooling systems, in order to improve animal performance and welfare in hot conditions.

LITERATURES CITED

Aarnink, A. J. A., J. W. Schrama, R. J. E. Verheijen, and J. Stefanowska. 2001. Pen fouling in pig houses affected by temperature. In: Livestock Environment VI, Galt House Hotel Louisville, Kentucky. p 180 - 186.

Aarnink, A. J. A., D. Swierstra, A. J. van den Berg, and L. Speelman. 1997. Effect of type of slatted floor and degree of fouling of solid floor on ammonia emission rates from fattening piggeries. Journal of Agricultural Engineering Research 66: 93-102.

Aarnink, A. J. A., van den Berg A. J., Keen A., Hoeksma P., and 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.

Bartussek, H. 1999. A review of the animal needs index (ani) for the assessment of animals' well-being in the housing systems for austrian proprietary products and legislation. Livestock Production Science 61: 179-192.

Bianca, W., and J. D. Findlay., 1962. The effect of thermally induced hyperpnea on the acid - base status of the bllod of calves. Res. Vet. Sci. 3: 38 - 49.

Bond, T. E., C. F. Kelly, and H. J. Heitman., 1967. Physiological responses of swine to cyclic environmental conditions. Anim. Prod. 9: 453 - 462.

Brody, S., 1945. Bioenergetics and growth. Reinhold, New York.

Broom, D. M., 1983. Stereotypies as animal welfare indicators. In: Current Topics in Veterinary Medicine and Animal Science - Indicators relevant to farm animal welfare, Mariensee Germany. p 81 - 88.

Broom, D. M., 1992. Animal welfare: Its scientific measurement and current relevance to animal husbandry in europe. In: C. Phillips and D. Pigginns (eds.) Farm animal and the environment. p 245 - 253. CAB, Wallingford UK.

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

Brown-Brandl, T. M., J. A. Nienaber, and L. W. Turner. 1998. Acute heat stress effects on heat production and respiration rate in swine. Transactions of the Asae 41: 789-793.

Brown-Brandl, T. M., J. A. Nienaber, L. W. Turner, and J. T. Yen. 2000. Manual and thermal induced feed intake restriction on finishing barrows. Ii: Effects on heat production, activity, and organ weights. Transactions of the Asae 43: 993-997.

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

Christon, R. 1988. The effect of tropical ambient temperature on growth and metabolism in pigs. Journal Animal Science 66: 3112-3123.

Close, W. H. 1981. The climatic requirements of the pig. In: J. A. Clark (ed.) Environmental aspects of housing for animal production. p 149 - 167. Butterworths, England.

Curtis, S. E. 1983. Environmental managements in animal agriculture. Iowa State University. Press, Ames.

Curtis, S. E. 1985. Physiological responses and adaptations of swine. In: M. K. Yousef (ed.) Stress physiology in livestock No. II. p 62 - 63. CRC Press, Las Vegas, Nevada.

Dantzer, R., and P. Mormede, 1980. Can physiological criteria be used to assess welfare in pigs? In: Current Topics in Veterinary Medicine and Animal Science - The Welfare of Pigs, Brussels. p 53 - 74.

Duncan, I. J. H., and M. S. Dawkins. 1982. The problem of assessing "well-being" and "suffering" in farm animals. In: Current Topics in Veterinary Medicine and Animal Science - Indicators relevant to farm animal welfare, Mariensee Germany. p 13 - 24.

Esmay, M. L., 1969. Principles of animal environment. The AVI Publishing Company, Inc., Westport, Connecticut.

Findlay, J. D., and G. C. Whittow. 1966. The role of arterial oxygen tension in the respiratory response to localized heating of the hypothalamus and to hyperthermia. J. Physiol. 186: 333 - 346.

Geers, R., W. van Der Hel, and V. Goedseels. 1987. Surface temperatures as parameters. In: V. M.W.A and H. A.M. (eds.) Energy metabolism in farm animals effects of housing, stress and diseases. p 105 - 114. Martinus Nijhoff, Dordrecht.

Hacker, R. R., J. R. Ogilvie, W. D. Morrison, and F. Kains. 1994. Factors affecting excretory behaviour of pigs. Journal Animal Science 72: 1455-1460.

Hahn, G. L., N. F. Meador, D. G. Stevens, M. D. Shanklin, and H. D. Johnson. 1975. Compensatory growth in livestock subjected to heat stress. In: ASAE Annual meeting, paper number 75 - 4008, Davis, California

Hahn, G. L., J.A., Nienaber and .J.A. DeShazer. 1987. Air temperature influences on swine performance and behavior. Appl-Eng-Agric. St. Joseph, Mich.: American Society of Agricultural Engineers 3: 295-302.

Heitman, H. J., and E. H. Hughes. 1949. The effects of air temperature and relative humidity on the physiological well being of swine. Journal Animal Science 8: 171 - 181.

Hesse, D., and T. Jackisch. 1995. The sloped floor system - an accomodating pen design Pig Progress No. June - July. p 29 - 31.

Holmes, C. W. 1973. The energy and metabolism of pigs growing at a high temperature. Animal Production 16: 117 - 133.

Ingram, D. L., and K. F. Legge. 1969 / 1970. Effect of environmental temperature on respiratory ventilation in pig. Respiration Physiology 8: 1 - 12.

Ingram, D. 1980. Physiology and behaviour of young pigs in relation to the environment. In: Current Topics in Veterinary Medicine and Animal Science - The Welfare of Pigs, Brussels. p 33 - 43.

Johnston, L. J., M. Ellis, G. W. Libal, V. B. Mayrose, and W. C. Weldon. 1999. Effect of room temperature and dietary amino acid concentration on performance of lactating sows. NCR-89 committee on swine management. J. Anim Sci. 77: 1638-1644.

Kadzere, C. T., M. R. Murphy, N. Silanikove, and E. Maltz. 2002. Heat stress in lactating dairy cows: A review. Livestock Production Science 77: 59–91.

Morrision, S. R., H. J. Heitman, and R. L. Givens. 1975. Effect of diurnal air temperature cycles on growth and food conversion in pigs. Anim. Prod. 20: 287 - 291.

Morrision, S. R., and L. E. Mount. 1971. Adaptation of growing pigs to change in environmental temperature. Anim. Prod. 13: 51 - 57.

Morrison, S. R., T. E. Bond, and H. J. Heitman. 1967. Effect of humidity on swine at high temperature, ASAE paper number 67 - 420

Mount, L. E. 1971. Environmental physiology in relation to pig production. In: D. J. A. Cole (ed.) Pig production. p 71 - 91. Butterworths, London.

Mount, L. E. 1974. The concept of thermal neutrality. In: J. L. Monteith and L. E. Mount (eds.) Heat loss from animals and man. p 425 - 440. Butterworths, Nottingham.

Mount, L. E. 1979. Adaptation to thermal environment: Man and his productive animals. Edward Arnold Limited, Thomson Litho Ltd, East Kilbride, Scotland.

Nienaber, J. A., G. L. Hahn, H. G. Klemcke, B. A. Becker, and F. Blecha. 1989. Cyclic temperature effects on growing - finishing swine. J. therm. BioL 14: 233 - 237.

Nienaber, J. A., G. L. Hahn, and T. McDonald. 1991. Thermal environment effect on feeding patterns and swine performance. Paper presented at the "1991 International Summer Meeting sponsored by the American Society of Agricultural Engineers", Albuquerque, New Mexico: 14.

Nienaber, J. A., G. L. Hahn, T. P. McDonald, and R. L. Korthals. 1996. Feeding patterns and swine performance in hot environments. Transactions of the Asae 39: 195-202.

NRC. 1981. Effect of environment on nutrient requirements of domestic animals. National Academic Press , Washington, DC: 607 - 618.

Randall, J. M., A. W. Armsby, and J. R. Sharp. 1983. Cooling gradients across pens in a finishing piggery : Ii. Effects on excretory behaviour. Journal of Agricultural Engineering Research 28: 247-259.

Ricalde, R. H. S., and I. J. Lean. 2002. Effects of feed intake during pregnancy on productive performance and grazing behaviour of primiparous sows kept in an outdoor system under tropical conditions. Livestock Production Science 77: 13-21.

Roller, W. L., and R. F. Goldman. 1969. Trans. Am. Soc. agric. Engrs. 12: 164.

Schein, M. W., and E. S. E. Hafez. 1969. The physical environment and behaviour. In: E. S. E. Hafez (ed.) The behaviour of domestic animals. p 65 - 84. Bailliere, Tindall & Cassell, London.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Production Science 67: 1-18.

Verstegen, M. W. A., and W. van der Hel. 1974. The effects of temperature and type of floor on metabolic rate and effective critical temperature in groups of growing pigs. Anim. Prod. 18: 1 - 11.

Verstegen, M. W. A., A. M. Henken, and W. van der Hel. 1987. Influence of some environmental, animal and feeding factors on energy metabolism in growing pigs. In: M. W. A. Verstegen and A.M.Henken (eds.) Energy metabolism in farm animals. p 478. Martinus Nijhoff, Dordrecht.

Verstegen, M. W. A., W. van der Hel, R. Duijghuisen, and R. Geers. 1986. Diurnal variation in the thermal demand of growing pigs. Journal of Thermal Biology 11: 131-135.

Yousef, M. K. 1985. Stress physiology: Definition and terminology. In: M. K. Yousef (ed.) Stress physiology in livestock No. 1. p 205. CRC Press.

SUMMARY

INTRODUCTION

Fast-growing lean pigs generate more heat from their feed intake. This, in combination with confined housing, makes it difficult for the pigs in intensive systems to regulate their heat balance. Whereas outdoor pigs can choose their own environment (e.g. shadow, mud pool, staying away from other pigs), indoor pigs have to cope with the confined environment. The opportunity to lose heat is especially important in the indoor climate. To date, the effects on pig performance of a climatic environment in which temperatures are constant or fluctuate diurnally or from day to day have not been investigated in detail. A fluctuating ambient temperature has a smaller effect on pig productivity than a constant temperature at the same mean. This is because a lower ambient temperature at night enables pigs to compensate for the lower feed intake in the day and improves the comfort stage of the pig. As both cases may occur in practice, it is important to understand how the pigs react to each situation. The problems described above might be more serious in combination with high humidity. In the literature it has even been stated that humidity contributes importantly in the thermoregulation of finishing pigs but quantitative evidence of this has been lacking.

The temperature above which the responses change (also called the critical temperature or inflection point temperature) may well differ depending on which parameter is studied. Animal parameters like wallowing, lying on slatted floor, respiration rate, rectal temperature, and heat production and voluntary feed intake were considered. To date, no adequate studies of the effect of relative humidity on these parameters have been available in the literature. The main objectives of the research described in this thesis were therefore firstly to quantify the short-term (chapter 2 and 3) and long-term responses (chapter 5) of growing-finishing pigs to different climatic conditions, and, secondly, to study cooling systems and their effects (chapter 4 and 5) on the pigs' physiological, behavioural responses and performance.

Effects of increasing temperatures on pigs' physiological changes at different relative humidities (chapter 2)

Little information is available about the critical ambient temperatures above which group-housed pigs start to adapt their mechanisms for balancing heat loss (evaporative heat loss, behavioural and physiological adaptation) and heat

production. The temperature above which the responses change (also called critical temperature or inflection point temperature) may well differ, depending on the parameter studied. In addition, the effect of relative humidity on these parameters is unknown.

For these reasons, the effects of relative humidity and high temperature on physiological responses and animal performance were studied using twelve groups (ten gilts per group) in pens inside respiration chambers. The microclimate in the chamber was programmed so that ambient temperature (T) remained constant within a day. Each day, the temperature was increased by 2^0 C from 16^0 C to 32^0 C. Relative humidity (RH) was kept constant at 50 %, 65 % or 80 %. The experiment consisted of a 4-d adaptation period followed by a 9-d data collection period. Physiological parameters were measured twice daily in 3 animals. Feed was measured twice a day per group of animals. Throughout the 9-day experimental period, heat production was measured and analysed at 6-minute intervals. We determined the ambient temperature above which certain animal variables started to change: the so-called inflection point temperature (IPt) or “upper critical temperature”.

We found inflection point temperatures for RR, RT, VFI, HP, evaporative water, and ratio of water and voluntary feed intake. The first indicator of reaction was respiration rate, with IPt’s in the range from 21.3 to 23.4^0 C. Rectal temperature was a delayed indicator of heat stress intolerance, with IPt’s in the range from 24.6 to 27.1^0 C. For both parameters IPt was lowest at 80% RH ($p<0.05$). In between the first and last indicators of pig responses to heat stress were HP, VFI, evaporative water and ratio of water and feed intake. The ambient temperature strongly affects the pigs’ physiological changes and performance; relative humidity has a relatively minor effect on heat stress in growing pigs. However, the combination of high temperature and high humidity lowered the daily gain in pigs. Decreased feed intake and increased rectal temperature are good indicators of reduced performance of heat stressed pigs. Temperatures in commercial pig houses regularly exceed the measured inflection point temperatures for feed intake and rectal temperature.

Thermal Behaviour of Growing Pigs in Response to High Temperature and Humidity (chapter 3)

Despite the many advances made in recent decades in the technological control of indoor climate in animal buildings, ambient temperatures will not always be within the thermal comfort zone of the pig. Previous research has demonstrated conclusively that behavioural elements such as lying behaviour and excreting behaviour are affected by ambient temperature. On hot days pigs changed their lying position from sternal to lateral and avoided physical contact with other pen mates. In addition, pigs are known to separate their lying and dunging areas. Under optimal housing conditions pigs will rest and sleep in a defined lying area and dung consistently in the dunging area. However, at high temperatures this distinction between lying and excreting area disappears. Though results are available on the effects of temperature on behavioural changes, there is a lack of quantitative relationships between temperature and thermoregulatory behaviour of pigs. Neither is information available on the effects of humidity at different temperatures on fattening pigs' behaviour.

To evaluate how pigs regulate their thermal regulatory behaviour under hot conditions we therefore designed an experiment with temperatures varying from low to high at three levels of humidity. The aim was to derive the upper limit of thermal neutral zone with respect to lying and excretion behaviour in growing pigs. For this study, 12 groups of growing pigs were used. The experiment consisted of 6 consecutive trials. During each trial, 2 groups were studied. After a 4-d adaptation period, the ambient temperature was gradually increased by two degrees daily, from 16^0 C to 32^0 C within a 9-day period. Relative humidity was maintained constant during the 13-d experimental period, at 50, 65, or 80 %. Space allowance per pig was 1.0 m^2. The floor was 60 % solid and 40 % slatted. Lying, excreting and fouling behaviour were studied using video recordings. A radar activity meter was used to record the physical activity of the pigs. With a regression model the heat produced by activity was calculated. The lying position of the pigs was classified e.g. Lateral, Sternal, Half lateral lying. Excreting behaviour was determined in terms of e.g. urination and defecation. Furthermore, thermoregulatory lying behaviour (huddling and wallowing) was recorded. All behaviours were recorded in terms of frequency and location.

The study showed that temperature affected lying and excretion behaviours. The number of pigs lying on slatted floor increased with increasing temperature ($p<0.001$). The inflection point temperature (IPt) for the pigs to lie on the slatted floor was clear and relatively low (18.8^{o}C). The heat produced by activity was relatively constant below the IPt of 24.2^{o}C, but once this IPt had been exceeded it down turned. Temperature was inversely related to huddling and positively related to wallowing. The total excretions on solid floor increased with temperature. It can be concluded that high temperatures greatly affect lying and excreting behaviour. The effect of humidity is smaller, but at high humidity, changes in behaviour occurred at lower temperatures.

Effects of Floor Cooling during High Ambient Temperatures on the Lying Behaviour and Productivity of Growing Finishing Pigs
(chapter 4)

When ambient temperature is high, pigs will change their position to increase their effective surface area for conductive and convective heat exchange. To be able to lie down fully to cool off, pigs need sufficient and comfortable floor space. Generally, there is not enough solid floor space in modern pig houses to enable all the pigs to lie down at the same time, so some pigs have to lie in the dunging area. Since a slatted floor is a cooler for pigs to lie on than an insulated solid floor, the number of pigs lying on the slatted floor is an important indicator that temperatures in the pig house are undesirably high. In addition to causing thermo-regulatory and behavioural problems, high ambient temperature also has a detrimental economic effect. Large daily fluctuations between extremes of hot and cold can also reduce performance.

The objective of this study was to determine how floor cooling in partially solid floor systems could change the behaviour and improve the performance of growing-finishing pigs at high temperatures. This study looked at effects of floor cooling on lying behaviour, pen fouling, feed intake, average daily gain, and animal health. The pigs were offered a cool floor to lie during periods of high ambient temperatures. Their behaviour and performance were compared with control pigs without floor cooling. The experiment was carried out under field conditions in two types of commercial pens commonly used in Dutch pig production. Pens in room 1 had a solid floor in the front (accounting for 60% of the pen's floor area) and a metal slatted floor at the back (40% of the area). The pens in room 2 had a concrete slatted floor at the front (15% of the pen area), then a convex solid floor (45% of the area), and finally a metal slatted floor at the back (40% of the area). Room 1 had six pens, each 25.0 m^2 and containing 24 pigs. Room 2 had 12 pens, each of 13.0 m^2 and containing 12 pigs. In half of the pens in each room the floor could be cooled by cold groundwater flowing through plates in room 1 or through pipes embedded in the solid concrete floor in room 2. The floor cooling was activated automatically at ambient room temperatures above 25^0 C in week 3 and above 20^0 C from week 7 onwards. Feed and water were accessible ad libitum. Lying behaviour was monitored by video recording once every 15 minutes. The video frames were used for analysis. Fouling of the solid floor was recorded by direct observations. Feed intake was determined at two - weekly intervals, and growth rate was calculated from weight measurements at the start and the end of the experiment.

The results show that floor cooling can improve the thermal comfort and performance of intensively reared growing and finishing pigs during hot weather. Cooling lowered the surface temperature of the solid floor (25.0^0 C vs. 26.8^0 C; $p < 0.001$), reduced the percentage of pigs lying on the slatted floor (15.0 % vs. 22.2 %; $p < 0.001$) and increased feed intake (2.04 vs. 1.95 kg d^{-1} pig^{-1}; $p < 0.01$) and growth rate (753.2 vs. 720.4 g d^{-1} pig^{-1}; $p < 0.05$). Cooling and pen design also affected fouling of the solid floor. The cooled pens were cleaner than the uncooled pens, and the pens in room 2 were cleaner than those in room 1.

Effects of Cooling Methods on Growing Pigs in a Tropical Climate (chapter 5)

Pig production plays an important role in Viet Nam, as it has remained a widespread and inexpensive alternative way of producing meat and providing economic support for the family, and it is essential in times of financial hardship. Situated in Southeast Asia, Viet Nam has a humid tropical climate. Pigs kept under this climate are generally exposed to daytime ambient temperatures that exceed the thermal neutral zone. Research was needed to find out whether the upper border of the thermal neutral zone does exist in practical situations of pig production in the tropics, and to elucidate the effect of actual hot humid conditions with variations within and between days on the responses of growing pigs. The experiment therefore set out to determine the influence of tropical climate conditions on the

physiological, behavioural and productivity responses of pigs raised on small-scale farms, and the effects of cooling systems on these responses. Effects were studied in a 2 x 3 factorial design within two blocks. Per block a batch of 60 crossbred pigs was reared in 12 groups of five pigs each. Each group was assigned to one of the 12 pens. The factors were cooling system and pen design. Cooling systems were tested within each of two pen types (with or without an additional outdoor yard). Physiological responses e.g. respiration rate, rectal temperature, skin temperature, and behaviours e.g. lying, excretion, and frequency of using sprinkler and water bath, and performance e.g. feed intake, water intake and daily gain were analysed.

The results showed that cooling method and type of pen had a significant effect on most parameters. The pigs experienced heat stress by maintaining a high respiration rate. The physiological, behavioural and productive responses of growing pigs in small-scale farming under tropical climate condition were affected positively by cooling facilities like a water bath or sprinkler. Water bath and sprinklers reduced respiration rate ($p < 0.01$) and skin temperature ($p < 0.05$), whereas rectal temperature was not influenced by any treatment. The water bath significantly reduced number of defecations and urinations in the resting area in pens without outside yard ($p < 0.001$). An outdoor yard reduced the number of excretions in the resting area ($p < 0.01$). There were significant interaction effects of cooling and type of pen on number of lying pigs ($p < 0.01$), lateral lying ($p < 0.001$) and huddling ($p < 0.01$). Daily weight gain increased in response to cooling either with water bath or sprinkler ($p < 0.05$). The highest daily weight gain for pigs was obtained when sprinkling was combined with a pen without an outdoor yard ($p < 0.01$).

GENERAL CONLUSIONS

This study on ad libitum, fast-growing, group-housed pigs leads to the following conclusions:

Upper critical temperatures (inflection point temperatures) could be derived not only for the change of heat production but also for many other animal parameters. In order of appearance, these include lying on slatted floor, evaporative water, respiration rate, heat production, ratio of water to feed intake, voluntary feed intake and rectal temperature. These inflection point temperatures are different for the different parameters and show the subsequent strategies an animal follows to balance heat production and heat loss as ambient temperature rises.

The best indicators for assessing heat stress of finishing pigs are: increased respiration rate and water to feed ratio, followed by reduced feed intake, and, finally, increased rectal temperature. Decreased feed intake and increased rectal temperature are good indicators of reduced performance of heat-stressed pigs. Observations of lying and excreting behavioural changes of the pigs may be useful to assess their very first reactions in thermal regulation. There are ranges of critical temperatures for behavioural responses of growing pigs. We found that huddling already decreased above 16^0 C; wallowing occurred above 16 to 17^0 C; lying on the slatted floor gradually increased above 19^0 C, and as a result of the changed lying behaviour the excretions on the solid floor increased when temperature rose above 20 to 22^0 C. Above those temperatures, activity and activity-related heat production also declined.

On the basis of our findings on thermoregulation we recommend that when determining the physical space required by fattening pigs the behavioural changes at increasing temperatures should be taken into account. The number of pigs lying on slatted floor could be the first indicator for assessing the welfare of pigs exposed to high ambient temperatures.

Ad libitum, fast-growing, group-housed pigs raised under tropical climate conditions clearly show physiological and behavioural responses to this climate similar to those of pigs kept under controlled environmental conditions. The pigs adapt to adverse tropical conditions by maintaining a high respiration rate in order to maintain homeostasis and performance.

The availability of cooling systems e.g. floor cooling, water bath or sprinklers has beneficial effects on pig performance compared to control groups without cooling. Floor cooling significantly increases pigs' feed intake and growth rate under summer conditions. The system might be further refined if more were known about how the cooling requirements of the pigs vary with ambient temperature and animal weight. In terms of cost, a water bath and sprinkler system are more suitable for animal production in a developing country like Viet Nam. A water bath contributes to a clean pen, while sprinklers increase pigs' feed intake and gain. In hot humid tropical conditions as in Vietnam with the open animal houses these two systems contribute only little to extra humidity of the air. The inflection point temperatures of the indicators for heat stress found in this study could be used as set points for cooling systems, in order to improve animal performance and welfare in hot conditions.

Generally, we found that humidity had minor effects on physiological parameters. However, we did find a significant difference in animal gain at the three levels of humidity we investigated. A combination of high humidity and high temperature clearly has a detrimental effect on daily gain.

ĐẶT VẤN ĐỀ

Heo thịt tăng trọng nhanh sản xuất nhiều nhiệt, kết hợp với điều kiện nuôi giam với diện tích hạn chế sẽ khiến heo gặp nhiều khó khăn trong điều kiện stress nhiệt. Trong khi heo nuôi trong điều kiện tự nhiên có thể tự chọn lựa hoặc bóng râm, bễ tắm bùn hoặc tránh xa heo khác khi chúng cần để điều chỉnh cơ thể theo nhiệt độ môi trường, heo nuôi trong điều kiện giam giử không có cơ hội như vây. Trong khi chính trong môi trường giam giữ, heo rất cần có các biện pháp hỗ trợ để tránh nóng. Cho đến nay, ảnh hưởng của nhiệt độ môi trường (ổn định hoặc thay đổi theo nhịp ngày đêm) lên heo nuôi trong điều kiện giam giữ chưa được nghiên cứu đầy đủ. Nhiệt độ môi trường lên xuống cao thấp tuỳ theo ngày hay đêm cho thấy có ảnh hưởng ít nghiêm trong trên sức sản xuất của heo hơn là nhiệt độ môi trường luôn luôn duy trì ở mức độ cao. Điều này là do khi nhiệt độ ban đêm xuống thấp, heo cảm thấy thỏai mái hơn và có điều kiện tự bù đắp bằng cách gia tăng mức thực phẩm ăn vào. Trong thực tế sản xuất, cả hai trường hợp đều xảy ra thường xuyên do đó rất quan trọng cho nhà sản xuất để hiểu biết cặn kẽ tất cả các phản ứng của heo trong từng điều kiện. Hơn thế nữa, những hậu quả gây ra trên heo sẽ trầm trọng hơn khi kết hợp với điều kiện ẩm độ cao. Thật ra, tầm quan trọng của ẩm độ đã được đề cập đến nhiều nhưng chưa đựoc thể hiện một cách cụ thể, hệ thống và chi tiết.

Nhiệt độ môi trường mà từ đó những phản ứng của gia súc bắt đầu xảy ra để thể hiện stress nhiệt (được gọi trong luận văn này là điểm stress nhiệt) có thể rất khác biệt tuỳ theo các thông số khác nhau. Những thông số như vùi mình trong nơi ẩm ướt, nằm trên sàn lưới thay vì sàn cement, tăng tần số hô hấp, tăng nhiệt độ hậu môn, tổng số nhiệt sản xuất, và thực phẩm ăn vào được khảo sát trong vòng luận văn này. Cũng cần phải nhắc lại rằng cho đến nay, chưa có thông tin đầy đủ và hệ thống về ảnh hưởng của nhiệt độ môi trường và ẩm độ trên sức sản xuất của gia súc, vì vậy mà mục đích của luận văn này bao gồm hai diểm chính yếu quan trọng như sau: đánh giá một cách đầy đủ, hệ thống ảnh hưởng của stress nhiệt ngắn hạn (chương 2 và 3) và dài hạn (chương 5) trên heo thịt; mục tiêu kế tiếp là nghiên cứu việc áp dụng các hệ thống làm mát và tác dụng của các hệ thống này trên các đáp ứng về sinh lý, hành vi và sức sản xuất của heo thịt.

ẢNH HƯỞNG CỦA NHIỆT ĐỘ MÔI TRƯỜNG CAO ĐỐI VỚI NHỮNG THAY ĐỔI SINH LÝ CỦA HEO TRONG ĐIỀU KIỆN ẨM ĐỘ MÔI TRƯỜNG KHÁC NHAU (CHƯƠNG 2)

Cho đến nay, chưa có thông tin đầy đủ và hệ thống về ảnh hưởng của nhiệt độ môi trường và ẩm độ trên khả năng của gia súc để điều chỉnh cân bằng nhiệt giữa nhiệt thóat ra (nhiệt thông qua bốc hơi nước, điều chỉnh hành vi, và sinh lý) với lượng nhiệt sản xuất. Nhiệt độ môi trường mà từ đó những phản ứng của gia súc bắt đầu xảy ra để thể hiện stress nhiệt (được gọi trong luận văn này là điểm stress nhiệt) có thể rất khác biệt tuỳ theo các thông số khác nhau. Thêm vào đó, ảnh hưởng của ẩm độ trên các thông số nêu trên cũng chưa được hiểu biết đầy đủ.

Vì các lý do trên, ảnh hưởng của ẩm độ và nhiệt độ đối với các đáp ứng sinh lý và sản xuất được nghiên cứu trên 12 nhóm heo cái hậu bị (mỗi nhóm gồm 10 heo), heo đựoc nuôi trong chuồng bên trong buồng hô hấp. Điều kiện khí hậu bên trong buồng hô hấp được điều chỉnh tự động đảm bảo nhiệt độ được duy trì ổn định hằng ngày. Nhiệt độ được tăng dần từ 16 đến 32 độ Celsius trong vòng 9 ngày, mổi ngày với 2 độ cao hơn. Ẩm độ được duy trì ổn định ở 3 mức độ 50%, 65% và 80%. Thời gian thí nghiệm bao gồm 4 ngày (cho heo thích nghi với điều kiện thí nghiệm) và kế tiếp là 9 ngày của giai đoạn chính thức đo đạc số liệu. Các số liệu sinh lý được đo đạc 2 lần hàng ngày trên 3 heo. Lượng thực phẩm ăn vào được đo lường 2 lần hàng ngày trên cả nhóm 10 heo. Trong suốt 9 ngày chính thức của giai đoạn thí nghiệm , tổng số nhiệt sản xuất được thu thập và phân tích mỗi 6 phút một lần. Thông qua tất cả các chỉ tiêu đo đạc chùng tôi tính toán diểm stress nhiệt, tại điểm này của nhiệt độ môi trường, heo bắt đầu bộc lộ phản ứng.

Chúng tôi xác định đựoc các điểm stress nhiệt cho các thông số như tần số hô hấp, nhiệt độ hậu môn, thực phẩm ăn vào, nhiệt sản xuất, nhiệt bốc hơi, tỷ số giũa lượng nước tiêu thụ và thực phẩm ăn vào. Dấu hiệu đầu tiên của heo mà chúng tôi ghi nhân dược là tăng tần số hô hấp tại các diểm nhiệt độ là 21.3 và 23.4 độ C. Nhiệt độ hậu môn được ghi nhận là xảy ra trễ nhất trong chuỗi phản ứng của heo tại 24.6 đến 27.1 độ C. Tại ẩm độ 80%, các điểm stress nhiệt của cả hai chỉ tiêu này đều xảy ra sớm hơn tại nhóm với ẩm độ 50 và 65%. Nằm giữa hai điểm stress nhiệt sớm nhất và trễ nhất là chuỗi phản ứng của nhiệt sản xuất, thực phẩm ăn vào, và tỷ số giũa nước uống và thức ăn. Nhiệt độ môi trưởng thể hiện ảnh hưởng rất rõ thông qua phản ứng của heo, trong khi đó, ẩm độ chỉ thể hiện ảnh hưỡng rõ ràng trên tăng trọng của heo khi kết hợp với nhiệt độ cao.

Chúng tôi kết luận rằng giảm thực phẩm ăn vào và, tăng thân nhiệt là những thông số rất hữu ích trong việc đánh giá có hay không heo bị stress nhiệt. Trong thực tế, nhiệt độ bên trong chuồng heo thường vượt quá hai điểm stress nhiệt nêu trên.

SỰ ĐIỀU CHỈNH HÀNH VI CỦA HEO THỊT DƯỚI TÁC ĐỘNG CỦA NHIỆT ĐỘ VÀ ẨM ĐỘ MÔI TRƯỜNG (CHƯƠNG 3)

Cho đến hiện nay, dù có rất nhiều nỗ lực cải thiện điều kiện tiểu khí hậu chuồng nuôi nhưng vẫn chưa thể hoàn toàn tạo được điều kiện nhiệt độ ôn hoà cho gia súc. Nhiều nghiên cứu trước đây cho thấy các hành vi như cách thức nằm và bài tiết của heo thể hiện rất rõ ảnh hưởng của nhệt độ môi trường. Vào ngày nóng nực, heo thay đổi dáng nằm của chúng từ nghiên sang ngữa và tránh tiếp xúc với các heo khác trong chuồng. Và mặc dù được biết là loài gia súc có khả năng phân biệt nơi ngủ nghĩ và nơi thải phân nhưng dưới điều kiện nhiệt độ môi trường cao khả năng này gần như biến mất. Cho đến nay, kiến thức về mối liên hệ định lượng giữa nhiệt độ môi trường và hành vi của heo vẫn còn là khoảng trống. Thêm vào đó, cũng chưa có thông tin đầy đủ về ảnh hưởng của ẩm độ lên hành vi điều nhiệt của heo.

Vì các lý do trên, ảnh hưởng của ẩm độ và nhiệt độ đối với các điều chỉnh hành vi của heo được nghiên cứu trên 12 nhóm heo cái hậu bị (mỗi nhóm gồm 10 heo), heo đựoc nuôi trong chuồng bên trong buồng hô hấp. Mục tiêu của nghiên cứu này nhằm tìm ra các điểm stress nhiệt mà tại đó heo thay dổi hành vi. Điều kiện khí hậu bên trong buồng hô hấp được điều chỉnh tự động đảm bảo nhiệt độ được duy trì ổn định hằng ngày. Nhiệt độ được tăng dần từ 16 đến 32 độ Celsius trong vòng 9 ngày, mổi ngày với 2 độ cao hơn. Ẩm độ được duy trì ổn định ở 3 mức độ 50%, 65% và 80%. Thời gian thí nghiệm bao gồm 4 ngày (cho heo thích nghi với điều kiện thí nghiệm) và kế tiếp là 9 ngày của giai đoạn chính thức đo đạc số liệu. Mỗi heo có diện tích lá 1.0 m^2. Sàn chuồng gồm 60% cement va 40% sàn lưới kim loại. Các hàn vi như nằm, bài tiết và làm bẩn chuồng được theo dõi thông qua hệ thống video. Một cảm báo được sữ dụng để ghi nhận các hoạt động của heo. Mô hình hồi qui được áp dụng để tính toán nhiệt sản xuất do hoạt động của heo. Các tư thế nằm của heo cũng được đánh giá như nghiêng, ngữa, và nũa ngồi nữa nằm. Hoạt động bài tiết cũng được theo dõi và ghi nhận như tiểu và bài phân. Thêm vào đó, heo nằm rời rạc hay chụm lại vào nhau, cũng như hành vi nằm lăn trong vũng ẩm ướt cũng được ghi nhận. Tất cả hành vi được ghi nhận thông qua tần số xuất hiện và vị trí xuất hiện.

Nghiên cứu cho thấy nhiệt độ ảnh hưỡng rất rõ đến viêc nằm và bài tiết của heo. Heo tăng tần số nằm trên sàn lưới cùng với việc tăng nhiệt độ môi trường ($p<0.001$). Điểm stress nhiêt khiến heo gia tăng tần số nằm trên sàn lưới rất thấp, nhiệt độ môi trường chỉ 18.8 độ C. Nhiệt sản xuất do hoạt động cơ học của heo giữ ổn định khi nhiệt độ môi trường thấp hơn 24.2 độ C, trên mức này heo giảm hẳn hoạt động. Trong khi nhiệt độ càng cao thì heo càng tăng cường bài phân trên sàn cement, tăng hành vi nằm lăn trong vũng ẩm ướt, thì ngược lại hành vi nằm sát cạnh nhau lại giảm hẳn. Chúng tôi kết luận rằng nhiệt độ môi trường cao ảnh hưởng rõ ràng đến hành vi của heo. Dù chỉ ở nhiệt độ môi trường thấp, nhưng với ẩm độ cao, heo đã thay đồi hành vi để giữ cân bằng nhiệt.

TÁC DỤNG CỦA SÀN LẠNH LÊN HÀNH VI VÀ SỨC SẢN XUẤT CỦA HEO THỊT TRONG ĐIỀU KIỆN NHIỆT ĐỘ MÔI TRƯỜNG CAO

(CHƯƠNG 4)

Khi nhiệt độ môi trường chuồng nuôi tăng cao, heo sẽ thay đổi tư thế nằm của chúng để tăng thải nhiệt thông qua tác dụng của trao đổi nhiệt qua tiếp xúc và đối lưu. Do đó, khi cần phải tăng tối đa diện tích cơ thể khi nằm, heo cần có diện tích sàn phù hợp. Yêu cầu này thường không được thỏa mãn trong điều kiện chăn nuôi với chuồng trại công nghệp. Do đó, khi cần tăng tối đa diện tích tiếp xúc để thải bớt nhiệt, heo thường phải nằm trẹn sàn lưới nơi được thiết kế để thải phân. D(iều này dẫn tới một thực té là, tần số heo nằm trên sàn lưới là một chỉ tiếu quan trọng để đánh giá nhiệt độ chuồng nuôi. Bên cạnh việc nhiệt độ chuồng nuôi gây ra rối loạn hành vi nằm và bài tiết, sức sản xuất của heo cũng sút giảm trầm trọng.

Mục đích của nghiên cứu này nhằm đánh giá tác động của sàn lạnh lên việc thay đổi hành vi của heo và gia tăng sức sản xuất trong điều kiện chăn nuôi công nghiệp với diện tích sàn chuồng bao gồm cement và lưới. Các chỉ tiêu được theo dõi bao gồm hành vi nằm, mức độ vấy nhiễm sàn chuồng, thực phẩm ăn vào, sức tăng trọng và tình trạng sức khoẻ của heo thịt. Heo được cung cấp sàn cement lạnh để nằm trong điều kiện nhiệt độ môi trường cao. Tất cả các chỉ tiêu được theo dõi và so sánh với heo trong điều kiện không có sàn lạnh. Thí nghiệm được tổ chức dưới điều kiện thực tế tại trại heo công nghiệp thương thấy trên đất Hà Lan. Chuồng heo trong khu I bao gồm sàn cement ở phần trước của chuồng (chiếm 60%), và một sàn lưới ở phía sau chiếm 40% diện tích sàn. Chuồng heo trong khu II bao gồm 15% sàn lưới (bằng cement) ở phía trước của chuồng, kếp tiếp là 45% sàn cement với phần giữa lồi lên tạo độ đốc về 2 phía của chuồng, ở phía cuối chuồng là 40% sàm lưới kim loại. Khu I có 6 chuồng với diện tích 25m^2 mỗi cái và chứa 24 heo thịt. Khu II gồm 12 chuồng, với diện tích 13m^2 chứa 12 heo thịt. Trong mỗi khu, một nữa số chuồng được thiết kế với sàn lạnh và một nữa đối chứng không có sàn lạnh. Hệ thống lạnh ở khu I gồm các vĩ chứa nước lạnh dẫn trực tiếp từ lòng đất trong khi hệ thống lạnh ở khu II gồm các ống nước tròn. Hệ thống lạnh được điều khiển tự động mở hoặc tắt tùy theo nhiệt độ thực tế trong chuồng. Trong 3 tuần đầu tiên hệ thống hoạt động khi nhiệt độ môi trường tăng hơn 25 độ C, sau đó, chỉ cần nhiệt độ chuồng cao hơn 20 độ C, hệ thống lạnh bất đầu hoạt động. Heo được cho ăn và uống tự do. Hành vi được theo dõi qua video mỗi 15 phút. Mức độ vấy bẩn chuồng được đánh giá bằng quan sát trực tiếp. Thực phẩm ăn vào được ghi nhận mỗi 2 tuần một lần. Tăng trọng của heo được đánh giá bằng cách cân heo khi bắt đầu thí nghiệm và khi kết thúc thí nghiệm.

Kết quả cho thấy sàn lạnh cung cấp sự thoải mái và làm tăng sức sản xuất cho heo nuôi trong điều kiện nóng. Hệ thống lạnh làm giảm nhiệt bề mặt của sàn chuồng đến 1.8 độ C ($p<0.001$), giảm tần số heo nằm trên sàn lưới (10.0 % so với 22.2%, $p<0.001$), tăng thực phẩm ăn vào (2.04 so với 1.95 kg ngày heo, $p<0.01$), và khả năng tăng trọng (753.2 so với 720.4 g d^{-1} pig^{-1}, $p<0.05$). Chúng tôi nhận thấy cả hai, hệ thống sàn lạnh và kiểu chuồng đều có ảnh hưởng đến sự vấy bẩn chuồng nuôi. Chuồng có sàn lạnh sạch hôn chuồng không có sàn lạnh và chuồng trong khi II sạch hơn chuồng trong khu I.

ẢNH HƯỞNG CỦA PHƯƠNG PHÁP LÀM MÁT TRÊN HEO NUÔI TRONG ĐIỀU KIỆN NHIỆT ĐỚI
(CHƯƠNG 5)

Chăn nuôi heo có tầm quan trọng đối với nền kinh tế của Việt Nam vì bằng nhiều phương thúc chăn nuôi khác nhau, ngành chăn nuôi heo không những cung cấp nguồn đạm động vật mà còn là cách người chăn nuôi nhỏ tiết kiệm tiền. Toạ lạc trong vùng Đông Nam Á, Việt Nam có khí hậu nhiệt đới ẩm. Heo thịt nuôi trong điều kiein này thường phải đối mặt với nhiệt độ cao vào ban ngày, nhiệt độ này được coi là vượt quá vùng nhiệt độ ôn hòa cho heo. Rõ ràng rằng kiến thức về ranh giới trên của nhiệt độ môi trường cùng với ẩm độ luôn cao ở vùng nhiệt đới, cũng như ảnh hưởng của sự biến thiên nhiệt độ trong vòng ngày đêm và giũa các ngày khác nhau là rất quan trọng cho nhà chăn nuôi trong vùng. Các chỉ tiêu sinh lý, hành vi, và sản xuất của heo nuôi trong điều kiện chăn nuôi nhỏ dưới ảnh hưởng của điều kiện nhiệt đới được nghiên cứu. Thí nghiệm được bố trí theo khối hoàn toàn ngẫu nhiên với 2 yếu tố kiểu chuồng (có hoặc không có sân chơi) và 3 yếu tố làm mát (đối chứng, vòi phun, và bễ tắm). Mỗi khối bao gồm 60 heo thịt được bố trí ngẫu nhiên vào 12 chuồng, mỗi chuồng chứa 5 heo thịt. Các yếu tố làm mát được kiểm tra tác dụng trong từng kiểu chuồng. Các chỉ tiêu sinh lý nhö tần số hô hấp, nhiệt độ hậu môn, nhiệt da, và hành vi như nằm, bài tiết, tần số sử dụng vòi phun và bễ tắm, sức sản xuất như thực phẩm ăn vào, nước uống và tăng trọng hàng ngày được phân tích.

Kết quả cho thấy kiểu chuồng và biện pháp làm mát có tác dụng rất rõ trên hầu hết các chỉ tiêu. Đây là lý do hệ thống làm mát (vòi phun và bễ tắm) có tác dụng rất rõ trên chỉ tiêu sinh lý, hành vi và sức sản xuất của heo thịt nuôi trong điều kiện chăn nuôi nhỏ trong vùng nhiệt đới. Bễ tắm và vòi phun làm thấp tần số hô hấp ($p<0.01$) và nhiệt độ ngoài da ($p<0.05$), trong khi đó nhiệt độ hậu môn không cho thấy sự thay đổi nào. Sử dụng bễ tắm, heo giảm bài tiết phân và nước tiểu trong vùng nghĩ ngơi, đặc biệt trong chuồng có sân chơi ($p<0.001$). Sân chơi có tác dụng tích cực trong việc heo giảm đi phân trong vùng nghĩ ngơi ($p<0.01$). Tác dụng tương tác giữa biện pháp làm mát và kiểu chuồng thể hiện rất rõ trên số heo nằm ($p<0.01$), heo nằm duỗi ($p<0.001$) và sự tiếp xúc với heo cùng chuồng khi nằm ($p<0.01$). Heo nuôi trong chuồng có bễ tắm và vòi phun tăng trọng nhanh hơn heo trong khu đối chứng ($p<0.05$). Heo trong lô thí nghiệm với sự kết hợp giữa vòi phun và chuồng không có sân chơi cho tăng trọng cao nhất ($p<0.01$).

KẾT LUẬN

Nghiên cứu tác dụng của stress nhiệt trên các điều kiện kể trên trên đối tượng là heo thịt cho ăn tự do, giống tăng trưởng nhanh, nuôi nhóm cho phép kết luận một số điểm như sau:

Điểm stress nhiệt (inflection point temperatures) có thể được xác định không chỉ cho tổng số nhiệt sản xuất như các tài liệu từ trước nêu lên mà còn cho rất nhiều chỉ tiêu khác trên gia súc nuôi. Theo thứ tự của sự xuất hiện các điểm stress nhiệt, có thể liệt kê theo thứ tự như sau: tần số nằm trên sàn lưới, nhiệt bốc hơi nước, tần số hô hấp, nhiệt tổng số, tỷ số giữa nước uống và thức ăn, thực ăn ăn vào, và nhiệt độ hậu môn. Những điểm stress nhiệt khác nhau này thể hiện diễn biến tuần tự, hệ thống mà heo phải thực hiện để cân bằng giữa sự sản xuất và thải nhiệt khi đối mặt với nhiệt độ môi trường cao.

Chỉ số tốt nhất để đánh giá stress nhiệt trên heo thịt là tăng tần số hô hấp, tỷ lệ giữa nước uống và thức ăn, sau đó là giảm thực phẩm ăn vào, cuối cùng là tăng thân nhiệt. Giảm thực phẩm ăn vào và tăng thân nhiệt là những chỉ số tốt để đánh giá sự giảm sức sản xuất của heo thịt. Bên cạnh đó, quan sát hành vi của heo cho phép nhận diện sớm hoạt động điều nhiệt của heo khi nhiệt độ môi trường tăng. Hành vi của heo thay đổi một cách hệ thống và tuần tự như sau: heo tránh nằm cạnh nhau ở nhiệt độ môi trường rất thấp chỉ khoảng 16 độ C; sau đó heo tăng việc nằm vùi mình vào phân và nước tiểu vào khoảng 16 đến 17^0 C; khi nhiệt độ môi trường tăng khoãng 19 độ C, heo bắt đầu nằm vào khu vực sàn lưới, hậu quả là vào khoảng 20 đến 22 độ C của môi trường, heo bắt đầu vấy bẩn khu vực sàn cement nơi chúng lẽ ra dùng nằm nghỉ. Sau cùng, quan sát sẽ cho thấy heo giảm hoạt động dẫn tới nhiệt sản xuất do hoạt động cơ học giảm rõ rệt. Dựa trên kết quả tìm được, chúng tôi đề nghị rằng khi thiết kế diện tích sữ dụng cho heo thịt, hành vi điều nhiệt của heo trong điều kiện nhiệt độ cao nên được đưa vào tính toán. Tần số heo nằm trên sàn lưới do điều kiện nhiệt độ chuồng nuôi cao nên được xem xét là yếu tố làm giảm sự "phúc lợi" của heo.

Dù heo được nuôi trong điều kiện thực tế vùng nhiệt đới hay trong điều kiện thí nghiệm đáp ứng về sinh lý và thay đổi hành vi của chúng khi phải đối phó với nhiệt độ môi trường cao được coi là tương đương. Trong điều kiện thực tế, nhiệt độ môi trường cao ổn định, heo duy trì tần số hô hấp cao nhằm duy trì sự cân bằng nhiệt và giữ ổn định sức sản xuất.

Các biện pháp làm mát cho heo như sàn lạnh, bễ tắm, vòi phun mang lại hiệu quả rất tích cực cho heo so với heo nuôi trong điều kiện đối chứng. Sàn lạnh giúp tăng cường lượng thực phẩm ăn vào và tăng trọng hàng ngày của heo nuôi trong điều kiện nóng vào mùa hè trong vùng ôn đới. Dù vậy, hệ thống sàn lạnh cần được nghiên cứu thêm để thiết kết độ lạnh cần thiết cho sàn lạnh theo sự thay đổi trọng lượng của heo và của nhiệt độ môi trường. So sánh về chi phí thì bễ tắm và vòi phun rất phù hợp cho điều kiện chăn nuôi ở Việt Nam. Bễ tắm giúp chuồng nuôi sạch hơn trong khi vòi phun giúp heo tiêu thụ thực phẩm nhiều và tăng trọng nhanh hơn. Hơn nữa, trong điều kiện nóng ẩm của Việt Nam, bễ tắm và vòi phun không làm tăng thêm ẩm độ chuồng nuôi. Điểm stress nhiệt được xác định từ nghiên cứu này có thể được sử dụng để xác lập chương trình tắt mở của hệ thống làm lạnh, từ đó sẽ giúp tăng cường sức sản xuất và phúc lợi cho heo nuôi trong điều kiện nhiệt độ cao.

Nhìn chung, ẩm độ chỉ có vai trò nhỏ trong các phản ứng với stress nhiệt của heo. Tuy vậy tăng trọng hàng ngày của heo bị ảnh hưỡng rất rõ khi ẩm độ cao kết hợp với nhiệt độ cao.

INLEIDING

Snel groeiende varkens produceren meer warmte uit voer. Dit in combinatie met huisvesting in stallen maakt het moeilijk voor varkens in intensieve houderijsystemen om hun warmtebalans te reguleren. Daar waar varkens in de vrije natuur hun eigen omgeving kunnen kiezen (b.v. schaduw, modderpoel, weg van andere varkens), moeten in stallen gehuisveste varkens het doen met de aan hun opgelegde omgeving. Vooral in stallen is het daarom belangrijk dat varkens de mogelijkheid krijgen om de warmte die ze produceren weer kwijt te raken. Op dit moment is nog weinig bekend over het effect van hoge omgevingstemperaturen, constant of fluctuerend, op de productie van varkens. Een dagelijks fluctuerende temperatuur heeft een geringer effect op de productiviteit dan een constante hoge temperatuur, aangezien varkens de voeropname, en daarmee de warmteproductie, voor een deel kunnen verschuiven van de dag naar de nacht. Beide situaties kunnen zich voordoen in de praktijk. Daarom is het van belang om beide situaties te bestuderen. Het effect van hoge omgevingstemperaturen zou versterkt kunnen worden door een hoge luchtvochtigheid. In de literatuur wordt gesteld dat luchtvochtigheid belangrijk is bij de thermoregulatie van vleesvarkens, maar kwantitatieve gegevens hierover ontbreken.

De temperatuur waarboven de reactie van varkens verandert (ook wel de kritieke temperatuur of breekpunt temperatuur genoemd) kan verschillen afhankelijk van de onderzochte parameter, b.v. voor wentelen in urine en mest, liggen op de roostervloer, ademhalingsfrequentie, rectale temperatuur, warmteproductie of voeropname. Tot nu toe is weinig bekend over het effect van temperatuur en met name ook van luchtvochtigheid op deze parameters. De belangrijkste doelstelling van dit onderzoek was daarom het bestuderen van korte termijn reacties (hoofdstuk 2 en 3) en lange termijn reacties (hoofdstuk 5) van vleesvarkens op verschillende klimatologische omstandigheden die tot hittestress kunnen leiden. De tweede doelstelling was het bepalen van het effect van koelsystemen op de fysiologische reacties, gedragsveranderingen en effect op productie van de varkens (hoofdstuk 4 en 5).

Effect van een toenemende temperatuur op de fysiologische veranderingen van varkens bij verschillende niveaus van relatieve luchtvochtigheid (hoofdstuk 2)

Weinig informatie is beschikbaar over de omgevingstemperaturen waarboven in groepen gehuisveste varkens hun mechanismen voor het balanceren van warmteproductie en warmteverliezen gaan veranderen (via waterverdamping, gedragsveranderingen of fysiologische veranderingen). De temperatuur waarboven reacties veranderen (ook wel de kritieke temperatuur of breekpunt temperatuur genoemd) verschillen waarschijnlijk afhankelijk van de parameter die wordt bestudeerd. De invloed van relatieve luchtvochtigheid op deze parameters is ook nog onbekend.

Het effect van luchtvochtigheid en hoge temperaturen op de fysiologische reacties en productieparameters van vleesvarkens is onderzocht bij 12 groepen van 10 gelten. De dieren werden gehuisvest in klimaatcellen. Het klimaat in de cellen werd dusdanig geregeld dat de temperatuur (T) constant bleef gedurende de dag en elke volgende dag met 2^{o} C steeg. In 9 dagen werd de temperatuur verhoogd van 16 naar 32^{o} C. Gedurende deze 9 dagen werd de relatieve luchtvochtigheid (RV) constant gehouden op 50, 65 of 80%. Voor de 9 dagen experimentele periode hadden de dieren 4 dagen de tijd om te wennen aan de cellen. Fysiologische parameters werden tweemaal per dag gemeten bij 3 dieren. Voeropname werd tweemaal per dag gemeten per groep van 10 dieren. Warmteproductie werd elke 6 minuten bepaald. Op basis van deze gegevens hebben we de kritieke temperaturen bepaald waarboven de gemeten parameters begonnen te veranderen: de zogenaamde breekpunttemperaturen (BPt's).

We vonden BPt's voor ademhalingsfrequentie, rectaal temperatuur, voeropname, warmteproductie, waterverdamping en voor water/voer verhouding. De ademhalingsfrequentie was de eerste parameter die veranderde (boven 21,3 – $23,4^{o}$ C); rectaal temperatuur de laatste (boven 24,6 – $27,1^{o}$ C). Voor beide parameters was het breekpunt het laagst bij 80% luchtvochtigheid ($p<0,05$). Tussen deze eerste en laatste indicator van veranderende reacties van het varken op hittestress werden veranderingen gemeten van warmteproductie, voeropname, waterverdamping en water/voer verhouding. De omgevingstemperatuur heeft een belangrijke invloed op verschillende fysiologische en productie parameters, terwijl de relatieve luchtvochtigheid slechts een geringe invloed heeft op hittestress bij het varken. Echter, de combinatie van een hoge temperatuur en een hoge relatieve luchtvochtigheid verlaagde de groei van de varkens. Een verlaagde voeropname en een verhoogde rectaal temperatuur zijn goede indicatoren van een verminderderde groei van de dieren. Temperaturen in commerciële varkensstallen overschrijden regelmatig de breekpunttemperaturen voor voeropname en rectaal temperatuur.

Thermoregulatoir gedrag bij vleesvarkens in reactie op hoge temperaturen en luchtvochtigheden (hoofdstuk 3)

Ondanks de technische vooruitgang die geboekt is bij de klimaatcontrole van stallen, kan de staltemperatuur niet altijd binnen de comfortzone van het varken worden gehouden. Eerder onderzoek heeft aangetoond dat diergedrag, zoals lig- en mestgedrag, belangrijk beïnvloed wordt door de omgevingstemperatuur. Op warme dagen nemen varkens een andere lighouding aan en vermijden ze fysiek contact met hokgenoten. Varkens zijn zindelijke dieren die in principe een scheiding aanbrengen tussen de lig- en mestplaats. Bij hoge omgevingstemperaturen verdwijnt deze scheiding echter. Alhoewel er vrij veel kwalitatieve informatie aanwezig is over het effect van temperatuur op de gedragsveranderingen van varkens, is er een gebrek aan kwantitatieve informatie. Ook is weinig bekend over het effect van luchtvochtigheid bij verschillende temperaturen op het gedrag van varkens.

Om te onderzoeken hoe varkens hun gedrag aanpassen onder warme omstandigheden is een experiment gestart waarbij de temperatuur geleidelijk toenam bij 3 verschillende niveaus van luchtvochtigheid. De doelstelling was om de breekpunttemperaturen te bepalen waarboven het varken zijn gedrag gaat aanpassen. Hiervoor werden 12 groepen van 10 vleesvarkens gebruikt. Het onderzoek werd gedurende 6 perioden in 2 klimaatcellen uitgevoerd. Na een adaptatieperiode van 4 dagen, werd de temperatuur in de klimaatcel gedurende 9 dagen geleidelijk verhoogd met 2^{o}C per dag van 16 – 32^{o} C. De relatieve luchtvochtigheid werd gedurende de gehele periode constant gehouden op 50, 65, of 80 %. Het hokoppervlak per varken was 1,0 m^2. Het hok bestond voor 60% uit een dichte vloer en voor 40% uit een roostervloer. Liggedrag, mestgedrag en hokbevuiling werden geobserveerd met behulp van video-opnamen. Activiteit werd gemeten met behulp van een radar sensor. Een regressiemodel werd vervolgens gebruikt om de warmteproductie als gevolg van activiteit te berekenen. De lighouding van de varkens werd geclassificeerd als Zijligging, Buikligging of Halve zijligging. Bij mestgedrag werd onderscheid gemaakt tussen urineren en mesten. Verder werd de mate van bij elkaar kruipen van de varkens en het wentelen in urine en mest geregistreerd. Alle gedragingen werden geregistreerd in termen van frequentie en locatie.

Het experiment liet een duidelijk effect zien van temperatuur op het lig- en mestgedrag. Boven het gemiddeld berekende breekpunt van 18,8^{o} C nam het aantal varkens dat op de roostervloer lag toe bij een stijgende temperatuur ($p<0.001$). De warmteproductie als gevolg van activiteit was relatief constant beneden het breekpunt van 24,2^{o} C, maar nam duidelijk af boven deze temperatuur. De temperatuur was negatief gerelateerd aan 'bij elkaar kruipgedrag' van de varkens en positief gecorreleerd met het wentelen in urine en mest. Het totaal aantal excreties op de dichte vloer nam toe met de temperatuur. Geconcludeerd kan worden dat temperatuur een belangrijke invloed heeft op het lig- en mestgedrag van varkens. Het effect van luchtvochtigheid was geringer, maar bij een hogere relatieve luchtvochtigheid traden veranderingen in het gedrag op bij lagere temperaturen.

Effect van vloerkoeling gedurende hoge temperaturen op het liggedrag en de productiviteit van vleesvarkens (hoofdstuk 4)

Bij een hoge omgevingstemperatuur gaan varkens hun lighouding zodanig aanpassen dat er een maximale warmteoverdracht plaatsvindt met de omgeving. Om voldoende warmte aan de vloer en aan de lucht te kunnen afgeven hebben de varkens een ruime en comfortabele ligruimte nodig. In het algemeen ontbreekt deze ruimte bij commercieel gehuisveste dieren. Aangezien een roostervloer koeler is dan een geïsoleerde dichte vloer, is het aantal dieren dat op de roostervloer ligt een goede indicator of de temperatuur in de stal te hoog is. Hoge temperaturen beïnvloeden niet alleen het liggedrag van de varkens, maar hebben ook een negatief effect op de productie en daarmee op de economische resultaten. Grote dagelijkse variaties in temperaturen kunnen de productie ook negatief beïnvloeden.

De doelstelling van dit onderzoek was om te bepalen in welke mate vloerkoeling in hokken met gedeeltelijk roostervloer het gedrag en de productie van vleesvarkens bij hoge temperaturen in positieve zin zou kunnen veranderen. In het onderzoek werden de effecten van vloerkoeling op het liggedrag, hokbevuiling, voeropname, groei en gezondheid van de dieren bepaald. Tijdens perioden van hoge staltemperaturen werd de vloer van de ligruimte gekoeld. Het gedrag en de productie van varkens in gekoelde hokken werd vergeleken met die van controle varkens in ongekoelde hokken. Het experiment werd in een normale stal uitgevoerd in 2 afdelingen met 2 verschillende hoktypen, die regelmatig worden toegepast in de Nederlandse varkenshouderij. De hokken in afdeling 1 hadden een dichte vloer voor in het hok (60% van het vloeroppervlak) en een metalen roostervloer achterin het hok (40% van het vloeroppervlak). De hokken in afdeling 2 hadden een betonnen rooster voor in het hok (15% van het vloeroppervlak), dan een bolle dichte vloer (45% van het vloeroppervlak) en een metalen rooster achterin het hok (40% van het vloeroppervlak). Afdeling 1 had 6 hokken met ieder een oppervlakte van 25,0 m^2 voor 24 varkens. Afdeling 2 had 12 hokken met ieder een oppervlakte van 13,0 m^2 voor 12 varkens. In de helft van de hokken in beide afdelingen kon de vloer gekoeld worden met grondwater. In afdeling 1 stroomde het water door panelen, terwijl in afdeling 2 het water door pijpen stroomde; beiden ware ingestort in het beton van de dichte vloer. Het vloerkoelingssysteem werd automatisch ingeschakeld bij staltemperaturen boven 25^o C vanaf week 3 en boven 20^o C vanaf week 7 in de mestperiode. Voer en water waren onbeperkt beschikbaar. Het liggedrag werd iedere 15 minuten vastgelegd op videobeelden. Bevuiling van de dichte vloer werd vastgelegd middels directe observatie. De totale voeropname werd per 2 weken vastgelegd. De groei werd bepaald door wegingen aan het begin en het eind van het experiment.

De resultaten laten zien dat vloerkoeling het thermisch comfort en de roductie van intensief gehouden vleesvarkens bij hoge temperaturen kan verbeteren. Vloerkoeling verlaagde de oppervlaktetemperatuur van de dichte vloer van 26,8 naar $25{,}0^0$ C ($p<0{,}001$), het reduceerde het percentage varkens dat op de roostervloer lag (15,0 % vs 22,2 %; $p<0{,}001$) en verhoogde de voeropname (2,04 vs 1,95 kg d^{-1} $varken^{-1}$; $p<0{,}01$) en de groei (753,2 vs 720,4 g d^{-1} $varken^{-1}$; $p<0{,}05$). Vloerkoeling en hoktype hadden ook invloed op de bevuiling van de dichte vloer. De gekoelde hokken waren schoner dan de ongekoelde hokken en de hokken in afdeling 2 waren schoner dan de hokken in afdeling 1.

Effect van koelmethode op vleesvarkens in een tropisch klimaat (hoofdstuk 5)

De varkenshouderij speelt een belangrijke rol in Vietnam. Het is wijdverspreid, aangezien het een relatief goedkope productiewijze is voor vlees en het biedt een inkomen voor families en een verzekering voor financieel slechte tijden. Vietnam is gelegen in Zuidoost Azië en heeft een vochtig tropisch klimaat. Varkens die gehouden worden in dit klimaat worden overdag meestal blootgesteld aan temperaturen die boven de thermoneutrale zone liggen. Onderzoek was nodig om uit te zoeken of de bovenste kritieke temperatuur ook is vast te stellen in een praktische situatie bij varkens gehuisvest in de tropen. Daarnaast is het belangrijk vast te stellen hoe de varkens reageren op een vochtig en warm klimaat, waarbij variaties optreden binnen en tussen dagen. In een experiment is het effect onderzocht van een tropisch klimaat op de fysiologische reacties, de gedragsveranderingen en de productieresultaten van varkens, gehuisvest in een stal die vergelijkbaar is met die op kleinschalige bedrijven in Vietnam. Daarnaast werd het effect van twee koelsystemen op deze reacties bestudeerd. De effecten werden vastgesteld in een 2 x 3 factoriële opzet in twee blokken. Per blok werden 60 varkens opgelegd in 12 groepen van 5 varkens. Elke groep werd toegewezen aan één van de twaalf hokken. De factoren waren koelsysteem en hoktype. De koelsystemen, een waterbad en een sproeiinstallatie, werden getest en vergeleken met een controle zonder koeling. De koelsystemen werden getest in twee soorten hokken, met of zonder een uitloop naar buiten. Fysiologische reacties (ademhalingsfrequentie, rectaal- en huidtemperatuur), gedragsveranderingen (lig- en mestgedrag en frequentie van gebruik van sproei-installatie of waterbad), en productiegegevens (voer- en wateropname, groei) werden geanalyseerd.

De resultaten lieten zien dat koeling en hoktype een significant effect hadden op de meeste parameters. Dat de varkens reageerden op de hoge temperaturen bleek o.a. uit de waargenomen hoge ademhalingsfrequentie. Koelsystemen bleken hittestress bij de varkens te verminderen. Ze verlaagden de ademhalingsfrequentie ($p<0,01$) en de huidtemperatuur ($p<0,05$). De rectaal temperatuur werd echter door geen van de behandelingen beïnvloed. Het waterbad reduceerde het aantal keren mesten en urineren in de ligruimte in hokken zonder uitloop ($p<0,001$). Een uitloop reduceerde het aantal excreties in de ligruimte ($p<0.01$). We vonden significante interacties tussen koelsysteem en hoktype ten aanzien van het aantal liggende dieren ($p<0.01$), aantal dieren in zijligging ($p<0.001$) en aantal dieren die bij elkaar kropen

($p<0.01$). De groei van de varkens was hoger in de hokken met een koelsysteem ($p<0.05$). De hoogste groei werd bereikt in hokken zonder uitloop met een sproei-installatie ($p<0.01$).

ALGEMENE CONCLUSIES

Deze studie bij onbeperkt gevoerde, snel groeiende, in groepen gehuisveste varkens leidt tot de volgende conclusies:

Bovenste kritieke temperaturen (breekpunttemperaturen) werden niet alleen gevonden voor warmteproductie, maar ook voor verschillende andere dierparameters. Bij toenemende temperatuur werden achtereenvolgens breekpunten gevonden voor ademhalingsfrequentie, waterverdamping, water/voer verhouding, warmteproductie, warmteproductie als gevolg van activiteit, liggen op de roostervloer, voeropname en rectaal temperatuur. Deze breekpunttemperaturen zijn verschillend voor de verschillende parameters en laten de achtereenvolgende strategieën van het varken zien om warmteproductie en warmteverlies in balans te houden bij toenemende temperaturen.

De beste indicatoren om hittestress waar te nemen bij vleesvarkens zijn: verhoogde ademhalingsfrequentie en water/voer verhouding, gevolgd door een verlaagde voeropname, en uiteindelijk een verhoogde rectaal temperatuur. Een verlaagde voeropname en een verhoogde rectaal temperatuur zijn goede indicatoren voor een verminderde productie als gevolg van hittestress. Observatie van het lig- en mestgedrag, en met name de veranderingen, zijn belangrijke eerste indicatoren van reacties van het varken op verhoogde omgevings-temperaturen. We vonden verschillende temperatuur ranges van kritieke temperaturen voor gedragsveranderingen van vleesvarkens. Het bij elkaar kruipen van varkens werd al minder boven de 16^0 C; het wentelen in urine en mest nam al toe vanaf 16 tot 17^0 C; liggen op de roostervloer steeg vanaf een temperatuur van 19^0 C en als een gevolg van het veranderende ligpatroon nam het aantal excreties op de dichte vloer toe boven 20 tot 22^0 C. Boven deze temperaturen nam ook de warmteproductie als gevolg van activiteit af.

Op basis van onze bevindingen ten aanzien van thermoregulatie van het varken raden wij aan om bij het bepalen van de benodigde ruimte voor het varken rekening te houden met de gedragsveranderingen die optreden bij toenemende temperaturen. Het aantal varkens dat op de roostervloer ligt zou een eerste indicatie kunnen zijn van een vermindert welzijn als gevolg van hoge omgevingstemperaturen.

Onbeperkt gevoerde, snel groeiende, in groepen gehuisveste varkens gehuisvest in een tropisch klimaat laten vergelijkbare fysiologische reacties en gedragsveranderingen zien als varkens die gehouden zijn onder gecontroleerde omstandigheden in klimaatcellen. De varkens reageren op een warme tropische omgeving door een hoge ademhalingsfrequentie te handhaven om het warmteverlies in evenwicht te brengen met de warmteproductie, bij een gelijkblijvende productie.

De beschikbaarheid van een koelsysteem, zoals vloerkoeling, waterbad of sproei-installatie, heeft positieve effecten op de productie van varkens bij hoge omgevingstemperaturen. Het gebruik van vloerkoeling bij hoge omgevingstemperaturen geeft een significant hogere voeropname en groei van de varkens. Het systeem kan echter nog verbeterd worden wanneer meer bekend is over de koelbehoefte van de varkens bij verschillende omgevingstemperaturen en gewichten. Vanwege de kosten is een waterbad of een sproei-installatie echter meer geschikt voor de varkenshouderij in een ontwikkelingsland als Vietnam. Een waterbad geeft een schoner hok, terwijl een sproei-installatie een sterk positieve invloed heeft op de voeropname en de groei. Onder tropische klimaatcondities en in de open stallen veroorzaken deze systemen slechts een geringe stijging van de vochtigheid in de lucht. De breekpunttemperaturen van de indicatoren voor hittestress gevonden in dit onderzoek kunnen gebruikt worden als setpoints voor koelsystemen, waardoor het welzijn en de productie van de varkens onder warme omstandigheden kunnen worden verbeterd.

In het algemeen vonden we een gering effect van luchtvochtigheid op de fysiologische parameters. Echter, we vonden wel een significant verschil in groei van de dieren bij de drie niveaus van luchtvochtigheid. Vooral de combinatie van een hoge luchtvochtigheid en een hoge temperatuur had een duidelijk negatief effect op de groei van de dieren.

ACKNOWLEDGEMENTS

For those reading this acknowledgement, please excuse its length. This milestone could not have been achieved alone. It is the greatest job in a scientific career that anyone could dream of, so this is just a very moderate expression of my appreciation for all the people who have been involved in this great achievement.

Ba kính yêu! Không có sự tưởng nhớ đến lòng khao khát của Ba được thấy con cái nên người, con không bao giờ có thể đủ dũng cảm để đi trọn quãng đường! Ba hãy an nghỉ bình yên nha Ba. Mẹ, có bao giờ con đủ lời để cảm ơn Mẹ! Cuốn luận văn này là lời cảm ơn của con cho lòng thương con của Me! Danh, con là gia tài duy nhất mà Mẹ có trên đời này và con luôn luôn là điểm tựa tinh thần mỗi khi Mẹ gặp khó khăn! Cảm ơn sự có mặt của con trong đời mẹ. Ngọc Hải Trúc, Phú, Phát Hằng Quỳnh Phương, Vân Thái Nhi, Nhất Tùng yêu qúy, cảm ơn gia đình ấm cúng của tôi đã cho tôi nghị lực đi trọn quãng đường khoa học gian nan!. Jos, special thank for being with me in this period of my life, and giving me enduring inspiration.

In Hue Viet Nam, in the winter of 1998, I met Dr. Ir. Canh, who had just received his Doctoral title from Wageningen University (WUR), and had come home to with many plans for his career. Attracted by his ambition, I immediately agreed when, six months later, he kindly asked if I would take the main part in one of his projects. The project related to Environmental Pollution from Animal Production in Ho Chi Minh city, my hometown. Then, in June, two years later (2001), I was given the greatest opportunity of my life when WOTRO, our sponsor, approved the PhD proposal "Heat Stress in Growing Pigs". Canh, I am grateful for being named to your team. Canh, a big hug to thank you!

I am grateful for the financial support from the Netherlands Foundation for the Advancement of Tropical Research. With their help, the gap between the rich and the poor is getting smaller.

In Schipol, June 2001, I met my daily supervisor, Dr. Ir. A.J.A Aarnink, for the first time. One week later, he brought me to Sterksel for my first experiment. He was in the Zodiac respiration chamber for my second and third experiments. And he was in Viet Nam for the very beginning steps of my last experiment. The places and times he has been at my side have been where and when, if truth be told, I have highly needed help. I also highly appreciate his tolerance in "endless" correcting my scientific paper writing! Andre', under your supervision, how quickly my proficiency has grown! I have learned from you your way of getting to the heart of the science. I have learned from you not only how to set up a question, but also how to gain insight into each question. Your style of scientific thinking that you transmit to your students will be used for life. Andre, during the past four years, you have been the wind beneath my wings, lifting me up to fly along all the rough roads toward gaining new knowledge. What you give to your students comes back. In reaching this milestone, your student pays you back for all you have done for her. I sincerely appreciate you, both personally and professionally, from the bottom of my heart.

Prof. Dr. Ir. Martin Verstegen, I am so proud to be your student. During my study, you have been my strongest pillar, and someone I could always rely on in a difficult situation. I remember consulting with you many times through rough and complicated issues. Once, when I was seriously considering quitting my PhD, I remembered your words to me: "don't let yourself suffer alone, tell us what is bothering you, and we can solve it together." That was the first time in my life that someone, without even knowing the full extent of my trouble, readily gave me their inspiration, encouragement, and trust. You are not only my scientific father, but also your personal interest in me, and your social know-how has also supported my spirit, Martin. From the bottom of my heart, a big warm hug in grateful thanks to you.

PhD, Dr. Ir. Bas Kemp, I am very happy for being one of your students. You show me the simplest solution for the most complicated problem. I know I always found your comments on my writing stressful (Sorry!). But this was only because your hand-written comments usually covered my whole manuscript. It was because of your comments, though, that my paper went so smoothly through publishing, afterward. You may not realize that in being my promoter, you strongly inspired me to get through my studies. Bas, please accept my sincere thanks for being my teacher from the beginning to the end of my studies.

Dr. Ir. Walter Gerrits, you are my special co-author. You may not be aware of it, but I have learned a lot from your research style and way of thinking. While you are not officially my supervisor, I have relied very much on your advice for my development as a scientist. I am very happy to have had the chance to work with you and to learn from you. Walter, three Dutch kisses and on Vietnamese kiss to thank you!

I am also grateful for the contribution to my manuscripts of Dr. Ir. Hans Spoodler. Your special skill in animal behaviour helped me a lot in this brand new area of my study. I appreciate your kindness to offer me your availability although we are working from two different locations: Lelystad and Wageningen. Hans, thanks a lot.

Marcel HeetKamp, I am grateful for your support and assistance from the start of our Zodiac experiment, and even days after. Without you, I could have been in a lot of trouble with such high-tech and complicated procedures in our "beloved" respiration chamber. I remember all the laughter, sweat, and tears that we all shared during the experimental measurement. It made my time in Zodiac a memorable time. I strongly believe that without you, the Zodiac chamber would be missing an important cog in the wheel to keep it running smoothly. Tamme, Peter Vos, Marleen Scheer, and the Zodiac respiration chamber staff, please accept my sincere thanks for your helpful assistance; a special thank you to Peter for caring for me the day of my injury. Thank you, Marleen, for your very special friendship. You not only provided technical assistance in my experiment, but you are also my Dutch sister. Anita Hoofs and the Sterksel staff, please accept my thanks for your support and assistance during my very first experimental period at your station. You were all so kind and helpful to me.

Dr. Ir. Bui Xuan An, I would like to express my special thanks to you during the Vietnamese experimental period. Thanks for lending me a hand at the most hectic time of my study, where I could have lost a lot of time during my field work in Viet Nam, and for allowing me to rely on you and for everything you have done for me. Special thanks to the Executive Board of Nong Lam University, to Dr. Ir. Khanh - Dean of Veterinary Faculty, Prof. Dr. Ir. Tuan and Prof. Dr. Ir. Dan for supporting my work in Viet Nam. I would also like to gratefully thank Mr. Con and Mrs. Tai for their helpful support with their animals. Many thanks also to my students who were not focused on the exposition of reality, or the solution of practical problems, but who trusted in me and had the motivation to gain new knowledge, and overcame lots of rough tasks that I could see some of you almost wanted to give up on.

To my IMAG colleagues: working amongst all of you has been like being in a dear Dutch family. The atmosphere and caring in our group brought me warmth and joy. Within a few short years, we have shared with each other many different experiences. Moving from our warm barrack in IMAG to a very modern and impressive “White House” A&F, we experienced frustration, growth, and many joys. The time I have spent with you has been memorable. Dear Nico, Gert-Jan, Karin, Dick, Roland, Paul, Cor, Johan, Martin, Peter Gijsel, Ardy, Ad Scheer, Hans, Max, Jos, Peter Hof, Simon, Lau, Wim, Eef, I would like to express my thanks to all of you for being so nice and kindly to me. I want to express my special thanks to Nico for your kindness and inspiration. To Michel and Annemiek for your special friendship to me, our laughs will be always in my mind wherever I go! I am also very much grateful for the help of Peter Nijhuisen, Valentin van de Berg, and Magriet Hendriks. You all taught me lots of new things during my PhD. Statistically, your roles were important with $p<0.05$! Thanks to Peter; you helped me become a researcher who could sit at her desk in IMAG "barrack" to observe her animals' behaviour from Sterksel experimental farm, 180 km away. Such a magical job, isn't it? I also would like to thank you, Joy Burrough for your contribution in correction my English.

Mariet, I am grateful for your ability to make me and many foreign students feel at home in the Netherlands. Thanks for your untiring support through our daily problems. Your warmth and kindness warm us up during our hard time being away from home. Yoke, I want you to know that you and your family occupy a big place in my heart! Because of your warmth, Herveld became my second home.

To all of my colleagues and friends in Viet Nam, thanks for all the encouragement and long-distance support during my studies in the Netherlands. Special thanks to Mr. Huynh, Loi, Director of Animal Health Department Ho Chi Minh city for all your trust and support.

Last but definitely not least, for all of the others not mentioned here by name, in the Netherlands, the Philippines, Germany, Italy, France, Spain, Portugal, Slovenia, Austria, Belgium, Poland, Canada, and in Viet Nam, it is difficult to express to my satisfaction my appreciation of you all. I will never forget the very important roles you have all played.

Training and Supervision Plan			**Graduate School WIAS**
Name PhD student	Huynh Thi Thanh Thuy		
Project title	Reducing Heat Stress of Pigs in Vietnam to Prevent Environmental Pollution		
Group	Animal Nutrition		
Daily supervisor(s)	Dr. André J.A.Aarnink		
Supervisor(s)	Prof. Martin M.W.Verstegen; Prof. B. Kemp, Dr. Canh T.Truong		
Project term	from: June 2001	until: April 2005	
Submitted / Approved	date: 20 January 2005	first plan / midterm / **certificate**	

One credit point (cp) equals a study load of approximately 40 hours.

EDUCATION AND TRAINING (minimum 21 cp, maximum 42 cp)		
The Basic Package (minimum 2 cp)	year	cp
WIAS Introduction Course (mandatory)	2003	1.0
WIAS Course Philosophy of Science and Ethics (mandatory)	2004	1.0
Subtotal Basic Package		**2.0**
Scientific Exposure (conferences, seminars and presentations, minimum 5 cp)	year	cp
International conferences *(minimum 2 cp)*		
Krakow (Poland) 20 - 24 June 2004	2004	1.0
Ottawa (Canada) 1 - 5 August 2004	2004	1.0
Leuven (Belgium) 11 - 15 September 2004	2004	1.0
Evora (Portugal) conference + workshop, 1 - 8 May, 2004	2004	1.6
Seminars and workshops		
WIAS Science Day, 14 March 2002 & 27 March 2003	2002-2003	0.4
PhD Retreat, Nijmegen, 13 - 14 May	2004	0.4
Presentations *(minimum 4 original presentations of which at least 1 oral, 0.5 cp each)*		
Nong Lam UR, 15, 24 April, 8, 28 May 2003 (oral presentations)	2003	2.0
Utrecht Wotro Researchers' Day (poster)	2004	0.5
Utrecht 14 Jan. 2004 (Climatic Controlling Experts Team) (oral)	2004	0.5
Ottawa, Canada (oral)	2004	0.5
Krakow, Poland (oral)	2004	0.5
Leuven, Belgium (oral)	2004	0.5
Subtotal International Exposure		**9.9**
In-Depth Studies (minimum 4 cp)	year	cp
Disciplinary and interdisciplinary courses		
Introductory Biostatistics for Researchers (University Utrecht) 10 - 18 June, 2004	2004	2.0
Undergraduate courses		
Nong Lam UR, advanced statistical course I	2001	1.0
Nong Lam UR, advanced statistical course II	2003	1.0
Subtotal In-Depth Studies		**4.0**

Professional Skills Support Courses (minimum 2 cp)	year	cp
Use of Laboratory Animals (mandatory when working with animals)	2001	3.0
Course Supervising MSc thesis work (advised when supervising MSc students), in Vietnam	2001	0.5
Endnote	2002	0.1
WIAS Course Techniques for Scientific Writing 2 - 5 July 2002	2002	0.8
Course Time Planning and Project Management	2004	1.0
Subtotal Professional Skills Support Courses		**5.4**
Didactic Skills Training (optional)	year	cp
Lecturing		
_ Nong lam UR (second grade students of Veterinary Department)	2002	1.0
_ Nong lam UR (last year students of Animal Husbandry group) (x 2)	2003	1.0
Supervising practicals and excursions		
_ Supervising BSc and MSc students during fieldwork and doing experiments	2003	8.0
(the experiments were intensively carried out from Oct. 2003 to June 2004)		
Supervising MSc theses *(maximum 1 cp per MSc student)*		
_ Miss Tran T.N.Dieu (Industrial College IV)	2001	1.0
_ Mr. Pham M. Dung (Nong Lam UR)	2002	1.0
Subtotal Didactic Skills Training		**12.0**
Management Skills Training (optional)	year	cp
Organisation of seminars and courses		
_ Courses for Nong Lam Urs	2001	0.4
_ Course for students and staff of Urs, staff of the two institutes, 2002 & 2003	2002-2003	0.6
Subtotal Management Skills Training		**1.0**
Education and Training Total (minimum 21 cp, maximum 42 cp)		**34.3**

Huynh Thi Thanh Thuy was born in Saigon, Viet Nam on the 28th of January in 1962. After finishing secondary school and high school in 1978, she stayed at home to help her father on her family's hobby farm before returning to school to study at the Agricultural and Forestry University in Ho Chi Minh city in 1985. She received two diplomas within seven years, one in Animal Husbandry Engineering and the other in Veterinary Medicine. She graduated with distinction from the BSc program in Veterinary Science. After finishing her studies, she worked as Meat Inspector for Veterinary Service in Ho Chi Minh city which belongs to Viet Nam Ministry of Agriculture and Rural Development. She was involved in Meat Inspection for domestic and export markets. In 1996, she became chief of Veterinary Service in the district Thu Duc, 9 and 2 districts. During her veterinary career, she studied several cases in animal infectious disease epidemiology. In 1999, one of these studies became the basis of her Master thesis, titled: "Foot and Mouth Disease Epidemiology in Domestic Animals in Ho Chi Minh city and its Neighbors". In recognition of her work in this area, she was named Valedictorian upon graduating with her MSc. degree in Veterinary Science. During this time, she had also studied in Food Hygiene Inspection Regulation and Ethics, and in 2000, for her work in Governmental and Economical Management Capacities, she was again named Valedictorian upon graduating class from the Rector of State Management Officer College of Ho Chi Minh city. She was manager in her professional positions until she received her PhD project in the Netherlands in June 2001.

Contact persons:

1. Dr. Ir. A.J.A. Aarnink, Livestock Environment, Wageningen University and Research Center, Wageningen, The Netherlands. Mail to: andre.aarnink@wur.nl
2. Prof. Dr. Ir. Nguyen Ngoc Tuan, Head of Post Graduation Department, Nong Lam University Ho Chi Minh city, Viet Nam. Thu Duc district, Linh Trung ward, Ho Chi Minh city Viet Nam. Mail to: nntuan@saigonnet.vn
3. Mr. Huynh Huu Loi, Director of Animal Health Department of Ho Chi Minh city, Ministry of Agriculture and Rural Development Viet Nam. 151 Ly Thuong Kiet street, district 11, Ho Chi Minh city Viet Nam.

Filename: Thesis final.doc
Directory: H:\Print
Template: C:\Documents and Settings\thuy001\Application Data\Microsoft\Templates\Normal.dot
Title: HEAT STRESS IN GROWING PIGS
Subject:
Author: Huynh T.T.Thuy
Keywords:
Comments:
Creation Date: 03-02-2005 14:37
Change Number: 2
Last Saved On: 03-02-2005 14:37
Last Saved By: Huynh T.T.Thuy
Total Editing Time: 1 Minute
Last Printed On: 03-02-2005 14:38
As of Last Complete Printing
Number of Pages: 167
Number of Words: 47,338 (approx.)
Number of Characters: 269,829 (approx.)