ACCLIMATION OF GROWING PIGS TO CLIMATIC ENVIRONMENT

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Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
in het openbaar te verdedigen
op dinsdag 14 april 1987
des namiddags te vier uur in de aula
van de Landbouwuniversiteit te Wageningen.

This thesis has been accomplished at:
Agricultural University Wageningen,
Department of Animal Husbandry,
Marijkeweg 40,
6709 PG Wageningen,
The Netherlands.

Cover design: W.J.A. Valen.
Illustrations: K. Boekhorst, W. Heye and W.J.A. Valen.

Stellingen

I

Actieve regulatie van de lichaamstemperatuur voor de handhaving van homeothermie kan alleen bij variërende omgevingscondities worden vastgesteld.
Dit proefschrift

II

Het fysiologisch effect van stress varieert niet alleen met het type en de duur van de stressor, maar is tevens afhankelijk van de variatie in aanpassingsvermogen.
Dit proefschrift

III

Voor het bestuderen van de invloed van klimaatsfactoren op de diergezondheid verdient het meten van de "deep-body" temperatuur de voorkeur boven de rectaal temperatuur.
Dit proefschrift

IV

In de praktijk dient er meer rekening mee gehouden te worden dat bij het opleggen van mestvarkens de aanpassing van de stofwisseling zelfs bij gunstige klimaatscondities minimaal 5 dagen duurt.
Dit proefschrift

V

Als indicator voor de interactie tussen klimaatsfactoren en weerstandsvermogen van mestvarkens kan, bij gebrek aan beter, *Haemophilus pleuropneumoniae* worden gebruikt.

VI

Een uitbetalingssysteem voor slachtvarkens op grond van het vleespercentage houdt in dat het effect van een slecht stalklimaat economisch belangrijker wordt.

VII

Het gebruik van SPF-varkens als modeldier ter bestudering van faktorenziekten is immunologisch en fysiologisch af te wijzen.

VIII

Het handhaven of kunnen bereiken van de "set-point" temperatuur is belangrijk voor het afweermechanisme van homeotherme dieren.

IX

Ter verbetering van het welzijn van landbouwhuisdieren in intensieve houderijsystemen dient meer aandacht te worden besteed aan de wijze van voeren en de voersamenstelling.

X

Bij literatuurverwijzigingen zoals "Jansen *et al.* vinden", ontbreekt veelal ten onrechte "ervan".

XI

Het welslagen van interdisciplinair onderzoek is sterk persoonsgebonden.

XII

De voortgang van een promotieonderzoek en de intensiteit van de sociale contacten zijn negatief gecorreleerd.

XIII

Een goede promotor is nooit weg.

J. M. F. Verhagen

Acclimation of growing pigs to climatic environment
Wageningen, 14 april 1987

Voor Yvonne
mijn ouders

VOORWOORD

Dit proefschrift bestaat uit een zevental wetenschappelijke artikelen, waarvoor het onderzoek is uitgevoerd bij de vakgroep Veehouderij van de Landbouwuniversiteit te Wageningen.

Aan het tot stand komen van dit proefschrift, alswel bij de opzet, de uitvoering en de analyse van de hiervoor uitgevoerde proeven heeft een groot aantal personen een direkte of indirekte bijdrage geleverd. Dit proefschrift is dan ook vooral een weergave van de inspiratie, de motivatie en de steun van een ieder die erbij betrokken is geweest.

Voor zijn of haar bijdrage wil ik een ieder dan ook hartelijk bedanken.
Tevens een woord van dank aan het LEB-fonds voor de financiële tegemoetkoming bij de vervaardiging van dit proefschrift.

CONTENTS

INTRODUCTION

Climatic environment is an important factor in animal production. Adaptation may be related to economic loss. To enable to minimize this it is necessary to determine the relation that exists between the thermal environment and the animal (Curtis, 1983). Exposure to a variety of environmental events elicites a wide range of physiological changes (Dantzer and Mormède, 1983). However despite fluctuating external surroundings animals need to maintain a steady state in their internal environment (Curtis, 1983). Homeothermic animals are characterized by maintaining a deep-body temperature within relatively narrow limits (Mount, 1979). To establish constancy of body temperature at various conditions animals respond through their thermoregulatory mechanisms.

Ambient temperature is a component of climatic environment. In figure 1 the relationship between ambient temperature, heat production and body temperature is represented. Figure 1 shows that heat production, as a physiological re-

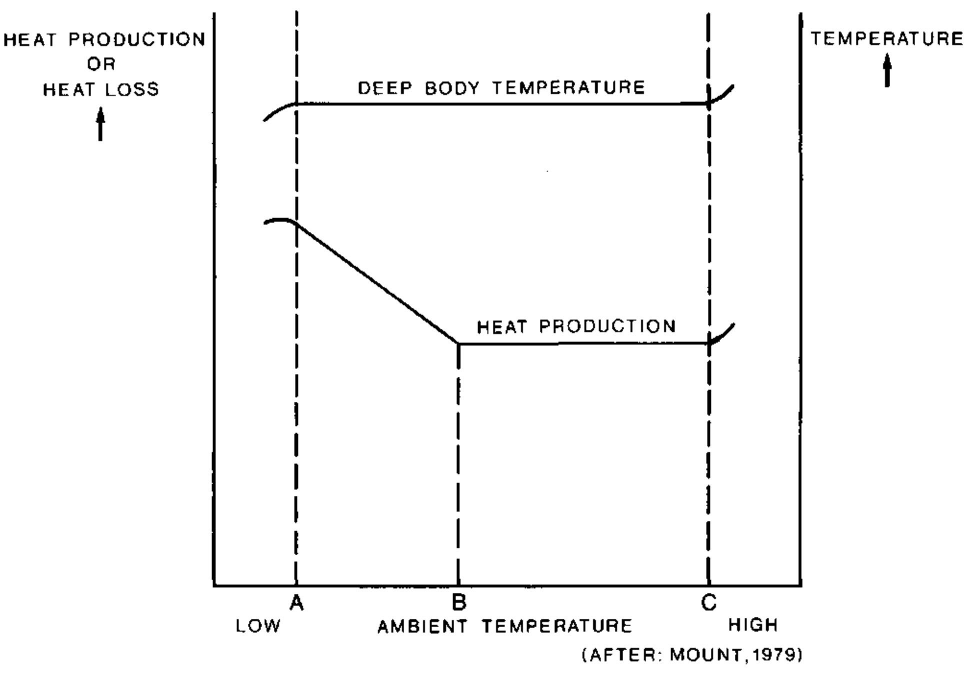

Figure 1. Relation between heat production, body temperature and ambient temperature.

sponse to heat loss, remains constant when environmental temperature ranges between B and C and thus deep-body temperature remains unaffected. This zone is called the zone of thermal neutrality or zone of minimal metabolism. Environmental temperatures above C, the upper critical temperature, will cause hyperthermia. Heat loss to the surrounding environment is limited causing body temperature to increase.
Environmental temperatures below B, the lower critical temperature, will cause an increase in heat loss to the environment which is compensated by an increase in heat production while deep-body temperature is maintained. At A the maximum of heat production is reached and below this point hypothermia occurs.

In intensive pig production the lower critical temperature of the animals (point B in figure 1) depends on several factors (Close, 1981). Body weight (Verstegen, 1971), condition (DeB. Hovell *et al.*, 1977) and thermal insulation (Ingram, 1964), as well as group size (Mount *et al.*, 1973) and level of nutrition (Close and Mount, 1978) contribute to this. The lower critical temperature decreases as body weight and thermal insulation (subcutaneous fat) increases. Higher level of energy intake results in higher metabolism and elevates the line B-C in figure 1. As a result B decreases. Temperatures below thermal neutrality will increase maintenance requirement at the cost of energy deposited in body weight gain. Overall efficiency of conversion of food energy into energy gain is thus lowered. Several studies described in literature were aimed to assess the effects of exposure to different ambient temperatures on metabolic rate and parameters of energy metabolism (Verstegen, 1971; Thorbek, 1975; Close and Mount, 1978).

Pigs can reduce heat loss to the environment by huddling (Mount, 1979; Boon, 1982). The effect of a climatic environment is modified through this behavioural thermoregulation. To allow this mechanism as an intrinsic part of the results of a particular climatic environment group-housed animals were used in the experiments described in this thesis. Housing of pigs in groups is common in practice.

Climatic factors may also act as stressors to the animals. According to Curtis (1983) stress is any environmental situation, and a stressor any environmental factor, that provokes an adaptive respons. The response to stressors is achieved through neural and endocrine systems (Dantzer and Mormède, 1983; Siegel, 1985). The neurogenic system (NS), consisting of the central nervous system and the adrenal medullary tissue, represents one such system; the hypothalamus-pituitary-adrenalcortex axis (HPA) represents another (Siegel, 1985). The NS is a rapid response, to increase energy production and delivery, through catecholamines, epinephrine and norepinephrine. Through these amines cyclic adenosine mono-phosphate is produced (Siegel, 1985). The activation of the HPA is a longer term adjustment by the animal to environmental change (Siegel, 1985). Through the output of ACTH by the pituitary, the adrenal secretion of corticol steroids is increased (Siegel, 1985; Dantzer and Mormède, 1983). The response curve to low temperature is illustrated in figure 2. This curve depends on the type of application of the stressor. It shows that low temperatures result in elevated levels of plasma cortisol. Type of exposure, gradual or acute, determines the pattern by which this elevated level is reached. The difference in cortisol level after a sudden

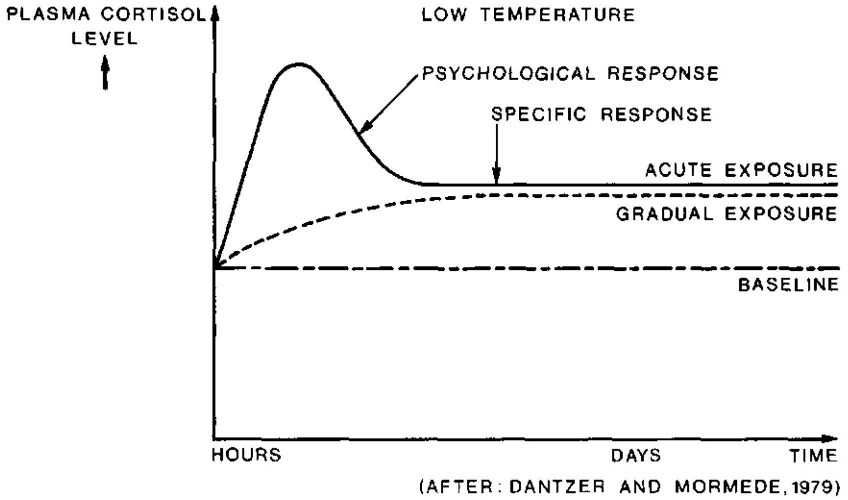

Figure 2. Plasma cortisol levels in relation to time after exposure to low temperature.

change or a gradual change to the same conditions is related to the emotional response (Dantzer and Mormède, 1983). The gradual change specifically reflects the reaction to the physical property of the climatic environment (Dantzer and Mormède, 1983). This implies that the effects of gradual or sudden changes have to be taken into account. It may be obvious that in intensive husbandry climatic environment cannot be regarded as constant. Fluctuation in temperature and increase in air velocity (wind or draught) may occur. Especially sudden changes in *e.g.* air velocity, in not properly climatically-controlled buildings may occur and these increases in air stream may be of lower temperature. Pigs may then be exposed to draught.

As a respons to such factors of the climatic environment metabolic rate may be changed but moreover metabolic adaptation can take place through the HPA-axis (Mount, 1979). Acclimation is defined when compensatory alterations due to a single environmental factor occurs (Curtis, 1983). If the climatic environment consists of several components that vary, the reaction of animals is referred to as acclimatization (Mount, 1979; Curtis, 1983). Acclimation with respect to metabolic rate is a form of adaptation that is also dependent on liberal food supply (Mount, 1979). The importance of food intake on acclimation to the thermal effects of climatic environment was also noted by Barnett and Mount (1967), Morrison and Mount (1971) and Close (1981). *Ad libitum* feeding strategy was therefore applied in the experiments described in this thesis. Moreover this feeding strategy is common for young-growing pigs in practice.
Morrison and Mount (1971) found that parameters as daily gain, food conversion and respiratory frequency were not suitable to clearly assess time of adaptation. A period of 10 days was required to reach steady values in rectal temperature of pigs after a change in environmental temperature (Morrison and Mount, 1971).

Kelley (1980, 1985) stated that a wide variety of environmental stimuli may alter several components of the immune system. It has been demonstrated that a single environmental stimulus, *e.g.* cold air, effectively reduced resistance to disease-causing organism in swine: *Escherichia coli* (Armstrong and Cline, 1977) and transmissible gastroenteritis virus (Shimuzu *et al.*, 1978).

Henken (1982) found that in pullets immunized with SRBC the humoral immune response was dependent on the change in thermoregulatory demand due to the climatic environment. An environment-disease interaction with respect to *Haemophilus pleuropneumoniae* infections at the beginning of the fattening period of growing pigs was found by Hunneman (1983). Unfavourable conditions as fluctuation in ambient temperature and increased levels of air velocity were found to be related to incidence and severity of the disease (Hunneman, 1983). It may be expected that the thermoregulatory demand of these environmental factors and the observed relation with incidence and severity of this disease in young growing pigs were thus related. Therefore it was decided to study to what extent the degree of acclimation to various climatic conditions take place in about two weeks.

The effect of a constant or sudden changes in climatic environment and inoculation of growing pigs with *Haemophilus pleuropneumoniae* on health and metabolism is described in the first chapter. It was studied if the effect of thermoregulatory demand of pigs to the climatic environment was similar if applied at time of inoculation or several days thereafter. Preliminary experiments had shown that standardization of inoculation was acceptable and clinical signs were pathogen specific (Verhagen *et al.*, 1987). Moreover pigs raised under standard practical conditions were preferable to SPF-pigs. Intranasal administration of the pathogen was preferable to intratracheal or aerosol challenge. In all experiments young growing pigs of about 9 weeks of age and a live weight of approximately 20 kg were used. In practice pigs of this age and live weight are normally transferred to fattening units.

Exposure to ambient temperature at or below thermal neutrality might affect the level of energy metabolism. This was studied in the second series of experiments (chapter II). Ambient temperatures of 25 °C and 15 °C were used to represent temperatures within (25 °C) and below (15 °C) thermal neutrality (Bruce and Clark, 1979). These temperatures are below (15 °C) and above (25 °C) the temperature that was found by Hunneman (1983) to be one of the climatic factors related to *Haemophilus pleuropneumoniae* infections. The effects on maintenance requirement, protein and fat deposition were studied.
In the third chapter acclimation of pigs with regard to heat production and activity at both temperatures was studied. In the following chapter (IV) experiments are described in which an increased air velocity (draught) was applied to pigs. This was done periodically during night time at the temperatures that were used in the previous studies (chapters II and III). Draught was made by increasing air velocity from 0.2 m/s to 0.8 m/s with the temperature of the air stream 5 K lower than ambient temperature. By applying this draught periodically, sudden changes in climatic environment will then occur. Acclimation to this condition was studied, and the effects of occurrence of draught within nights was emphasized. Chapter V

deals with a serie of experiments in which temperature fluctuated during the 24 hour period ; 25 °C during day time and 15 °C during night time. This condition was compared with the occurrence of draught, similar as used at constant ambient temperatures. Such conditions may also occur in practice.

Gross and Siegel (1983) concluded that blood cell ratio's could be used to determine stress upon animals rather than the use of levels of corticosteroids. In the sixth chapter the effects of different climatic environments on these blood parameters was studied.
In the last chapter (VII) an experiment is described in which a constant or changing climatic environment was compared with draught to determine the effects on body temperature. These effects were related to the effects of climatic factors on heat production and activity-related heat production.

References

Armstrong W.D. and Cline, T.R. 1977. Effects of various nutrient levels and environmental temperature on the incidence of colibacillary diarrhoea in pigs. *J. Anim. Sci.* **45**: 1042-1050.

Barnett, S.A. and Mount, L.E. 1967. Resistance to cold in mammals, *Thermobiology*. Ed. A.H. Nose, Academic Press London and New York. p. 411- 477.

Boon, C.R. 1982. The lower critical temperature and group postural behaviour of pigs. *Livestock Environment II*. 2nd Int. Liv. Env. Symp. Am. Soc. of Agric. Eng.

Bruce, J.M. and Clark, J.J. 1979. Models of heat production and critical temperature for growing pigs. *An. Prod.* **28**: 353-369.

Close, W.H. 1981. The climatic requirements of the pig, *Environmental aspects of housing for animal production*. Ed. J.A. Clark. Butterworths. London. p. 149-166.

Close, W.H. and Mount, L.E. 1978. The effect of plane of nutrition and environmental temperature on the energy metabolism of the growing pig, 1. Heat loss and critical temperature. *Br. J. Nutr.* **40**: 413-421.

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

Dantzer, R. and Mormède, P. 1983. Stress in farm animals: a need for reevaluation, *J. Anim. Sci* **57**: 6-18.

DeB. Hovell, F.D., Gordon, J.G. and MacPherson, R.M. 1977. Thin Sows. 2. Observations on the energy and nitrogen exchanges of thin and normal sows in environmental temperatures of 20 and 5 °C. *J. agric. Sci. Cambr.* **89**: 523-533.

Henken, A.M. 1982. The effect of environmental temperature on immune response and metabolism of the young chicken. *Thesis. Wageningen. The Netherlands.*

Hunnemann, W.A. 1983. Vóórkomen, economische betekenis en bestrijding van *Haemophilus pleuropneumonia* infekties bij varkens. *Thesis. Utrecht. The Netherlands.*

Ingram, D.L. 1964. The effect of heat loss and thermal insulation in the young pig. *Res. Vet. Sci.* **5**: 357-364.

Morrison, S.R. and Mount, L.E. 1971. Adaptation of growing pigs to changes in environmental temperatures, *An. Prod.* **13**: 51-57.

Mount, L.E., Close, W.H. and Verstegen, M.W.A. 1973. The effective critical temperature in groups of pigs. 256th Scientific. Meeting of the Nutrition Society.

Mount, L.E. 1979. *Adaptation to thermal environment: man and his productive animals*. Edward Arnold. London.

Shimizu, M., Shimizu, Y., and Kodama, Y. 1978. Effects of ambient temperatures on induction of Transmissible gastroenteritis in feeder pigs. *Inf. Immun.* **21**: 747-752.

Siegel, H.S. 1985. Immunological responses as indicators of stress. *WPSA Journal*. **41**: 36-45.

Snedecor, G.W. and Cochran, C. 1976. *Statistical Methods*. Iowa State University Press.

Thorbek, G. 1975. Study on energy metabolism in growing pigs. *Beretning frå Statenshusdyrbrugsforsøg 424, Copenhagen. Denmark.*

Verhagen, J.M.F, Verstegen, M.W.A., Boon, J.H., de Jong, M.F., Jaartsveld, F.H.J. and Hoogerbrugge, A. 1987. De relatie tussen klimaatsomstandigheden en gezondheid van landbouwhuis-

dieren: *Haemophilus pleuropneumoniea* infekties bij biggen als model van een faktorenziekte. Tijdschrift voor Diergeneeskunde. Submitted.
Verstegen, M.W.A. 1971. Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups. *Thesis, Wageningen. The Netherlands.*

CHAPTER I

The effect of different climatic environment on metabolism and its relation to time of *Haemophilus pleuropneumoniae*-infection in pigs

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Livestock Production Science: submitted.

Abstract

The effect of time of inoculation of young growing pigs (liveweight 20 to 28 kg) with *Haemophilus pleuropneumoniae* was studied with respect to time of occurrence of climatic stress. In exp. I pigs were inoculated before the occurrence of climatic treatments, whereas in exp. II inoculation was after 12 days exposure to the climatic treatments. In each experiment 2 treatments were applied; an ambient temperature of 25 °C (control-group) or a fluctuation in temperature (25 °C during day time, 15 °C during night time), with a superimposed occurrence of draught (air velocity of 0.8 m/s with a temperature of 5 K lower than ambient temperature; treatment-group). Draught was applied during night time, periodically during 2 hour periods. Pigs were housed in groups of 9 or 10 pigs and 2 groups were exposed to the treatments. In exp. I pigs in the treatment-group had higher mortality than pigs in the control-group. Increase in rectal temperature was delayed by 2 days compared with the control-group. Increase in specific antibody level was found after 12 days, and was significantly higher for the treatment-group at day 12 p.i.. In exp. II antibody level was increased after inoculation, but no significant differences were found between control- and treatment-group. Inoculation affected daily gain, maintenance requirement and fat deposition during the first 6 days p.i. in both groups. The importance of acclimation to an unfavourable climatic environment on the outcome of inoculation with *Haemophilus pleuropneumoniae* is stressed.

Introduction

Climatic conditions in animal husbandry can induce physiological alterations which influence the animals' susceptibility to infectious diseases (Nielsen, 1982; Osborne *et al.*, 1984; Kelley, 1985; Siegel, 1985). Schultz *et al.* (1984) stated that unfavourable conditions could cause stress and that is an important cause for provoking diseases in animals. With slaughter pigs, Tielen (1974) found that the incidence of micro-organism induced lung lesions was influenced by climatic factors during the fattening period. Draught, defined as the degree of temperature fluctuation inside and outside the piggery multiplied with air velocity, had a marked effect on the frequency of lung lesions (Tielen, 1974). In young growing-pigs outbreaks of *Haemophilus pleuropneumoniae*-infections on farms are frequently reported to be related to unfavourable climatic conditions (Nicolet *et al.*, 1980; Nielsen, 1982; Hunneman, 1983). Hunneman (1983) found that climatic factors like temperature and carbondioxide in the air, relative humidity and increased air velocity (*i.e.* draught) significantly contributed to the incidence and severity of *Haemophilus pleuropneumoniae*-infections in fattening pigs. Nielsen (1982) stated that the severity of these infections could be related to climatic factors such as draught. Osborne *et al.* (1984) noted that moment of challenge of pigs with *Haemophilus pleuropneumoniae* in relation to stressors as heat, cold and transport was important since more lung lesions were found if inoculation with *Haemophilus pleuropneumoniae* was before application of the stressor compared with inoculation thereafter. Apparently the difference in time between the first occurrence of climatic stress and the contact with antigen or pathogen affects the immune response (Kelley, 1985) and resistance to *Haemophilus pleuropneumoniae* (Osborne *et al.*, 1984). Henken (1982) found that immune response to SRBC was related to the thermoregulatory demand of the climatic environment.

In the present study the effect of *Haemophilus pleuropneumoniae* inoculation *prior* to, or *after* the occurrence of an unfavourable climatic condition was studied. The unfavourable climatic condition applied in this study was aimed at simulating sudden and intermittent changes in climatic environment.

Material and methods

Animals and housing

Young growing pigs (Dutch Large White × Dutch Landrace) were obtained from one commercial farm. Pigs, about similar numbers of females and castrated males, were approximately 10 weeks of age and kept at similar pre-treatment environment. In each experiment pigs were randomly assigned to two climatically-controlled respiration chambers by balancing mean weight between chambers. Description of chambers used in these experiments is given by Verstegen (1971). Each chamber has a floor of non-toxic asphalt and two pens with an area of 9 m^2 per pen. About 20% of the floor is covered with slats to enable collection of faeces. Before start of the experiments pigs were allowed to adapt for 6 days to the chamber.

Experimental design

Experiment I

Pigs were inoculated with *Haemophilus pleuropneumoniae prior* to the climatic treatment. Pigs in one chamber were exposed to a diurnal rhythm in ambient temperature with a draught applied during the night period (=treatment-group). Pigs in the second chamber were exposed to a constant temperature of 25 °C (=control-group). Initial weight is given in table 1. One pig was taken out before start of the experiment. Per group 20 pigs were used, with 10 pigs in each pen.

Experiment II

Inoculation of pigs with *Haemophilus pleuropneumoniae* was done 12 days *after* the climatic treatment. The climatic treatments were identical to those in exp. I.

Table 1. Initial weight (kg) of pigs in experiment I and II (n = number of pigs; mean and standard deviation (sd)).

Experiment I						Experiment II					
control-group			treatment-group			control-group			treatment-group		
n	mean	sd	n	mean	sd	n	mean	sd	n	mean	sd
—	—	—	—	—	—	18*	20.3	2.0	18	20.7	2.0
20**	24.9	3.4	19	24.1	3.4	18	28.1	2.8	18	28.7	3.4

* weight at start of climatic treatment
** weight at day 0

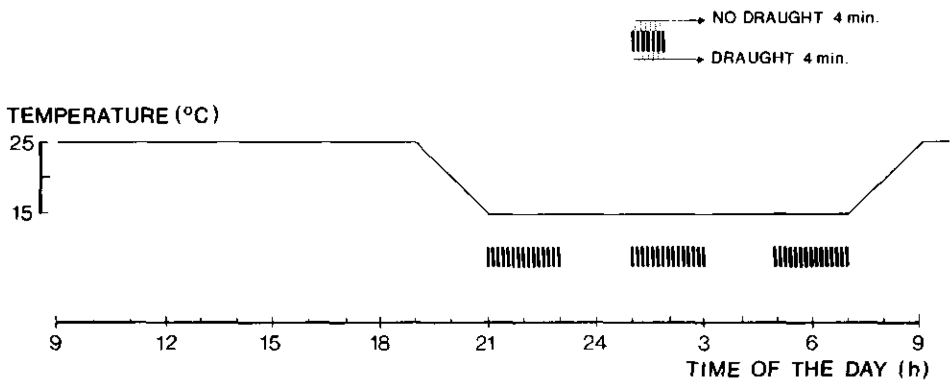


Figure 1. Experimental design of the treatment-group.

After inoculation the temperature for both the control- and the treatment-group was held at 20 °C. Per group 18 pigs were used. Initial weight is given in table I.

In both experiments the pigs in the treatment group were exposed to a diurnal rhythm in ambient temperature and a draught treatment was superimposed upon this ambient temperature (figure 1). In the treatment group the draught occurred during three 2-hour periods alternated with 2-hour periods of absence of draught (figure 1). During these draught periods air velocity was increased to 0.8 m/s and the temperature of the air stream lowered 5 K. In these periods draught was on for 4 minutes and subsequently 4 minutes off. When draught was absent air velocity was below 0.2 m/s. Relative humidity was kept at about 65% throughout each experiment.

Experimental procedure

In figure 2 the experimental procedure is illustrated. In each experiment pigs were weighed, blood samples were taken and rectal temperature was measured at the start of the experiment and at days 6 and 12 of the treatment period (exp. I and II) and at days 7 and 14 post inoculation (p.i.) in exp. II. At day 2, 3 and 4 in exp. I and days 3 and 5 p.i. in exp. II rectal temperature was determined also. Measurements in both experiments were made between 10.00 and 12.00 h. In each experiment attention was paid to clinical symptoms as a reaction to the inoculation, *i.e.* coughing, abdominal type of breathing, buccal breathing and sitting on their hind legs (Nielsen, 1982).

Pigs were fed *ad libitum*. The feed contained approximately 17 kJ gross energy per gram and 17% crude protein. Water was available throughout the experimental period. In each period intake of metabolizable energy was determined from intake of energy in feed and loss through urine and faeces. Protein deposition was determined similarly. Feaces and urine were collected, weighed and sampled over subsequent collection periods (figure 2). After inoculation heat production was measured continuously from gaseous exchange of oxygen and carbon-

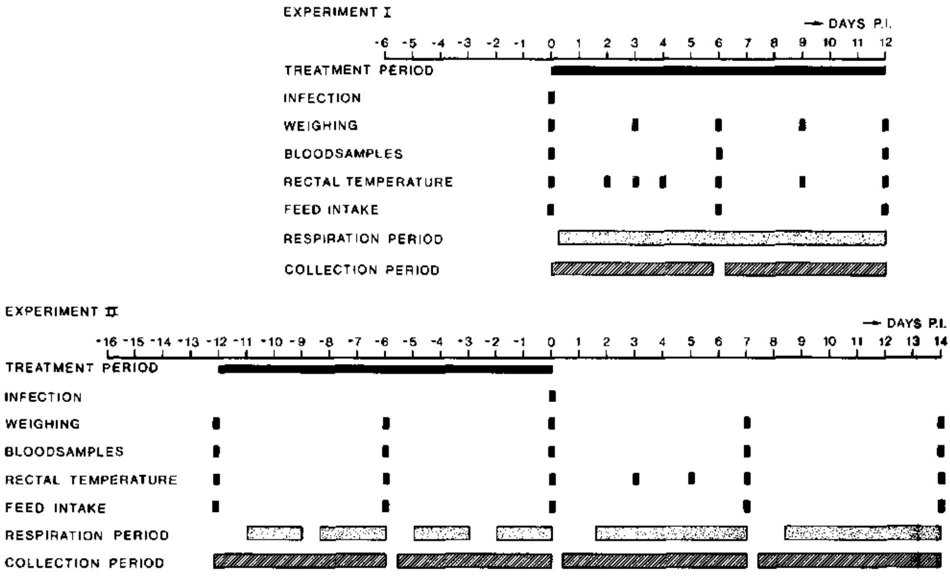


Figure 2. Experimental procedure.

dioxide of pigs within a chamber. In the remaining 6-day periods heat production was calculated for two 48-hour periods. Principles of respiration chambers and procedures of measurements of heat production are described by Verstegen (1971).

Energy retained was calculated by substracting heat production from intake of metabolizable energy. Deposition of energy in fat was calculated from energy retained and energy deposited in protein (ARC, 1981). By dividing calorific values for deposition of fat and protein by their efficiency the amount of metabolizable energy for deposition can be obtained. Maintenance requirement is subsequently derived from ME-intake and energy gain. Calorific values per gram of fat and protein deposited were 39.6 and 23.7 respectively (ARC, 1981). Efficiency of utilization of metabolizable energy for protein (k_p) and fat (k_g) deposition are assumed to be 0.54 and 0.74 respectively.

Haemophilus pleuropneumoniae (serotype 9) was obtained from the lungs of a pig succumbed from infection. Lungs were stored in small pieces at — 20 °C. Prior to the day of inoculation thawed pieces of lung were incubated on PPLO-agar plates at 37 °C under 10% CO_2 for 24 hours. Serotype was checked by agglutination to specific antisera. The bacteria was subsequently reincubated on PPLO-agar. Phosphate buffered saline (PBS, pH = 7.3) with 10% bovine serum was used to wash bacteria. Suspension obtained was spectrofotometrically adjusted to an extinction of 50% corresponding to 10^8 cfu per ml. The suspension was diluted to 2×10^6 cfu per ml and kept on ice until time of inoculation (Jaartsveld, personal communication, 1986). Prior to inoculation the suspension was warmed up to ± 30 °C. Pigs were inoculated with 1 ml per nostril between 16.00 h and 17.00 h.

Antibody levels against *Haemophilus pleuropneumoniae* were determined by an enzyme-linked immuno-sorbent assay (ELISA) (see Verhagen *et al.*, 1986) and expressed as an *F*-value according to Schmeer (1982). Pigs in experiment I were sacrified at d. 13 p.i.. After slaughtering the respiratory tract and heart were examined. In exp. II pigs were removed from the chambers at day 35 p.i.. They were kept and fattened elsewhere (about 100 days p.i.). After slaughter the respiratory tract and heart were examined similarly as in exp. I. Differences between both groups were tested by Student's *t*-test (Snedecor and Cochran, 1976).

Results

In exp. I one pig in the treatment-group was removed before the start of the experiment.

Morbidity and mortality

In exp. I coughing of pigs was noted during the first night after inoculation. Increased respiration rate and abdominal type of breathing were evident in the second night for animals in both chambers. In exp. I two animals in the treatment group succumbed during the third night post inoculation. *Haemophilus pleuropneumoniae* was cultured from the lungs of these pigs. In exp. II symptoms were less clear but coughing and increased respiration rate were observed during the third night after inoculation onwards.

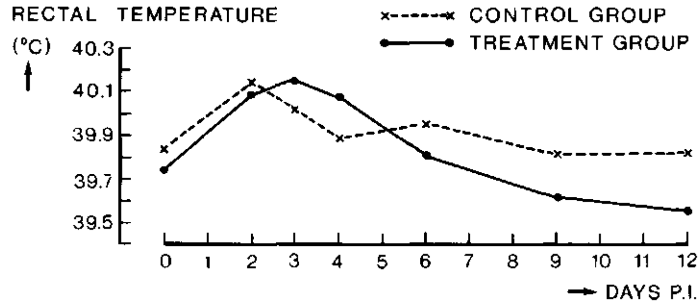
Rectal temperature

In figure 3 data on rectal temperature are given. In exp. I pigs in the control-group had increased rectal temperature from 39.8 °C at day of inoculation to 40.1 °C at day 2 p.i.. Pigs of the treatment group had highest level of rectal temperature at day 3 p.i. (40.2 °C) compared with day 0 (39.7 °C). Standard deviation was significantly higher at day 3 and 4 p.i. than that in the control-group (figure 3). Mean rectal temperature was significantly lower at day 9 and 12 for pigs in the treatment-group. The two pigs succumbed at day 4 p.i. had rectal temperatures above 41.5 °C at day 3 p.i.. Mean values for the control- and treatment-group from day 0 to 12 were 39.9 °C for both groups.
In exp. II the pattern of rectal temperature was different from exp. I. For the control and treatment-group patterns were similar and an increase was found at day 5 p.i.. This increase was significant in the treatment-group. As an average increase in rectal temperature was 0.15 °C. Standard deviation was also increased at day 5 p.i.. Mean values of rectal temperature from day 0 to 14 for the control- and treatment-group were 39.9 °C for both groups.

Post mortem examination

Examination of the two succumbed pigs of the treatment group in exp. I revealed an acute fibrigenic pleuropneumoniae with foaming blood in the upper airways and on the snout. The results of *post mortem* examination of the respiratory tract and heart of the slaughtered pigs are given in table 2. In the first experiment 4 and 3 pigs of the control and treatment group respectively showed fibrigenic pleuropneumoniae. In exp. II chronical pleuritis was found in two pigs of the control and

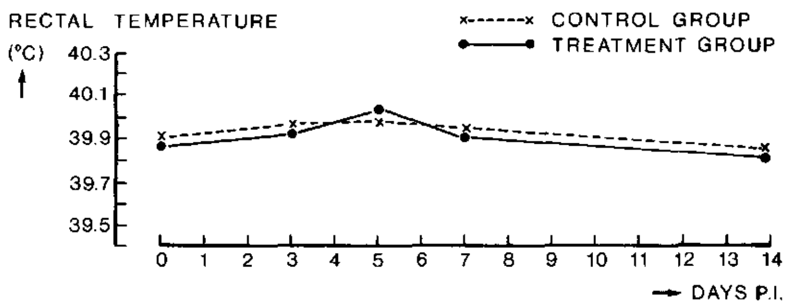
EXPERIMENT I



		0	2	3	4	6	9	12
CONTROL GROUP	sd	0.30	0.40	0.36	0.33	0.22	0.25	0.21
	n	20	20	20	20	20	20	20
TREATMENT GROUP	sd	0.31	0.39	0.68	0.74	0.29	0.29	0.34
	n	19	19	19	17[1)]	17	17	17

[1)] 2 PIGS SUCCUMBED AT DAY 4 NOT INCLUDED

EXPERIMENT II



		0	3	5	7	14
CONTROL GROUP	sd	0.34	0.25	0.35	0.28	0.13
	n	18	18	18	18	18
TREATMENT GROUP	sd	0.28	0.31	0.44	0.27	0.19
	n	18	18	18	18	18

Figure 3. Rectal temperature.

Table 2. Pathological-anatomical results at slaughter.

Lungs	Experiment I		Experiment II	
	Control-group	Treatment-group	Control-group	Treatment-group
Fibrigenic pleuropneumoniae	4	3	—	—
Pleuritis	—	—	2	1
Brides	2	1	1	1
Abcesses	—	—	—	—
Heart				
pericarditis	1	—	—	1
No. of animals	20	17*	18	18

* 2 pigs succumbed at day 4 p.i. not included

in one of the treatment group. In all cases lesions were found in the *lobus diafragmaticus* and the pleuritis on the corresponding *pleura parietales*. Fibrigenic tissue between the *pleura viscerales* and *parietales* (brides) was found in all groups. Pericarditis was found in one pig of the control-group in experiment I and in one pig in the treatment-group in exp. II.

Antibody titers

In figure 4 the average *F*-value of antibodies against *Haemophilus pleuropneumoniae* is presented for the control and treatment group in each experiment. In exp. I the F-value at day 6 p.i. and at day 12 p.i. was significantly increased compared with day 0. Pigs in the treatment-group had significantly higher antibody level at day 12 p.i. compared with the control-group. In exp. II mean antibody level was significantly higher at day 14 p.i. compared with day 0. Correlation between the index of antibody level at day 0 and the increase in antibody level from day 0 to 6 p.i. and from day 6 to 12 p.i. were -0.67 and -0.34 respectively. In exp. II correlations between day 0 and increase from day 0 to 7 and day 0 to 14 were -0.57 and -0.32 respectively. Differences between levels of antibodies at day of inoculation were thus related to the increase in antibody level after infection.

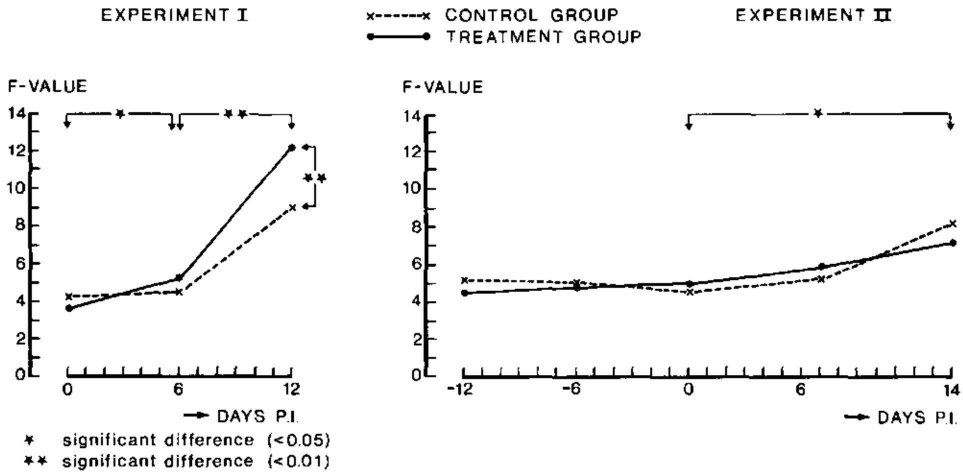


Figure 4. Antibody level, expressed as *F*-value.

Daily gain and feed conversion

In table 3 daily gain and feed conversion are presented per collection period. In exp. I daily gain from day 0 to 6 p.i. of pigs in the treatment-group was lowered by 95 g/d compared with pigs of the control-group. During days 6 to 12 p.i. difference in daily gain was 55 g/d, whereas feed conversion was similar between groups. In exp. II pigs in the treatment group had lower daily gain during days -12 to -6 p.i. (74 g/d) and higher feed conversion. Daily gain and feed conversion were similar from days -6 to 0 p.i.. After inoculation of pigs in exp. II the treatment-group had higher daily gain (102 g/d). Differences were no longer present thereafter.

Table 3. Daily gain and feed conversion (g/d).

		Daily gain		
Days p.i.			*0-6*	*6-12*
Exp. I Control-group	—	—	662	819
Treatment-group	—	—	567	764
Days p.i.	*−12-6*	*−6-0*	*0-7*	*7-14*
Exp. II Control-group	735	664	773	888
Treatment-group	661	672	875	867
		Feed conversion		
Days p.i.			*0-6*	*6-12*
Exp. I Control-group			2.03	1.95
Treatment-group			2.36	1.96
Days p.i.	*−12-6*	*−6-0*	*0-7*	*7-14*
Exp. II Control-group	1.63	1.98	2.04	1.99
Treatment-group	1.85	2.07	1.80	2.03

Table 4. Metabolizable energy for maintenance (ME_m), retained energy (RE) in $kJ/kg^{0.75}$ and protein deposition (g) per animal per day.

	ME_m			
Days p.i.			*0-6*	*6-12*
Exp. I Control-group	—	—	467	515
Treatment-group	—	—	526	518
Days p.i.	*−12-6*	*−6-0*	*0-7*	*7-14*
Exp. II Control-group	501	582	408	573
Treatment-group	516	561	494	559
	RE			
Days p.i.			0-6	6-12
Exp. I Control-group	—	—	719	724
Treatment-group	—	—	594	669
Days p.i.	*−12-6*	*−6-0*	*0-7*	*7-14*
Exp. II Control-group	721	598	807	670
Treatment-group	713	676	733	673
	Protein deposition			
Days p.i.			*0-6*	*6-12*
Exp. I Control-group	—	—	128	148
Treatment-group	—	—	111	137
Days p.i.	*−12-6*	*−6-0*	*0-7*	*7-14*
Exp. II Control-group	124	125	152	160
Treatment-group	121	131	149	160

Heat production

Data on heat production are presented in figure 5. Since draught was applied during the night period values of heat production of this period are shown. Pigs in the treatment-group in exp. I had higher values for heat production compared with the control-group until day 9 p.i.. As an average it was 20.4 $kJ/kg^{0.75}$ higher from days 0 to 9 p.i. ($p < 0.05$). In exp. II the treatment of fluctuating temperature and draught prior to inoculation was associated with an increase in heat production by 35.4 $kJ/kg^{0.75}$ ($p < 0.01$). After inoculation heat production between both groups was not significantly different. At day 2 p.i. heat production of both control- and treatment-group was lower (by 92 kJ) compared with values before inoculation. From day 6 p.i. onwards level of heat production was similar to that of the periods before inoculation.

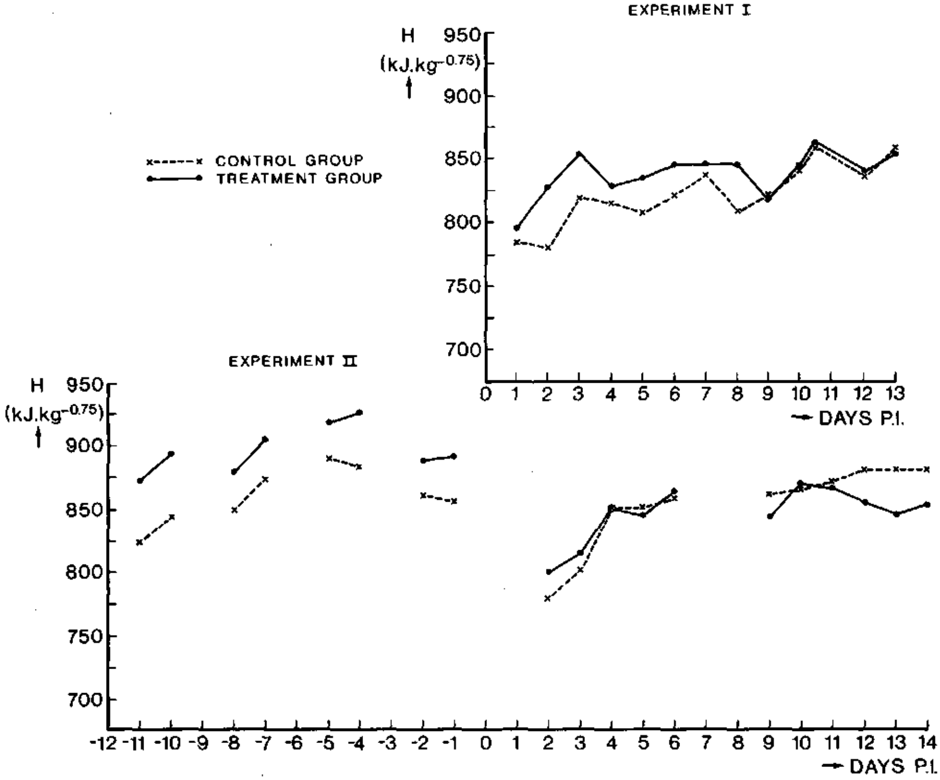


Figure 5. Heat production ($kJ/kg^{0.75}$).

Energy metabolism

In each collection period intake of metabolizable energy (ME) and deposition of protein were determined. Retained energy was calculated from subtracting heat production from ME. Values of heat production determined over 24-hour periods were used for this. Maintenance requirement (ME_m) was calculated for each period. Results are given in table 4. Pigs in the treatment-group in exp. I and exp. II showed a decrease in protein deposition and in retained energy in the first six days p.i.. ME_m was increased by 59 kJ/kg$^{0.75}$ in exp. I and by 86 kJ/kg$^{0.75}$ in exp. II. ME_m after day 6 was similar between treatment- and control-groups. During the 12 days prior to inoculation in exp. II there was no difference in ME_m between both groups.

Discussion

Recent studies have indicated that the humoral immune response to antigen is related to time of beginning of climatic stressor (Henken, 1982; Siegel, 1985; Kelley, 1985). Henken (1982) suggested that the way of acclimation by thermoregulatory response was related to this effect of timing. It was therefore studied if a particular form of climatic stress (fluctuating temperature and draught) can modulate immune response to a pathogen. Such climatic stress is known to occur under farming conditions and is related to lung lesions (Tielen, 1974; Hunneman, 1983). Moreover, difference in reaction of animals to inoculation could indicate that acclimation to climatic environment is important for the resistance of animals to infectious disease. In the present study relationship between time of inoculation of pigs with *Haemophilus pleuropneumoniae* and climatic conditions was therefore studied. *Post mortem* findings in pigs succumbed and pigs slaughtered showed typical signs of this infection (Shope, 1963; Nielsen, 1982; Hunneman; 1983). Fibrigenic pleuropneumoniae was found in pigs in exp. I in the *lobus diafragmaticus*. In exp. II pigs were slaughtered at the end of the fattening period. *Post mortem* findings showed that the chronic pleuritis was also only present in the *lobus diafragmaticus*. Therefore this might be ascribed to the experimental inoculation.

Pigs inoculated prior to the climatic treatment showed higher mortality and different level of antibodies at day 12 p.i. compared with the control group. Moreover, a delayed response in rectal temperature increase for the treatment group was found and remained for 3 days at higher levels. Variation in rectal temperature of climatically stressed pigs was increased. Blecha and Kelley (1981) observed an increased antibody level against SRBC of young weaned pigs housed at 0 °C compared with pigs kept at 25 °C. Shimizu *et al.*, (1978) similarly found an increase in antibody level against Transmissible Gastro Enteritis (TGE) virus in pigs housed at lower ambient temperatures compared with higher ambient temperatures. In our study inoculation at time of first occurrence of climatic stress clearly increased antibody level (exp. I). Inoculation after 12 days exposure to climatic stress showed no relation to it. This is in agreement with results from Osborne *et al.* (1984). Moreover the exposure to climatic treatment (exp. II) had no effect on antibody levels. Presence of antibodies after 12 or 14 days after inoculation was also found by Nicolet *et al.*, (1980) and Nielsen (1982). It is concluded that response of pigs to inoculation with *Haemophilus pleuropneumoniae* is affected by climatic environment and the response is dependent on the time difference between inoculation and first occurrence of climatic stress.

The climatic treatment directly after inoculation resulted in increased heat production and increased maintenance requirement and a decrease in retained en-

ergy and protein deposition during the first six days. Exposure 12 days before inoculation resulted in increased heat production during the night period especially. This increase was not reflected in difference in energy metabolism parameters nor protein deposition. Results indicate that the effects of inoculation on heat production can not be seperated from previous exposures to climatic conditions. Data of whole-day heat production is of limited value since an increase at night may be compensated by a decrease during day-time. Van der Hel *et al.* (1984) similar found that heat production and activity during one part of the day was affected by other parts of the day.
The decrease in heat production of pigs in exp. II after inoculation compared with values before day 0 might also be related to a reduced activity of the animals. Progress of recovery from inoculation and increase in activity could well be related in this respect.

From results of our study it can be derived that the effect of adverse climatic conditions on the reaction of pigs to inoculation with a pathogenic micro-organism, *i.e. Haemophilus pleuropneumoniae*, is dependent on time of both inoculation and first application of draught. Pigs exposed to unfavourable climatic environments directly after inoculation seem to have more problems to cope with this compared to pigs that were previously exposed to such an environment. The occurrence of draught to pigs will cause an increase in heat loss. As a consequence animals respond to heat loss by producing heat to remain homeotherm. However if body temperature is increased due to immunological responses as a reaction to invading micro-organisms heat loss by draught might be increased further. If pigs are not able to produce the extra heat required within short time body temperature might be lowered. Climatic conditions that are associated with sudden changes of the environment (*e.g.* draught) might provoke this. It may then be speculated that immunological defence mechanisms could be impaired being in favour of the pathogenic micro-organisms.
If such an effect is to occur it would implie that the removal or the inhibition of the bacteria is decreased, resulting in a prolonged presence of the bacteria. As a result the challenge to the animals is prolonged and could explain the increase in antibody level of pigs in the treatment group compared with the control group in exp. I.
Immune processes and thus the reaction to pathogenic micro-organisms seem to depend on adaptive processes (Kelley, 1985). It is therefore important to determine the state of adaptation of animals to a climatic environment because results of inoculation were related to time of exposure to the climatic environment.

Acknowledgements

The authors thank Mr. W. van der Hel, Mr. K. van der Linden, Mr. H.A. Brandsma, Mr. J. Michels and Mrs. M. Kreukniet for their assistance with the experiments. Mr. M. De Jong and Mr. F. Jaartsveld are acknowledged for their cooperation in the experiments.

References

ARC, 1981. The nutrient requirements of pigs, *Commonwealth Agr. Bur.* p. 1-44.

Blecha, F., 1984. Neonatal pigs reared artificially have suppressed in vivo and in vitro cellular immune response. J. Anim. Sci., 59: supl. 1, p. 190.

Blecha, F., Kelley, K.W., 1981. Effects of cold and weaning stressors on the antibody mediated immune response of pigs. J. Anim. Sci., 53: p. 439-447.

Bruce, J.M. and Clark, J.J., 1979. Models of heat production and critical temperature for growing pigs. Anim. Prod. 28: p. 353-369.

Henken, A.M., 1982. The effect of environmental temperature on immune response and metabolism of the young chicken. Thesis. Wageningen. The Netherlands.

Hunnemann, W.A., 1983. Vóórkomen, economische betekenis en bestrijding van *Haemophilus pleuropneumonia* infekties bij varkens. Dissertatie, Utrecht. The Netherlands.

Jaartsveld, F., 1986. Personal Communication.

Kelley, K.W., 1985. Immunological consequences of changing environmental stimuli. In: Animal Stress. American Physiological Society: p. 193-223.

Mount, L.E., 1979. Adaptation to thermal environment: man and his productive animals, Edward Arnold, London.

Nicolet, J., Brugmann, St., Paroz, Ph., 1980. Serological investigations on enzootic pneumonia with an enzyme-linked immunosorbent assay (Elisa). IPVS, Copenhagen, p. 225.

Nielsen, R., 1982. *Haemophilus pleuropneumonia* infection in pigs. Thesis. Copenhagen, Denmark.

Osborne, A.D., Saunders, J.R., Willson, P., 1984. Some observations on *Haemophilus pleuropneumoniae* infections in pigs with particularly reference to the effects of stress. IPVS, Gent: p. 95.

Schmeer, N., 1982. Enzyme-linked immunosorbent assay (Elisa) zur Nachweis von Antikörpern bei der Taube am Beispiel der Ornithrose. Thesis, Giessen.

Schultz, B.R., Cue, T., Anderson, M.D., 1984. Evaluation of tiamulin water medication in treatment of *Haemophilus pleuropneumoniae* in swine. A summary of three trials. IPVS, Gent: p. 100.

Shope, A.E., 1963. Porcine contagious pleuropneumoniae I. Experimental transmission, etiology and pathology. J. Exp. Med. 119: p. 357.

Siegel, H.S., 1985. Immunological responses as indicators of stress. WPSA Journal 41: p. 36-45.

Snedecor, G.W. and Cochran, C. 1976. Statistical Methods, Iowa State University Press.

Tielen, M.J.M., 1974. De frekwentie en de zoötechnische preventie van long- en leveraandoeningen bij varkens. Thesis. Wageningen. The Netherlands.

Van der Hel, W., Verstegen, M.W.A., Baltussen, W. and Brandsma, H., 1984. The effect of ambient temperature on diurnal rhythm in heat production and activity in pigs kept in groups. Int. J. of Biomet. 28: p. 303-315.

Verhagen, J.M.F., Verstegen, M.W.A., Boon, J.H. and van Herwijnen, J.R. 1986. An enzyme-linked immuno-sorbent assay (ELISA) as a tool to determine specific serum antibody levels in pigs after an experimental infection with *Haemophilus pleuropneumoniae*. IVth International Symposium of Veterinary Laboratory Diagnosticians. Amsterdam. The Netherlands.

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

CHAPTER II

Effect of ambient temperature on energy metabolism in growing pigs

J.M.F. Verhagen, A.A.M. Kloosterman, A. Slijkhuis and M.W.A. Verstegen

Animal Production 44: in press.

Abstract

Group-housed young growing pigs, fed *ad libitum*, were exposed to two temperatures, one within thermal neutrality (25 °C) and one around the lower critical temperature (15 °C). Pigs at 15 °C had reduced daily gain by (57 g per day) for 6 days after initial exposure. Food intake was increased significantly after 6 days at 15 °C but not at 25 °C. Maintenance requirement was increased by 58 kJ/kg$^{0.75}$ and energy retained as protein was decreased by 49 kJ/kg$^{0.75}$ for the first 6 days after exposure to the treatment of 15 °C and thereafter both became equivalent to those of pigs at 25 °C afterwards. It is concluded that animals were acclimated after 6 days exposure.

Introduction

The effect of climatic environment on pig production can be important. The effect depends on the combined effects of the various components of the climatic environment which influence heat loss. It is generally accepted that below thermal neutrality heat production is increased. The lower critical temperature (LCT) is the temperature below which pigs have to generate additional heat to maintain body temperature constant. This increased heat production (extra thermoregulatory heat production, ETH) can be considered as an increase in maintenance requirement. Total heat production of pigs is composed of the maintenance requirement (related to the metabolic body size), normal activity, ETH and in addition heat production associated with the synthesis of fat and protein. Heat loss is therefore dependent on both environmental temperature and plane of nutrition (Close, 1978; Verstegen *et al.*, 1973; Close and Mount, 1978). When food intake is constant, temperatures below LCT cause an increase in heat production and maintenance requirement (Close, 1978; Fuller and Boyne, 1972; Verstegen, 1971). Change of food intake can also be an important response of pigs to changes in environment (Morrison and Mount, 1971). Moreover, alteration of group behaviour (huddling) is a means by which group housed pigs cope with a non-optimal environment (Mount, 1979) and in these ways animals will adapt to their climatic environment.

The aim of the present experiments was to study how the duration of exposure to 25 °C or 15 °C affects food intake and partitioning of metabolizable energy into heat production and fat and protein gain.

Material and Methods

Animals and housing

In each experiment 2 groups of 10 pigs, about equal numbers of castrated males and females, were housed in a climatically controlled respiration chamber. Each chamber has a volume of 80 m^3 and 2 pens of 9 m^2 with a floor of non-toxic asphalt embedded in foam glass. In each experiment 20 pigs (Large White × Dutch Landrace) of approximately 10 weeks of age were housed in the calorimeter. Mean initial weight was balanced for a more accurate comparison of the variables mea-

Table 1. Weight of animals at start of the experiments (Mean and sem).

Treatment	Experiment	No. of Animals	Weight (kg) Mean	sem
15 °C	I	20	21.7	0.50
	II	20	21.5	0.42
	III	20	22.5	0.76
	IV	19	20.5	0.41
25 °C	V	20	22.3	0.43
	VI	20	20.4	0.55
	VII	20	21.5	0.57
	VIII	20	21.7	0.47

sured in the experiments. Initial mean weight and variance are given in table 1. Each experiment started on the second day after arrival of the pigs. Temperature was 20 °C until initiation of the experiment.

Plan of experiment

Ambient temperatures were 25 and 15 °C. Four experiments were carried out at each temperature in random order. Experiments at 15 °C are denoted exp. I to IV., experiments at 25 °C exp. V. to VIII. Temperature treatments were chosen to be within thermal neutrality (25 °C) and just below or around LCT (15 °C) for group-housed young growing pigs. Holmes and Mount (1967) stressed the importance of assessing the effects of ambient temperature in group-housed pigs as more relevant to farm conditions compared with estimates obtained from single-housed animals.

Experimental procedure

Each experiment lasted 12 days and was divided in two consecutive 6 day collection periods. Animals were weighed at the beginning of each collection period and at the end of the second period. During each collection period food, food residues, faeces and urine were collected and analysed for their energy and nitrogen content. Nitrogen loss as ammonia in the air was estimated by continuous aspiration of an air sample through a sulfuric acid solution. Ammonia content of water condensed on heat exchange was also determined. Energy and nitrogen balance were estimated for 20 pigs within the calorimeter. In each collection period gaseous exchange was measured in two 48-hour periods on day 2+3, 5+6, 8+9 and 11+12. It was assumed that within each 6 day period metabolizable energy intake and accretion of protein and fat were related to food intake in the same period. In this way energy balance data were obtained during 4 separate two-day periods in each 12 day experimental period. Heat production was measured continuously by determining of exchanges of oxygen and carbondioxide and was calculated according to the formulae of Brouwer (1965). Food residues were collected and sampled after each respiration period to determine food intake during respiration measurements.
Intake of metabolizable energy (ME) was determined from the energy values of the food minus losses of energy in faeces, urine, dust and food refusals. Similarly

protein deposition was estimated from N in food intake, faeces, urine, and NH_3 in the air. Retained energy (RE) was calculated by substracting heat production from ME. Fat accretion was obtained by the following equation:

$$F = (ER - 23.7 \times P)/39.6 \qquad (1)$$

where ER = energy retention ($kJ/kg^{0.75}$)
F = fat deposition ($g/kg^{0.75}$)
P = protein deposition ($g/kg^{0.75}$)

The values of 23.7 and 39.6 in equation 1 represent the calorific values of body protein and fat respectively (ARC, 1981).
The efficiency of utilization of metabolizable energy for protein (k_p) and fat deposition (k_f) are assumed to be 0.54 for protein and 0.74 for fat (ARC, 1981). The amount of metabolizable energy available for production was then calculated as:

$$ME_p = \frac{1}{k_p} \times 23.7 \times P + \frac{1}{k_f} + 39.6 \times F \qquad (2)$$

Maintenance requirement, expressed per $kJ/kg^{0.75}$, was then estimated by subtracting food available for production (ME_p) from total ME.

$$ME_m = ME\text{-}ME_p \qquad (3)$$

In each experiment energy metabolism was determined in this manner at each temperature. Values were calculated in each experimental period, each collection period and each respiration period. Differences between temperature treatments and between periods within temperature treatments were analysed by Students *t*-test (Snedecor and Cochran, 1976).

Results

Daily gain and food intake

In table 2 daily gain and food intake are presented as means for each experimental period of 12 days and separately for each of the 2 collection periods. Overall mean values were not significantly different between temperatures. During the first collection period the daily gain of pigs kept at 15 °C was significantly lower ($p < 0.05$) than that of pigs kept at 25 °C. At 15 °C daily gain improved significantly (by 85 g) during the second period ($p < 0.05$). At 25 °C the improvement between both periods was 22 g. Although differences between temperatures in mean food intake were not significant, pigs at 15 °C had a greater food intake in the second period than in the first ($p < 0.05$). Pigs at 15 °C had lower food intake (by 81 g) during the first period and higher food intake (by 21 g) during the second period, compared with pigs kept at 25 °C.

Table 2. Daily gain and food intake (g/d) for both temperature treatments during the experimental period (Day 1-12) and during collection period I (Day 1-6) and collection period II (Day 7-12). Mean (sem).

	Daily gain			
Treatment	*Day 1-12*	*Day 1-6*	*Day 7-12*	*Period I-II*
15 °C	596 (38)	554 (28)	639 (33)	−85[a]
25 °C	622 (41)	611 (41)	633 (43)	−22
Difference	−26	−57*	6	
	Food intake			
Treatment	*Day 1-12*	*Day 1-6*	*Day 7-12*	*Period I-II*
15 °C	1219 (46)	1102 (18)	1337 (17)	−235[a]
25 °C	1249 (51)	1183 (50)	1316 (82)	−133
Difference	−30	−81	21	

rows: superscript (a) indicates significant differences between collection periods within temperature treatment ($p < 0.05$)

columns: superscript (*) indicates significant differences between temperature treatments within periods ($p < 0.05$).

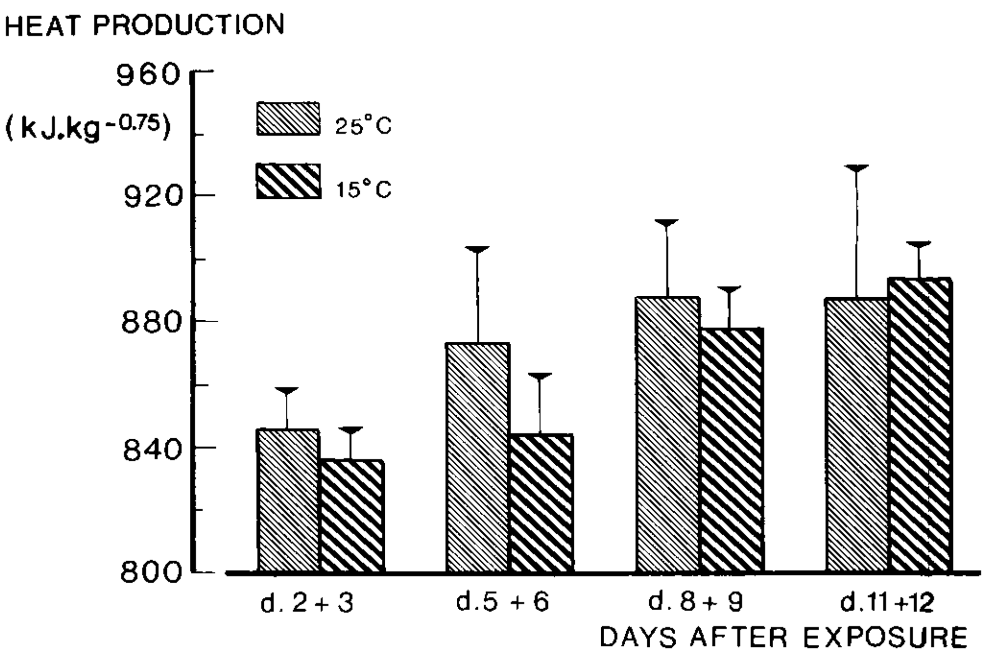


Figure 1. Heat production ($kJ/kg^{0.75}$) in successive days after exposure to each temperature

Heat production

Heat production data in each respiration period are presented in figure 1. Heat production of pigs at 15 °C was lower during the first three respiration periods compared with pigs at 25 °C. During the fourth respiration period heat production at 15 °C was similar to that at 25 °C. Over the whole experiment heat production was lower at 15 °C.

ME and protein deposition

Dailly metabolizable energy, retained energy and energy retained in protein are presented in table 3. Overall, intake of metabolizable energy per $kg^{0.75}$ was not significantly lower at 15 °C than at 25 °C. However ME of pigs at 25 °C was significantly higher than at 15 °C during the first period ($p < 0.05$). During collection period I, pigs at 15 °C had reduced protein gain but this increased in the second collection period ($p < 0.05$). RE was not significantly different between treatments. Energy deposited in protein at 15 °C was lower than at 25 °C during the first 6 days after exposure, but was similar thereafter.

Table 3. Daily metabolizable energy (ME), retained energy (RE) and energy deposited in protein ($kJ/kg^{0.75}$) for both temperature treatments during the experimental period (Day 1-12) and during collection period I (Day 1-6) and collection period II (Day 7-12). Mean (sem).

		ME		
Treatment	*Day 1-12*	*Day 1-6*	*Day 7-12*	*Period I-II*
15 °C	1368 (48)	1304 (65)	1431 (63)	−127
25 °C	1462 (76)	1470 (98)	1454 (132)	16
Difference	−94	−166*	−23	
		RE		
	Day 1-12	*Day 1-6*	*Day 7-12*	*Period I-II*
15 °C	505 (60)	463 (57)	567 (102)	−104
25 °C	579 (169)	611 (76)	547 (55)	64
Difference	−74	−148	20	
		Energy retained in protein		
	Day 1-12	*Day 1-6*	*Day 7-12*	*Period I-II*
15 °C	239 (6)	226 (10)	251 (6)	−25[a]
25 °C	266 (13)	275 (19)	257 (18)	18
Difference	−27	−49*	−6	

rows: superscript (a) indicates significant differences between collection periods within temperature treatment ($p < 0.05$)
columns: superscript (*) indicates significant difference between temperature treatments within periods ($p < 0.05$)

Maintenance requirement and fat deposition

Maintenance requirements for both temperature treatments are given in table 4. Deposition of fat, expressed in $kJ/kg^{0.75}$ was calculated from equation (2) and is also presented in table 4. During the first 6 day period the maintenance requirement (ME_m) of pigs housed at 15 °C was 11% (58 $kJ/kg^{0.75}$) higher compared with pigs kept at 25 °C ($p < 0.05$). In the second 6 day period this difference was markedly reduced and ME_m of pigs at the two temperatures became similar (567 and 559 $kJ/kg^{0.75}$ for temperature treatments of 15 and 25 °C, respectively). Fat gain was 41% higher in period I at 25 °C compared with 15 °C ($p < 0.05$). In period II the difference was 5% (not significant).

Table 4. Maintenance requirement (ME_m) and fat deposition ($kJ/kg^{0.75}$) for both temperature treatments during the experimental period (Day 1-12) and during collection period I (Day 1-6) and period II (Day 7-12). Mean and sem.

	ME_m				Fat			
Treatment	*Day 1-12*	*Day 1-6*	*Day 7-12*	*Period I-II*	*Day 1-12*	*Day 1-6*	*Day 7-12*	*Period I-II*
15 °C	566 (11)	565 (17)	567 (18)	−2	266 (35)	237 (52)	295 (50)	−58
25 °C	533 (17)	507 (15)	559 (25)	−52	323 (49)	335 (62)	311 (85)	24
Difference	33	58*	8		−57	−98*	−16	

columns: superscript (*) indicates significant differences between temperature treatments within periods ($p < 0.05$)

Discussion

The present experiments show that during the first 6 days of exposure the effect of a low ambient temperature is much more pronounced than during the following 6-day period. In the present experiments a temperature of 15 °C resulted in a decrease of 60 g/d in daily gain in the first 6 days compared with 25 °C. Animals held at 15 °C clearly increased food intake after the first 6 days of exposure. This is in agreement with results of Christison and Williams (1982) and Mount *et al.* (1980). Animals in this study did not respond immediately to the lower temperature treatment by means of increased food intake. A similar delayed response was observed with rats (Leung and Horowitz, 1976). Barnett and Mount (1967) reported experiments in which mice took 5 days before adjusting their food consumption after being transferred to a cold environment. Moreover, Mount (1979) stated that a rise in metabolic response to cold can bring about metabolic adaptation in the form of an increased resting metabolism at thermal neutrality. Experiments in this study did not cover a period long enough to estimate this effect. Animals at 15 °C reached higher rates of food intake and heat production during days 11 and 12 after exposure and had an increased maintenance requirement compared with 25 °C.

Mount (1979) and Close *et al.* (1981) indicated that activity of the animals interacts with climatic environment. Therefore, food intake might be lowered due to reduced physical activity. The decrease in food intake is reflected in a lower in-

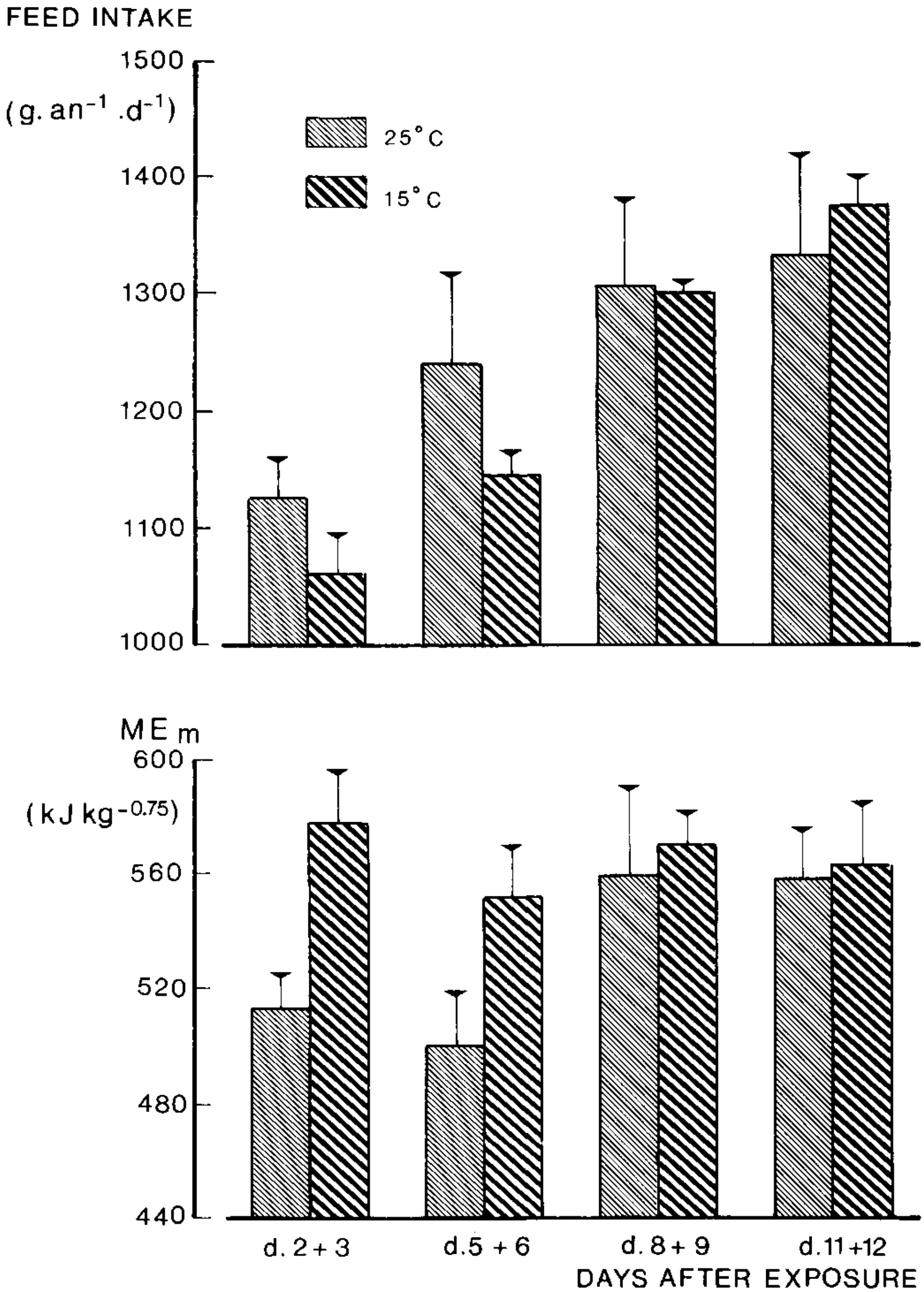


Figure 2. Feed intake (g/d) and maintenance requirement (ME_m, kJ/kg$^{0.75}$) at each temperature treatment

take of metabolizable energy (by 166 kJ/kg$^{0.75}$) during the first collection period. To assess the effect of reduced food intake and lowered heat production by thermoregulatory behaviour the net effect of both phenomena is assessed by calculating maintenance requirement (ME_m). In figures 1 and 2 heat production, food intake and ME_m are shown. During the first two respiration periods (day 2 and 3 and day 5 and 6) ME_m was significantly increased ($p < 0.05$) at 15 °C compared with 25 °C. However differences became smaller with duration of the experiments.

In these experiments adaptation of young growing pigs to a moderate deviation of ambient temperature from thermal neutrality was accompanied by a reduced food intake. The heat production at 15 °C did not cover the thermal demand at this temperature so that energy gain was lower (table 3) and maintenance requirement (ME_m) increased. The results show that during days 9 and 10 maintenance requirements at both temperatures were similar. This equality in ME_m means that the pigs are not distinctly different in this respect and can be considered as acclimated to the climatic environment. Therefore, it is concluded that acclimation to 15 °C compared with 25 °C was completed about 8 days after initial exposure. The increased weight of the pigs during the experiments cannot have caused such an effect because an increase of 10 kg in liveweight reduces by 0.7 to 1 °C a lower limit of thermal neutrality (Close, 1982).

Estimates of the maintenance requirements of pigs from data in the literature were reviewed by the Agricultural Research Committee (1981). For a liveweight range of 20 to 90 kg the estimate of ME_m was 458 kJ/kg$^{0.75}$. Values were derived from measurements with individually housed pigs at different feeding levels. Maintenance requirements are not consistent with age and with liveweight of growing animals (Verstegen, 1971; Thorbek *et al.*, 1983), and it is desirable to keep pigs close to normal behaviour in order to get results more applicable in practice (Thorbek, 1975). For group-housed pigs of 20-25 and 25-35 kg liveweight Thorbek *et al.*, (1983) calculated ME_m to be 627 and 619 kJ/kg$^{0.75}$ respectively. Close (1978) estimated values of 440 and 577 kJ/kg$^{0.75}$ at temperatures of 25 and 15 °C for individually housed pigs at comparable liveweight. Verstegen and van der Hel (1976) calculated an increase in maintenance requirement of 4.5% for group-housed pigs (32 kg) kept at 15 °C compared with pigs kept at 25 °C.

The difference in maintenance requirement between 15 °C and 25 °C in this study was 11.4%, clearly higher than found by Verstegen and van der Hel (1976). This discrepancy was probably due to the difference in liveweight and thus in deviation from the lower critical temperature. If it is accepted that pigs are acclimated in the second period then ME_m in this period may be compared to estimates in the literature. The value of ME_m of 567 kJ/kg$^{0.75}$ is comparable to the estimate of Thorbek *et al.*, (1983).

In practice, climatic conditions in buildings that are not climatically controlled vary constantly and therefore the relevance of the present data to farm conditions may be greater than in most experiments reviewed by Close (1981). From the experiments reviewed by the ARC (1981) it was concluded that the effects of deviations from thermal neutrality may be greater during the first days or weeks after exposure compared with longer exposure to deviations. The present results also suggest such effects. Therefore, it is to be expected that the fluctuating conditions in practice probably result in gains less than predicted from exposure to constant temperature for a longer period.

Acknowledgements

The authors acknowledge Mr. W. van der Hel, Mr. H.Brandsma and Mr. J.M. van der Linden for their assistance with the experiments, Mrs. I. Janssens is gratefully thanked for typing the manuscript.

References

Agricultural Research Committee (1981). The nutrient requirements of pigs, *Commonwealth Agr. Bur.* p. 1-44.

Barnett, S.A. and Mount, L.E. (1967). Resistance to cold in mammals, *Thermobiology, Ed. A.H. Nose, Academic Press London and New York*, p. 411-477.

Brouwer, E. (1965). Report of subcommittee on constants and factors. Third Symposium on Energy Metabolism. Troon Scotland. *EAAP-publ.* **11**: 441-443.

Christison, G.I. and Williams, C.M. (1982). Effects of cold on animal production. *CRC Handbook of Agricultural Productivity*, vol. II. p. 69-76.

Close, W.H. (1978). The effects of plane of nutrition and environmental temperature on the energy metabolism of the growing pig, 3. The efficiency of energy utilization for maintenance and growth, *Br. J. Nutr.* **40**: 433-438.

Close, W.H. (1981). The climatic requirements of the pig, *Environmental aspects of housing for animal production (Ed. J.A. Clark), Butterworth, London*, p. 149-166.

Close, W.E. and Mount, L.E. (1978). The effect of plane of nutrition and environmental temperature on the energy metabolism of the growing pig, 1. Heat loss and critical temperature, *Br.J. Nutr.* **40**: 413-421.

Close, W.H., Heavens, R.P. and Brown, D. (1981). The effects of ambient temperature and air movement on heat loss from the pig, *An. Prod.* **32**: 75-84.

Fuller, M.F. and Boyne A.W. (1972). The effects of environmental temperature on the growth and metabolism of pigs given different amount of foods, 2. Energy metabolism, *Br. J. of Nutr.* **28**: 373-384.

Holmes, C.W. and Mount L.E. (1967). Heat loss from groups of growing pigs under various conditions of environmental temperature and air movement, *An. Prod.* **9**: 435-442.

Leung, P.B.M., and Horowitz, B.R., (1976). Free-feeding patterns of rats in response to changes in environmental temperature, *Am. J. Phys.* **231**: 1220-1224.

Morrison, S.R. and Mount, L.E. (1971). Adaptation of growing pigs to changes in environmental temperatures, *An. Prod.* **13**: 51-57.

Mount, L.E. (1979). *Adaptation to thermal environment: man and his productive animals*, Edward Arnold, London.

Mount, L.E., Start, I.B. and Brown, D (1980). A note on the effects of forced air movement and environmental temperature on weight gain in the pig after weaning, *An. Prod.* **30**: 295-298.

Snedecor, G.W. and Cochran, C. (1976). *Statistical Methods*, Iowa State University Press.

Thorbek, G. (1975). *Study on energy metabolism in growing pigs*, Beretning frå Statenshusdyrbrugsforsøg 424, Copenhagen.

Thorbek, G., Chwalibog, A. and Henckel, S. (1983). Energetics of growth in pigs from 20 to 120 kg live weight, *Zeitschr. f. Tierphys., Tierern., Fttmtk.* **49**: 238-249.

Verstegen, M.W.A. (1971). *Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups*, Thesis, Wageningen, The Netherlands.

Verstegen, M.W.A., Close, W.H., Start, J.B. and Mount, L.E. (1973). The effects of environmental temperature and plane of nutrition on heat loss, energy retention and deposition of protein and fat in groups of growing pigs, *Br. J. Nutr.* **30**: 21-35.

Verstegen, M.W.A. and van der Hel, W. (1976). Energy balances in groups of pigs in relation to air velocity and ambient temperature, *Energy Metabolism of Farm Animals (Ed. M. Vermorel), EAAP No.* **19**:347-350.

CHAPTER III

Acclimation of growing pigs to ambient temperature in relation to duration of exposure

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Netherlands Journal of Agricultural Science: submitted.

Summary

Acclimation of young growing pigs of 20 kg liveweight to ambient temperatures of 25 and 15 °C was determined through the effects on daily gain, food intake and heat production. Activity of the pigs was also included to determine how long acclimation took. Four replicates with 20 group-housed pigs were carried out per temperature. Daily gain and food intake of pigs at 15 °C were less for the first 6 days than in pigs at 25 °C. Then they improved. Pigs showed a different response to ambient temperature at different times of the day. Animals acclimated to low ambient temperature more during daytime than night. Acclimation was mainly related to activity of the pigs and was established 8 days after initial exposure.

Introduction

The climatic environment is an important factor for optimizing productivity of pig production. To define optimal farm conditions the range of climatic requirements that allows maximum efficiency in utilization has to be determined (Close, 1981). Moreover influences of the climatic environment upon animal welfare and health of pigs, especially with respect to factorial diseases, may play a significant role in productivity (Blecha and Kelley, 1981; Close, 1981). Here duration of exposure to extreme cold and warm thermal conditions is also important (Siegel, 1980). Adjustment of pigs to low ambient temperatures include behavioural, physiological and morphological adaptation (Mount, 1979). Metabolic acclimation can be considered as a metabolic response to an environmental stimulus, usually environmental temperature (Mount, 1979). This metabolic acclimation is a form of adaptation that is dependent on liberal food supply if the animal is not to waste progressively by using food energy to produce heat in the cold at the expense of body tissue (Mount, 1979). Moreover, group housed pigs exposed to lower ambient temperatures alter their behaviour (huddling) and activity levels, to reduce heat loss (van der Hel *et al.*, 1986). If ambient temperature falls below the lower border of thermoneutrality *i.c.* the lower critical level, metabolic heat production is increased by the thermoregulatory response of the pigs (Mount *et al.*, 1980). Pigs adapt to a chronic exposure to cold and this may result in morphological changes and increased thermal insulation due to changes in coat and subcutaneous fat (Mount, 1979; Christison and Williams, 1982).

In the present study acclimation of group-housed young growing pigs during a period of 12 days of exposure was estimated. Acclimation is described as alteration in metabolic rate with duration of exposure. It is thought that pigs become acclimated if metabolic rate becomes relatively constant after some days of exposure. The effect of exposure to temperature on metabolic rate altering or disappearing may also be described as acclimation. Acclimation includes levels of heat production and activity of the pigs.

Material and Methods

Animals

In these experiments pigs from 2 herds were used. They were (Large White × Dutch Landrace) crossbreds. In each experiment pigs originated from the same herd and were gilts and castrated males. They had been housed in a similar environment during post-weaning on the farm. Mean initial live weight of the pigs is presented in table 1.

Table 1. Mean initial weight and standard deviation at start of the experiments (sem = standard error of the mean).

Temperature	Replicate	No. of animals	Initial weight (kg)	(sem)
25 °C	1	20	22.3	0.43
	2	20	20.4	0.55
	3	20	21.5	0.57
	4	20	21.7	0.47
15 °C	1	20	21.7	0.50
	2	20	21.5	0.42
	3	20	22.5	0.76
	4	19	20.5	0.41

Plan of experiment

Two ambient temperatures (25 °C and 15 °C) were applied. Per temperature treament 4 replicates were carried out at random. Temperatures chosen were within thermoneutrality (25 °C) and below or around thermoneutrality (15 °C) for group-housed growing pigs of approximately 20 kg liveweight (Bruce and Clark, 1979). Holmes and Mount (1967) stressed the importance of assessing effects of ambient temperatures in group housed pigs instead of obtaining estimates from single-housed pigs. The experiments were carried out in two large, identical respiration chambers of the Department of Animal Husbandry at the Agricultural University.

In the open-circuit calorimeter climatic environment (*e.g.* ambient temperature, air humidity and air velocity) can precisely be controlled and accurately measured. For each temperature treatment applied relative humidity was kept at approximately 65% and air velocity was below 0.2 m/s.

Feeding and Housing

Pigs were fed *ad libitum*. Pigs in replicate 1, 2 and 3 received food containing 16.4 kJ gross energy per gram and 17% crude protein. In replicate 4 protein content in the food was similar to that in replicates 1-3, whereas energy content was somewhat higher (17 kJ gross energy per gram). Feed was offered in pelleted form in self-feeders. Animals had free acces to water provided by a water bowl. Artificial light regime was from 07.00-19.00 h. The respiration chamber has a volume of 80 m³ and 2 groups of 10 pigs each can be housed with an area per pen of 9 m². The floor of the pens consists of non-toxic asphalt with 10% of the pen covered with slats.

Experimental routine

Directly after arrival pigs were weighed individually and alloted to the pens. They were kept at 20 °C for two days after arrival. Pigs acclimatize to the respiration chambers within 2-3 days. Then the temperature treatment was applied. In this way all pigs were treated similarly before temperature was increased to 25 °C or lowered to 15 °C. Each temperature treatment lasted 12 days (figure 1). Metabolizability of food was determined in two successive 6 d collection periods. Data obtained during the periods were used to calculate partitioning of energy and accretion of protein and fat. (see Verhagen *et al.*, 1987). Pigs were weighed after each collection period. Feed intake was expressed in metabolizable energy intake per kg metabolic weight ($kg^{0.75}$) and calculated from energy in food and subtraction of energy in faeces, urine and food refusals.

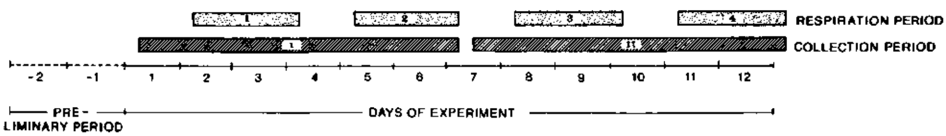

Figure 1. Experimental routine

Measurements

Heat production from gaseous exchange of oxygen and carbon dioxide was measured continuously during 48-hour respiration periods (see figure 1) and calculated according to Brouwer (1965). Measurements of heat production covered day 2 + 3, 5 + 6, 8 + 9 and 11 + 12 of each experiment. A detailed procedure of measurements of gaseous exchange is given by Verstegen *et al.*, (1987). Briefly the procedure was as follows: the oxygen and carbon dioxide content of the air entering the chambers was measured for 6 minutes. During a subsequent 6-minute period the oxygen and carbon dioxide content of the air leaving one respiration chamber was measured. Again 6 minutes later this was done for the other chamber and subsequently for the air entering the chambers. This procedure was done continuously for 48-hour periods. Difference between levels of gases entering and leaving each chamber represented oxygen-consumption and carbondioxide-production of pigs. Thus heat production data was obtained per 18- minute period.

According to the method used by Wenk and van Es (1976) physical activity of the pigs was measured with an ultrasonic device. Through this system quantitative estimates of the activity of pigs are recorded during 6 min. Each pen within the chamber was monitored with one device. Thus two devices were used per chamber. In this way data on heat production and physical activity were obtained on 8 days during the 12 day period of each experiment. The data was grouped according to periods of the day and day of exposure. Acclimation was estimated from this data.

Statistical analysis

Acclimation of pigs at days (D) after initial exposure to ambient temperature (T) was analysed with the following statistical model (SAS, 1985):

$$Y_{ijk} = \mu + T_i + R_{j(i)} + D_k + (T \times D)_{ik} + e_{ijk} \qquad \text{(model I)}$$

where Y_{ijk} = heat production at temperature treatment i in replicate j at day k,
μ = overall mean,
T_i = effect of temperature treatment i (i = 1,2),
$R_{j(i)}$ = effect of replicate j within treatment i (j = 1,....,4),
D_k = effect of day number k after start of the experiment (k = 2, 3, 5, 6, 8, 9, 11, 12),
$(T \times D)_{ik}$ = effect of interaction of day number with temperature treatment,
e_{ijk} = residual error term.

To analyse acclimation in relation to activity and metabolic acclimation activity-free heat production (AFH) was calculated. Activity was regressed on heat production within each replicate and within the light and dark periods separately. In this regression analysis values of heat production and of total activity values over 18-minute intervals were used. Activity-associated heat production (AH) was calculated from this, whereas activity-free heat production was obtained by subtracting it from heat production. Because pigs are diurnal animals, metabolic rate and level of activity during day are not equal to those during the night (Mount, 1979). Moreover, metabolic rate and activity are affected by ambient temperature (Close, 1971; Mount, 1979; Van der Hel *et al.*, 1984). Mean values of heat production, AH and AFH were thus calculated per day number within the light and dark periods. Model I was used to determine acclimation with respect to activity-associated and activity-free heat production.
The effect of replicate and day number was also analysed for each temperature treatment separately. The following model was used to analyse heat production, AFH and AH with respect to day number:

$$Y_{jk} = \mu + R_j + D_k + e_{jk} \qquad \text{(model II)}$$

where Y_{jk} = heat production (H, AH or AFH),
μ = overall mean,
R_j = effect of replicate j (j = 1, ..., 4),
D_k = effect of day number k (k = 2,3,5,6,8,9,11,12),
e_{jk} = residual error term.

Model III was used to estimate day of acclimation after initial exposure to ambient temperature.

$$Y_{jk} = \mu + R_j + b \, . \, x_k + e_{jk} \qquad \text{(model III)}$$

where Y_{jk} = heat production (H, AH, or AFH)
μ = overall mean.
R_j = effect of replicate j (j = 1, ..., 4),
b = regression coefficient,
x_k = day number after initial exposure (k= 2,3,5,6,8,9,11,12),
e_{jk} = residual error term

Model III was used in analysis within temperature treatment and over temperature treatments. Within each temperature treatment, a significant regression coefficient indicated a significant change of values of heat production with duration of exposure. Coefficients per temperature treatment were tested against a pooled coefficient over temperatures (*F*- test; Snedecor and Cochran, 1976) to obtain differences in change of heat production between temperature treatments.

Results

Mean liveweight of pigs at the start of the temperature treatments were similar in all experiments (see table 1). Mean intake of metabolizable energy and heat production per replicate are presented in table 2. Intake of metabolizable energy is averaged over the whole experimental period, whereas heat production is an average of the four respiration periods. Moreover, data on daily gain and food conversion are given in this table. Animals exposed to 15 °C showed a lower intake of metabolizable energy (ME), produced less heat and had a lower daily gain compared with pigs at 25 °C. Feed conversion of pigs at both temperature treatments were similar. In figure 2 daily gain and ME-intake are given per 6-day period. During the first 6 days of the temperature treatments pigs at 25 °C had a significantly higher daily gain of 57 g/d compared with those at 15 °C ($p < 0.05$). Pigs kept at 15 °C, however, significantly improved daily gain and ME-intake during day 7 to 12 of the treatment ($p < 0.05$). Food intake per respiration period is given in table 3. Intake of food of pigs at 25 °C increased 203 g/d from day 2 + 3 to day 11 + 12. At 15 °C the increase was 313 g/d. In figure 3 heat production

Table 2. Intake of metabolizable energy (kJ/kg$^{0.75}$ per day), mean heat production (kJ/kg$^{0.75}$ per day), daily gain (g/d) and feed conversion.

Temperature	Replicate	Metabolizable energy	Heat production	Daily gain	Feed conversion
25 °C	1	1417	881	707	1.77
	2	1420	878	467	2.49
	3	1254	808	522	2.24
	4	1773	941	794	1.87
Mean ± sem		1462 ± 109.4	876 ± 27.2	622 ± 76.8	2.09 ± 0.17
15 °C	1	1390	879	591	2.06
	2	1388	878	553	2.23
	3	1196	830	563	2.14
	4	1497	864	680	1.80
Mean ± sem		1368 ± 62.7	865 ± 11.4	596 ± 28.9	2.06 ± 0.09

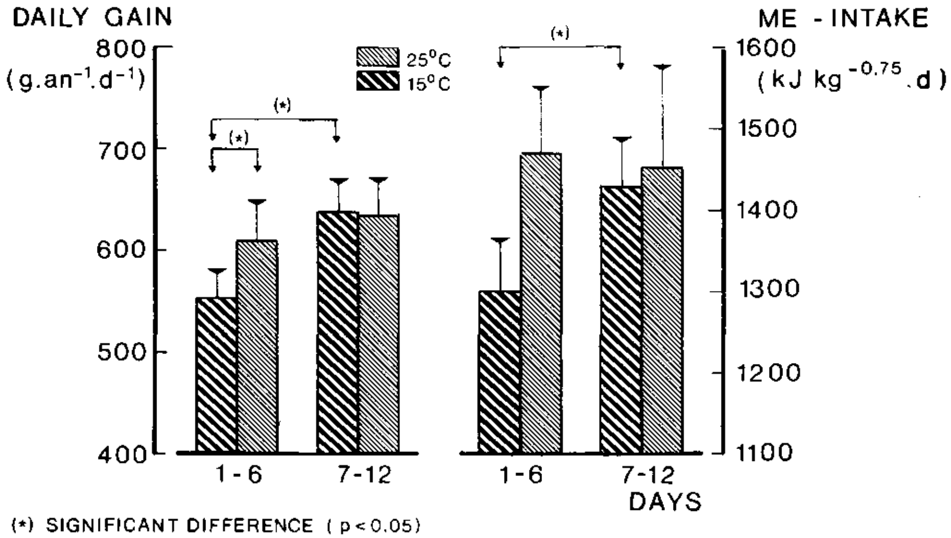

Figure 2. Daily gain (g/d per day) and intake of metabolizable energy (ME) (kJ/kg$^{0.75}$ per day) per temperature treatment and per 6-day period.

Table 3. Feed intake of animals at various days after initial exposure to 25 and 15 °C in g/d.

	Temperature treatment			
	25 °C		15 °C	
Days after exposure	Mean	sem	Mean	sem
d. 2 + 3	1125	29.0	1060	37.0
d. 5 + 6	1241	73.5	1144	19.5
d. 8 + 9	1305	75.0	1300	11.0
d. 11 + 12	1328	99.0	1375	26.5

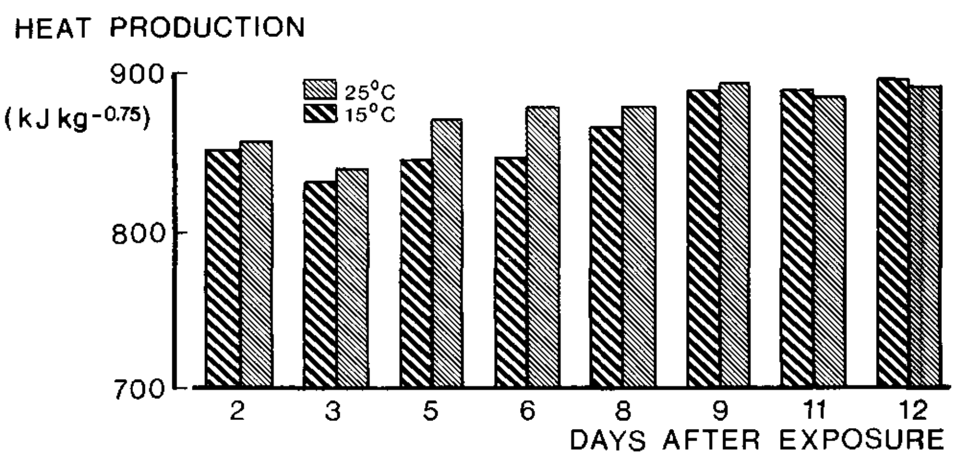

Figure 3. Heat production (kJ/kg$^{0.75}$ per day) at each temperature treatment at successive days after exposure

during the successive days after exposure to both temperature treatments is shown. Heat production of pigs for the temperature treatment of 15 °C was lower compared with that of pigs at 25 °C until day 11 after exposure. At 15 °C heat production increases from day 2 until day 9 after exposure.

Table 4. Heat production (kJ/kg$^{0.75}$) for the dark (19.00-07.00 h) and light period (07.00-19.00 h).

Temperature	Replicate	Heat production during			
		Dark		Light	
		Mean	sem	Mean	sem
25 °C	1	808	11.6	960	11.8
	2	806	8.3	920	21.8
	3	767	8.3	856	7.4
	4	894	19.5	997	15.2
Mean		819	11.9	933	14.1
15 °C	1	850	8.6	913	14.9
	2	831	7.3	931	15.6
	3	796	10.0	867	15.6
	4	820	12.1	917	16.3
Mean		823	9.5	906	15.6

In table 4 mean values of heat production during the light (07.00-19.00 h) and dark period (19.00-07.00 h) are given per temperature treatment. During the light period heat production is clearly higher than during the dark period ($p < 0.05$). The difference was 115 kJ for the temperature treatment of 25 °C whereas it was 83 kJ at 15 °C. Data indicates that to estimate acclimation of group-housed pigs to different temperature treatments the light and dark period must be taken into account separately. To differentiate acclimation associated with activity (AH), heat production of the pigs, without activity, was calculated. For this the regression of heat production on physical activity measurements was carried out within each replicate and for the light and dark period separately. By subtracting activity associated heat production (AH) from total heat production (H) the activity-free heat production (AFH) of the pigs was obtained. In this way metabolic rate and activity can be distinctly analysed with respect to acclimation to both temperature treatments. Analysis of variance (model I) was carried out for the values of heat production during the light and dark period. In table 5 results of this analysis is presented. Data show that the effect of replicate within temperature on heat production values was significant when tested against the residual error term. The effect of temperature treatment on heat production is significant during the light period but absent during the dark period. As a contrast the effect of temperature on activity-associated heat production (AH) was significant during the dark period and absent during the light period ($p < 0.01$). Effect of temperature treatment tested against error term of replicate within temperature was not significant. Analysis of variances showed that variances within both temperature treatments were heterogenous. Therefore acclimation with respect to duration of treatment was analysed with model II.

Table 5. Significance of the effects of temperature, replicate and day number for heat production (H), activity associated heat production (AH) and activity-free heat production (AFH).
R^2 = determination coefficient: % of variance explained by the statistical model (model I).

	Light period			Dark period		
	H	AH	AFH	H	AH	AFH
Temperature	**	n.s.	**	n.s.	**	n.s.
Replicate within temperature	**	**	**	**	**	**
Day number	**	**	**	n.s.	**	**
Temperature × Day Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R^2	85.2	89.9	83.9	73.7	88.6	71.2

n.s. = not significant
** = significant ($p < 0.01$)

The results of the analysis of variance at each temperature treatment are given in table 6. At 15 °C heat production (H), activity-free (AFH) and activity associated (AH) heat production are significantly affected by day number during the light period. At this temperature AFH is significantly affected by day number during the dark period. For the treatment of 25 °C a significant influence of day number on activity free heat production during the light period and on activity related heat production during the dark period was found. Figure 4 shows least squares means for the light and dark period, respectively. The level of heat production is different during day and night. Especially the difference in heat production between both treatments was most pronounced during 2 days after initial temperature exposure and it diminished thereafter.

During the dark period heat production at both temperature treatments was not

Table 6. Significance of the effects of day number and replicate on heat production (H), activity-associated heat production (AH) and activity-free heat production (AFH) during light and dark period at each temperature treatment.
R^2 = determination coefficient: % of variance explained by the statistical model (model II)

	Light period					
	H		AH		AFH	
	25	15	25	15	25	15
Replicate	**	**	**	**	**	**
Day number	n.s.	**	n.s.	**	**	**
R^2	82.5	88.6	90.3	87.8	82.5	84.6
	Dark period					
	H		AH		AFH	
	25	15	25	15	25	15
Replicate	**	**	**	**	**	**
Day number	n.s.	n.s.	**	n.s.	n.s.	*
R^2	74.2	70.8	82.8	94.8	70.4	73.2

n.s. = not significant
* = significant ($p < 0.05$)
** = significant ($p < 0.01$)

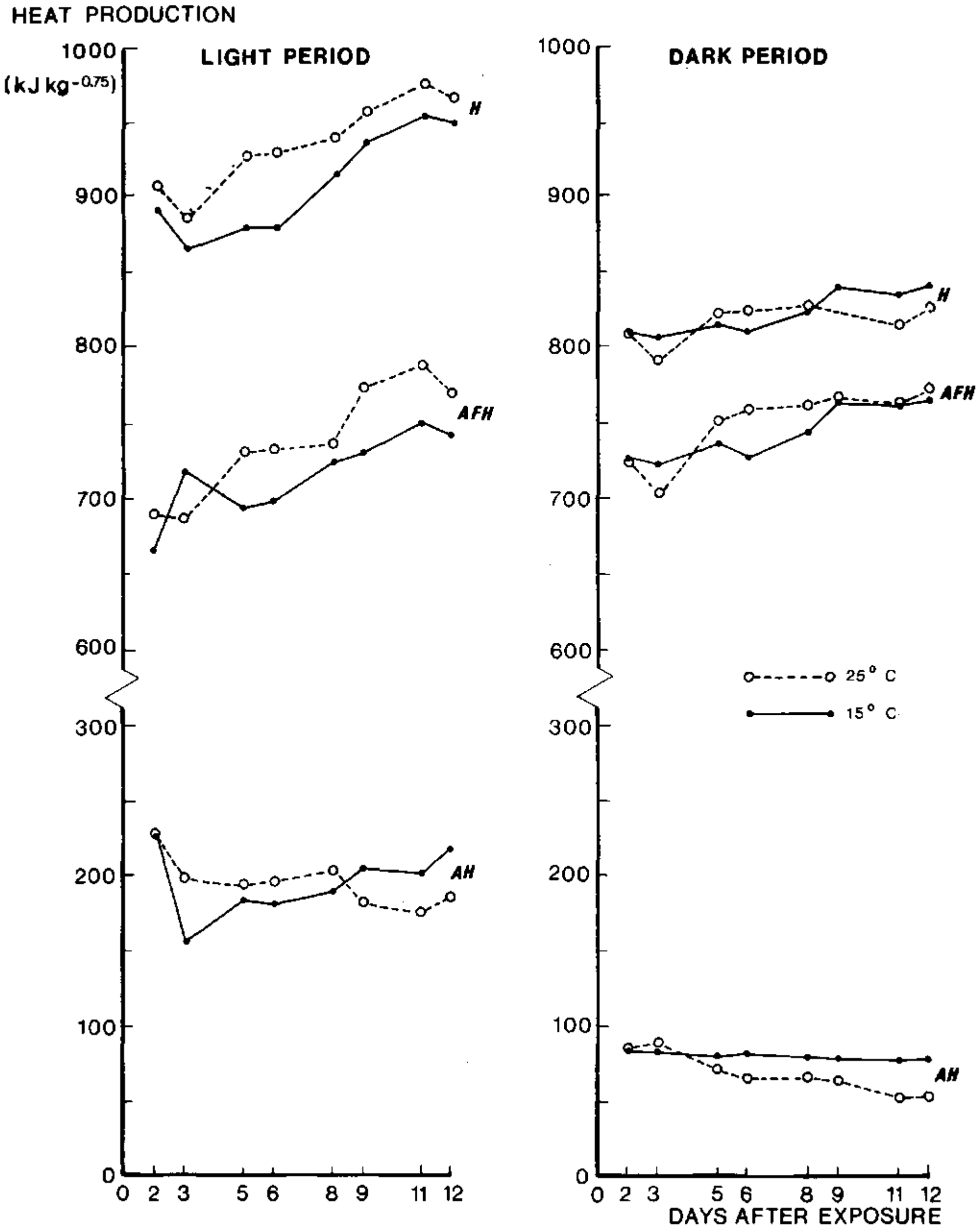

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Figure 4. Least squares means of heat production (H), activity-free heat production (AFH) and activity-related heat production (AH) for each temperature treatment at the light and dark period (kJ/$kg^{0.75}$ per day).

significantly effected by duration of the treatment. Activity related heat production remains constant during the 15 °C treatment whereas it declined at 25 °C. Activity free heat production however, was clearly increased at 15 °C from day 3 onwards, and became similar to heat production at 25 °C at day 9. For both treatments the effect of replicate is significant ($p < 0.01$).

Discussion

The ability of pigs to deal with variation in environmental factors such as ambient temperature and other climatic conditions is mainly dependent on the factors insulation, food intake and metabolic adaptation (Christison and Williams, 1982). Metabolic acclimation is a form of adaptation that is also dependent on food intake. Liberal food supply can be used to compensate for increased heat loss if the animal is not to waste energy progressively through using food energy to produce heat in the cold at the expense of body tissue (Mount, 1979). Long term exposure to cold will lead pigs to increase food intake, but sometimes a delay in response may occur (Leung and Horowitz, 1976). In the present experiment such a delayed response was noted. After day 6 to 8, the level of intake increased considerably. In laboratory pigs a response in delayed adjustment of food intake was similarly found after 5 days exposure to a cold climatic environment (Barnett and Mount, 1967).

Hacker *et al.* (1973) and Fuller and Boyne (1972) found that exposure to cold and restricted food intake is an additive effect. Because the experiments were aimed at studying the effect of ambient temperature *per se* and allowing pigs to use their physiological and behavioural mechanisms in acclimation to environmental temperature an *ad libitum* feeding strategy was preferred.

Results in this experiment showed that pigs in the temperature treatment of 15 °C, compared with those at 25 °C, had a reduced intake of metabolizable energy during the first six days after exposure. Thereafter food intake reached a similar level to that for pigs at 25 °C. This effect was similarly reflected in daily gain of the pigs.
Close (1971) and van der Hel *et al.* (1984) found that variation in metabolic rate for different parts of the day is influenced by ambient temperature. In the present study a difference in heat production between the light and dark period was also found. This difference was influenced by ambient temperature. The data of the study show that heat production of pigs during the light period and kept at an ambient temperature of 15 °C was less that that of pigs held at 25 °C. During the dark period values were similar.

Verstegen *et al.* (1982) and Thorbek *et al.* (1982) stated that physical activity of pigs cannot be neglected and might account for 10-30% of total heat production of young growing pigs. As was also indicated by Mount (1979) and Close *et al.* (1981) different environments interact with activity and group behaviour (huddling) so that it is important to include physical activity in acclimation. Results of our study showed that the effects of temperature on metabolic rate depend on day number after initial exposure. Moreover it cannot be fully excluded that partly this acclimation was related to acclimatization to the respiration chamber. However, it was thought that after 2-3 days and thus at initiation of the temperature treatment acclimatization was nearly complete. Dantzer (1973) found that 3 days after introduction to a pen the hyperactivity of the pigs had disappeared. The huddling of pigs together effectively modifies the impact of the environment and reduces the need for metabolic response in the cold (Mount, 1979). The increased overall insulation that follows the behavioural response of huddling are related to a smaller metabolic response to cold for group-housed pigs compared with single housed pigs (Mount, 1979). Therefore, metabolic rate was separated into a component which relates heat production to activity. The remainder can be considered as activity-free heat production.

Results showed that activity related heat production at 15 °C was less than at 25 °C with increase in duration of exposure until day 9 during the light period. The same occurred with regard to activity-free heat production. Heat production is less at 15 °C than at 25 °C from day 5 onwards. With progress of exposure to the temperature treatment acclimation leads to an increase in heat production. The difference between total heat production at 25 °C and 15 °C was especially related to increase of activity during the light period.
At night activity related heat production at 15 °C remained above the level at 25 °C with progress in days of exposure. The activity-free heat production at 15 °C at night was similar to that at 25 °C from day 9 onwards. As a result total heat production for the dark period at 15 °C was higher from day 9 onwards compared with that of pigs kept at 25 °C.

Acclimation can be considered as that duration of exposure to a temperature after which there is no change in heat production. It can also be defined as that duration after which day number after initial exposure has a similar effect on heat production regardless of temperature. It can then be regarded as the first day at which the temperature effect does not change or becomes absent. For this purpose heat production and its components (AH and AFH) were regressed on day number with model III. Analysis was carried out per temperature treatment and for the light and dark period separately. Regression coefficients were calculated in a stepwise fashion by leaving out days after exposure (day number 2, 3, 4, 5, 6 and 8 successively). Results of this analysis are presented in table 7. At 15 °C heat production during day time was increased with day until day 8 and at 25 °C until day 5. During night time the duration of exposure affected heat production until day 6 whereas at 25 °C the duration had no significant effect. This shows that with regard to acclimation the day number becomes absent at day 8 at 15 °C and after day 5 at 25 °C. Thus acclimation can be considered to occur at a more rapid rate at 25 °C than at 15 °C. Activity related heat production (AH) was affected in a different way at 15 °C from that at 25 °C. This part of the metabolism will be associated with more or less change in huddling of the pigs. Results showed that during daytime there was hardly any effect of day number at 25 °C whereas at 15 °C a significant regression coefficient was present until day 6. Differences between regression coefficients at each temperature were significantly different until day 8 during the light period and day 3 during the dark period. Therefore, acclimation was different during both periods.

Table 7. Regression coefficients of heat production on day number and night number at both temperature treatments

	Light period										
Temperature	15 °C				25 °C				F-test		
Days	n	b_H	b_{AH}	b_{AFH}	n	b_H	b_{AH}	b_{AFH}	H	AH	AFH
2 to 12	30	9.42	—	8.07	32	6.33	−3.55	9.88		*	
3 to 12	27	11.67	4.42	7.25	28	7.60	—	9.79		**	
5 to 12	24	12.04	3.98	8.06	24	5.29	—	7.88	*	**	
6 to 12	20	11.81	4.07	7.74	20	—	—	8.41	*	**	
8 to 12	16	7.89	—	5.20	16	—	—	—		*	
9 to 12	12	—	—	—	12	—	—	—			
	Dark period										
Temperature	15 °C				25 °C				F-test		
Nights	n	b_H	b_{AH}	b_{AFH}	n	b_H	b_{AH}	b_{AFH}	H	AH	AFH
2 to 12	30	3.56	−0.74	4.30	32	—	−3.54	5.51		*	
3 to 12	27	4.07	—	4.81	28	—	−3.60	5.74		*	
5 to 12	24	4.23	—	4.90	24	—	−2.67	—	*		
6 to 12	20	4.66	—	5.67	20	—	−2.73	—			
8 to 12	16	—	—	—	16	—	−3.97	—			
9 to 12	12	—	—	—	12	—	—	—			

— regression coefficient not significant
** significant difference between regression coefficient at 25 and 15 °C compared to regression coefficient over temperature treatments ($p < 0.01$)
* $p < 0.05$

These experiments showed that acclimation of pigs to deviation from optimal temperature (*i.e.* thermal neutrality) is a combined effect of regulation of food intake and thus metabolic rate. Pigs showed different response to temperature at different times of the day. Pigs seem to acclimate to low ambient temperature more during daytime than during night time. This differential effect is related to the effect of temperature on activity related heat production especially during night time. Moreover, for acclimation studies pigs should be in similar experimental conditions to compare the effect of a different temperature. Under the present experimental conditions pigs were acclimated to an ambient temperature after 8 days of exposure. It remains to be investigated to what extent other components of the climatic environment influence acclimation.

In intensive pig production the effects of these components are not only important with regard to metabolic rate but moreover they may be related to the severity and incidence of factorial diseases (Kelley, 1980; Dantzer and Mormède, 1983; Hunneman, 1983). Hence, the importance of studying acclimation of pigs is stressed.

References

Barnett, S.A. and L.E. Mount. 1967. Resistance to cold in mammals. In: Thermobiology. Ed. A.H. Nose. Academic Press. London and New York : 411-477.

Blecha, F. and K.W. Kelley. 1981. Effects of cold and weaning stressors on the anti-body mediated immune response of pigs. *Journal of Animal Science* 53: 439-447.

Brouwer, E. 1965. Report of subcommittee on constants and factors. *3rd Symposium on Energy Metabolism*. Troon. Scotland EAAP publ. 11: 441-443.

Bruce, J.M. and J.J. Clark. 1979. Models of heat production and critical temperature for growing pigs. *Animal Production* 28: 353-369.

Christison, G.I. and C.M. Williams, 1982. Effects of cold on animal production. In: CRC Handbook of Agricultural Productivity Vol. II: 69-76.

Close, W.H. 1971. The influence of environmental temperature and plane of nutrition on heat losses from individual pigs. *Animal Production* 13: 295-302.

Close, W.H. 1981. The climatic requirements of the pig. In: Environmental aspects of housing for animal production. (Ed. J.A. Clark), Butterworths. London: 149-166.

Close, W.H., R.P. Heavens and D. Brown. 1981. The effects of ambient temperature and air movement on heat loss from the pig. *Animal Production* 32: 75-84.

Dantzer, R. 1973. Etude de la stabilisation des rythmes d'activité locomotrice de porcelets introduit dans un nouvel environment. *Journal de Physiologie* 66: 495-503.

Dantzer, R. and P. Mormède. 1983. Stress in farm animals: a need for reevaluation. *Journal of Animal Science* 57: 6-18.

Fuller, M.T. and A.W. Boyne. 1972. The effects of environmental temperature on the growth and metabolism of pigs given different amount of foods. 2. Energy metabolism, *British Journal of Nutrition* 28: 373-384.

Hacker, R.R., M.P. Stefanovics and T.R. Batra. 1973. Effects of cold exposure on growing pigs: growth, body composition and 17-ketosteroids. *Journal of Animal Science* 37: 739-744.

Holmes, C.W. and L.E. Mount. 1967. Heat loss from groups of growing pigs under various conditions of environmental temperature and air movement. *Animal Production* 9: 435-452.

Hunneman, W.A. 1983. Vóórkomen, economische betekenis en bestrijding van *Haemophilus pleuropneumoniae* infekties bij varkens. Thesis. Boxtel. The Netherlands.

Kelley, K.W. 1980. Stress and immune function: a bibliographic review. *Annuale Recherche Veterinaire* 11: 445-478.

Leung, P.B.M. and B.R. Horowitz. 1976. Free-feeding patterns of rats in response to changes in environmental temperature. *American Journal Physiology* 231: 1220-1224.

Morrison, S.R. and L.E. Mount. 1971. Adaptation of growing pigs to changes in environmental temperatures. *Animal Production* 13: 51-57.

Mount, L.E. 1979. Adaptation to thermal environment: man and his productive animals. Edward Arnold, London.

Mount, L.E., I.B. Start and D. Brown. 1980. A note on the effects of forced air movement and environmental temperature on weight gain in the pig after weaning. *Animal Production* 30: 295-298.

SAS. Statistical Analysis System. 1985. SAS Institute Inc., Cary NC.

Siegel, H.S. 1980. Physiological stress in birds. *Bioscience*: 529-534.

Snedecor, G.W. and C. Cochran. 1967. *Statistical Methods*. Iowa State University Press.

Thorbek, G., A. Chwalibog and S. Henckel. 1982. Energy requirements for maintenance and growth in pigs from 20-100 kg live weight. *Proc. 9th Symposium Metabolism of Farm Animals*. Lillehammer. Norway.

Van der Hel, W., M.W.A. Verstegen, W. Baltussen and H. A. Brandsma. 1984. The effect of ambient temperature on diurnal rhythm in heat production and activity in pigs kept in groups. *International Journal of Biometeorology* 28: 303-315.

Van der Hel, W., R. Duijghuisen and M.W.A. Verstegen. 1986. The effect of ambient temperature and activity on the daily variation in heat production of growing pigs kept in groups. *Netherlands Journal of Agricultural Science* 34: 173-184.

Verhagen, J.M.F., A.A.M. Kloosterman, A. Slijkhuis and M.W.A. Verstegen. 1987. Effect of duration of ambient temperature exposure on energy metabolism in growing pigs. *Animal Production*: in press.

Verstegen, M.W.A., W. van der Hel, A.A. Jongebreur and G. Enneman. 1976. The influence of ammonia and humidity on activity and energy balance in groups of pigs. *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 37: 255-263.

Verstegen, M.W.A., W. van der Hel, H.A. Brandsma and E. Kanis. 1982. Heat production of groups of growing pigs as affected by weight and feeding level. *Proc. 9th Symposium Energy Metabolism of Farm Animals*. Lillehammer. Norway.

Verstegen, M.W.A., W. van der Hel, H.A. Brandsma and J. Wallinga. 1987. Indirect calorimetry with large groups of animals. *Netherlands Journal Agricultural Science*: submitted.

Wenk, C. and A.J.H. van Es. 1980. Untersuchungen über den Stoff- und Energiewechsel wachsender Küken unter besonderer Berücksichtigung der Aktivität. *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 43: 241-154.

CHAPTER IV

Acclimation of growing pigs to draught at constant ambient temperatures

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Animal Production: submitted

Abstract

Two experiments with 40 pigs, each housed in groups of 10, were performed to study effects of draught on heat production. Draught was applied during night periods at intermittent intervals in pigs housed at either 25 or 15 °C. Draught increased heat production and equivalent thermal demand was increased with about 11.7 °C at 15 °C and 3.9 °C at 25 °C. This extra requirement diminished after 10 to 12 days after exposure. Effects of draught on heat production were minimal at about 5 to 8 days after initial exposure and were especially related to activity of the animals. Moreover effects of draught and thus acclimation was also present in periods in between application of draught. Acclimation to draught was achieved more rapidly in late night compared with early night exposure.

Introduction

The effects of climatic environment on thermal regulation and metabolic rate of animals are mostly measured at constant ambient temperatures (Mount, 1979). In recent years some studies focussed on other climatic factors such as air velocity (Verstegen and van der Hel, 1974; Close *et al.*, 1981). Various combinations of climatic components normally will occur in a pig-house. Therefore pigs have to adapt to the effects of the various conditions and their combinations with regard to metabolic rate and productivity. This adaptational response to such an environment is usually termed acclimatization (Mount, 1979; Curtis, 1983). Acclimation will occur when animals have to adapt to single climatic factors (Mount, 1979; Curtis, 1983). Acclimation may include both behavioural (Boon, 1982) and metabolic responses (Mount, 1979). There is ample evidence that the response of pigs to a combination of climatic factors is not identical to the addition of the effects of each factor.

Increase in air velocity when accompanied by a "locally" lowered temperature of the air stream in an otherwise constant ambient temperature is defined as draught (Tielen, 1974). The importance of draught on metabolism and productivity in pigs has been stressed by Holmes and Mount (1967) and Close (1981). Literature on the magnitude of acclimation to draught is lacking.

The present experiments were designed to measure the response in metabolic rate and activity of group-housed young growing-pigs when exposed to draught. Acclimation was estimated from data of measurements at successive days since first exposure.

Material and Methods

Animals and housing

Two experiments were done. In each experiment 40 young growing-pigs (Large White × Dutch Landrace) were used. Pigs were allotted to one of two identical climatically-controlled respiration-chambers by balancing mean weight between chambers. Each chamber has a volume of 80 m^3 and two pens of 9 m^2 with a floor of non-toxic asphalt. Per chamber 20 animals were housed in two groups of 10 animals in a separate pen each. Groups of pigs consisted of about similar numbers of female and castrated male pigs. Temperature was kept at 20 °C until the start of the experiment. All pigs originated from the same herd and were housed at similar pre-experimental conditions. The climatic treatment started on the second day after arrival of the pigs. Mean weight at the start of the experiments is given in table 1.

Table 1. Initial weight of the experiments (mean + standard error of the mean (sem).

Experiment	I		II	
Treatment	25 °C	25 °C + draught	15 °C	15 °C + draught
No. of animals	20	20	20	20
Initial live weight:				
mean	21.5	21.3	22.5	22.3
sem	0.57	0.63	0.76	0.53

Plan of experiment

The effect of a periodical draught treatment was investigated at two ambient temperatures, 15 °C and 25 °C (figure 1). Ambient temperature of 25 °C was consid-

	Control-group	Treatment-group
Experiment	Temperature	Temperature + Treatment
I	25 °C	25 °C + periodical draught
II	15 °C	15 °C + periodical draught

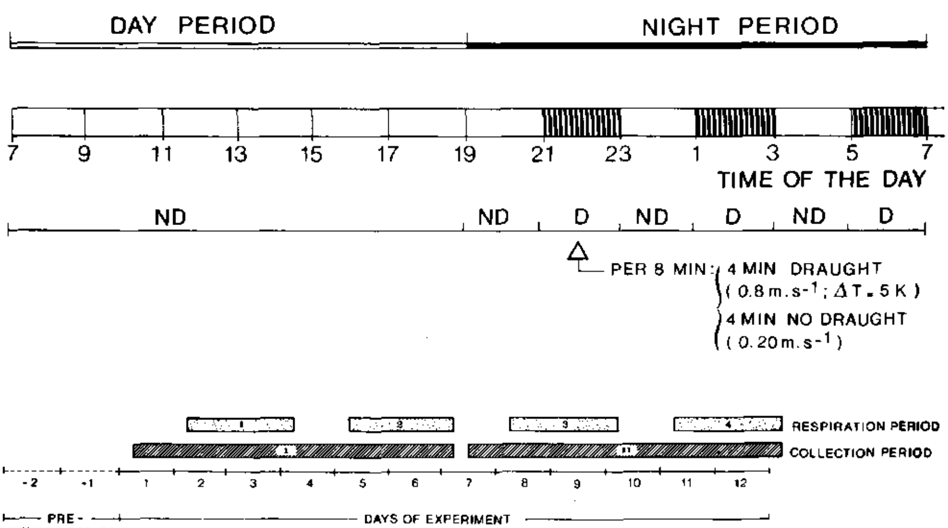

Figure 1. Experimental design and procedure

ered to be within thermoneutrality, whereas 15 °C was considered to be slightly below the lower critical temperature for group-housed pigs at this live-weight (Bruce and Clark, 1979). In experiment I and II the control-groups were exposed to ambient temperatures of 25 °C or 15 °C. The pigs in the treatment-group were additionally exposed to a superimposed draught during the night period (19.00-07.00 h). This period was chosen because normal level of metabolism and activity is low (Schouten, 1986). It is to be expected that specific effects on metabolic rate and activity will be present in this period. Draught was applied periodically from 21.00-23.00 h, 01.00-03.00 h and 05.00-07.00 h and these periods are referred to as draught-periods (figure 1). During these draught-periods air velocity within the chamber was increased to 0.8 m/s and temperature of the air stream was lowered by 5 K compared with the ambient temperature in the chamber. In each 2-hour draught-period air velocity was increased intermittently. This was done in a sequence of 4 minutes on and 4 minutes off (figure 1). During the absence of draught air velocity was below 0.2 m/s.

Experimental procedure

Increase of air velocity was achieved with 4 devices consisting of 3 fans each. The devices were installed over the whole lenght of the respiration chamber and operated by time switches. To lower the temperature of the air stream each device was equipped with a heat exchanger. Prior and during activation of the fans glycol (T = 0-2 °C) was run through the heat exchanger. In this way the air stream (draught) was always 5 K lower in temperature. Relative humidity was kept at 65% throughout the experiments. Pigs were exposed to the experimental treatments of ambient temperature (25 °C or 15 °C) for 12 days (figure 1). At day 1 the draught treatment started. Daily gain, food intake and metabolizable energy intake were determined during two subsequent 6-day periods. During each 6-day period two respiration measurements of 48 hours each were made for the determination of heat production of the pigs (figure 1). Principles and procedures of measurements of heat production by gaseous exchange of oxygen and carbondioxide of animals were described by Verstegen (1971). Values of heat production are obtained in 18-minute periods and recorded. Physical activity of the pigs was measured continuously per pen with the use of ultrasonic devices according to the method described by Wenk and van Es (1976). Values were recorded in 18-minute periods also.

Statistical analysis

Data on heat production was regressed on activity counts (18-minute data) per experiment and per treatment. Separate analysis were performed for data from the day and night period. Regression equations were used to obtain activity-related heat production (AH). Values of heat production and AH were averaged per day and night period and day number after initial exposure (day 2,3,5,6,8,9,-11 and 12). Acclimation with respect to duration after initial exposure was analysed with model I.

$$y_i = a + b_1.x_i + b_2.x^2_i + e_i \quad \text{(I)}$$

where: y_i = heat production value,
a = intercept,
b_1 = linear regression coefficient,
b_2 = quadratic regression coefficient,
x_i = day number after initial exposure (i= 2,3,5,6,8,9,11,12),
e_i = residual error term.

Values of H and AH were averaged for the draught and no-draught periods during the night period (see figure 1). This was done for each day number. Effect of draught on H and AH was analyzed for each temperature and for the control and treatment group separately.
Model II was used.

$$y_i = \mu + A_i + e_i \quad \text{(II)}$$

where: y_i = value of heat production during 2-hour period,
μ = overall mean,
A_i = application of draught (i=1,2),
e_i = residual error term.

Within ambient temperature (25 or 15 °C) differences in heat production between control and treatment group for each 2-hour period and daily gain were tested with Students' *t*-test (Snedecor and Cochran, 1976). Differences in daily gain were tested by *t*-test also.

Results

Daily gain and food intake

In table 2 data on food intake and daily gain are presented. Average daily gain was 552 and 544 g/d at ambient temperatures of 25 °C and 15 °C respectively. During the first 6-days (period I) average daily gain was significantly greater at 25 °C (by 102 g) compared with 15 °C ($p < 0.01$).

Rate of gain at draught treatments did not differ significantly from the control-groups, daily gain was 552 and 535 g/d respectively. Draught treatment at 25 °C compared with 15 °C resulted in a significant higher daily gain in period I ($p < 0.01$). Feed intake of pigs at 15 °C was lower than at 25 °C. During period II daily gain and food intake were markedly increased for pigs at 15 °C and 15 °C + draught compared with period I. In table 3 data on metabolizable energy (ME) intake, mean heat production (H) and retained energy (RE=ME-H) are given. During the first 6-day period draught treatment tends to increase ME-intake compared with day 7-12 after initial exposure. ME-intake during day 7-12 was similar for both control and draught treatment at 25 °C. ME-intake at 15 °C increased markedly with 157 kJ/kg$^{0.75}$ from day 1-6 to day 7-12. Pigs exposed to draught at 15 °C had an increased ME-intake (by 23 kJ) between these periods. During day

Table 2. Feed intake, daily gain (g/d) and heat production (kJ/kg$^{0.75}$) for each respiration period and each temperature and treatment.

Treatment	25 °C				25 °C + draught			
Respiration period	I	II	III	IV	I	II	III	IV
Daily gain	555 ± 25		489 ± 25		625 ± 28		535 ± 24	
Feed intake	1115	1164	1237	1131	1194	1209	1246	1202
Heat prod.	817	812	820	783	822	828	812	801
Treatment	15 °C				15 °C + draught			
Respiration period	I	II	III	IV	I	II	III	IV
Daily gain	506 ± 28		619 ± 35		470 ± 35		579 ± 40	
Feed intake	1076	1086	1305	1346	1125	1055	1219	1217
Heat prod.	831	790	845	855	848	785	801	804

Table 3. Intake of metabolizable energy (ME), heat production (H) and retained energy (RE) in kJ/kg$^{0.75}$.

Treatment	25 °C			25 °C + draught		
Period	Day 1-6	Day 7-12	Average	Day 1-6	Day 7-12	Average
ME	1286	1222	1254	1340	1214	1277
H	814	802	808	825	806	815
RE	472	420	446	515	408	462
Treatment	15 °C			15 °C + draught		
Period	Day 1-6	Day 7-12	Average	Day 1-6	Day 7-12	Average
ME	1117	1275	1196	1148	1171	1160
H	811	850	831	816	802	809
RE	306	425	366	332	369	351

1-6 mean heat production, ME-intake and retained energy (RE) were slightly higher with the draught treatments at 15 °C and 25 °C compared with controls.

Heat production during day and night period

In figure 2 data of heat production (H) and activity-related heat production (AH) for the day and the night period are given for the control- and the treatment-groups. Figure 2 shows that H and AH during the night were lowest for pigs at 25 °C. Draught at 25 °C increased heat production and activity-related heat production during the night period compared with pigs at 25 °C. At 15 °C the pigs exposed to draught had an increased AH during the night period compared with the 15 °C control-group. Data obtained during the day-time showed that at 25 °C heat production was similar. At 15 °C draught diminished heat production. Activity-related heat production was similar for the control- and draught-group at 25 °C. At 15 °C draught caused an increase in AH during the day. The occurrence of draught at 25 °C diminished the difference in heat production between the day and the night period from 92 to 62 kJ/kg$^{0.75}$. Draught at 15 °C resulted in a decrease from 73 to 7 kJ/kg$^{0.75}$.

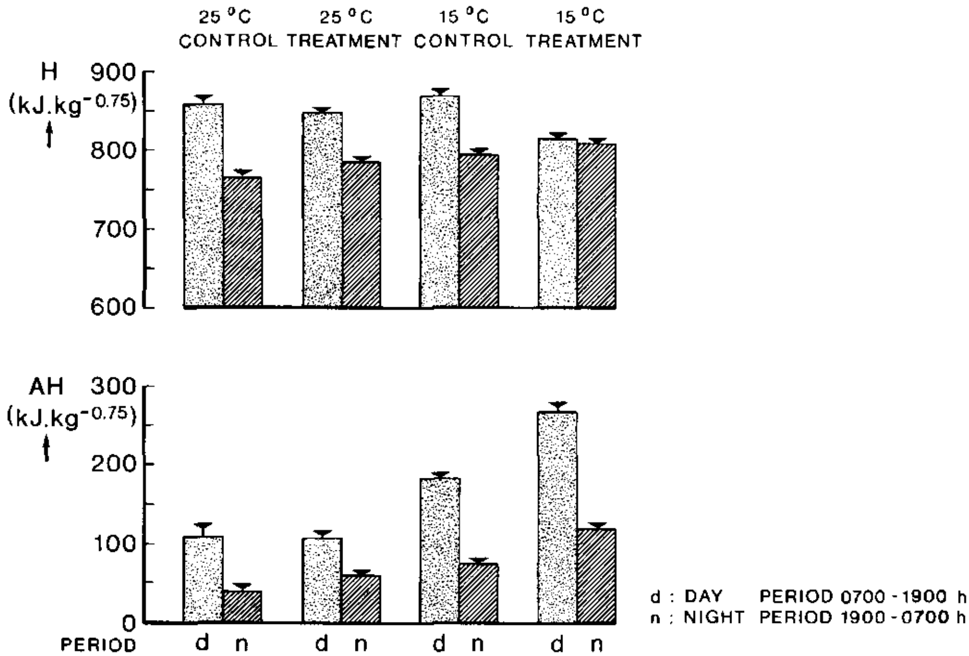

Figure 2. Mean heat production (H) and activity-related heat production (AH) ($kJ/kg^{0.75}$) during day and night period

Heat production during successive days

Values of H and AH were calculated separately per day and night period for each day number. Values of H and AH during the night and day period were regressed on day number (day 2,3,5,6,8,9,11 and 12). Results from analyses with model I are given in table 4. Results from the day-period showed a curvilinear relation of H with day number for controls at 15 °C and draught at 25 °C. AH was curvilinear related to day number for the control-group at 25 °C and for both groups exposed to draught. For the night-period H changed linearly with day number for both groups at 25 °C and curvilinearly with draught at 15 °C. AH during night was less affected by day number than during the day-period. Linear effects were found at 15 °C with draught and for the control- group at 25 °C.

In figure 3 data of H and AH derived from significant regression analyses are given, otherwise mean values are given. At 15 °C H of the controlgroup declined with day until 5-6 during the day period. Thereafter an increase occurred. The draught at 25 °C affected both H and AH; they increased until day 5 to 6 and remained on a plateau until day 9-10. For the controlgroup at 15 °C, H reached a minimum at day 6 and increased thereafter, whereas for AH no significant change with days since first exposure was found. During the night period heat production at 25 °C was increased with the draught. The effect declines with duration of days after exposure. At 15 °C a more rapid decline of heat production with days occurred and a minimum was reached at day 8 and 9.

Table 4. Linear and quadratic regression coefficients of regression of heatproduction (H) and activity-related heat production (AH) during the day and night period on day number (model I).

		Day period			
		15 °C + draught	15 °C control	25 °C + draught	25 °C control
Coefficient					
H	linear	n.s.	−25.14	16.24	n.s.
	quadratic	n.s.	2.18	−1.18	n.s.
	R^2	--	76.3	75.2	--
AH	linear	−18.10	n.s.	17.00	−47.86
	quadratic	−1.78	n.s.	−1.06	2.62
	R^2	84.5	--	5.4	92.5
		Night period			
		15 °C + draught	15 °C control	25 °C + draught	25 °C control
Coefficient					
H	linear	−37.71	n.s.	−4.35	−3.85
	quadratic	1.98	n.s.	n.s.	n.s.
	R^2	90.9	—	69.8	55.1
AH	linear	−4.7	n.s.	n.s.	−4.36
	quadratic	n.s.	n.s.	n.s.	n.s.
	R^2	87.0	—	—	64.7

n.s.: non-significant regression coefficient ($p > 0.05$)

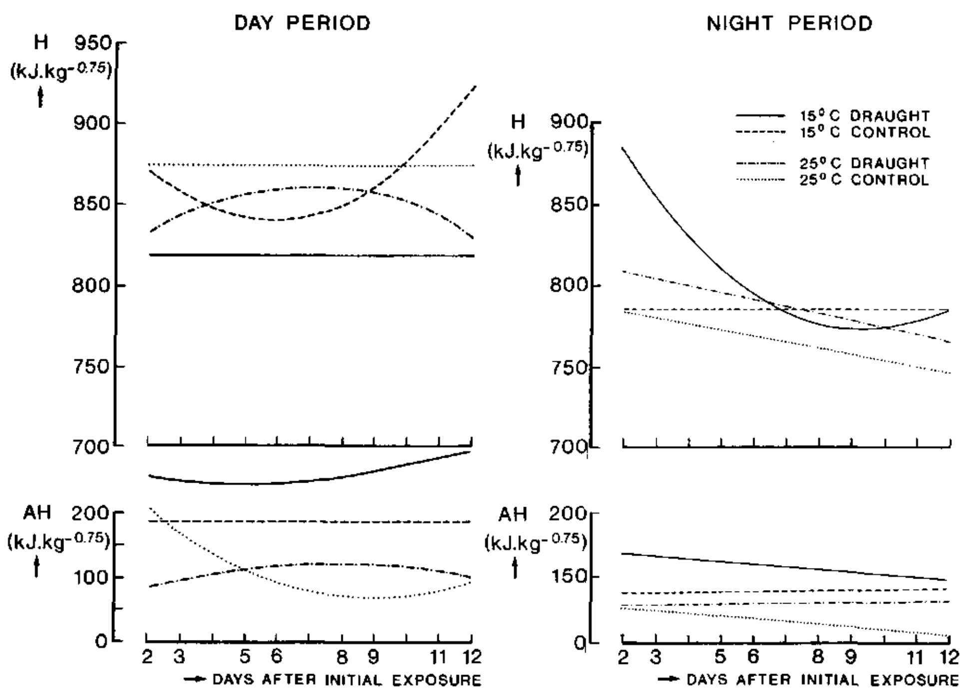

Figure 3. Heat production (H) and activity-related heat production (AH) (kJ/kg$^{0.75}$) during day and night period at successive day after exposure, derived from regression equations

Heat production during 2-hour periods at night

Draught had been applied periodically for 2 hours during the night period. Therefore H and AH were calculated separately for periods with draught (D) or without draught (ND) for the treatment groups. Similarly these data of H and AH were calculated for the control-group at 25 and 15 °C . Mean values and significance of difference (model II) during the night-period are presented in figure 4. Data show that heat production diminishes with proceeding of the night period for the both control-groups. At 15 °C level of heat production was higher than at 25 °C, especially from 21.00 to 23.00 h. With the application of draught a different pattern is observed. Heat production is increased during the draught (D) periods. During these periods values of AH were also significantly increased. Results of 2-hour periods without draught did not significantly differ. At 25 °C the application of draught increased H and AH with 36.5 and 53.2 $kJ/kg^{0.75}$ respectively. At 15 °C effects of draught were 38.1 and 82.7 $kJ/kg^{0.75}$ for H and AH respectively.

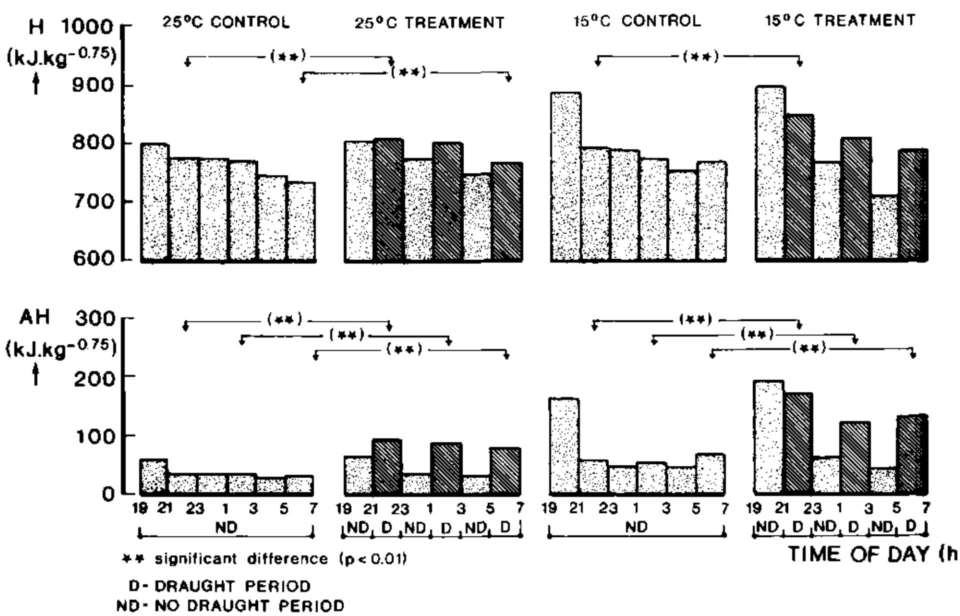

Figure 4. Mean heat production (H) and activity-related heat production (AH) ($kJ/kg^{0.75}$) during adjacent 2-hour periods at night.

Heat production during 2-hour periods at night for successive day numbers

Mean values of the 2-hour periods of draught (D) or no-draught (ND) for the successive days after initial exposure were analysed with model I. Arbitrarely it was chosen to omit data from 19.00 to 21.00 h from this analysis, since van der Hel *et al.* (1986) had shown that the activity in the cold (15 °C) is especially increased in this period. Analyses were done similarly for the control-groups. In table 5 results

Table 5. Significance of the effect of application or absence of draught on heat production (H) and activity-related heat production (AH) (model II).
Application of draught: 21.00-23.00 h, 01.00-03.00 h, 05.00-07.00 h.
Absence of draught: 23.00-01.00 h, 03.00-06.00 h.

	15 °C		25 °C	
Effect	H	AH	H	AH
Draught	***	***	***	***
R^2	28.5	67.9	23.1	80.5

*** : significant effect ($p < 0.001$)

of significance are presented for the treatments-groups. Table 5 shows that total heat production (H) and activity-related heat production (AH) at night were significantly affected by draught within ambient temperature. At 25 °C the draught increased H and AH by 35 and 53 $kJ/kg^{0.75}$ respectively. At 15 °C this difference was greater (66 and 90 $kJ/kg^{0.75}$) respectively (see figure 4). In the control-groups no significant effect of periods on H and AH was found.

To differentiate acclimation for each 2-hour period analysis for testing (curvi)linearity (model I) were performed for each period of D and ND (table 6). Values derived from regression of H and AH on day number are shown in figure 5. Analysis showed that at 15 °C heat production changed curvilinear with day number both during the draught and no-draught periods. At days 8 to 9 minimum was reached. Pigs in the control group showed a curvilinear response of heat production with progress in days. Minimum level of heat production occured at day 5 to 6. Activity-related heat production decreased linear with day and remained constant during no-draught periods. At 25 °C a different pattern was observed. During the no-draught periods heat production remained constant whereas it declined with progress in days during the draught periods. Heat production in the control group at 25 °C also declined with progress in days. Activity-related heat production was higher during the draught but no linear relationship with days after exposure was found.

Table 6. Linear and quadratic regressioncoefficients of regression of heat production (H) and activity-related heat production (AH) on day number for periods when draughts was applied (draught-periods) or absent (no-draught periods).
Application of draught: 21.00-23.00 h,01.00-03.00 h, 05.00-07.00 h.
Absence of draught: 23.00-01.00 h, 03.00-06.00 h.

		15 °C + draught		25 °C + draught	
Regression coefficient		Draught periods	No-draught periods	Draught periods	No-draught periods
H	linear	−44.7	−34.4	−6.0	n.s.
	quadratic	2.4	2.0	n.s.	n.s.
	R^2	59.8	68.6	29.2	—
AH	linear	−6.3	n.s.	n.s.	1.3
	quadratic	n.s.	n.s.	n.s.	n.s.
	R^2	34.3	—	—	42.6

n.s.: non-significant regression coefficient ($p > 0.05$).

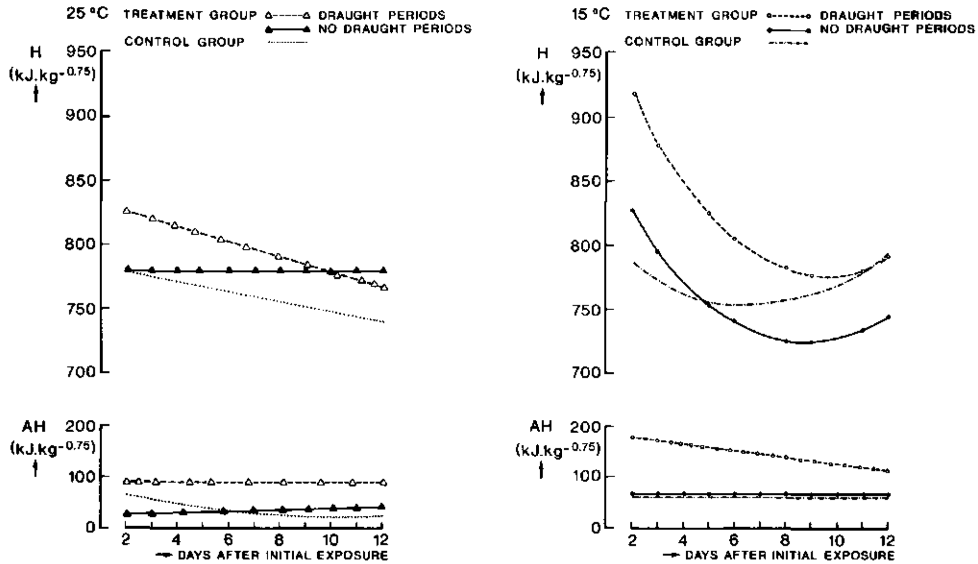

Figure 5. Heat production (H) and activity-related heat production (AH) (kJ/kg$^{0.75}$), during draught and no-draught periods, calculated from regression on day number.

Discussion

In intensive pig production the climatic environment cannot be regarded as constant (Close, 1981). The majority of experiments concerning climatic requirements were performed with constant treatments such as ambient temperature. Fluctuations in ambient temperature and air velocity (wind, draught) will be more common at practical conditions (Close, 1981). In the present study the effect of the occurrence of an increased air velocity with a lowered temperature (draught) in comparison with constant ambient temperature was studied at two ambient temperatures. At thermoneutral conditions heat production is affected by food intake (Mount, 1979). Thermal conditions below thermal neutrality or equivalent effects of other climatic components will also directly influence metabolic rate and subsequently maintenance requirement. Under these climatic conditions heat production is determined mainly by thermal demand of the animals in that environment (Close, 1981; Van der Hel *et al.*, 1986). Animals can acclimate to these thermal conditions. *Ad libitum* feeding provide an additional way of acclimation to adverse conditions. Therefore it is also more relevant to assess the effect of climatic environment with *ad libitum* feeding. Results in this study showed that young-growing pigs kept at ambient temperature of 15 °C had reduced intake of food and metabolizable energy during the first six days after exposure compared with day 7-12. Pigs exposed to a superimposed draught at 15 °C had also increased intake of metabolizable energy in day 7-12. A similar delayed response due to climatic environment was found by Christison and Williams (1982) and Mount *et al.* (1980) in pigs and by Leung and Horowitz (1976) and Barnett and Mount (1967) for laboratory animals. Maintenance requirement (ME_m) of pigs at the different climatic conditions was calculated (ARC, 1981). The control groups at 25 °C and

15 °C had a ME_m of 524 and 587 $kJ/kg^{0.75}$ respectively. Draught resulted in a ME_m of 531 $kJ/kg^{0.75}$ at 25 °C and 574 $kJ/kg^{0.75}$ at 15 °C. Difference in ME_m due to the effect of ambient temperature was thus present. Application of draught (a total of 180 minutes per day) only had a minor effect on ME_m.

The results of the present study showed that pattern of heat production within a night was clearly affected due to draught. This indicates a direct effect on heat loss *c.q.* heat production. Stephens and Start (1972) also noted such an effect of air velocity and temperature on heat loss. Close (1981) concluded, that with an air velocity above 0.20 m/s heat loss will be increased by forced convection. In pigs housed in groups this increased thermal demand effected activity level and thus the group behaviour. Activity-related heat production changed with day number after initial exposure and can be regarded as a major component in acclimation. This may be termed thermoregulatory behavioural response (Mount, 1979). The effect of this activity was taken into account by relating activity to heat production. This has been done similarly by Wenk and Van Es (1976), Geuyen et al. (1984) and Van der Hel *et al.* (1984, 1986). Draught during the night period resulted in an overall increase in H compared with control-groups of 31 kJ at 25 °C and of 46 kJ at 15 °C. Values for AH were 50 and 67 kJ respectively. Extra thermoregulatory heat production (ETH) can be assumed to be 11 $kJ/kg^{0.75}$ (Close, 1982). Draught at 25 °C and 15 °C would have been equivalent to a lowered ambient temperature of 2.8 °C and 4.2 °C respectively. This indicates that heat loss due to increased air velocity is dependent on ambient temperature and is in agreement with results found in literature (Verstegen and Van der Hel, 1974; Mount *et al.*, 1980; Close *et al.*, 1981). Geuyen *et al.* (1984) and Van der Hel *et al.* (1986) found that metabolic rate and activity in various parts of the day was affected by ambient temperature. Heat production and activity-related heat production were affected by draught and temperature (figure 2 and 3). At an ambient temperature of 15 °C heat production during the beginning of the night period was increased as was activity (figure 4). Such effects of ambient temperature were also found by Van der Hel *et al.* (1986) for restrictedly fed animals. It can thus be concluded that heat production and activity level of pigs kept at 15 °C compared with 25 °C increase during the evening. If data of the beginning of the night (19.00 — 21.00 h) is omitted then the extra thermal demand due to draught was 35 kJ (3.2 °C) at 25 °C and 66 kJ (6.0 °C) at 15 °C.

The occurrence of draught resulted in a major shift in heat production and acclimation was delayed by two days. Moreover it appears that at 15 °C both in the actual period of occurrence of draught and the periods thereafter this delayed acclimation takes place (figure 5). Activity of pigs at draught will result in an increase of body surface exposed to the environment. Heat loss through forced convection by the lowered temperature and the increase in air velocity will be thus increased. It may be argued that activity-corrected heat production, as a measure of non-shivering heat production may still be affected between draught-periods. At 25 °C the occurrence of draught resulted in a linear decrease in heat production with days, especially the activity-related component, decreased. Level of heat production remained constant during the no-draught periods. Results in this study indicated that draught at 15 °C, applied during the night period, also altered

Table 7. Effect of draught on extra heat production (δH in $kJ/kg^{0.75}$) and lower critical temperature* (δT_{cr})at day 2 and 12 after initial exposure.
D-periods: 21.00 — 23.00 h, 1.00 — 3.00 h, 5.00 — 7.00 h.
ND-periods: 23.00 — 1.00 h, 3.00 — 5.00 h.

A. Within treatments: D-periods and ND-periods.
B. Between treatment and control: D and C, ND and C.

A.		Daynumber 2		Daynumber 12	
Temperature	Contrast	δH	δT_{cr}	δH	δT_{cr}
15 °C	D vs ND	95.5	8.7	45.3	4.1
25 °C	D vs ND	47.8	4.3	−12.1	−1.1

B.		Daynumber 2		Daynumber 12	
Temperature	Contrast	δH	δT_{cr}	δH	δT_{cr}
15 °C	D vs C	128.2	11.7	−17.7	−1.6
	ND vs C	19.3	1.8	−71.8	−6.5
25 °C	D vs C	42.5	3.9	−17.4	−1.6
	ND vs C	−1.1	−0.1	38.4	3.5

* Calculated by assuming that 1°C difference in T_{cr} is equivalent to 11 $kJ/kg^{0.75}$ per °C (Close, 1981).

heat production pattern within days. Additionally the heat production at 15 °C was related to both activity and non-activity related heat production. Acclimation at this temperature was reached at 5 to 8 days with draught or no draught. Results in figure 5 showed that the effects of draught within the night period diminished with duration of exposure. To quantify the degree of acclimation the increase in thermal demand due to draught was calculated for day number 2 and 12 at each temperature (table 7A). The occurrence of draught at day number 2 was equivalent to an increase in thermal demand of 8.7 and 4.3 °C at 15 and 25 °C respectively. At day number 12 increased thermal demand was still present at 15 °C (4.1 °C). In table 7B values of heat production during periods of draught are compared with similar periods of the control-group. Extra thermal demand with draught at day number 2 is then 11.7 and 3.9 °C at 15 and 25 °C respectively. At day number 12 this was no longer present at 25 °C nor at 15 °C. It should thus be concluded that a periodical increase in heat loss to the environment due to draught will have a large effect on thermal demand at the moment of occurrence. After application of draught some effects still remain. The influence of increased thermal demand due to unfavourable climatic environment may have effect on other aspects of animal production. It is known that climatic environment may influence resistance and health of animals (factorial diseases). Henken (1982) and Tielen (1974) noted that changes in climatic environment are to have an important influence compared with absolute levels of climatic environment.

References

ARC. 1981. *The nutrient requirements of pigs.* Commonwealth Agr. Bur. p. 1-44.

Barnett, S.A. and Mount, L.E. 1967. Resistance to cold in mammals, *Thermobiology*, (Ed. A.H. Nose), Academic Press. London and New York, p. 411-477.

Boon, C.R. 1982. The lower critical temperature and group postural behaviour of pigs. Livestock Environment II. 2nd Int. Liv. Env. Symp. Am. Soc. of Agric. Eng. 1982.

Bruce, J.M. and Clark, J.J. 1979. Models of heat production and critical temperature for growing pigs. *Anim. Prod.* **28:** 353-369.

Christison, G.I. and Williams, C.M. 1982. Effects of cold on animal production. CRC Handbook of Agricultural Productivity Vol II: 69-76.

Close, W.H. 1981. The climatic requirements of the pig, *Environmental aspects of housing for animal production.* (Ed. J.A. Clark), Butterworth, London, p. 149-166.

Close, W.H., Heavens, R.P. and Brown, D. 1981. The effects of ambient temperature and air movement on heat loss from the pig, *Anim. Prod.* **32:** 75- 84.

Curtis, S.E. 1983. *Environmental Management in Animal Agriculture.* Iowa State University Press.

Geuyen, T.P.A., Verhagen, J.M.F. and Verstegen, M.W.A. 1984. Effect of housing and temperature on metabolic rate of pregnant sows. *Anim. Prod.* **38:** 477- 485.

Henken, A.M. 1982. *The effect of environmental temperature on immune response and metabolism of the young chicken.* Thesis. Wageningen. The Netherlands.

Holmes, C.W. and Mount, L.E. 1967. Heat loss from groups of growing pigs under various conditions of environmental temperature and air movement, *Anim Prod.* **9:** 435-452.

Leung, P.B.M. and Horowitz, B.R. 1976. Free-feeding patterns of rats in response to changes in environmental temperature, *Am. J. Phys.* **231:** 1220- 1224.

Mount, L.E. 1979. *Adaptation to thermal environment: man and his productive animals*, Edward Arnold, London.

Mount, L.E., Start, I.B. and Brown, D. 1980. A note on the effects of forced air movement and environmental temperature on weight gain in the pig after weaning, *Anim. Prod.* **30:** 295-298.

Schouten, W.G.P. 1986 . *Rearing conditions and behaviour in pigs.* Thesis, Wageningen, The Netherlands.

Snedecor, G.W. and Cochran, C. 1976. *Statistical Methods.* Iowa State University Press.

Stephens, D.B. and Start,I.B. 1972. Schlieren photography of the piglet's microenvironment. The Cornell Veterinarian, Vol. LXII.

Tielen, M.J.M. 1974. *De frekwentie en de zoötechnische preventie van long- en leveraandoeningen bij varkens.* Thesis. Wageningen. The Netherlands.

Van der Hel, W., Verstegen, M.W.A., Baltussen, W. and Brandsma, H. 1984. The effect of ambient temperature on diurnal rhythm in heat production and activity in pigs kept in groups. *Int. J. of Biomet.* **28:** 303-315.

Van der Hel, W., Duijghuisen, R. and Verstegen, M.W.A. 1986. The effect of ambient temperature and activity on the daily variation in heat production of growing pigs kept in groups, *Neth. J. of Agr. Sci.* **34:** 173-184.

Verstegen, M.W.A. 1971. *Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups.* Thesis, Wageningen, The Netherlands.

Verstegen, M.W.A. and van der Hel, W. 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

Wenk, C, and van Es, A.J.H. 1976. Eine Methode zur Bestimmung des Energieaufwandes für die körperliche Aktivität von wachsender Küken. *Schweizerische Landwirtsch. Monatshefte* **54:** 232-236.

CHAPTER V

Acclimation of young-growing pigs to fluctuating temperature and draught

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Journal Animal Physiology and Animal Nutrition: accepted.

Summary

Acclimation of young-growing pigs after 12 days of exposure to two climatic treatments was studied with pigs of 21 kg in two replicates. One climatic treatment consisted of a 24-hour fluctuation in ambient temperature, 25 °C during day and 15 °C during night time. In the other treatment draught was superimposed on this fluctuating temperature during night time. Draught was applied during three 2-hour periods (21.00- 23.00 h; 1.00-3.00 h and 5.00-7.00 h). With draught air velocity was increased to 0.8 m/s with a 5 K lower temperature of the air stream than ambient temperature. Within each 2-hour period draught was alternated as 4 min on and 4 min off. Light regime was 12 h off and 12 h on. Heat production varied between day and night. In the fluctuating temperature-group heat production and activity during night time decreased with days untill day 5 and 6. With the application of draught total heat production decreased with days to a minimum at day 8. However the acclimation in the first half of the night was reached sooner than in the second half of the night period.

Introduction

Pigs housed under natural conditions are normally subjected to fluctuations in temperature which are related to diurnal variation (Morrison *et al.*, 1976). Probably this diurnal nature of pigs is related to the higher metabolic rate, body temperature and activity level during light periods than during dark periods (Ingram and Legge, 1970; Mount, 1979). Close (1971) and van der Hel *et al.* (1984, 1986) showed that the magnitude of variation in metabolic rate between different parts of the day was influenced by ambient temperature. Metabolic rate under adverse climatic conditions may be altered also by change in activity. This mechanism is also associated with the occurrence of huddling which enables group-housed animals to reduce heat loss under adverse conditions (Mount, 1979; Boon, 1982). In addition to the direct effect of changes in metabolic rate on energy gain and related aspects of productivity unfavourable climatic conditons, such as fluctuating temperature and draught, are thought to effect resistance and susceptibility of animals to infectious diseases (Nielsen, 1982; Tielen, 1984; Osborne *et al.*, 1984; Kelley, 1985; Siegel, 1985). Abrupt changes in climatic environment will effect heat loss and thus thermoregulation and may induce thermal stress (Dantzer and Mormède, 1983). Group-housed animals can reduce the extra heat loss by means of huddling (Mount, 1979). Therefore heat production associated with activity has to be taken into account also.

Previously, experiments have been made with respect to acclimation to constant ambient temperature (Verhagen *et al.*, 1987a) and temperature with superimposed draught (Verhagen *et al.*, 1987b).

The present study deals with the effects of fluctuating temperature and draught (increased air velocity with air temperature lower than the ambient temperature) on metabolic rate and its activity related component in relation to duration after initial exposure.

Material and Methods

Animals and housing

In each experiment 40 young-growing pigs (Dutch Large White × Dutch Landrace) were housed with 20 in each of two climatically-controlled respiration chambers. Each chamber has a volume of 80 m^3 and 2 pens of 9 m^2 with a floor of non-toxic asphalt embedded in foam glass. Mean initial weight was balanced for a more accurate comparison of the variables measured in the experiments. Initial mean weight and variation are given in table 1. All pigs originated from the same herd and were housed in the same pre-experimental conditions. Groups consisted of about equal numbers of female and castrated male pigs. Temperature was kept at 20 °C until initiation of the experiment. Each experiment started on the second day after arrival.

Table 1. Initial weight (kg) in each trial and in each group (mean and sd).

	Temperature-group		Treatment-group	
Experiment	I	II	I	II
No. of animals	20	20	20	20
Initial weight mean	21.7	22.5	22.4	20.6
s.d.	2.1	2.0	2.1	1.8

Plan of experiment

Two groups of 10 pigs each were used in each of the treatments in each of the two experiments. In each experiment one group of pigs was exposed to diurnal rhythm in ambient temperature, (temperature-group), whereas the other group was exposed to a periodical draught treatment superimposed on a diurnal rhythm in ambient temperature (treatment-group). The diurnal rhythm consisted of an ambient temperature of 25 °C during day time (9.00 h to 19.00 h) and a temperature of 15 °C during night time (21.00 h to 7.00 h). Temperature was increased from 7.00-9.00 h and decreased 19.00-21.00 h. The treatment of superimposed draught was applied during 2- hour periods, namely 21.00-23.00 h, 01.00-03.00 h and

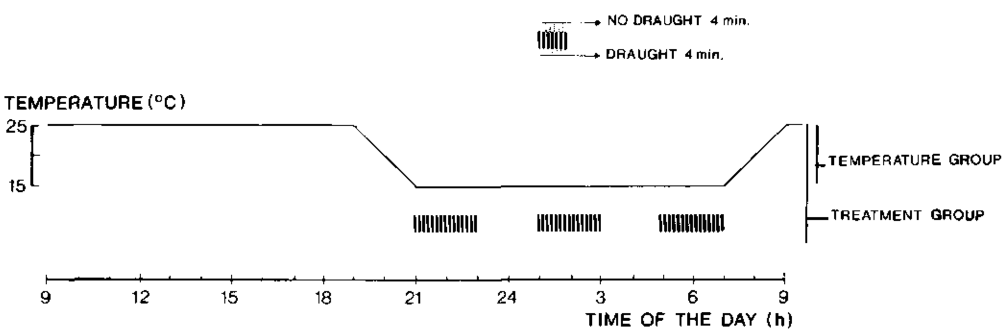

Figure 1. Experimental design for the temperature- and treatment-group.

05.00-07.00 h (figure 1). Air velocity was increased to 0.8 m/s and the temperature of the air stream was lowered 5 K. Within these draught-periods the treatment of draught was intermittently, 4 minutes on alternated with 4 minutes off throughout the 2-hour period. When draught is absent as well as in the control-group air velocity was below 0.2 m/s. Draught-treatment was done as in experiments described previously (Verhagen *et al.*, 1987b).

Experimental procedure

The experimental period consisted of two 6-day periods (figure 2). Feed intake and daily gain were measured per 6-day period. Heat production of pigs in one chamber was measured continuously during 48 hour periods (see figure 2). Procedures for measurement of gaseous exchange to determine heat production of animals are given by Verstegen (1971). Description of apparatus to create draught is described by Verhagen *et al.* (1986b). Physical activity was measured with ultrasound devices, according to the method described by Wenk and van Es (1976). During each 48-hour period of measurement values of heat production and physical activity were recorded at 18-minute intervals.

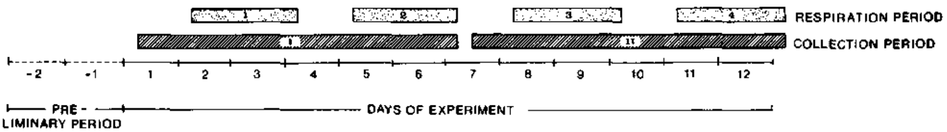

Figure 2. Experimental procedure.

Statistical analysis

To analyse acclimation in relation to activity and metabolic rate activity-related heat production (AH) was calculated. Heat production was regressed on physical activity within each replicate and within the day and night period separately. Values of heat productions and physical activity obtained per 18-minutes intervals were used. Activity-related heat production was calculated from the difference between total heat production and the intercept. Mean values for each day number were subsequently calculated for the day and night period. A similar procedure was used by Wenk and van Es (1976), Geuyen *et al.* (1984), Van der Hel *et al.* (1984) and Van der Hel *et al.* (1986).
Acclimation with respect to day number after initial exposure to the treatments of fluctuating temperature and a superimposed treatment of draught was analyzed with the following model.

$$y_{ij} = \mu + T_i + b_1.x_j + e_{ij} \qquad (I)$$

in which:

y_{ij} = heat production of pigs in experiment i at day number j,
μ = overall mean,
T_i = effect of experiment number (i = 1,2),
x_j = day number j after initial exposure (j=2,3,5,6,8,9,11,12),

b_1 = regression coefficient,
e_{ij} = residual error term.

To estimate acclimation with respect to the effect of day number after initial exposure regression analyses were carried out by leaving out day number in a stepwise increasing fashion. Day of acclimation can then be defined as that daynumber after which the treatment exposure has no significant effect. Moreover, comparison of error terms obtained from the model applied within and over treatments can be used to test (F-test) if acclimation is different between treatments. (Snedecor and Cochran, 1976). Thus the model was applied for heat production and activity-related heat production values from day 2 to 12, day 3 to 12, day 4 to 12, etc.

Results

Daily gain and feed intake

In table 2 daily gain and feed intake are given. During the first 6-day period daily gain of pigs exposed to the draught was 155 g/d lower when compared with pigs exposed to the fluctuating temperature alone. Feed intake was also lower (by 152 g/d). In the second 6-day period pigs at the draught treatment had increased daily gain and feed intake by 223 and 365 g/d respectively compared with period I. Pigs kept at the fluctuating temperature improved daily gain and feed intake during days 7-12 by 81 and 233 g/d respectively compared with day 1-6.

Table 2. Daily gain and feed intake (g/d).

	Temperature-group			Treatment-group		
Experiment	I	II	Mean	I	II	Mean
Day 1-6						
Daily gain mean	760	630	695	527	553	540
s.d.	115	118	117	98	104	101
Feed intake	1337	1160	1249	1138	1056	1097
Day 7-12						
Daily gain mean	773	799	776	804	722	763
s.d.	114	149	152	143	99	121
Feed intake	1483	1480	1482	1470	1382	1462

Heat production during day and night period

In table 3 the effect of day number on heat production (H) and activity-related heat production (AH) is given. Data show that heat production during day and night time in the temperature-group increased with daynumber. The increase in heat production per day is less with progress in time. This effect disappeared at day 9 during day time and after day 5 during night time. In the treatment-group (treatment applied during night) effect of day number disappeared also at day 5 during day time and after day 8 at night time. Regression coefficients obtained from values of H from day number 2 to 12 were significantly different between both groups during the night period. AH with respect to day number after initial

Table 3. Regressioncoefficients of heat production (H) and activity-related heat production (AH) on daynumber after initial exposure of exposure to fluctuating temperature (temperature-group) and superimposed draught (treatment-group).

		Day-period													Significance of Treatment	
		Temperature-group						Treatment-group								
		H			AH			H			AH					
Day-number	df_e	R^2	b_1	sign.	R^2	b_1	sign.	R^2	b_1	sign.	R^2	b_1	sign.		H	AH
2-12	13	90.4	11.3	***	35.1	1.2	n.s.	60.1	9.6	***	47.6	1.1	n.s.		n.s.	n.s.
3-12	11	89.0	11.9	***	51.4	1.1	n.s.	56.3	10.5	**	57.2	1.0	n.s.		n.s.	n.s.
5-12	9	85.7	11.4	**	51.7	1.7	n.s.	43.9	10.0	n.s.	69.4	1.5	n.s.		n.s.	n.s.
6-12	7	84.8	10.6	**	41.8	0.5	n.s.	36.4	9.0	n.s.	73.9	1.6	n.s.		n.s.	n.s
8-12	5	85.6	11.3	*	33.1	0.6	n.s.	70.6	−1.9	n.s.	83.5	−2.4	n.s.		n.s.	n.s.
9-12	3	80.9	7.3	n.s.	17.3	1.1	n.s.	91.4	−8.2	n.s.	89.8	−0.1	n.s.		n.s.	n.s.
Night-period																
2-12	13	53.9	3.9	*	67.9	−2.3	***	80.3	9.6	***	51.3	2.0	n.s.		*	*
3-12	11	50.7	4.2	*	67.6	−2.2	***	76.2	9.5	***	44.4	2.1	n.s.		n.s.	*
5-12	9	36.8	3.3	n.s.	51.7	−1.9	*	67.7	9.2	*	56.8	4.0	n.s.		n.s.	**
6-12	7	28.9	3.9	n.s.	35.4	−1.6	n.s.	63.8	7.3	*	42.4	3.1	n.s.		n.s.	n.s.
8-12	5	6.8	1.7	n.s.	19.2	−1.5	n.s.	91.1	−3.7	n.s.	27.0	−0.7	n.s.		n.s.	n.s.
9-12	3	6.7 --	2.1	n.s.	65.3	−3.0	n.s.	94.2	−5.2	n.s.	33.5	−1.3	n.s.		n.s.	n.s.

n.s. = non-significant difference ($p > 0.05$)
* = significant difference ($p < 0.05$)
** = significant difference ($p < 0.01$)
*** = significant difference ($p < 0.001$)

exposure was analyzed with the model. No significant effect of day number on AH was found during the day time for both the temperature- and treatment-group. During the night period AH was significantly affected by day number untill day 6 in the treatment-group. Data show that increase with days was different between treatments. Calculated values for H and AH (day number 2 to 12) for the

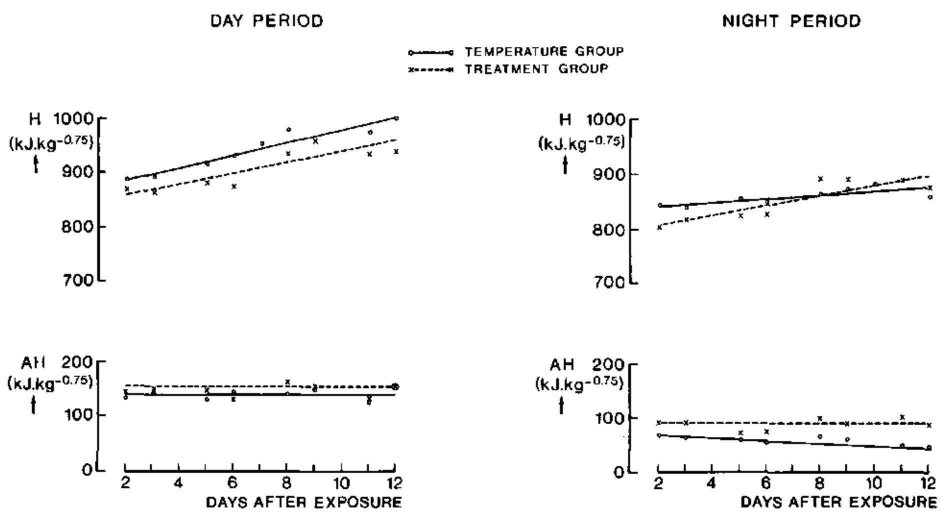

Figure 3. Heat production (H) and activity-related heat production (AH) (kJ/kg$^{0.75}$) during the day- and night-period.
Lines drawn from regression of H and AH on day number.

day and night periods are given in figure 3. Figure 3 shows that AH was not changed with day number during the day period. This is also indicated in table 3.

Heat production within the night period

The draught treatment superimposed on fluctuating temperature was applied during the night period and only during three 2-hour periods. Heat production (H) and activity-related heat production (AH) were therefore calculated separately for periods of draught (D-periods) or absence of draught (ND-periods; see figure 1). In figure 4 H and AH for the successive 2-hour periods during the night are given for the treatment-group and the temperature-group. Values of H and AH are expressed on a 24-hour basis. Data show that H and AH were highest during

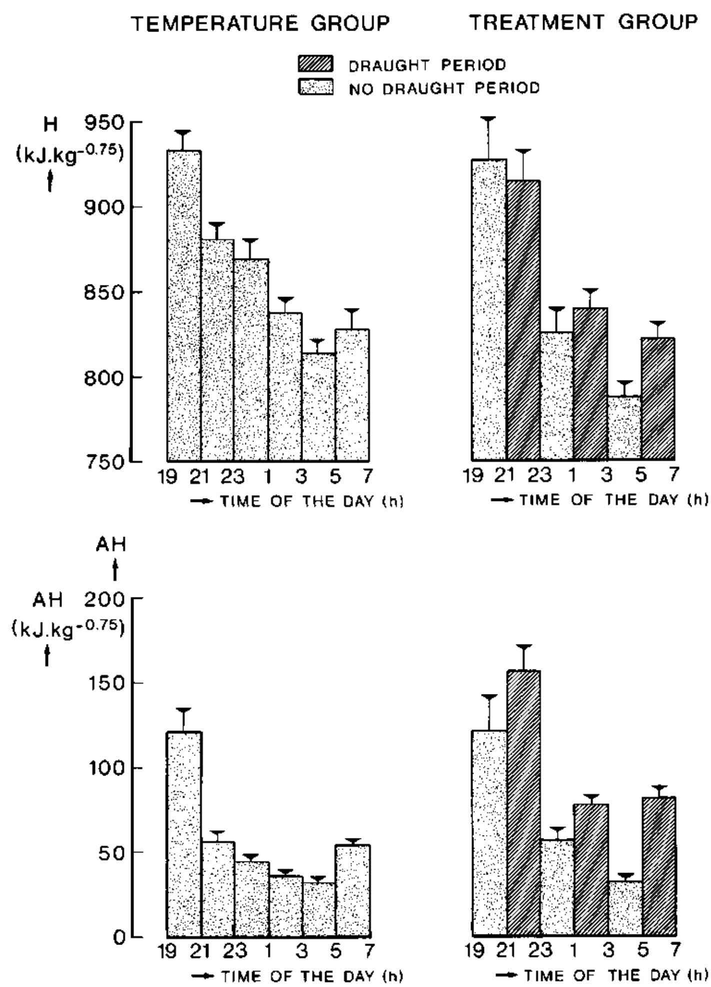

Figure 4. Heat production (H) and activity-related heat production (AH) (kJ/kg$^{0.75}$) during 2-hour-periods at night.

19.00 to 21.00 h when temperature was lowered from 25 °C to 15 °C. In the temperature-group H and AH subsided until 5.00 h and were slightly increased from 5.00 to 7.00 h. During the draught-periods a clear increase in H and AH was observed as compared with the adjacent periods. It is evident from figure 4 that the pattern of H and AH with progress of the night is affected by draught. Average heat production during draught periods (D) was 59 kJ higher than that in periods of absence of draught (ND), *i.e.* 23.00 to 1.00 h and 3.00 to 5.00 h. If calculated similarly the difference for the temperature-group was only 9 kJ.

Heat production during different periods at night

Results of regression of 2-hour values of H and AH on daynumber, for data during the night period, are given in table 4. The regression lines are presented in figure 5. The change of ambient temperature during 19.00-21.00 h reduced heat production with days in the temperature-group. In the draught-group a sharp incline was found in this period. Regression coefficients of H and AH in the temperature-group were parallel. Levels of H at later times of the night were lower. Variability within levels in the draught-group was changed. During the 2-hour periods of 23.00-1.00 h and 1.00-3.00 h (ND-periods) lines were different from those of the periods of 3.00-5.00 h and 5.00-7.00 h (D-periods).

Table 4. Regression coefficients of heat production (H) and activity-related heat production (AH) on day number for each 2-hour period during the night-period.

	H			
	Temperature-group		Treatment-group	
Period	b	se_b	b	se_b
1900—2100	−5.6	3.23	14.1	4.20
2100—2300	6.1	2.88	7.1	2.96
2300—0100	7.1	2.09	11.5	2.41
0100—0300	5.0	1.87	9.8	2.09
0300—0500	4.5	1.36	7.4	2.58
0500—0700	5.3	1.99	6.6	2.54
	AH			
1900—2100	−14.0	2.30	(−1.3)	4.31
2100—2300	(−1.1)	1.92	(3.2)	3.80
2300—0100	(0.0)	0.60	(2.6)	1.57
0100—0300	(−0.8)	0.66	3.6	1.66
0300—0500	(1.0)	0.51	(−0.7)	0.69
0500—0700	(0.3)	0.98	4.3	1.80

( ): indicates non-significant regression coefficient.

The alteration of pattern of heat production (H) as obtained from the regression equations of each 2-hour period is shown separately for day number 2 and 12 in figure 6 . Figure 5 shows that average level of heat production was increased with day number. In addition to that data in figure 6 show that the pattern of heat production is different at day 2 than that at day 12. In the treatment group heat production from 19.00 to 21.00 h at day 12 was higher than at day 2. The application of draught coincided with a change in heat production in these 2-hour periods especially during early night. Curvilinearity of the effect of daynumber was also tested by adding a quadratic term to the model. No significant effects were found however.

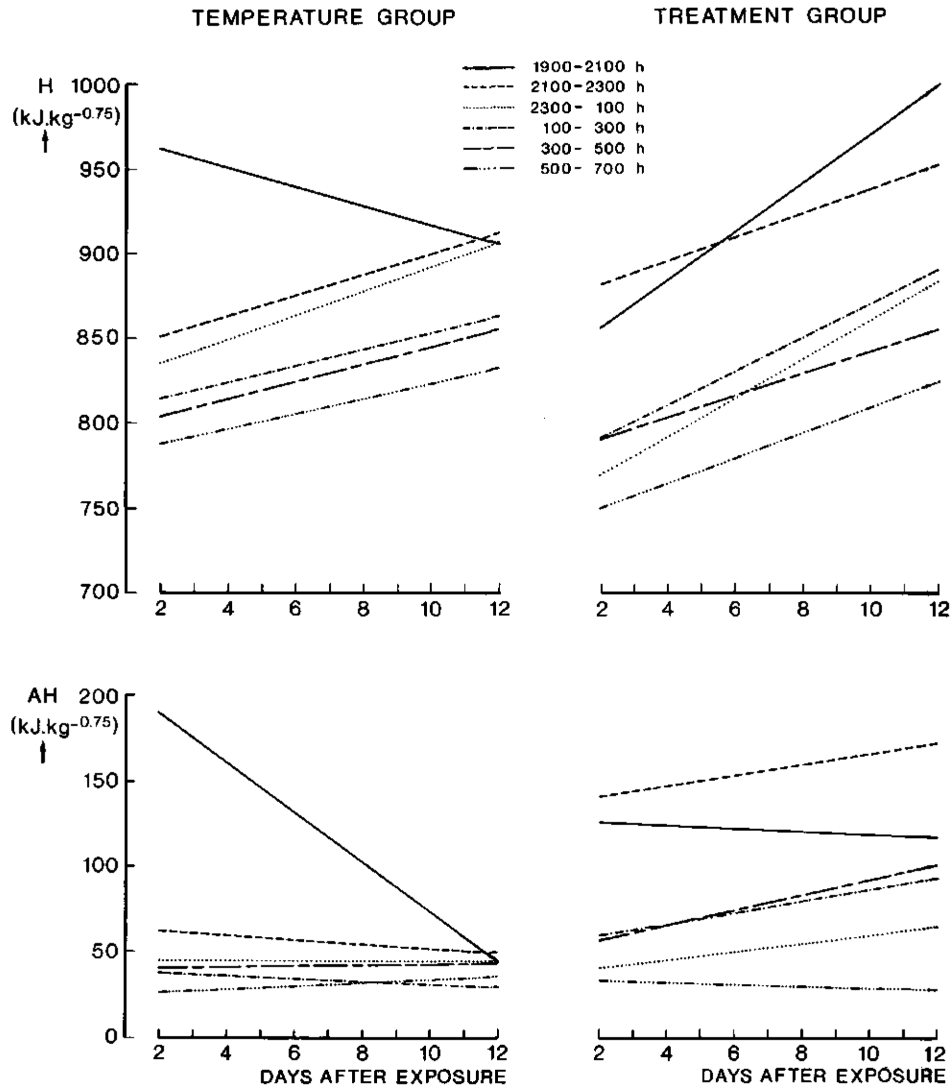

Figure 5. Heat production (H) and activity-related heat production (AH) ($kJ/kg^{0.75}$) for 2-hour periods at night for successive day-numbers. Regression-lines are given for the temperature- and treatment-group.

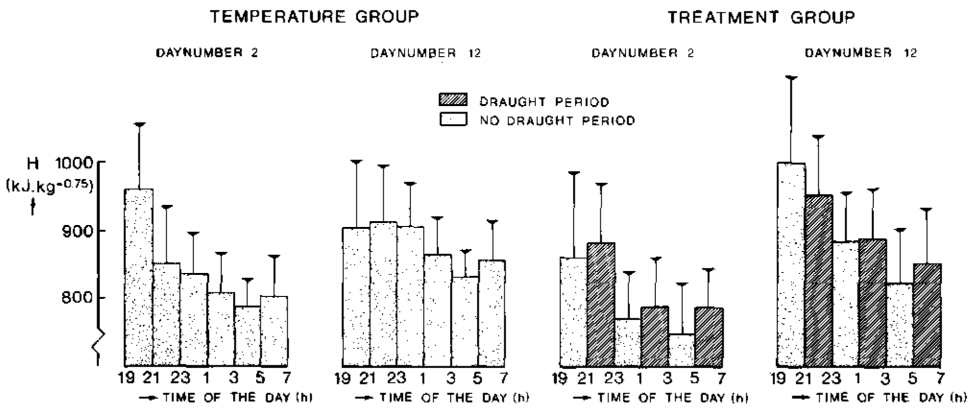

Figure 6. Heat production (H) and activity-related heat production (AH) (kJ/kg$^{0.75}$) during 2-hour-periods at night for day number 2 and 12.

Discussion

Several components of the climatic environment contribute to the thermal environment in intensive pig production. In addition to fluctuation of temperature a short term increase in air movement and or draught may occur in pig houses. Stephens and Start (1972) showed that increase in air movement around the body of an animal disrupts the insulative boundary layer around it resulting in an increase in convective heat loss. These sudden changes in thermal environment rather than constant deviation from optimal thermal environment may provoke immunological changes (Henken, 1982). Pigs fed *ad libitum* can also use feed intake as an additional source of thermal regulation (Morrison and Mount, 1971). Changes in feed intake during the application of treatment are affected by the treatment itself. During the first six days of exposure to draught pigs had lowered feed intake and daily gain compared with pigs in the temperature-group. With duration of the exposure feed intake and daily gain of pigs in the treatment-group improved more than that of pigs in the temperature-group. This was found also for various adverse climatic conditions in experiments by Verhagen *et al.*, (1987 a+b), Barnett and Mount (1967), Mount *et al.* (1980) and Christison and Williams (1982). Bond *et al.* (1967) noted that in general physiological functions are lagged behind the change in thermal environment. Pigs housed in groups may cope with an unfavourable climatic environment by reducing the extra heat loss through behavioural thermoregulation (Ingram and Legge, 1970; Boon, 1982; Mount, 1979). Boon (1982) found that the degree of huddling of pigs increased linearly with lowering the ambient temperature. In this study temperature was different between the day and the night period and application of draught was during the night period Therefore analyses were performed separately for these periods. Days since first exposure affected heat production differently in the temperature and the treatment-group. The effect was only present at night, *i.e.* the periods of draught. In these periods fluctuating temperature influenced both heat production and activity-related heat production until day 5 and 6 respectively. The draught treatment affected total heat production until day 8 whereas acclimation was not reflected in activity-related heat production. An increase in air velocity however might disturb the huddling of pigs. Verhagen *et al.* (1987b) found that application of a similar draught as applied in this study had a differential effect when applied at thermal neutrality or around the lower critical temperature. The magnitude of these effects was related to ambient temperature. Results in the present study showed that a diurnal fluctuation rhythm in ambient temperature accompanied by draught affected heat production during different parts of the night period. In agreement with van der Hel *et al.* (1984) activity in treatment with fluctuation in temperature was increased during the beginning of the night period. Acclimation to fluctuating temperature can be most clearly seen from a decrease in heat production and also in the activity-related component during this period (figure 5). It should be noted also that change in feed intake pattern may have contributed to the increased heat production during early periods of the night in the treatment-group. The occurrence of draught resulted in a changed pattern of acclimation in the course of days compared with fluctuating temperature *per se*. Acclimation to fluctuating temperature appeared to be delayed with draught. As an average over the 12-day experimental period the draught caused an increase in heat production of 50 kJ compared with the control treatment. If a value of 11 kJ per °C coldness for extra thermoregulatory heat is assumed (Close, 1981), than the lower critical temperature T_{cr} would be increased by 4.5 °C due to draught.

It should be stressed that the effect of draught depends also on time of occurrence at night (figure 6). Pigs acclimate to draught but acclimation is not the same at various parts of the night (figure 5). Acclimation seems to be reached sooner (within days) in the first half compared to the second half of the night.

Effect of draught on total heat production during the night diminished with prolonged exposure. However there remained still an effect during periods of draught exposure (table 5A). The application of draught during 2-hour periods increased heat production by 61 kJ at day number 2 compared with the tempera-

Table 5A. The effect of draught on extra heat production (δH, kJ/kg$^{0.75}$) and lower critical temperature (δT_{cr}) within group at day number 2 and 12.
D-period: 21.00 — 23.00 h, 1.00 — 3.00 h, 5.00 — 7.00h.
ND-periods: 23.00 — 1.00 h, 3.00 —5.00 h.

	Daynumber 2	Daynumber 12
	δH δT_{cr}	δH δT_{cr}
Treatment-group	61 (5.5 °C)*	45 (4.1 °C)
Temperature-group	11 (1.1 °C)	7 (0.6 °C)

* Extra thermal demand, assuming extra thermoregulatory heat of 11 kJ/kg$^{0.75}$ per °C (Close, 1981).

Table 5B. Difference in heat production (δH) between temperature- and treatment-group after 12 days of exposure, during 2- hour periods at night (kJ/kg$^{0.75}$). Extra thermal demand (δTcr) is given also.

		δH δT_{cr}
Period:	19.00 — 21.00 h	91 (8.3 °C)*
	21.00 — 23.00 h	41 (3.7 °C)
	23.00 — 1.00 h	−23 (−2.1 °C)
	1.00 — 3.00 h	25 (2.3 °C)
	3.00 — 5.00 h	− 9 (−0.8 °C)
	5.00 — 7.00 h	− 1 (—)

* Extra thermal demand, assuming extra thermoregulatory heat of 11 kJ/kg$^{0.75}$ per °C (Close, 1981).

ture-group. At day number 12 the difference was 45 kJ. This would be equivalent to an increase in thermal demand during draught by 5.5 and 4.1 °C respectively. Comparison of similar periods for pigs exposed to fluctuating only gave minor differences (table 5A). It can thus be concluded that with respect to acclimation overall values of heat production may conceal effects by compensating effects of draught in periods thereafter. This is illustrated in table 5B. Heat production of pigs exposed to the draught treatment after 12 days of exposure is compared to that of pigs exposed to fluctuating temperature. It should be noted that daily gain and feed intake of both groups may be assumed equal (table 2). The treatment of draught resulted in increased heat production during periods of draught and during the beginning of the night period. However during periods of absence of draught heat production was decreased thus indicating carry-over effects of the treatment. Variation in thermal demand may be still present although not estimable from overall effects.

Therefore it is important to distinguish overall effects from effects within a day. This may have large consequences for physiological mechanisms related to thermal demand and stress. The results of the present experiments stress the importance of such investigations.

Acknowledgements

The authors thank Mr. K. van der Linden, Mr. H. Brandsma and Mr.J. Hermans for their assistance with the experiments. Mr. S. Ojik carefully typed the manuscript.

References

Barnett, S.A.; Mount, L.E., 1967: Resistance to cold in mammals, Thermobiology, Ed. A.H. Nose, Academic Press London and New York, p. 411-477.

Bond, T.E.; Kelley, C.F.; Heitman, H.; 1967: Anim. Prod. **9**, p. 453.

Boon, C.R. , 1982: The lower critical temperature and group postured behaviour of pigs. Livestock Environment II. 2nd Int. Liv. Env. Symp. Am. Soc. of Agric. Eng. 1982.

Christison, G.I.; Williams, C.M., 1982: Effects of cold on animal production, CRC Handbook of Agricultural Productivity Vol. II. p. 69-76.

Close, W.H., 1971: Anim. Prod. **13**, p. 295- 302.

Close, W.H. (1981). The climatic requirements of the pig, Environmental aspects of housing for animal production. Ed. J.A. Clark, Butterworth, London, p. 149-166.

Dantzer, R.; Mormede, P., 1983: J. Anim. Sci. **57**, p. 6-18.

Geuyen, T.P.A.; Verhagen, J.M.F.; Verstegen, M.W.A., 1984: Anim. Prod. **38**, p. 477-485.

Henken, A.M., 1982: The effect of environmental temperature on immune response and metabolism of young growing chickens. Thesis. Wageningen.The Netherlands.

Ingram, D.L. ; Legge, K.F.,1970: J. Physiol. **210**, p. 989-998.

Kelley, K.W., 1985. Immunological consequences of changing environmental stimuli. In: Animal Stress. American Physiological Society, p. 193-223.

Morrison, S.R.; Mount, L.E., 1971: Anim. Prod. **13**, p. 51-57.

Mount, L.E., 1979: Adaptation to thermal environment: man and his productive animals, Edward Arnold, London.

Mount, L.E.; Start, I.B.; Brown, D., 1980: Anim. Prod. **30**, p. 295-298.

Nielsen, R., 1982: *Haemophilus pleuropneumonia* infection in pigs. Thesis. Copenhagen. Denmark.

Osborne, A.D.; Saunders, J.R.; Willson, P., 1984: Some observations on *Haemophilus pleuropneumoniae* infections in pigs with particularly reference to the effects of stress. IPVS, Gent. p. 95.

Siegel, H.S., 1985: WPSA Journal **41**, p. 36-45.

Snedor, G.W.; Cochran, C., 1976: Statistical Methods. Iowa State University Press.

Stephens, D.B.; Start,I.B, 1972: The Cornell Veterinarian, Vol. LXII.
Tielen, M.J.M., 1974. De frekwentie en de zoötechnische preventie van long- en leveraandoeningen bij varkens. Thesis. Wageningen. THe Netherlands.
Van der Hel, W.; Verstegen, M.W.A.; Baltussen, W.; Brandsma, H, 1984: Int. J. of Biomet. **28**, p. 303- 315.
Van der Hel, W.; Duijghuisen, R.;Verstegen, M.W.A.,1986: Neth. J. Agr. Sci.34, p. 173-184.
Verhagen, J.M.F.; Verstegen, M.W.A.; Geers, R., 1987a: Neth. J. Agric. Sci.: submitted.
Verhagen, J.M.F. ;Kloosterman, A.A.M.; Brandsma, H.A., 1987b: Anim. Prod.: submitted.
Verstegen, M.W.A., 1971: Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups, Thesis, Wageningen, The Netherlands.
Wenk, C.; van Es, A.J.H., 1976: Schweiz. Landwirtsch. Monatshefte **54**, p. 232-236.

CHAPTER VI

The effect of exposure to climatic environment on some blood parameters of young-growing pigs

J.M.F. Verhagen, M.B. Kreukniet, W. Visser and J.R. van Herwijnen

Netherlands Journal of Agricultural Science: in press.

Abstract

Young growing pigs, liveweight 22 kg, were exposed to 4 climatic treatments during 16 days. Treatments were at 25 °C, 15 °C, fluctuating temperature over 24 hour (9.00-19.00 h: 25 °C; 21.00-7.00 h: 15 °C) and draught superimposed on the fluctuating temperature. In each treatment 20 group-housed pigs were used. Each treatment applied was performed in two replicates. Levels of albumin and globulins before and after exposure were measured in 6 pigs, chosen at random. Leucocytic cells were differentiated. Levels of albumin and globulins were not affected by treatments. Percentage lymphocytes was decreased, whereas percentage neutrophils was increased after 16 days exposure to fluctuating temperature and draught.

Introduction

Climatic environment is known to interfere with resistance and susceptibility of animals to disease (Borysenko and Borysenko, 1982; Dantzer and Mormède, 1983; Kelley, 1985). An adverse climatic environment will increase levels of hormones, such as ACTH and corticosteroids, and these may have an indirect or direct effect on the immune system (Blatchford *et al.*, 1978; Dantzer and Mormède, 1983; Siegel, 1985). These effects are important since they are associated with animal health (Kelley, 1985).

Kelley (1983) found an increase in number of lymphocytes and a decline in number of neutrophils after acute cold stress. With chronic cold stress both lymphocytes and neutrophil numbers were decreased. Widowski et al. (1984) observed a change in the ratio of neutrophils to lymphocytes in pig's blood after oral administration of cortisol. Administration of ACTH to pigs did not influence number of lymphocytes nor neutrophils (Blecha, 1984).
In this study experiments were conducted to investigate the effects after 16 days exposure to different climatic environments on relative numbers of leucocytes and levels of albumin and globulins in peripheral blood of young-growing pigs.

Material and Methods

Four climatic treatments were applied, with two replicates per treatment. Treatments of climatic environment consisted of ambient temperatures of 25 °C and 15 °C, fluctuation in temperature (25 °C from 09.00 h to 19.00 h and 15 °C from 21.00 h to 07.00 h) and a similar rhythm with a superimposed treatment of draught. The draught consisted of an air stream with increased air velocity (0.8 m/s) with a temperature 5 K lower than ambient temperature. Draught was applied periodically at night time during 2-hour periods (21.00-23.00 h, 01.00-03.00 h and 05.00-07.00 h). In the other parts of the night, conditions were as in the other treatments and air velocity was below 0.2 m/s. During the 2-hour draught-periods the draught occurred in an alternating sequence of 4 minutes on and off. Ambient temperature of 25 °C is within thermal neutrality whereas 15 °C is below the lower critical temperature for pigs of this study (Bruce and Clark, 1979). Each climatic treatment lasted for 16 days.

In each experiment 20 pigs, housed in two groups of 10 pigs each, were exposed to a climatic treatment. Liveweight of pigs at the initiation of the different treatments was 21.7 kg (± 2.1 kg) and was not significantly different between treatments and replicates.
At day 0 of each treatment six pigs were randomly chosen and blood samples were taken from the *vena brachialis*. The same pigs were resampled at day 16 after initial exposure to the climatic treatment. Heparinized blood was used to make blood smears and stained cells (Giemsa) were differentiated according to Juncqueira and Carneiro (1980). A total number of 200 cells was counted and differentiated into neutrophils, lymphocytes, monocytes, eosinophils and basophils and they were expressed as a percentage.
The amount of albumin, α-, β- and γ-globulin in the serum was determined by electroforesis (IBL, West-Germany).
Analysis of variance was carried out with replicate and climatic treatment as factors (SAS, 1985). Tukey's HSD-test was used for multiple range comparison of treatments.

Results

At day 0 values of traits were similar, apart from % monocytes which was slightly different between groups ($p < 0.05$). Analysis of variance of the blood parameters at day 16 after initial exposure is given in table 1. Data show that % lymphocytes and % neutrophils were significantly affected by climatic treatment. Exposure to fluctuation in ambient temperature combined with a superimposed draught resulted in a significant lower % of lymphocytes and higher % of neutrophils compared with 25 °C. The amount of α-, β- or γ-globulin was not significantly affected by climatic treatment.

Table 1 Results of analyses of variance after exposure to different climatic treatments (n = 47).

	Replicate	Treatment	MSE	R^2	LS-Means Treatments#				Overall mean
					25 °C	25 °C	25-15 °C	25-15+ Draught	
% lymfocytes	n.s.	**	198.6	24	71.5[a]	70.9[a]	72.5[a]	54.8[b]	67.4
% neutrophils	n.s.	*	202.8	22	27.7[a]	27.4[ab]	25.5[ab]	42.9[b]	30.9
% monocytes	***	n.s.	0.74	32	—	—	—	—	1.1
% eosinophils	n.s.	n.s.	0.58	10	—	—	—	—	0.8
% basophils	n.s.	n.s.	0.001	9	—	—	—	—	0.01
albumine	n.s.	n.s.	29.5	14	—	—	—	—	48.4
α-globuline	n.s.	n.s.	8.3	13	—	—	—	—	22.5
β-globuline	n.s.	n.s.	4.0	10	—	—	—	—	16.2
γ-globuline	n.s.	n.s.	12.3	16	—	—	—	—	13.1

n.s. : non-significant effect
* : significant effect ($p < 0.05$)
** : significant effect ($p < 0.01$)
*** : significant effect ($p < 0.001$)
# : LS-means are given if treatment-effect is significant.
a,b : Different superscripts within rows indicate significant difference ($p < 0.05$)

Discussion

Dantzer and Mormède (1983) showed that thermal stress of cattle was elicited by changes in cortisol levels as a result from pituitary-adrenal responses. Low temperature resulted in increased cortisol level which reflected the reaction to the physical quality of the environmental temperature (Dantzer and Mormède, 1983). This was found also by Blatchford *et al.* (1978), Hacker *et al.* (1973) and Bate and Hacker (1985) for pigs. The effects of steroid hormones or stress on lymphatic tissue lies in the cardinal role played by this tissue in the immune response (Siegel, 1985). The direct effects of corticosteroids, or the indirect effects of ACTH or stress include reductions in lymphatic tissue mass (*i.e.*, thymus, spleen, bursa van Fabricius), a depression in the number of circulating lymphocytes and an increase in neutrophilic or heterophilic granulocytes in chickens (Siegel, 1985). Results obtained in this study support the theory of this mechanism since it was found that pigs exposed to a diurnal rhythm in ambient temperature with a superimposed draught-treatment also had a lower % lymphocytes and a higher % neutrophils. Ambient temperatures within thermoneutrality (25 °C) or below the lower critical temperature (15 °C) and 24-hour fluctuation in ambient temperature did not cause a change in bloodcell ratio's at day 16. It may be that adaptation to other treatments than draught has been completed at this day. Dantzer and Mormède (1983) and Kelley (1985) stated that changes in the immune system depended on the physical quality of the stimulus. According to Kelley (1985) immune responses might be subjected to adaptive processes. Kelley *et al.* (1984) found that the cell-mediated response of young calves was modulated by duration of exposure to adverse climatic conditions. It may be assumed that the magnitude of the effect of the applied climatic treatments in these experiments depend on the deviation from the optimal environment (*i.e.* thermoneutrality) and the combined effect of the duration of the climatic stress. It is therefore important to estimate this deviation and the mechanisms involved in adaptation of animals to adverse climatic factors. State of acclimation will thus interfere with endocrinological status and thus immunological parameters.

Acknowledgements

The authors acknowledge Mr. Th. Wensing from the Veterinary Faculty, Clinic for Large Animal Medicine, State University Utrecht for assistance.
Mrs. G. de Vries is thanked for her cooperation.

References

Bate, L.R. and R. Hacker. 1985. Effect of variation and environmental temperature on the concentration of serum cortisol in pregnant sows. *Canadian Journal of Animal Science*, 65: 399- 404.

Blatchford, D., M. Holzbauer, D. L. Ingram and D.F. Sharmann. 1978. Responses of the pituitary-adrenal system of the pig to environmental changes and drugs. *British Journal Pharmacology* 62: 244-254.

Blecha, F., 1984. Neonatal pigs reared artificially have suppressed in vivo and in vitro cellular immune response. *Journal of Animal Science* 59: supl. 1, p. 190.

Borysenko, M. and J. Borysenko. 1982. Stress behavior and Immunity: Animal models and mediating mechanisms. *General Hospital Psychiatry* 4: 59-67.

Bruce, J.M. and J.J. Clark. 1979. Models of heat production and critical temperature for growing pigs. *Animal Production* 28: 353-369.

Dantzer, R. and P. Mormède. 1983. Stress in farm animals: a need for reevaluation, *Journal of Animal Science* 57: 6-18.

Hacker, R.R., Stefanovics, M.P. and Batra T.R. 1973. Effects of cold exposure on growing pigs: growth, body composition and 17-ketosteroids, *Journal of Animal Science* 37: 739-744.

Juncqueira, L.C. and J. Carneiro. 1980. Basic Histology. Lange Medical Publications. Los Altos California.

Kelley, K.W., 1983. Immunobiology of domestic animals as affected by hot and cold weather. Trans American Society Agricultural Engineers.

Kelley, K.W., R.E.Greenfield, M.T. O'Connor and C.T. Gaskins. 1984. Acute cold stress in zeranol-implanted steers. *Journal of Animal Science* 53:supl 1. p.184. Kelley, K.W., 1985. Immunological consequences of changing environmental stimuli. In: Animal Stress. American Physiological Society: 193-223.

SAS. Statistical Analysis System. 1985. SAS Institute Inc., Cary NC.

Siegel, H.S., 1985. Immunological responses as indicators of stress. *WPSA Journal*, 41: 36-45.

Widowski, T., S.E. Curtis and J.M. McFarlane. 1984. Neutrophil/lymfocyte ratio in pigs fed cortisol. *ASAS Midwestern Section*, March, 1984, Chicago.

CHAPTER VII

The relation between body temperature, metabolic rate and climatic environment in young-growing pigs

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Journal thermal Biology: accepted.

Abstract

Young growing pigs (18 kg) were housed in two climatically controlled respiration chambers and exposed to 5 different climatic environments. Per chamber 20 pigs were housed in two groups of 10 pigs each. Climatic environment applied to the treatment-group in one chamber was subsequently 25/15 °C+draught, 25 °C, 25 °C+draught, 15 °C+draught and 15 °C. The control-group in the other chamber was exposed to similar temperatures but draught was not applied to this group. Each treatment lasted 2 days, with one day in between. The treatment 25/15 °C consisted of a fluctuation in ambient temperature during 24 hour (25 °C during day time, 15 °C during night time). With draught air velocity was increased from 0.2 m/s to 0.8 m/s and temperature of the air stream was 5 K lower than ambient temperature. Draught occurred intermittently at night during period of two hours. Within a draught period it was alternated: 4 min. on, 4 min off. Heat production was measured during 24 hours and activity was related to this. In the treatment-group two pigs had implanted transponders to measure body temperature. Results showed that heat production and activity-related heat production were increased during periods of draught. Body temperature was affected also during draught. Effects on body temperature was lagged behind heat production and activity-related heat production. Moreover effects were dependent on temperature at which draught occurred. With constant ambient temperature and absence of draught such effects were not present. The effect of the influence of sudden changes in climatic environment on body temperature and heat production is stressed.

Introduction

In intensive pig production the climatic environment is important. Not only productivity of fattening pigs is dependent on climatic environment but adverse climatic factors may alter the immune response (Henken, 1982; Siegel, 1985; Kelley, 1985). The climatic environment cannot be regarded as constant in intensive production systems (Bond *et al.*, 1967), since animals will be exposed to variations in air velocity and fluctuations in ambient temperature (Close, 1981). Moreover air velocity may occur as draught when temperature of the air is lower than local ambient temperature (Tielen, 1974; Verhagen *et al.*, 1987). Animals may loose extra heat when such factors occur.

Pigs are homeothermic animals and they will thus compensate for increased heat loss by increase in heat production in order to maintain their body temperature. Hammel *et al.* (1963), cited by Ingram and Legge (1970), noted that the influence of ambient temperature on body temperature is greater during night than during day time because metabolic rate and activity level are higher during day time. Behavioural thermoregulation (huddling) is an important mechanism for coping with adverse climatic environment in group-housed pigs (Mount, 1979; Boon, 1982). Huddling of pigs will reduce extra thermal heat loss and can subsequently modify the effect on body temperature. Activity of pigs has to be considered also since activity is related to heat production. In this respect both are related to body temperature (Aschoff, 1974; Ingram and Mount, 1973).

The present investigation was made to study body temperature and metabolic rate of pigs exposed to different climatic environments. Factors of climatic environment studied were ambient temperature (25 °C and 15 °C), fluctuating temperature (25 °C during day and 15 °C during night) and draught. Especially abrupt changes in effective temperature may act as climatic stressors. Therefore changes caused by draught were used in this study and the impact on heat production and body temperature was estimated. The influences of these factors were studied during night time in group-housed pigs.

Material and Methods

Animals and housing

Young growing pigs of approximately 9 weeks of age were purchased from a commercial farm. Pigs were Large White × Dutch Landrace and were kept at similar pre-experimental conditions. Pigs were alloted to two identical climatized respiration chambers. In each chamber 20 pigs were housed in two pens with 10 pigs per pen. Mean weight between both chambers was balanced and was 17.8 kg (sd 2.4) at the start of the experiment. Each pen had an area of 9 m^2 and 10% of it was covered with slats. The floor consisted of non-toxic asphalt.

Feeding

Feed was provided *ad libitum* by two selffeeders per pen from 8.00 to 20.00 h. Calculated gross energy content of the feed was about 16 kJ per gram, whereas crude protein content was 16.7%. Water was available *ad libitum*.

Telemetry

To measure body temperature an automatic recording system was developed by TFDL (Technical and Physical Engineering Research Institute, The Netherlands). The system consists of transponders, a receiver, an interface and a microcomputer (figure 1). Every 30 seconds a signal from a transponder is transmitted through the antenna to the receiver. The transponder is operated by a quartz clock and its identification and the measurement of temperature are transmitted in time intervals. Each transponder operates at a different frequency (about 30 MHz). The interface converts the length of the signal into milliseconds which in turn are converted to actual data by the microcomputer. Data were stored as mean value over 15-minute intervals. Transponders were calibrated before and after the experiment (TFDL).
The dimensions and weight of a transponder are given in figure 1 also. The transponder is made of glass and stainless steel. One week prior to the start of the experiment transponders were placed intra-abdomenal in pigs after laperotomy in the left side under complete halothane anaesthesia. The transponder was located near the ventral part of the abdomen and this was confirmed by palpation and X-ray photo's of pigs. After the experiment transponders were retrieved similarly. No macroscopic effects of transponders on intra-abdomenal organs were observed.

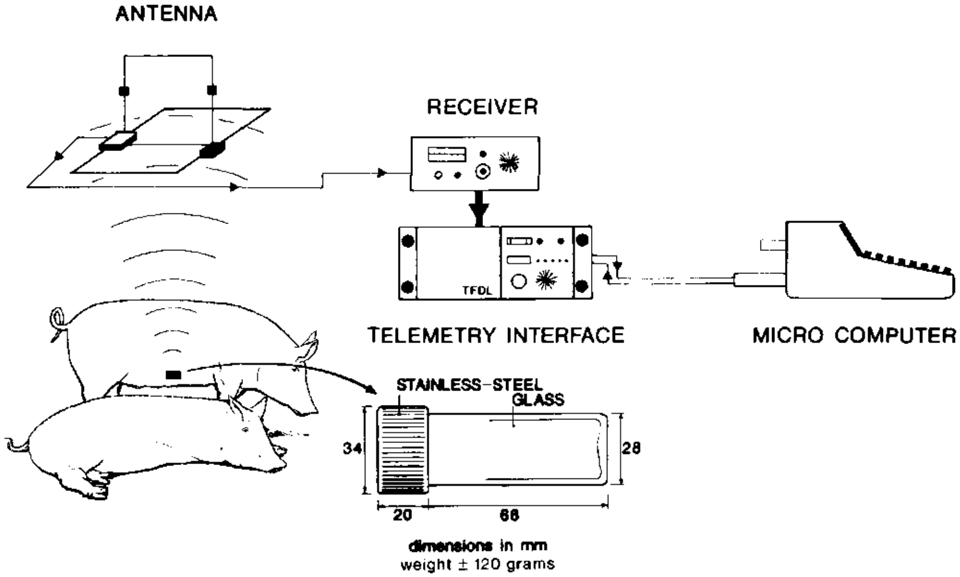

Figure 1. System of telemetrically measurements of body temperature. Weight and dimensions of transponders.

Experimental design

The experiment lasted 15 days and was divided in 5 treatment periods of 2 days each. Treatments are given in table 1. Pigs in one chamber were exposed to the various temperatures (control-group), whereas pigs in the other chamber were exposed to the same temperatures but in addition draught was applied in periods I, III and IV (treatment-group). An ambient temperature of 25 °C was chosen in order to represent temperature within thermoneutrality, whereas 15 °C ambient temperature is below thermoneutrality of pigs of this liveweight (Bruce and Clark, 1979).
Two pigs with a transponder were housed in the treatment-group, in one pen of 10 animals. In period I temperature was 25 °C from 9.00 to 19.00 h and 15 °C from

Table 1 Experimental design.

Treatment period	Day	Control-group	Treatment-group
I	1-2	Fluctuating temperature	Fluctuating temperature + draught
II	4-5	Constant temperature (25 °C)	Constant temperature (25 °C)
III	7-8	Constant temperature (25 °C)	Constant temperature (25 °C) + draught
IV	10-11	Constant temperature (15 °C)	Constant temperature (15 °C) + draught
V	13-14	Constant temperature (15 °C)	Constant temperature (15 °C)

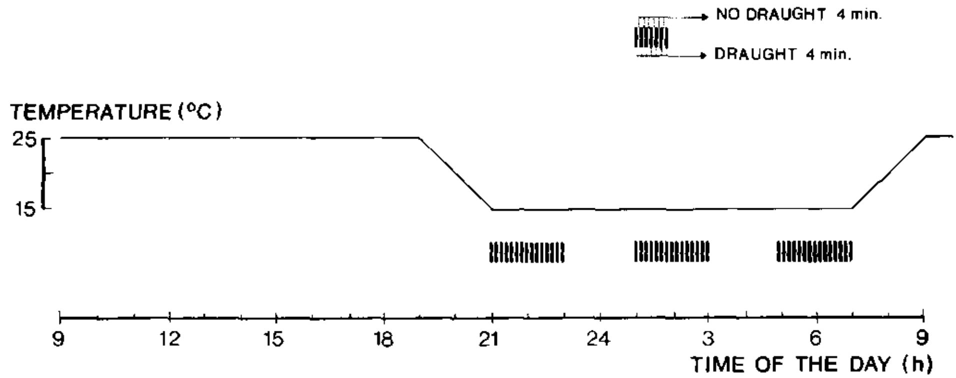

Figure 2. Time scale (h) of fluctuation in ambient temperature and application of draught.

21.00 to 7.00 h (figure 2). The draught in the treatment-group was applied during three 2-hour periods and was alternated (4 min on/4 min off) within these periods (figure 2). Draught consisted of an air stream with a velocity of 0.8 m/s and a temperature of 5 K below ambient temperature. It was directed laminair across each pen. Otherwise air velocity was below 0.2 m/s. Throughout the experiment relative humidity was kept at 65%. Artificial light was from 8.00 to 20.00 h.

Experimental routine and measurements

In figure 3 the experimental routine is presented. Pigs were weighed between and feed intake was determined during the different climatic treatments. Each climatic treatment period of 2 days was covered by a 48-hour respiration period (figure 3) during which gaseous exchange of oxygen and carbon dioxide of pigs was measured continuously and recorded at 18-minute intervals. Heat production was determined from this, according to Brouwer (1965). Detailed description of principles and procedures of open-circuit calorimetry were given by Verstegen (1971). Physical activity was measured by an ultrasound device above each pen and recorded at the same 18-minute intervals also. This was done similarly amongst others by Wenk and Van Es (1976) and Geuyen *et al.* (1984). Rectal temperature was determined between each climatic treatment.

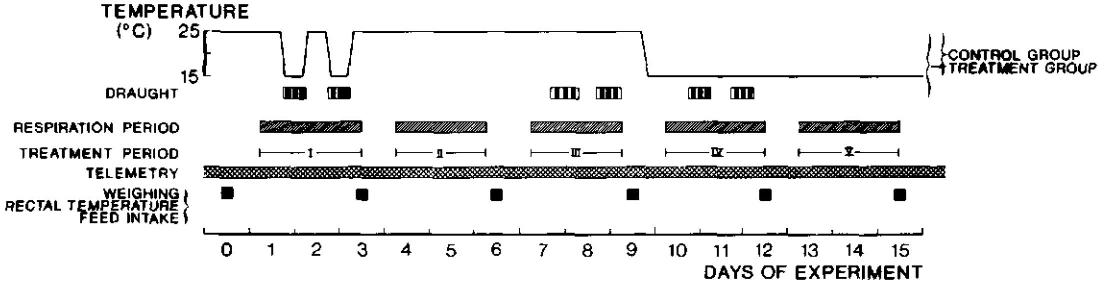

Figure 3. Experimental design and procedure.

Statistical analysis

Activity-related heat production was obtained from regression of heat production on activity. This was done for the day (8.00 — 20.00 h) and night (20.00 — 8.00 h) periods and for each treatment period separately. Body temperature at the different climatic treatments was analyzed by periodic regression (Bliss, 1970). During the night-period three subsequent 4-hour periods were distinquished and measurements in 2 night-periods were obtained in each climatic treatment. It is thus assumed that a similar pattern within each 4-hour period will be present. Each 4-hour period than consisted of subsequently 1 hour no-draught, 2-hour draught and 1 hour no- draught. In each such period t = 0 at start and t = 240 at the end. Measurements were then at t = 0, 15, 30,....., 240. The following formula was used:

$$y = a_o + a_1 \cos(ct) + b_1 \sin(ct) \qquad \text{(I)} \qquad \text{(Bliss, 1970)}$$

where y is body temperature, $a_o = \bar{y}$ and the constant c converts the units of the independent variable in one cycle to angular measure in radians (Bliss, 1970). The semi-amplitude (A), one-half the range in y from maximum to minimum, can be computed from the regressioncoefficients a_1 and b_1 by:

$$A = \sqrt{a_1^2 + b_1^2} \qquad \text{(II)} \qquad \text{(Bliss, 1970)}$$

Daily gain between control- and treatment-group was tested by *t*-test (Snedecor and Cochran, 1976).

Results

Daily gain and feed intake

For each treatment period daily gain and feed intake are given in table 2. Differences in daily gain between control- and treatment-group were not significant in any treatment period. As an average over the experimental period daily gain of pigs in the control- and treatment-group was 655 and 675 g/d respectively. The 2 pigs with transponder had daily gain of 622 and 601 g/d.

Heat production

In figure 4 heat production per kg metabolic body weight ($kg^{0.75}$) is presented as an average per treatment-period. It appears that pigs exposed to draught had an increase in heat production of 50 kJ (about 4%) in treatment period I. In periods III and IV draught was applied also for the treatment-group but heat production was not increased.
Application of draught was during the night-period (see figure 3), values of heat production (H) and activity-related heat production (AH) were therefore calculated for this period. This is presented in figure 5. Data show that H and AH were increased for the treatment-group in periods of draught (periods I, III and IV). Draught in these periods occured during 2-hour periods with intermediate periods of absence of draught (see figure 3). Therefore H and AH were calculated for

Table 2 Daily gain and feed intake per animal (g/d) at the successive climatic treatments.

	Control	Treatment	Control	Treat-ment	Control	Treatment	Control	Treatment	Control	Treat-ment
(°C)	25/15	25/15 + draught	25	25	25	25 + draught	15	15 + draught	15	15
Daily gain										
mean	695	640	615	647	665	659	620	673	677	757
sd	168	167	193	211	156	143	191	213	169	209
Feed intake										
mean	839	832	1016	1018	1125	1152	1237	1242	1306	1324
sd	73	7	47	67	89	30	82	0	105	60

Table 3 Rectal temperature after climatic treatments for pigs in the control and treatment group. Mean and standard deviation (sd).

	Control-group				Treatment-group			
Period		n	mean	sd		n	mean	sd
I	25/15 °C	18*	39.44	0.25	25/15 °C + draught	20	39.48	0.28
II	25 °C	20	39.59	0.30	25 °C	20	39.63	0.24
III	25 °C	20	39.79	0.30	25 °C + draught	20	39.87	0.41
IV	15 °C	19	39.80	0.23	15 °C + draught	20	39.66	0.33
V	15 °C	19	39.64	0.24	15 °C	20	39.85[a]	0.36[b]

a: significant difference between mean values ($p < 0.05$)
b: significant difference between standard deviations ($p < 0.05$)
*: measurements not included due to restraint of animal(s)

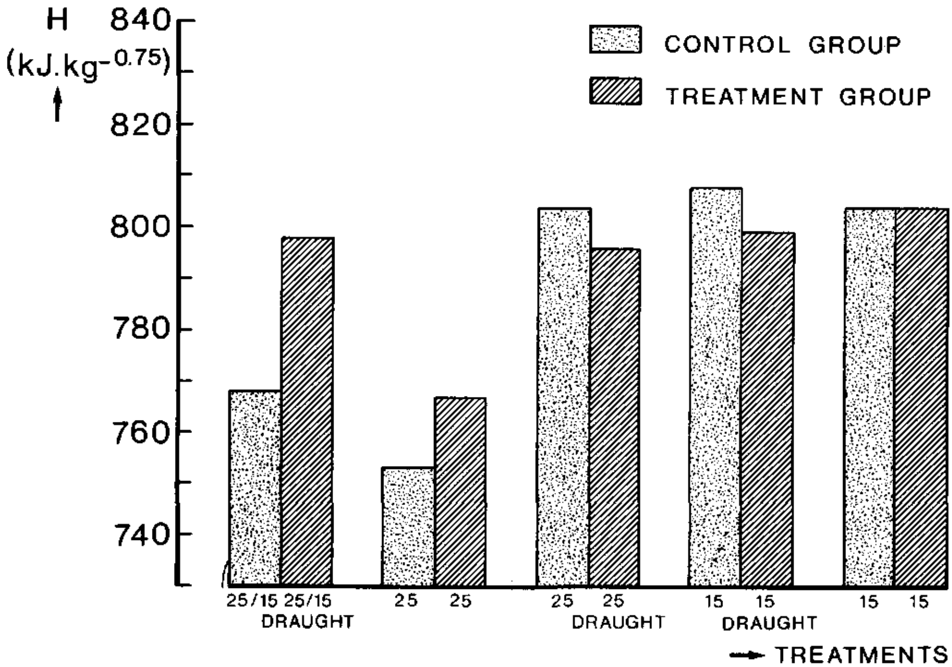

Figure 4. Heat production (H, kJ/kg$^{0.75}$) for the control and treatment group during the successive treatments.

each 2-hour period during the night (figure 6). In each treatment period heat production of pigs in the control-group declined with progress of the night. Also heat production in the treatment-group during no draught declined (periods II and V). Pattern of AH did not show major differences. Draught, in periods I, III and IV, clearly altered the pattern of heat production. Especially AH was increased during periods of draught.

Rectal temperature

After each treatment period the rectal temperature of the pigs was measured (table 3). Mean rectal temperature was somewhat higher for pigs in the treatment-group, except after period IV. After period V pigs in the treatment-group had significantly higher rectal temperature and standard deviation.

Body temperature

In the treatment-group two pigs (1, 2) were equipped with a transponder in the abdomen for measurements of body temperature. Measurements were from 20.00 h to 8.00 h. In period II only 16 measurements were obtained during the first night-period. Mean values of body temperature during the night-period were calculated for each treatment period and are given in table 4. Data show that mean values of pigs with a transponder were not similar. Values were highest for the pig with transponder II during the second night of period V.

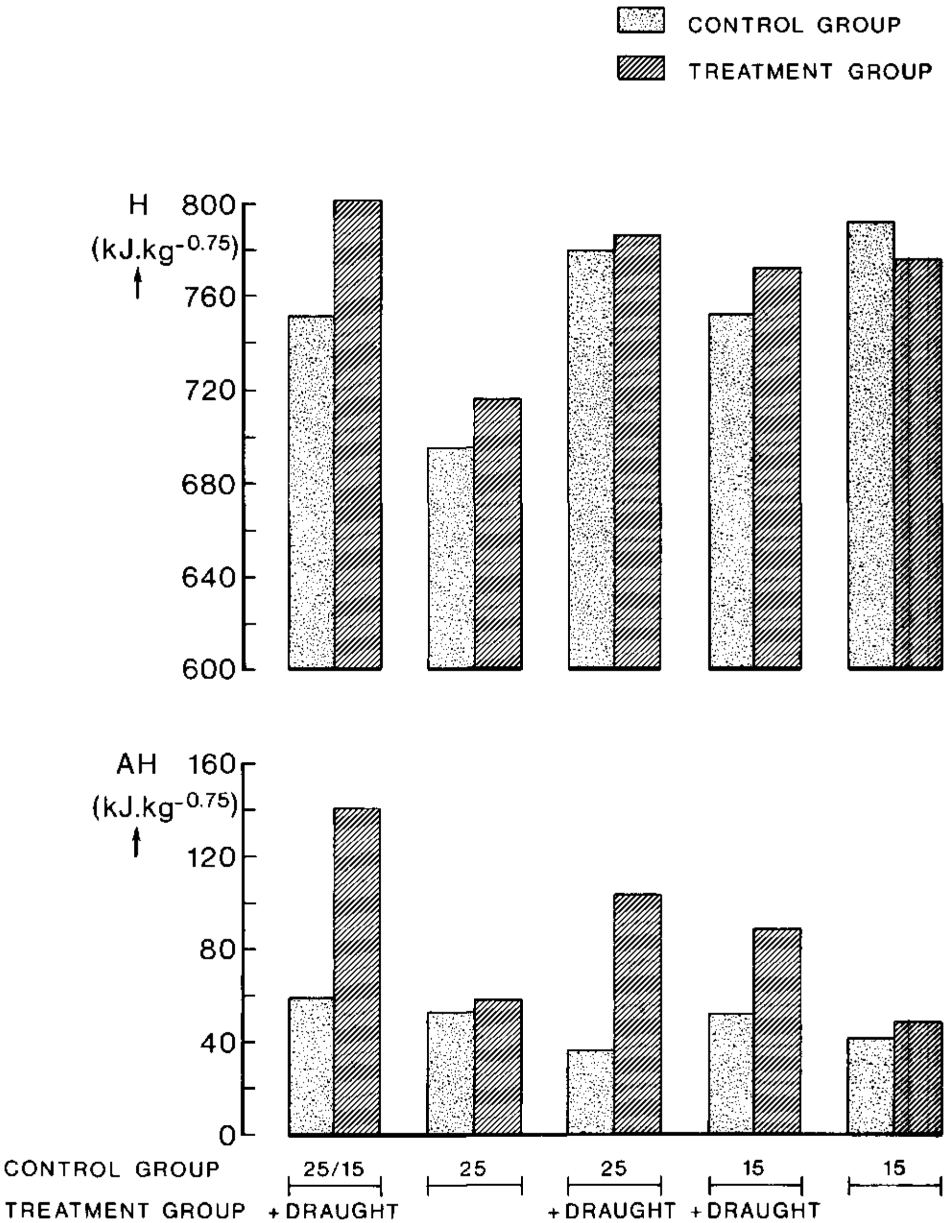

Figure 5. Heat production (H, $kJ/kg^{0.75}$) and activity-related heat production (AH, $kJ/kg^{0.75}$) **during** night time for the control and treatment group at the successive treatment periods.

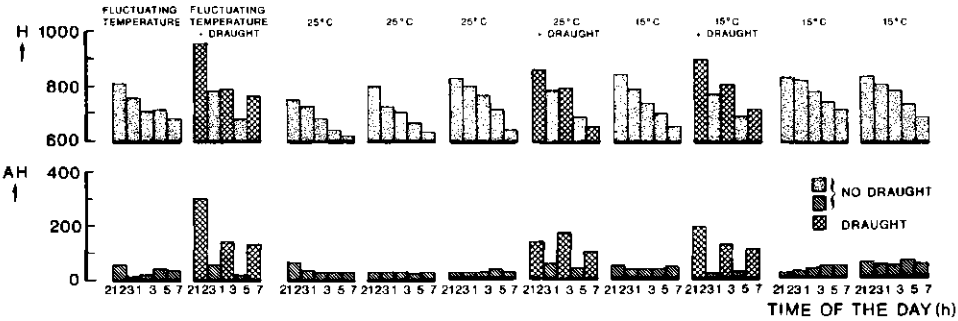

Figure 6. Heat production (H, kJ/kg$^{0.75}$) and activity-related heat production (AH, kJ/kg$^{0.75}$) during 2-hour periods at night for the control and treatment group at the successive treatment periods.

Table 4 Mean body temperature of pigs with a transponder housed in the treatment group (n = number of measurements, sd = standard deviation).

Period		Pig I			Pig II		
		n	mean	sd	n	mean	sd
I	25+15 °C + draught	96	40.4	0.30	96	40.0	0.29
II	25 °C	64	40.3	0.33	64	40.1	0.25
III	25 °C + draught	96	40.3	0.27	96	40.2	0.40
IV	15 °C + draught	96	40.4	0.25	96	40.5	0.45
V	15 °C	96	40.6	0.26	96	40.9	0.69

Periodic regression

Body temperature was regressed on time by means of periodic regression (eq. I). Lines derived from regression equations are shown in figure 7A. Semi-amplitude (eq. II) is also shown. Regression of body temperature on time was only significant in treatment periods with draught (periods I, III and IV). Significant periodicity was not found at 25 °C and 15 °C (periods II and V). For the sake of clearity however obtained equations at these temperatures are given also. Data show that the patterns of body temperature of both pigs were similar in each treatment period. Time of the peak in body temperature was reached near the end or after the application of draught in treatment periods I, III and IV. Lowest levels of temperature were at the beginning of the draught (t = 60). At ambient temperatures of 25 °C and 15 °C this was not the case. Pig with transponder I had the same semi-amplitude (A) in treatment periods with draught. The pig with the second transponder had highest value of A at 15 °C with draught (period IV) and similar A in periods I and III.

Values of heat production (H) and activity-related heat production (AH) were analyzed similarly. Lines obtained from regression equations are given in figure 7B. Highest semi-amplitude (A) was present with fluctuating temperature and draught. Semi-amplitude was lowest with application of draught at 15 °C. Values

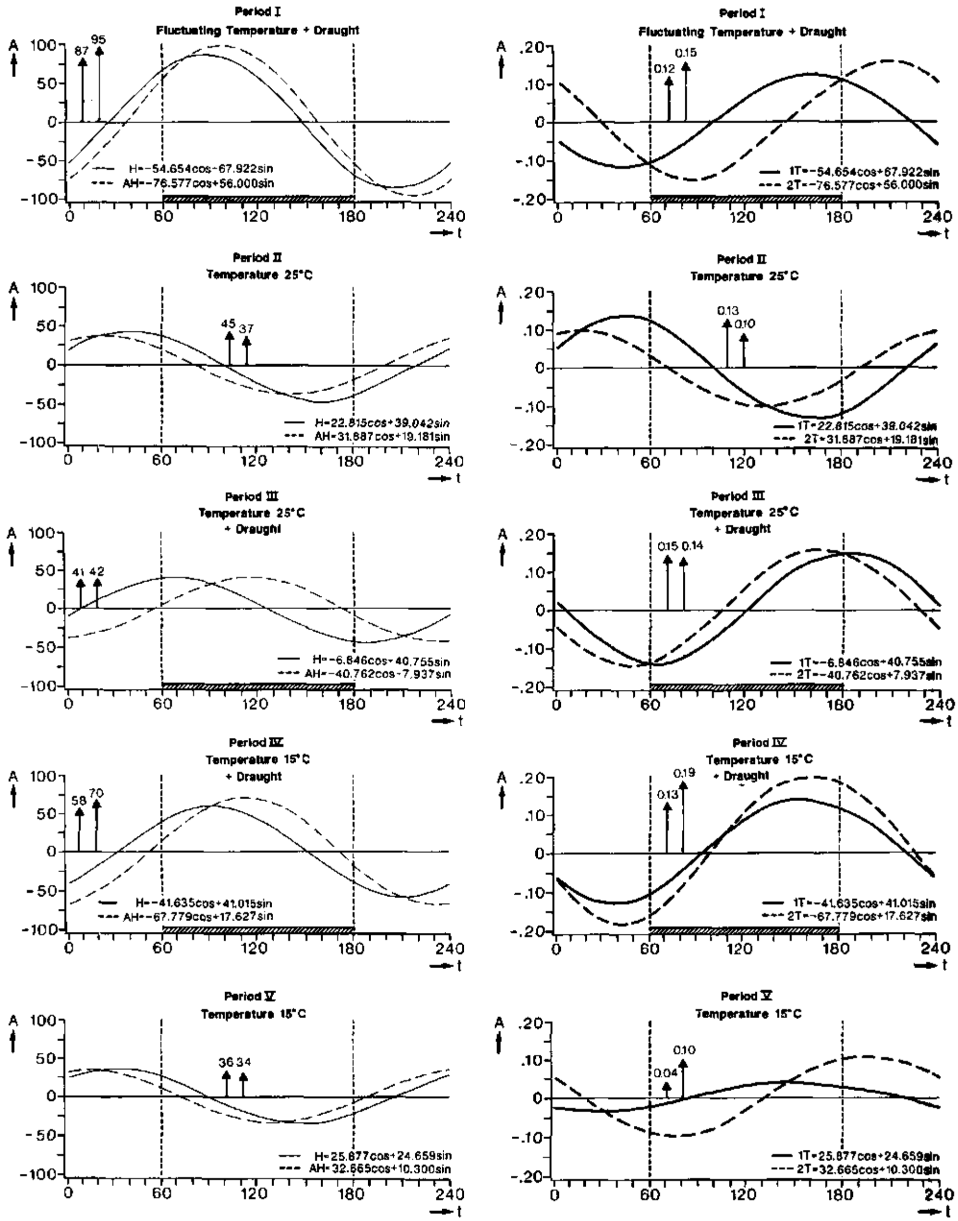

Figure 7. Lines from periodic regression equations.
$t = 0,\ldots,60,120\ldots,180$: absence of draught,
$t = 60,\ldots,120$: application of draught; periods I, III, and IV
Left: Heat production (H) and activity-related heat production (AH).
Right: Body temperature, measured by transponder 1 (1T) and 2 (2T).
A = amplitude.

obtained in the other treatment periods were similar. Figure 7B shows that periodicity of heat production and activity-related heat production were similar when temperature was constant. With the application of draught the peak of activity-related heat production occurred at a later time compared with the peak of heat production. This difference was most pronounced with application of draught at 25 °C.

Heat production was calculated for periods of draught (t = 60,.....,120) and absence of draught (t = 0,.....60, 120,......,180). Values obtained in the treatment-group were compared with those calculated for the control- group for each period. Results are given in table 5. The draught in the treatment-group in periods I, III and IV increased thermal demand. Highest value was found in period I. In periods of absence of draught heat production was lower for the treatment-group, except in period I.

Table 5 Effect of different periods on heat production ($kJ/kg^{0.75}$) and lower critical temperature* (T_{cr} °C).
H_1 = Difference in heat production between treatment- and control-group during t = 0,........,60,120,........,180
H_2 = Difference in heat production between treatment- and control-group during t = 120,........,180.

Period	H_1	T_{cr}	H_2	T_{cr}
I	0.1	--	102.7	9.3 °C
II	14.6	1.3 °C	25.0	2.3 °C
III	−14.0	−1.3 °C	14.9	1.4 °C
IV	−3.3	−0.3 °C	39.5	3.6 °C
V	−18.7	−1.7 °C	−17.2	−1.6 °C

* Assuming extra thermoregulatory heat 11 $kJ/kg^{0.75}$ per °C (Close, 1981)

Discussion

Climatic environment is important for productivity of animals. Heat production may be increased at unfavourable climatic conditions and maintenance requirement will consequently be higher and energy available for production is diminished. Animals exposed to climatic conditions below thermoneutrality, either constantly or temporarely, will have variable heat loss to the environment. Data in figure 4 showed that heat loss was dependent on ambient temperature. The additional draught applied to the treatment-group did not increase heat production during 24 hours. However a clear increase during draught periods was found (figure 5). It can be assumed that heat production during the night period is related to that during the day. The periodical application during 2-hour periods resulted in an increase of heat production mainly during periods of draught itself (figure 6). The effect of draught on thermal demand (table 5) showed that lower critical temperature (T_{cr}) was increased in these periods. The extent depends on ambient temperature. In periods II and V values of treatment- and control-group were similar, indicating that carry-over effects of previous treatment periods were not present.

For maintaining constant body temperature extra heat production has to be generated to compensate heat loss. Ingram and Legge (1970) stated that under constant climatic environment very little demand will be made on the regulatory system of animals and body temperature remains constant. However changes in environmental temperature that affect total heat loss will also need homeothermic regulation (Ingram and Legge, 1970). The effect of ambient temperature is greater at night than during day time (Hammel *et al.*, 1963, cited by Ingram and Legge, 1970).

Rodbard *et al.* (1980) have discussed the importance of regulation of body temperature with respect to infectious diseases in animals. Pigs in steady state do apparently have no difficulties in maintaining body temperature when ambient temperature ranged from 10 to 30 °C (Ingram and Legge, 1970). However when ambient temperature was suddenly changed from 30 to 10 °C body temperature was increased during a short period and decreased thereafter. Bond *et al.* (1967) and Close (1981) remarked that climatic environment cannot be regarded as constant; fluctuations in temperature and air velocity (wind or draught) may occur. Results showed that draught increased heat production and especially activity-related heat production.

At constant ambient temperatures heat production (and activity-related heat production) between the control and treatment-group were similar. Body temperatures found in this experiment were similar to values obtained by Ingram and Legge (1970) and Ingram and Mount (1973) in the carotid artery. Pigs used in their study were of similar age as pigs used in this study. In their experiments body temperature between and within pigs ranged by 0.7 and 0.5 °C respectively. Although mean values between pigs and between treatments varied, responses in periodicity due to the application of draught were consistent in amplitude and phase within treatments for both pigs. At constant ambient temperatures no periodic rhythm as found with draught was present. Ingram and Legge (1970) concluded that the degree of thermostability achieved by active thermoregulation cannot readily be assessed at a single environmental temperature. Results in this study obtained at constant ambient temperatures support this also.

According to Aschoff (1974) body temperature and activity may be regarded as two coupled oscillators. Moreover metabolic rate could be added as an oscillator (Ingram and Legge, 1970). Data in figure 7B showed that heat production and activity-related heat production were nearly in phase, although the small lag between both seems to depend on the treatment. In contrast a marked difference in phase between body temperature and both values of heat production was present (figure 7A and 7B). It may be argued that pigs exposed to draught had a delayed response in body temperature compared with the response in heat production. This indicates that the severity of the climatic environment interferes with the regulatory mechanism of body temperature. Sudden changes in climatic environment result in an increase in heat loss. This can cause body temperature to decrease and heat production will lag behind. Chowers *et al.* (1977) noted that guinea pigs acclimated to either cold or fluctuating temperatures. The heat generating mechanism was elicited only when body temperature was already on the decrease. Morrison and Mount (1971) found that rectal temperature and respiratory frequency were not suitable for determining adaptation of pigs to changes in environmental temperatures.

Acknowledgements

The authors gratefully thank Mr. Jansen and Mr. van Ingen from the technical and Physical Engineering Institute in Wageningen for their cooperation in the experiment. Mr. van der Hel, Mr. van der Linden and Mr. Brandsma are acknowledged for assistance in performing the experiments. Mr. Verstegen is thanked for his comments while preparing the paper. Mr. J. Boon is thanked for performing the churgery to implant the transponders. Mrs. van Dijk carefully typed the manuscript.

References

Aschoff, J., Biebach, H., Heise, A. and Schmidt, T. (1974). Day-night variation in heat balance. In: *Heat loss from animals and man* (eds. J.L. Monteith and L.E. Mount). Butterworths, London, p. 147-172.

Bliss, C.I. (1970). *Statistics in Biology*. Vol II. McGraw Hill Book

Bond, T.E., Kelley, C.F., and Heitman, H. (1967). Physiological response of swine to cycling environmental conditions. *An. Prod.* **9**, p. 453.

Boon, C.R. (1982) The lower critical temperature and group postural behaviour in pigs, *Livestock Environment II.* 2nd Liv. Env. Symp. American Society of Agricultural Engineers.

Brouwer, E. (1965). Report of subcommittee on constants and factors. *3rd Symposium on Energy Metabolism*. Troon, Scotland, EAAP publ. **11**, p. 441-443.

Bruce, J.M. and Clark, J.J. (1979). Models of heat production and critical temperature for growing pigs. *Anim. Prod.* **28**, p. 353- 369.

Chowers, I., Siegel, R.A., Conforti, N. and Baranes, A.L. (1977). The effects of acclimation to alternating environmental temperature on metabolic and endocrine responses in guinea pigs, during acute heat and cold exposure. *Int. J. Biometeor.* **21**, p. 64-74.

Close, W.H. (1981). The climatic requirements of the pig, *Environmental aspects of housing for animal production*. (Ed. J.A. Clark), Butterworths, London, p. 149- 166.

Geuyen, T.P.A., Verhagen, J.M.F. and Verstegen, M.W.A. (1984). Effect of housing and temperature on metabolic rate of pregnant sows. *An. Prod.* **8**, p. 477-485.

Henken, A.M., 1982. *The effect of environmental temperature on immune response and metabolism of the young chicken*. Thesis. Wageningen. The Netherlands.

Ingram, D.L. and Legge, K.F. (1970). Variations in deep body temperature in the young unrestrained pig over the 24 hour period. *J. Physiol.* **210**, p. 989- 998.

Ingram, D.L. and Mount, L.E. (1973). The effects of food intake and fasting on 24-hourly variations in body temperature in the young pig. *Pflügers Arch.* **339**, p.299-304.

Kelley, K.W., (1985). Immunological consequences of changing environmental stimuli. In: *Animal Stress*. American Physiological Society, p. 193-223.

Morrison, S.R. and Mount, L.E. (1971). Adaptation of growing pigs to changes in environmental temperatures, *Anim. Prod.* **13**, p. 51-57.

Mount, L.E. (1979). *Adaptation to thermal environment: man and his productive animals*, Edward Arnold, London.

Rodbard, D., Wachslicht-Rodbard, H. and Rodbard, S. (1980). Temperature: a critical factor determining localization and natural history of infections, metabolic and immunological diseases. *Persp. in Biology and Medicine*, p. 439-474.

Siegel, H.S. (1985). Immunological responses as indicators of stress. *WPSA Journal*, **41**, p. 36- 45.

Snedecor, G.W. and Cochran, C. (1976). *Statistical Methods*, Iowa State University Press.

Tielen, M.J.M. (1974). *De frekwentie en de zoötechnische preventie van long- en leveraandoeningen bij varkens*. Thesis. Wageningen. The Netherlands.

Verhagen, J.M.F., Kloosterman, A.A.M. and Brandsma, H.A. (1987). Acclimation of growing pigs to draught at constant ambient temperatures. *Anim. Prod.* submitted.

Verstegen, M.W.A. (1971). *Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups*, Thesis, Wageningen, The Netherlands.
Wenk, C. and van Es, A.J.H. (1976). Eine Methode zur Bestimmung des Energieaufwandes für die körperliche Aktivität von wachsender Küken. *Schweiz. Landwirtsch. Monatshefte* **54**, p. 232-236.

GENERAL DISCUSSION

Introduction

The climatic environment imposed on pigs may have a large influence on their well-being, productivity and health. Especially the thermal demands of pigs are thought to play an important role for productivity and health. Pigs interact with the climatic environment and it is therefore important to assess this interaction between pigs and their environment. Animals will attempt to maintain a homeothermic equilibrium with their environment through physiological response. If pigs are exposed to a low ambient temperature, they will respond physiologically by increasing insulation and, if that is not sufficient for homeothermy, an increase in heat production. In this way body temperature remains constant and homeothermy is maintained. The climatic environment is a resultant of several physical, chemical and biological factors. In the investigations described in this thesis increased air velocity and ambient temperature, as two specific physical stimuli of the environment, were studied. The effects were studied in group-housed pigs which were fed *ad libitum*. Group-housing was chosen since thermoregulatory behaviour (huddling) of pigs is one of the components of their reaction to the climatic environment. Regulation of feed intake may also attribute to this reaction and therefore this feeding strategy was used. Both group housing and *ad libitum* feeding are common in practice for these kind of pigs. To interpretate the results of the experiments described in this thesis they were compared with data in literature.

Climatic environment and health

Environmental conditions under which pigs are housed may have a major impact on their health. In fattening pigs, Tielen (1974) found that the percentage of pigs with lung lesions at slaughter was related to climatic environment during the fattening period. With respect to infectious diseases Hunneman (1983) also found that the incidence and severity of *Haemophilus pleuropneumoniae* infections in young growing pigs were related to the climatic environment at the start of the fattening period. According to these authors fluctuations in ambient temperature and air velocity are important factors. With respect to *Haemophilus pleuropneumoniae* infections in pigs Nicolet *et al.* (1980) and Nielsen (1982) also stressed that climatic conditions influence the reaction of pigs to this pathogen.
Their studies suggested that the thermoregulatory demand of climatic conditions may be important for the reaction of pigs to the pathogen. Probably immune response is altered simultaneously with thermoregulation. It may also be that increased heat loss and heat production resulting from deviations from thermal neutrality are associated with the level and changes in the humoral immune response.

Henken (1982) found that the extra thermoregulatory demand of the climatic environment influenced the SRBC-induced humoral immune response in pullets. His data suggested that the magnitude of the deviation from thermal neutrality and the way in which animals can maintain homeothermic were important for their immune response. It is well known that acclimation to ambient temperature can reduce the amount of extrathermoregulatory heat (Irving *et al.*, 1956; Close, 1971). The degree of acclimation is important with respect to immune responsiveness (Henken, 1982). This could probably be related to a decrease in extra thermoregulatory demand of the climatic environment after prolonged exposure (Verstegen, 1971). Moreover, Henken (1982) noted that sudden (temporary) changes in thermal conditions might be more important than the thermal condition itself.

Young (1975) concluded that after prolonged exposure extra thermoregulatory demand of animals in the cold can be altered by an increase of the basal metabolic rate. Dantzer and Mormède (1983) furthermore emphasized the importance of determining the degree of acclimation, since this degree is related to stress in farm animals. Therefore, it was studied first in two experiments whether the reaction of pigs to inoculation with *Haemophilus pleuropneumoniae* was dependent on time since first exposure to the climatic environment (degree of acclimation). The results are described in the first chapter. Results clearly showed that the effect of inoculation of young growing pigs with *Haemophilus pleuropneumoniae* was dependent on the time of occurrence of climatic stress in relation to time of inoculation. Marked differences were found in rectal temperature and specific serum antibody levels if pigs were exposed to a "bad" climatic environment compared with a "good" environment, directly after inoculation. No such differences were found in pigs that were inoculated after 12 days exposure to these environments. The "bad" or adverse environment that was used in these experiments was a fluctuation of ambient temperature (25 °C during daytime; 15 °C during night time). In addition a draught occurred intermittently during night time. This environment is a simulation of climatic conditions that may occur in practice and which were concluded to be related to severity and incidence of *Haemophilus pleuropneumoniae* infections (Hunneman, 1983). In fact these factors are sudden changes in thermal conditions.

A significant increase in specific serum antibody level as a response to the inoculation was found in both experiments. When exposure to the adverse climatic treatment was directly after inoculation, mortality and morbidity were higher. Specific serum antibody levels were higher than in inoculated pigs kept at a thermal neutral temperature (25 °C). Shimizu *et al.* (1978) also found that inoculation with transmissible gastroenteritis (TGE) virus had resulted in higher antibody levels and gave more clinical symptoms in pigs kept at 4 °C than in pigs kept at 30 °C. The number of pigs with clinical symptoms observed by Shimizu *et al.* (1978) was related to duration of exposure to the low ambient temperature before inoculation with the TGE-virus. If exposure to the low temperature before inoculation was longer then a smaller number of pigs showed clinical symptoms. Kelley *et al.* (1982; 1984) found that cold exposure affected also cell mediated immune response in young calves. Tuberculin and dinitrofluorobenzene reaction of calves was enhanced directly after exposure to cold but was suppressed after two weeks of exposure. These reaction were thus modulated by the length of time the calves were exposed. Enhancement of humoral immune response to SRBC after cold exposure was found by Subbao Rao and Glick (1971), Blecha and Kelley (1981) and Henken (1982). Blecha and Kelley (1981) argued that elevation of antibody levels due to cold exposure increased resistance to infectious disease.

Results found in this study indicated that increase in serum antibody levels induced by the adverse climatic treatment could be caused by the following mechanism. If the local resistance of pigs is lowered this may result in a relatively longer time of contact with, and if multiplication occurs, higher dose of the pathogen. Results found by Curtis *et al.* (1976) support this. In their experiments pulmonary bacterial clearance of *Escherichia coli* was impaired in pigs kept at low ambient temperature. Moreover Lockard *et al.* (1973) found that stress decreased bactericidal activity of alveolar macrophages of rabbits. The increased response found in the experiments described here, is then merely a consequence of prolonged contact with the antigen and related to extra thermoregulatory heat production. If the extra thermoregulatory demand decreases with prolonged exposure to the adverse climatic environment and the resistance is thus higher, inoculation with the pathogen can result in a smaller increase in humoral immune response and rectal temperature. This is in agreement with the results of Shimizu *et al.* (1978). Therefore it may be important to determine the time that pigs need to acclimate to a single climatic factor (*e.g.* ambient temperature) or to a combination of factors (*e.g.* ambient temperature and air velocity). This would explain the difference in reaction of pigs to inoculation before or after acclimation. If acclimation to climatic factors used in chapter I occurs within 12 days this may explain the difference in results. If acclimation and the influence on susceptibility to disease can be assessed, this will avoid the necessity to perform a large number of experiments with inoculation of pigs at different days after exposure.

Climatic environment and acclimation

In general adaptation is often connected to survival or reproduction of animals at extreme or adverse conditions (Mount, 1979; Curtis 1983). Acclimatization is merely used if a combination of several factors vary at the same time. The term acclimation refers to the reaction of animals to a single stressor (Mount, 1979; Curtis, 1983). In the chapters II, III, IV and V the reaction of pigs to two different climatic factors were comparitively studied. This reaction was therefore termed acclimation.

Responses of pigs to physical and/or behavioural stressors occur through neural and endocrine pathways (Siegel, 1985). In general the neurogenic system is a rapid response through the release of catecholamines and results in the mobilization of energy (Siegel, 1985). Through the hypothalamus-pituitary-adrenalcortex axis the secretion of corticosteroids is increased and chronical exposure to *e.g.* adverse ambient temperatures will lead to chronically different levels (Dantzer and Mormède, 1979). The route along which these different levels are established is dependent on type of exposure, acute or gradual.

Although concentrations of corticosteroids in serum were not measured in the experiments described in this thesis, other investigations have shown an increased concentration in the serum of cold-stressed pigs (Marple *et al.*, 1972; Hacker *et al.*, 1973; Blatchford *et al.*, 1974; 1978). The effects of these hormones on the metabolism of animals is, through glycolysis, the enhancement of energy availability (calorigenesis) (Johnson and Blanchard, 1974). This implicates that the effects of different environments, sudden or constant deviations from thermal neutrality, will affect heat production and energy metabolism.

In the second chapter the effect of exposure of pigs to temperatures at thermal neutrality (25 °C) or below thermal neutrality (15 °C) on energy metabolism was studied. Results showed that the first six days of exposure to 15 °C resulted in a decrease in food intake by the *ad libitum* fed pigs. Heat production at 15 °C was similar as in pigs kept at 25 °C. This finding, in combination with the lowered food intake, resulted in an increase in maintenance requirement during the first six days of exposure. Retained energy and fat deposition were decreased during this period. After this period feed intake was markedly increased. Maintenance requirement and fat deposition were than similar at both temperatures. A delayed adjustment of food intake of *ad libitum* fed animals to compensate increased thermal demand was similarly found by Christison and Williams (1982) and Mount *et al.* (1980) in pigs and by Barnett and Mount (1967) and Leung and Horowitz (1976) in laboratory animals.
From this study it can be concluded that the differential effects of ambient temperatures of 25 °C and 15 °C with regard to energy metabolism parameters were no longer present at day 11 and 12 after initial exposure.

Acclimation of pigs to different climatic environments was studied in experiments described in the chapters III, IV, V. Acclimation can be defined as that time after which the effect of the climatic treatment remains constant. It was thought to have occurred at that day after which exposure to the treatment does no longer affect either overall heat production or activity. In chapter III the effect of a constant ambient temperature of 25 °C or 15 °C was described with respect to heat production and activity. Mount (1979) and Close *et al.* (1981) indicated that the physical activity of animals is influenced by climatic environment. In practice sudden increases in air velocity may occur, depending on type of ventilation and the weather outside the fattening unit. If the temperature of the ingoing air has a lower temperature then inside (*e.g.* in winter time) draught may occur. This increased air velocity may disrupt the huddling of pigs at lower ambient temperature. In chapter IV the occurrence of draught at ambient temperatures of 25 °C and 15 °C was studied. Draught consisted of an increase in air velocity from 0.2 to 0.8 m/s and a lower temperature of the air stream by 5 K. It was applied during the night time because it is the main rest period of pigs. Draught treatment occurred periodically. In this way it is possible to study the effects of occurrence and absence of draught within nights. In the experiments described in the fifth chapter draught was similarly applied as in chapter IV but ambient temperature was varied during 24-hour (25 °C during day time and 15 °C during night time).
Day of acclimation to the various climatic treatments was determined for the day

and night period separately from total heat production. The results are summarized in table 1.

Table 1. Day of acclimation for the different climatic treatments; constant ambient temperature (25 °C or 15 °C); fluctuating temperature (25/15 °C) and with a superimposed draught (25 °C + draught, 15 °C + draught or 25/15 °C + draught) for the day and night period.

Treatment	Day period	Night period
25 °C	5	—
15 °C	8	6
25/15 °C	8	3
25 °C + draught	5-6	5
15 °C + draught	—	5-8
25/15 °C + draught	3	8

Results showed that acclimation of young growing pigs is achieved differently with regard to time of the day (day or night). During day time acclimation to an ambient temperature of 25 °C occured more rapidly than to an temperature of 15 °C. During night time acclimation to an ambient temperature of 15 °C was established at day 6. At 25 °C acclimation could not be assessed, since heat production was not altered. With fluctuating temperature data showed that temperature during the day period (25 °C) influenced time of acclimation during the night (15 °C) compared with constant temperatures. The occurrence of draught influenced acclimation, as well during night time as during day time.
The effects of draught at 15 °C were measurable during the periods of absence of draught. Acclimation estimated from heat production in periods of draught was achieved in 5 days and in the periods of absence of draught in about 8 days after initial exposure. At 25 °C effect of draught was found in periods of draught during 5 days.
Acclimation to fluctuation in temperature was reached in 8 and 3 days after initial exposure for the day and night respectively. It was delayed at night with draught and achieved after 8 days exposure. Shift in levels of activity within a 24-hour period due to the effect of low ambient temperature as such (chapter IV and V) may change the effects. A shift in activity from the day period to the beginning of the night period was found at low and fluctuating temperature. Van der Hel *et al.* (1986) also noted these effects. The difference in heat production between the day and night period is associated with this shift and influences day of acclimation. Therefore in analyses of the effect of draught during night time the beginning of the night period (19.00-21.00 h) was omitted. In table 2 the increase in heat pro-

Table 2. Effect of superimposed draught at various climatic treatments (25 °C, 15 °C, 25/15 °C) on heat production (H, $kJ/kg^{0.75}$). Values in parenthesis represent extra thermal demand, as a change in critical temperature (T_{cr}, °C), assuming 11 $kJ/kg^{0.75}$ per °C (Close, 1981).

Treatment	H	T_{cr}
25 °C + draught vs 25 °C	31	(2.8 °C)
15 °C + draught vs 15 °C	46	(4.2 °C)
25/15 °C + draught vs 25/15 °C	50	(4.5 °C)

duction with draught is compared with values of heat production of the control-group.

The overall effect of draught on thermal demand was equivalent to a lowered ambient temperature of 2.8 °C at 25 °C and 4.2 °C at 15 °C. This difference can be explained as follows. The occurence of draught at low ambient temperature will disrupt the huddling of pigs. Therethrough a greater area of the body will be exposed to the draught. Increased heat loss will then result. The application of draught at fluctuating temperature resulted in an increase in thermal demand of 4.5 °C.

Draught was applied during three 2-hour periods at night. Hence the effect of draught can be estimated within night and within treatments. The results are summarized in table 3.

Table 3. The effect of superimposed draught at various climatic treatments (25 °C, 15 °C, 25/15 °C) on heat production (H, $kJ/kg^{0.75}$) within nights. Values in parenthesis represent extra thermal demand, as a change in critical temperature (T_{cr}, °C), assuming 11 $kJ/kg^{0.75}$ per °C (Close, 1981).

Treatment of draught at	H	T_{cr}
25 °C	35	(3.2 °C)
15 °C	66	(6.0 °C)
25/15 °C	59	(5.4 °C)

These data show that within nights draught increased heat production to a greater extent as compared with the control-groups (see table 2). This is due to a lower heat production during periods without draught and implicates that draught effects heat production during periods thereafter. Determination of the day of acclimation does not implicate that draught no longer effected heat production or thermal demand after day of acclimation. The effect of draught during the beginning (day number 2) and the end (day number 12) of the various treatments is illustrated in table 4.
Although acclimation as estimated from overall values of heat production was achieved before day 12 after initial exposure, extra thermal demand due to draught was still present at day 12.

Table 4. Difference in heat production (H, $kJ/kg^{0.75}$) between periods with and without draught, at constant or fluctuating temperature. Values in parenthesis represent extra thermal demand, as a change in critical temperature (T_{cr}, °C), assuming 11 $kJ/kg^{0.75}$ per °C (Close, 1981). Day of acclimation estimated from overall heat production is also presented.

Temperature	Day number 2 H T_{cr}	Day number 12 H T_{cr}
25 °C	47.8 (4.3 °C)	−12.1 (−1.1 °C)
15 °C	95.5 (8.7 °C)	45.3 (4.1 °C)
25/15 °C	61.0 (5.5 °C)	45.0 (4.1 °C)

The draught regime was arbitrarily chosen. However the application at different ambient temperatures determined the effects on thermal demand of pigs. Temperatures during other parts of the day are also important to determine acclimation. They interfere with the extra thermal demand at the moment of occurrence of draught.

Climatic environment and blood parameters

In the previous chapters it has been shown that climatic treatments affect the day of acclimation. A superimposed draught may delay acclimation. However it is not clear which relation with other parameters such as resistance and blood parameters exists. Therefore the change in blood parameters due to climatic environment was studied at constant temperatures (25 °C or 15 °C) and at fluctuating temperature with or without draught (chapter VI).
Dantzer and Mormède (1983), Blatchford *et al.* (1974; 1978), Hacker *et al.* (1973) and Bate and Hacker (1985) had shown that levels of corticosteroids are increased due to cold stress. Increase of steroid hormones influence the number and ratio of white blood cells (Widowsky *et al.*, 1984; Gross and Siegel, 1983; Kelley, 1983). Results described in the chapter showed that pigs exposed to the 24-hour fluctuation in temperature and the superimposed draught had a significant lower % of lymphocytes and an increased % of neutrophils. Gross and Siegel (1983) stated that these type of parameters could be useful as indicators of the stress imposed on animals. Dantzer and Mormède (1983) and Kelley (1985) stated that changes in the immune system are dependent on the physical quality of the environmental stimuli and moreover the immune response might be subjected to adaptive processes. These parameters might be useful to determine whether animals have been exposed to stressors. The magnitude of the effect of climatic stressors will depend on deviation and duration from optimal climatic environment. Thus parameters as bloodcell ratio would require to be measured daily to determine time of acclimation.

Climatic environment and body temperature

In homeothermic animals heat loss due to adverse climatic factors will be compensated by heat production in order to maintain a constant body temperature. Results in chapters IV and V showed that draught considerably increased heat production and thus thermal demand of pigs. Moreover results showed that at low ambient temperature draught also had an effect on heat production in periods without draught. Therefore it might be that body temperature is affected by sudden changes in climatic environment if heat production does not compensate completely the heat loss. Henken (1982) stressed the possibility that body temperature cannot be maintained during changes of the climatic environment. Rodbard *et al.* (1980) indicated that a change in body temperature is a critical factor in the succeptibility of the host in infectious diseases. Therefore the effect of the various climatic factors on body temperature was studied. The effects on (activity related) heat production was determined in combination with the effects on body temperature. Results showed that temperature alone had no effect on body temperature. With the application of draught the body temperature was clearly affected. During the beginning of the draught period body temperature was lowered. With prolongation of time body temperature increased. Heat production and activity were increased during periods of draught and decreased during periods without draught. Results showed that the range in body temperature increased with draught as compared with constant ambient temperatures of 25 °C and 15 °C. The rhythm in heat production and activity was not the same at the different climatic treatments. The discrepancy of the rhythms of both factors with the rhythm in body temperature was also dependent on the temperature at which draught was applied. Range in heat production, activity and body temperature was also influenced by the temperature at which draught was applied. It may be assumed that acclimation will result in a lowered effect on the range in body temperature because the extra thermal demand is lowered. Moreover the lag between the peak in heat production and body temperature may be shortened as a result of acclimation.

General

In this thesis inoculation of young-growing pigs with *Haemophilus pleuropneumoniae* was used to indicate the effect of adverse climatic conditions on health and metabolism parameters. The occurrence of climatic stress directly after inoculation seemed to have pronounced effects on resistance as compared with pigs exposed to thermal neutral conditions.

As a result of inoculation the set-point temperature may be raised with the onset of fever and body temperature will start to increase (Bligh, 1973). The occurrence of fever will have beneficial effects on the defence mechanisms of the animal (Roberts, 1979). It was shown that draught influenced body temperature in such a way that body temperature was lowered during some time of the draught period. During draught heat loss is increased. If the pigs are not able to respond immediately by increased heat production to remain homeothermic body temperature will decrease (chapter VII).
If with the beginning of fever increase of heat loss occurs, which is not adequately compensated for by extra heat production, a conflict between the urge of increasing body temperature and the lowering thereoff due to heat loss (draught) may occur. Especially since the effect of draught on heat loss might be more pronounced at higher levels of body temperature. As an overall result the time, after inoculation, at which body temperature has actually reached the set-point temperature will be delayed. Data of rectal temperature, as in chapter I, support this.

According to Rodbard *et al.* (1980) body temperature is a critical factor in host susceptibility. If the development of fever is delayed then the beneficial effect of enhancing resistance and increasing changes of survival (Kluger, 1978; Rodbard *et al.*, 1980) will be altered. Hence the presence and/or multiplication of the pathogen might be enhanced. As a result the "internal" challenge will be increased, resulting in an increase chance of morbidity and mortality in pigs after infection with a pathogen.

Conclusions

The experiments in this thesis were aimed to study the relation of climatic environment to acclimation and health of growing pigs. It is concluded that the occurrence of an unfavourable climatic environment directly after inoculation is disadvantegeous for pigs to cope with infection. However, after prolonged exposure to an unfavourable climatic environment pigs are more capable to cope with infection. The effects of unfavourable climatic environments are related to the body temperature of the pigs. Pigs will increase their body temperature to enhance immune response to infection. A decrease in body temperature due to sudden changes in the climatic environment, as with draught, was found. Therethrough the enhancement of the immune response can subsequently be dealyed or impaired, resulting in a lower capability of pigs to cope with an infection.
Pigs can acclimate to an adverse climatic environment but time of acclimation is dependent on deviation from thermal neutrality. It is therefore important to study the extra thermoregulatory demand of climatic environment and the relationship with body temperature and the achievement of acclimation.

References

Barnett, S.A. and Mount, L.E. 1967. *Resistance to cold in mammal.* Thermobiology. Ed. A.H. Nose. Academic Press London and New York. p. 411-477.

Bate, L.R. and Hacker, R. 1985. Effect of variation and environmental temperature on the concentration of serum cortisol in pregnant sows. *Can. J. Anim. Sci.* **65:** 399-404.

Blatchford, D., Holzbauer, M., Ingram, D.L. and Sharmann, D.F. 1978. Responses of the pituitary-adrenal system of the pig to environmental changes and drugs. *Br. J. Pharmac.* **62:** 244-254.

Blatchford, D.R., Buckingham, J.C., Hodges, J.R., Holzbauer, M., Ingram, D.L., Legge, K.L. and Rees, L.H. 1974. The effect of thermal stress and frustration on the pituitary adrenal axis of the young pig. *J. of Phys.* **242:** 18.

Blecha, F. and Kelley, K.W. (1981). Effects of cold and weaning stressors on the anti-body mediated immune response of pigs. *J. Anim. Sci.* **53:** 439- 447.

Bligh, J. 1973. *Temperature regulation in mammals and other vertebrates.* North Holland Publ. Co.

Christison, G.I. and Williams, C.M. 1982. *Effects of cold on animal production.* CRC Handbook of Agricultural Productivity Vol. II. p. 69-76.

Close, W.H., 1971. *Nutrition-environmental interactions of growing pigs.* Thesis. Belfast. U.K.

Close, W.H. 1981. *The climatic requirements of the pig.* Environmental aspects of housing for animal production. Ed. J.A. Clark. Butterworth. London. p. 149-166.

Close, W.H., Heavens, R.P. and Brown, D. 1981. The effects of ambient temperature and air movement on heat loss from the pig, *Anim. Prod.* **32:** 75-84.

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

Curtis, S.E., Kingdom, D.A., Simon, J. and Drummond, J.G. 1976. Effects of age and cold on pulmonary bacterial clearance in the young pig. *Am. J. Vet. Sci.* **37:** 299.

Dantzer, R. and Mormède, P. 1983. Stress in farm animals: a need for reevalution. *J. Anim. Sci.* **57:** 6-18.

Dantzer, R. and Mormède, P. 1979. *Le Stress en Elevage Intensif.* Masson. Paris.

Gross, W.B. and Siegel, H.S. 1983. Evaluation of the heterophil/lymphocyte ratio as a measure of stress in chickens. *Avian Dis.* **27:** 972-979.

Hacker, R.R., Stefanovics, M.P. and Batra T.R. 1973. Effects of cold exposure on growing pigs: growth, body composition and 17-ketosteroids. *J. Anim. Sci.* **37:** 739-744.

Henken, A.M. 1982. *The effect of environmental temperature on immune response and metabolism of the young chicken.* Thesis. Wageningen.

Hunnemann, W.A. 1983. *Vóórkomen, economische betekenis en bestrijding van Haemophilus pleuropneumonia infekties bij varkens.* Thesis. Utrecht. The Netherlands.

Irving, L., Peyton, L.J. and Monson, M. 1956. Metabolism and insulation of swine as bare-skinned mammals. *J. Appl. Phys.* **9**: 421-426.

Johnson, D.E. and Blanchard, J.M. 1974. A literature review of some animal stress responses. Food and Drug Administration. Bureau of Veterinary Medicine. Colorado State University.

Kelley, K.W. 1983. *Immunobiology of domestic animals as affected by hot and cold weather*. Trans Am. Soc. Ag. Engineers.

Kelley, K.W. 1984. Immune responses and plasma hormone concentrations in cold- exposed-, xeranol-implanted calves. *Am. J. Vet. Res.* **45**: 2617- 2621.

Kelley, K.W. 1985. *Immunological consequences of changing environmental stimuli*. In: Animal Stress. American Physiological Society. p. 193-223.

Kelley, K.W., Greenfield, R.E., Evermans, J.F., Parish, S.M. and Perryman L.E. 1982. Delayed-type hypersensitivity, contact sensitivity and PHA skin-test responses of heat- and cold-stressed calves. *Am. J. Vet. Res.* **43**: 775-779.

Kluger, M.J. 1978. The evolution and adaptive value of fever. *Am. Sci.* **66**: 38-43.

Leung, P.B.M. and Horowitz, B.A. 1976. Free-feeding pattern of rats in response to changes in environmental temperature. *Am. J. Phys.* **231**: 1220- 1224.

Lockard, V.G., Grogan, J.B. and Brunson, J.G. 1973. Alterations in the bactericidal ability of rabbit alveolar macrophages as a result of tumbling stress. *Am. J. Path.* **70**: 57-62.

Marple, D.N., Aberle, E.D., Forest, J.C., Blake, W.H. and Judge, M.D. 1972. Endocrine responses of stress susceptibility and stress resistant swine to environmental stressors. *J. Anim. Sci.* **35**: 576-584.

Mount, L.E. 1979. *Adaptation to thermal environment: man and his productive animals*. Edward Arnold. London.

Mount, L.E., Start, I.B. and Brown, D. 1980. A note on the effects of forced air movement and environmental temperature on weight gain in the pig after weaning. *Anim. Prod.* **30**: 295- 298.

Nicolet, J., Brugmann, St. and Pharoz, Ph. 1980. Serological investigations on enzootic pneumonia with an enzyme-linked immunosorbent assay (ELISA). IPVS. Copenhagen. p. 225.

Nielsen, R. 1982. *Haemophilus pleuropneumoniae infection in pigs*. Thesis. Copenhagen. Denmark.

Roberts, N.J. 1979. Temperature and host defense. *Microbiol. Rev.* **43**: 241-259.

Rodbard, D., Wachslicht-Rodbard, H. and Rodbard, S. 1980. Temperature: a critical factor determining localization and natural history of infections, metabolic and immunological diseases. *Persp. in Biology and Medicine*: 439-474.

Shimizu, M., Shimizu, Y. and Kodama, Y. 1978. Effects of ambient temperatures on induction of transmissible gastroenteritis in feeder pigs. *Inf. Imm.* **21**: 747-752.

Siegel, H.S. 1985. Immunological responses as indicators of stress. *WPSA Journal* **41**: 36-45.

Subba Rao, D.S.V. and Glick, G. 1977. Effect of cold exposure on the immune response of chickens. *Poultry Sci.* **56**: 992-996.

Tielen, M.J.M. 1974. *De frekwentie en de zoötechnische preventie van long- en leveraandoeningen bij varkens. Thesis. Wageningen. The Netherlands.*

Van der Hel, W. Duijghuisen, R. and Verstegen, M.W.A. 1986. The effect of ambient temperature and activity on the daily variation in heat production of growing pigs kept in groups, *Neth. J. Agr. Sci.* **34**: 173-184.

Verstegen, M.W.A. 1971. *Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups*. Thesis. Wageningen. The Netherlands.

Widowski, T., Curtis, S.E. and McFarlane, J.M., 1984. Neutrophil/lymfocyte ratio in pigs fed cortisol. ASAS Midwestern Section. March. Chicago.

Young, B.A. 1975. Effects of winter acclimatization on resting metabolism of beef cows. *Can J. Anim. Sci.* **55**: 619-625.

GENERAL ABSTRACT

In intensive pig production the climatic environment has an important impact on productivity and health of the animals. Since factors as draught and fluctuating temperatures are known to influence the incidence and severity of *Haemophilus pleuropneumoniae* infections in growing pigs at the beginning of the fattening period. These aspects of climatic environmment in young growing pigs were studied.

It is known that climatic factors influence metabolic rate and energy metabolism of animals. Moreover, acclimation to adverse conditions, *e.g.* low ambient temperature, may occur. This implicates that the outcome of infection might be related to time of occurrence of climatic stress. This was studied in chapter I. Pigs infected with *Haemophilus pleuropneumoniae* and exposed to climatic stress (fluctuating temperature and draught) thereafter had a higher mortality and morbidity rate compared with pigs exposed to thermoneutral conditions (25 °C). Specific serum antibody levels of pigs were increased at day 12 p.i. and higher for pigs exposed to climatic stress compared with pigs kept at 25 °C. Infection of pigs with *Haemophilus pleuropneumoniae* after 12 days of exposure to both conditions (25 °C vs fluctuating temperature and draught) showed no distinct differences between both groups. Acclimation of pigs could be related to this.

Time and day of achievement of acclimation of pigs to different adverse climatic conditions was studied also. Exposure to ambient temperatures of either 25 °C or 15 °C influenced energy metabolism. Pigs housed at 15 °C reduced their *ad libitum* feed intake during the first 6 days after exposure compared with pigs at 25 °C. Heat production was equal to that of pigs at 25 °C. As a result maintenance requirement was increased by 11% and the amount of energy available for production was lowered. Daily gain and fat deposition were subsequently lowered at 15 °C. At day 11 — 12 after initial exposure to the climatic treatments differences between the temperature groups were no longer present. The effect of both ambient temperatures on heat production and activity was also studied. Day of acclimation was determined as that day after which heat production or activity-related heat production remained constant.
Besides ambient temperature, acclimation was also studied with respect to the occurrence of draught during the night period. Draught was applied at either constant ambient temperatures of 25 °C or 15 °C or fluctuating temperature (25 °C during the day period and 15 °C during the night period). Draught consisted of an increased air velocity from < 0.2 m/s to 0.8 m/s with a lower temperature of 5 °C. Acclimation estimated from heat production of pigs at a constant ambient temperature of 25 °C was achieved during the day period at day 5 after initial exposure. At a constant temperature of 15 °C and also at the fluctuating temperature accli-

mation was delayed with a few days as compared with a temperature of 25 °C and reached at day 8. During the night period acclimation at 25 °C could not be determined since heat production did not alter with increasing daynumber after initial exposure. Acclimation during the night period at 15 °C and at the fluctuating temperature was achieved at day 6 and 3 respectively. This showed that acclimation during the night period differed from that during the day period. Moreover with fluctuating temperature, the temperature during the day period (25 °C) influenced acclimation during the night period (15 °C).

The occurrence of draught delayed day of acclimation. At 15 °C and at the fluctuating temperature a "shift" in heat production and activity was found from the day period to the beginning of the night period. For the determination of the day of acclimation at 25 °C, 15 °C or fluctuating temperature this period was omitted first. Data in literature showed that an increase in heat production by 11 kJ per kg metabolic body weight ($kg^{0.75}$) is equivalent to an increase in lower critical temperature (LCT) by about 1 °C. The effect of draught on heat production was expressed as change in LCT. At 25 °C draught increased LCT by 2.8 °C, at 15 °C by 4.2 °C and with fluctuating temperature by 4.5 °C when compared with control groups exposed to a similar temperature. Draught had thus a differential effect on the LCT, depending on the ambient temperature. Draught was applied during three 2-hour periods at night (21.00-23.00 h, 1.00-3.00 h and 5.00-7.00 h) and made it possible to estimate the effect of draught within nights. At 25 °C draught increased LCT by 3.2 °C, at 15 °C by 6.0 °C and with fluctuating temperature by 5.4 °C. It showed that, within nights, influences of draught on heat production were greater.

The effect of exposure to various climatic conditions on blood parameters was also studied. Pigs exposed to fluctuating temperature and draught had an increased percentage of lymphocytes and a decreased percentage of neutrophils in peripheral blood after 16 days of exposure.

Homeothermic animals maintain a constant ambient temperature. An increased heat loss to the environment will be compensated by an increase in heat production thus enabling body temperature to remain constant. With the use of telemetrical measurements of body temperature the effect of various climatic conditions on body temperature were determined. Results showed that body temperature was not affected by a constant ambient temperature. With application of draught body temperature was changed. A rhythm was found with the occurrence of draught at 25 °C, 15 °C and fluctuating temperature. A rhythm in heat production and activity-related heat production in relation to the occurrence of draught was also present. However rhythm of body temperature was not similar to that of heat production or activity-related heat production. Heat production and also activity-related heat production were at their maximum directly after the onset of draught, whereas body temperature was lowered first and increased thereafter. Difference in the peak of heat production and body temperature was correlated with the effect of draught on heat production.

As a response to infection pigs will alter their set-point temperature and body temperature will incline. Consequently the defence mechanism is increased. Thus lowering body temperature due to sudden changes in climatic environment as with draught, will delay or diminish this enhancement. As a result of the effect of draught on body temperature the ability of animals to cope with infection is impaired.

SAMENVATTING

In de intensieve varkenshouderij heeft het stalklimaat een belangrijke invloed op de produktie en de gezondheid. Het is dan ook belangrijk om de invloed van klimaatsfaktoren vast te stellen. Onderzoek op praktijkbedrijven heeft aangetoond dat ongunstige faktoren van het stalklimaat, zoals het optreden van tocht en schommelingen in staltemperatuur, een nadelige invloed op de gezondheid hebben. Met name in het begin van de mestperiode bleken *Haemophilus pleuropneumoniae* infekties meer voor te komen en ernstiger te zijn bij die mestvarkensbedrijven waarbij niet aan de stalklimaatsnormen, zoals temperatuur en luchtsnelheid, werd voldaan.

Vanuit de literatuur is bekend dat faktoren als een te lage staltemperatuur de warmteproduktie en de stofwisseling beïnvloeden. Bovendien kunnen dieren zich aan ongunstige omstandigheden aanpassen. Dit houdt in dat aanpassing een rol kan spelen bij de reactie van dieren op een infektie. Twee experimenten zijn uitgevoerd om de relatie tussen klimaatsomstandigheden en het tijdstip van infektie te onderzoeken. In deze experimenten werden jonge mestvarkens (leeftijd ± 10 weken, gewicht ± 20 kg) afkomstig van een praktijkbedrijf, geïnfecteerd met *Haemophilus pleuropneumoniae*. Deze proeven, alsook alle overige, werden uitgevoerd in 2 klimaatsrespiratiecellen. Per cel werden 20 dieren gehuisvest in 2 hokken van elk 10 dieren. De dieren in een respiratiecel werden blootgesteld aan een konstante temperatuur van 25 °C. In de andere cel fluktueerde de temperatuur gedurende 24 uur (gedurende de dag 25 °C en gedurende de nacht 15 °C). Bovendien werden de dieren in deze cel gedurende de nacht aan tocht blootgesteld. Tocht bestond uit een verhoogde luchtsnelheid van normaal < 0.2 m/s tot 0.8 m/s met een temperatuur die 5 °C lager was dan de heersende temperatuur. Uit deze experimenten bleek dat infektie direkt gevolgd door een ongunstig stalklimaat tot een verhoogde mortaliteit en morbiditeit leidde in vergelijking met geïnfecteerde varkens gehuisvest bij een konstante temperatuur van 25 °C. Bovendien bleek een duidelijk hogere antilichaamstiter aanwezig te zijn 12 dagen na infektie bij varkens gehuisvest in een ongunstig stalklimaat. Infectie na 12 dagen huisvesting bij eenzelfde ongunstig stalklimaat gaf geen verschillen te zien ten opzichte van varkens gehuisvest in een gunstig stalklimaat. Aanpassing aan het ongunstige stalklimaat had dus invloed op de gezondheid van de dieren na infektie.

Het tijdstip en de wijze van aanpassen van mestvarkens aan verschillende klimaatsfaktoren werd nader onderzocht. De invloed van konstante temperatuur, fluktuatie in temperatuur gedurende 24-uur en het optreden van tocht bij deze gekozen temperatuur regimes werd bestudeerd. Deze klimaatsfaktoren simuleren praktijkkondities.

De gekozen temperaturen waren binnen en beneden de thermoneutrale zone, respectievelijk 25 and 15 °C. De fluktuatie in temperatuur bestond uit 25 °C gedurende de dag en 15 °C gedurende de nacht. Het effekt van deze temperaturen werd vergelijkenderwijze bestudeerd met het optreden van tocht gedurende de nacht. Gedurende de nacht werd in 2-uurs intervallen tocht gecreëerd. Tocht bestond uit een verhoging van de luchtsnelheid van normaal < 0.2 m/s tot 0.8 m/s. Bovendien was de luchtstroom 5 °C lager dan de heersende temperatuur. Tocht werd toegepast in een cyclus van 4 min. aan/4 min. uit, gedurende drie 2-uursperioden tijdens de nacht. Dit tochtregime was identiek aan dat bij de infektieproeven.

Dieren bezitten het vermogen om zich tot op zekere hoogte aan ongunstige klimaatsomstandigheden aan te passen. Bij een lage temperatuur zal een dier zijn houding veranderen om het contact en dus het warmteverlies aan de omgeving te beperken. Varkens gehuisvest in groepen zullen eveneens het totale blootgestelde oppervlak verkleinen door tegen elkaar aan te gaan liggen (huddling). Bij het optreden van een verhoogde luchtstroom langs het lichaam, veroorzaakt door wind of tocht, zal het warmteverlies door convectie toenemen. Bij in groepen gehuisveste dieren kan bovendien de huddling verbroken worden. Daartoe is de aktiviteit van de dieren met behulp van ultrasone apparatuur gemeten.
Als fysiologische reaktie op warmteverlies zal warmte geproduceerd worden. Warmteproduktie kan in respiratiecellen gemeten worden via de zuurstofconsumptie en de kooldioxide-produktie van de gehuisveste dieren. De gekozen klimaatskondities kunnen tevens gecreëerd worden.

Het effekt van een omgevingstemperatuur van 25 °C of 15 °C op het energiemetabolisme en de aanzet van vet en eiwit werd allereerst onderzocht. Mestvarkens gehuisvest bij een temperatuur van 15 °C hadden een verlaagde voeropname gedurende de eerste 6 dagen. De warmteproduktie was overeenkomstig die van varkens gehouden bij 25 °C. Dit resulteerde in een verhoogde onderhoudsbehoefte van 11% en een verlaagde hoeveelheid energie voor produktie en dus een lagere groei en een verlaagde vetaanzet. De eiwitaanzet was nauwelijks beïnvloed. Het verschil was op dag 11 en 12 niet langer aanwezig.
Het effekt van konstante temperatuur (25 °C of 15 °C) op warmteproduktie en aktiviteit werd eveneens geanalyseerd. Het tijdstip van aanpassing aan temperatuur werd bepaald door te analyseren op welke dag na begin van de blootstelling de temperatuur geen verandering meer te weeg bracht in warmteproduktie of in de aan de aktiviteit gerelateerde warmteproduktie (de aktiviteitswarmte). Behalve temperatuur werd aanpassing eveneens bestudeerd met betrekking tot het optreden van tocht gedurende de nacht. Tocht werd toegepast bij konstante temperatuur (25 °C of 15 °C) en bij fluktuerende temperatuur (25 °C overdag; 15 °C 's nachts). In de experimenten werd het effect van additionele tocht vergeleken met het effect van de temperatuursbehandeling zelf (controle groepen).

Onderscheid werd gemaakt in aanpassing gedurende de dag en nacht periode. De dieren bleken een verschillend tijdstip van aanpassing te hebben voor de dag en voor de nachtperiode. Aanpassing, gemeten aan warmteproduktie, bleek bij een konstante temperatuur van 25 °C op dag 5 gedurende de dag periode plaats ge-

vonden te hebben. Bij konstant 15 °C alsook bij de fluktuerende temperatuur waren de varkens aangepast op dag 8 gedurende de dag periode. Gedurende de nacht werd bij konstant 25 °C geen dag van aanpassing vastgesteld omdat de warmteproduktie niet veranderde. Bij konstant 15 °C en bij fluktuerende temperatuur trad aanpassing, gedurende de nachtperiode, op respectievelijk dag 6 en 3 op. Hieruit blijkt dat bij de fluktuerende temperatuur de temperatuur van 25 °C overdag het tijdstip van aanpassing gedurende de nacht (temperatuur is dan 15 °C) beïnvloedde in vergelijking met een konstante temperatuur van 15 °C.
Tocht gedurende de nacht had een duidelijk effekt op de dag van aanpassing. Niet alleen werd de aanpassing gedurende de nacht maar ook gedurende de dag beïnvloed. Bij een konstante temperatuur van 15 °C en bij de fluktuerende temperatuur bleek een verschuiving in warmteproduktie en aktiviteit van de dag periode naar het begin van de nacht periode plaats te vinden. In de literatuur werd dit eveneens gevonden. Voor een zuivere schatting van het effekt van tocht werd de periode van 19 tot 21 uur dan ook buiten beschouwing gelaten.
Het effekt van tocht op de warmteproduktie werd vergeleken met de warmteproduktie (gedurende dezelfde tijd) van varkens bij een temperatuur zonder tocht.

Uit literatuurgegevens is bekend dat een verhoging van de warmteproduktie van 11 kJ per kilogram metabolisch gewicht ($kg^{0.75}$) overeenkomt met een verhoging van de onderste kritieke temperatuur van 1 °C. Aldus werd het effekt van tocht op de warmteproduktie omgerekend in een effekt op de onderste kritieke temperatuur. Voor een konstante temperatuur van 25 °C werd bij tocht een verhoging van de onderste kritieke temperatuur van 2.8 °C, bij konstant 15 °C van 4.2 °C en bij fluktuerende temperatuur van 4.5 °C gevonden. Hieruit bleek het effekt van tocht afhankelijk te zijn van de temperatuur waarbij tocht voorkwam.

Een verklaring kan het effekt van tocht op het groepsgedrag (huddling) zijn. Indien de bijeen liggende groep varkens ten gevolge van de tocht de groep verbreken, wordt een groter gedeelte van het lichaamsoppervlak aan de tocht en aan de lagere temperatuur blootgesteld en resulteert dit een verhoogd warmteverlies en dus warmteproduktie. Dit werd bevestigd door de gevonden verhoging van de aktiviteitswarmte gedurende perioden van tocht.

De tocht werd gedurende drie 2-uursperiodes 's nachts toegepast (21.00-23.00 uur, 1.00-3.00 uur en 5.00-7.00 uur). Daardoor kon binnen nachten eveneens een vergelijking tussen perioden met en zonder tocht gemaakt worden. Bij konstant 25 °C resulteerde tocht in een effekt op de warmteproduktie van 3.2 °C, bij konstant 15 °C van 6.0 °C en bij fluktuerende temperatuur van 5.4 °C. Hieruit bleek dat het optreden van tocht invloed had op perioden zonder tocht. Binnen nachten was het effekt dus groter dan ten opzichte van de controle groepen.

Aanpassing gemeten via de totale warmteproduktie gedurende de nacht impliceerde niet dat na de dag van aanpassing eveneens het effekt van tocht afwezig was. Op dag 12 na blootstelling aan tocht werd bij 15 °C en bij fluktuerende temperatuur een effekt van 4.1 °C gemeten. De totale warmteproduktie gedurende de nacht verhult de effekten van tocht op de perioden erna. De effekten zijn weliswaar verminderd ten opzichte van de tweede dag na blootstelling, waren echter nog duidelijk aanwezig. Dit betekent dat het moment en de duur van het optreden van tocht belangrijk zijn.

Eveneens werd het effekt van blootstelling aan de verschillende klimaatskondities op de percentages aanwezige witte bloedcellen onderzocht. In de literatuur wordt aangegeven dat veranderingen in de percentages van witte bloedcellen als maat kunnen dienen voor de stress waaraan dieren blootgesteld zijn. Een daling in het % lymphocyten en een stijging in het % neutrofielen na een blootstelling van 16 dagen werd gevonden bij varkens gehuisvest bij fluktuerende temperatuur en tocht. Dergelijke parameters zijn echter minder geschikt voor het bepalen van het tijdstip waarop dieren aangepast zijn, mede omdat het tijdstip van aanpassing afhankelijk is van het tijdstip van de dag.

Homeotherme dieren bezitten een konstante lichaamstemperatuur. Dit betekent dat warmteverlies aan de omgeving gecompenseerd wordt door warmteproduktie waardoor de konstante lichaamstemperatuur gehandhaafd blijft. Onderzocht is of de lichaamstemperatuur door de verschillende klimaatskondities werd beïnvloed. Daartoe zijn in 2 biggen zenders in de buikholte gebracht, waarna deze varkens in een groep met 8 andere varkens bij verschillende klimaatsomstandigheden werden gehouden.
Per 15 minuten werd de gemiddelde lichaamstemperatuur geregistreerd. De dieren werden achtereenvolgens gedurende 2 dagen aan fluktuerende temperatuur en tocht, 25 °C, 25 °C en tocht, 15 °C en tocht en 15 °C blootgesteld. De tocht en de fluktuerende temperatuur welke in deze proef toegepast werden waren gelijk als in de hierboven omschreven proeven. Tussen de opeenvolgende behandelingen was een periode van 1 dag. De konstante temperaturen van 25 °C en 15 °C hadden geen effekt op de lichaamstemperatuur gedurende de nacht. Het optreden van tocht beïnvloedde de lichaamstemperatuur. Een ritmiek in de lichaamstemperatuur werd aangetoond bij tocht, zowel bij konstante als fluktuerende temperatuur. Voor beide dieren met een zender waren deze ritmes aanwezig. Een ritmiek in warmteproduktie en aktiviteitswarmte ten gevolge van tocht was eveneens aantoonbaar. De ritmiek in warmteproduktie en aktiviteitswarmte was niet synchroon met de ritmiek in lichaamstemperatuur. Het maximum voor de warmteproduktie en de aktiviteit werd direkt na het begin van de tocht gevonden. Op dit tijdstip was de lichaamstemperatuur verlaagd, terwijl een verhoging in de lichaamstemperatuur tegen het einde of na de tochtperiode werd gevonden. Het verschil in tijd tussen het maximum van warmteproduktie en het maximum in lichaamstemperatuur was gecorreleerd met het effekt van tocht op de hoeveelheid extra geproduceerde warmte.

Uit de resultaten van de uitgevoerde en beschreven experimenten kan gekonkludeerd worden dat aanpassing van mestvarkens aan ongunstige klimaatsomstandigheden plaats vindt. Het tijdstip van aanpassing is echter verschillend voor de dag en nacht periode, en evenzo voor de diverse tijdstippen van het etmaal. Plotselinge veranderingen van het klimaat zijn echter nog steeds aantoonbaar nadat aanpassing, bepaald via bijvoorbeeld totale warmteproduktie of aktiviteit, bereikt lijkt te zijn. Aanpassing aan een ongunstig stalklimaat bepaalt in sterke mate de reaktie van varkens op infektie. Niet aangepaste dieren blootgesteld aan een on-

gunstig stalklimaat direkt na infektie hebben duidelijk meer problemen dan aangepaste dieren of dieren gehuisvest in een thermoneutraal klimaat.
Onderzoek toonde aan dat met name gedurende de beginperiode de lichaamstemperatuur beïnvloedt is. Een verlaging treedt op indien het warmteverlies niet direkt door warmteproduktie gecompenseerd kan worden. Bij dieren wordt de setpoint temperatuur en dus de lichaamstemperatuur verhoogd (koorts) als reactie op infektie ten behoeve van een verbetering van het afweermechanisme. Een daling in lichaamstemperatuur tengevolge van b.v. tocht zal dan de verbetering uitstellen of verminderen. Bovendien kan een lagere lichaamstemperatuur in het voordeel van de pathogeen zijn.
Het effekt van tocht op de lichaamstemperatuur leidt aldus tot een verminderde kans van het dier om de infektie te bestrijden en dus zijn gezondheid te waarborgen.

Curriculum vitae

Johannes Martinus Franciscus Verhagen werd op 31 oktober 1954 geboren te Arnhem. Hij behaalde in 1972 het HAVO-diploma aan het Katholiek Gelders Lyceum te Arnhem. Van 1972 tot 1975 volgde hij de Christelijke Hogere Landbouw School te Dronten. Van september 1975 tot oktober 1976 vervulde hij zijn dienstplicht bij de Koninklijke Landmacht. In oktober 1976 begon hij met zijn studie Zoötechniek aan de Landbouwhogeschool in Wageningen. Na het afstuderen in maart 1983 was hij werkzaam als geneticus bij de varkensfokkerijgroepering Fomeva te Cuyk. In april 1984 keerde hij terug naar de huidige Landbouwuniversiteit voor een 3-jarig promotieonderzoek bij de vakgroep Veehouderij, hetgeen resulteerde in dit proefschrift.