INFLUENCE OF ENVIRONMENTAL TEMPERATURE ON ENERGY METABOLISM OF GROWING PIGS HOUSED INDIVIDUALLY AND IN GROUPS

M. W. A. VERSTEGEN

Dit proefschrift met stellingen van

MARTINUS WILHELMUS ANTONIUS VERSTEGEN,

Landbouwkundig ingenieur, geboren te Helden (L) op 31 maart 1941, is goedgekeurd door de promotoren, Dr. Th. STEGENGA, hoogleraar in de veeteeltwetenschap en Drs. A. M. FRENS, hoogleraar in de dierfysiologie, waarin begrepen de stofwisselingsleer van mens en dier.

De Rector Magnificus van de Landbouwhogeschool,

J. M. POLAK

Wageningen, 10 december 1970

636.4:591.128:591.133.1.05:591.134.036

INFLUENCE OF ENVIRONMENTAL TEMPERATURE ON ENERGY METABOLISM OF GROWING PIGS HOUSED INDIVIDUALLY AND IN GROUPS

(with a summary in Dutch)

PROEFSCHRIFT
TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWWETENSCHAPPEN
OP GEZAG VAN DE RECTOR MAGNIFICUS MR. J. M. POLAK,
HOOGLERAAR IN DE RECHTS- EN STAATSWETENSCHAPPEN
VAN DE WESTERSE GEBIEDEN,
IN HET OPENBAAR TE VERDEDIGEN
IN DE AULA
VAN DE LANDBOUWHOGESCHOOL TE WAGENINGEN
OP WOENSDAG 3 FEBRUARI 1971 TE 16.00 UUR

DOOR

M. W. A. VERSTEGEN

H. VEENMAN & ZONEN N.V. - WAGENINGEN - 1971

This thesis is also published as Mededelingen Landbouwhogeschool Wageningen 71-2 (1971)
(Communications Agricultural University Wageningen, The Netherlands)

STELLINGEN

I

Lage staltemperaturen beïnvloeden vooral in het eerste deel van de mestperiode de eiwitaanzet minder dan de vetaanzet.

M. F. FULLER. Br. J. Nutr. 19(1965) 531–541.
Dit proefschrift

II

Voor het verklaren van effekten van stalklimaat op de groei van groepen mestvarkens dient men niet voorbij te gaan aan het gedragspatroon van de dieren onder de verschillende klimaatsomstandigheden.

Dit proefschrift

III

De invloed van huisvesting en stalklimaat op mestvarkens dient uit veeteeltkundig oogpunt te worden bestudeerd met groepen dieren.

IV

Het gebruik van het begrip 'grootvee – eenheid' (G.V.E.) voor de berekening van ventilatienormen resulteert in een te ruime norm voor zware dieren en een te krappe norm voor lichte dieren.

V

Jonge groeiende landbouwhuisdieren kunnen bij een lang verblijf in een bepaald stalklimaat hun lichaamsbouw en -samenstelling hieraan aanpassen. Bij onderzoekingen naar de invloed van stalklimaat op de energiebehoefte van deze dieren dient hiermee rekening te worden gehouden.

SUGAHARA, M. et al., J. An. Sci. 31(1970) 59–63.

VI

Selektie op verlaging van de voederkonversie en ook op verlaging van de verhouding tussen voor produktie beschikbaar voer en de produktie, wil niet zeggen dat ook geselekteerd wordt op verhoging van de energetische efficiëntie.

VII

Bij de vergelijking van de groei van jonge landbouwhuisdieren wordt veelal te weinig rekening gehouden met verschillen in voederopname.

VIII

De ontwikkeling van éénmansbedrijven in de melkveehouderij dient niet te worden bevorderd.

IX

Een goede overgangsmogelijkheid van wetenschappelijk onderwijs naar hoger beroepsonderwijs is meer in het belang van het wetenschappelijk, dan van het hoger beroepsonderwijs.

Proefschrift M. W. A. VERSTEGEN
Wageningen, 3 februari 1971.

Aan mijn ouders
Aan Mariet, Harold en Christian

VOORWOORD

Het onderzoek dat beschreven is in deze dissertatie werd uitgevoerd in het Laboratorium voor Fysiologie der Dieren in samenwerking met het Laboratorium voor Veeteeltwetenschap van de Landbouwhogeschool te Wageningen.

Bij deze gelegenheid wil ik iedereen bedanken die tijdens dit onderzoek en de voorbereiding van het manuscript op enigerlei wijze behulpzaam is geweest.

Dr. ir. A. J. H. van Es was intensief betrokken bij de uitvoering van de proeven, de bewerking van de resultaten en het voorbereiden van het manuscript. Via hem werd inzicht in de methode en de interpretatie van uitkomsten van energiebalansproeven verkregen.

De promotoren Prof. dr. Th. Stegenga en Prof. A. M. Frens ben ik erkentelijk voor de discussies en suggesties tijdens het onderzoek.

Technische medewerking verleenden de heren J. E. Vogt, R. Terluin en G. A. Bangma van de afdeling Fysiologie der Dieren en de heer J. Huisman van het I.L.O.B.

De heer H. J. Nijkamp en zijn medewerkers op de afdeling Fysiologie der Dieren verrichtten de analyses, die nodig waren voor de bepaling van de beschikbare energie en de N-balansen.

De heren G. S. Slotman en W. Willemsen verzorgden de dieren.

Bij de verwerking van de resultaten was vooral de heer W. van der Hel intensief betrokken.

De heren C. van Eden en W. Heije verzorgden het tekenwerk en het typewerk werd verricht door de centrale typekamer en de dames van de afdelingen Veeteelt en Fysiologie der Dieren.

Dr. L. E. Mount van het A.R.C. Institute of Animal Physiology Babraham, Cambridge corrigeerde mede de Engelse tekst.

CONTENTS

1. INTRODUCTION

Rapid changes in the structure of pig husbandry in The Netherlands during the last decade have focussed attention on several aspects of housing. It was considered that information should be available on the effects of temperature, humidity, rate of ventilation, shape of the pens, material of the floors, etc. on the animals. Furthermore information was needed on the heat and water vapour production of pigs to be able to construct piggeries in which a desired climate could be produced with least costs. Knowledge of physiological data such as heat production and water vapour production of the pig kept at optimal stall-climates is important to ensure a correct rate of ventilation. Also it should be known to what extent a pig needs a certain temperature inside the piggery.

In the spring of 1967 two new respiration chambers were ready for use at the Department of Animal Physiology of the Agricultural University, Wageningen. It was decided in a cooperative project of the Departments of Animal Husbandry and Animal Physiology to investigate the heat production and energy balances of fattening pigs from 20–90 kg under different climatic conditions. Such investigations may be necessary because they can provide data on which the ventilation rate of a piggery can be based and they can also give information on the effect of its climate on the energy metabolism of the pigs.

Instead of measuring the heat production of the pig one can also determine the effect of different climatic conditions e.g. temperature on its growth. As due to the fact that the composition of the body weight gain may depend also on temperature (SÖRENSEN, 1961; PFEIFFER, 1968; HICKS, 1966), the results of such experiments are difficult to interpret. Moreover, such experiments require a rather long period, before eventually significant differences in weight as a result of temperature effects can be noticed, a.o. due to errors in weighing. The advantage of measuring the energy balances is the possibility to investigate the quantitative effects of small changes in temperature during a rather short time. If the technical equipment provides facilities to change the temperatures more or less similarly to changes which occur in a piggery, it may be possible to detect differences in energy metabolism of pigs when the temperature is changing each day.

Determinations of the effect of climatic conditions on pigs will only apply to practical conditions if the animals are kept in groups, or if one should know the differences in reactions of groups of pigs and singly housed pigs. MOUNT (1960) and HOLMES (1966) have shown the importance of including groups of animals in the investigations. It was decided therefore to study both the reactions in metabolism of single pigs as well as groups of pigs to different climatic conditions.

The main subject of this study has been the heat production of growing pigs kept singly or in groups under normal conditions of temperature with some variation in the level of metabolisable energy intake of the animals. The use of different levels of metabolisable energy in some of these experiments made it possible to compute their eventual effect on heat production. In many balance-experiments described in the literature also different levels were used. The data of these and of similar experiments known from the literature have been studied statistically to obtain more information on this aspect.

Finally this study deals with the investigations of the influence of low temperatures on heat production of pigs kept singly or in groups.

During these experiments the feeding level was kept as constant as possible and in accordance with practical feeding standards (CENTRAAL VEEVOEDERBUREAU, 1965).

2. LITERATURE

2.1. INTRODUCTION

The literature on the heat production of pigs can be divided into two parts. One part of the investigations deals with the determinations of the heat production and energy retention of animals of different weights, fed different kinds and amounts of feed. In all these studies the assumption has been made that the investigations have been performed within the zone of thermoneutrality. These studies can provide information on the feeding value of the feed and on the requirements of the pigs. However, they can also give information on the heat production of pigs at various weights and fed different amounts of different kinds of feed. For comparison with these experiments on the influence of varying amounts of feed on the heat production, the results of literature need a statistical treatment. This will be done in chapter 6.

Another part of the investigations described in the literature deals with measurements on heat production or heat transfer in pigs of different weight at different temperatures. In these studies the amount of feed intake in kcal metabolisable energy is rarely given, often not even measured. Consequently also the energy retention of the animals, equal to metabolisable energy minus heat production is not known. Therefore it is not possible to make a distinction between the effects on heat production and energy retention of feeding and of environment separately. This part of the literature will be reviewed in the present chapter.

In the literature sometimes different definitions for the critical temperature are given depending on the feeding level of the animal concerned. In this review the critical temperature is defined by that temperature, below which the pig or a group of pigs of a certain weight and at a certain feeding level will increase the heat production in order to maintain the body temperature.

For fasting heat production the definition of BRODY (1945) can be used:
Basal metabolism or fasting heat production is the metabolism of a fasting animal, which:

a. is in a state of complete rest,

b. is kept within the zone of thermoneutrality,

c. is not metabolizing feedstuffs or other materials which stimulate heat production.

2.2. HEAT TRANSFER AND INSULATION OF THE PIG

Like other farm animals the pig is a homeothermic animal. Under different climatic conditions it will keep its body temperature constant within a rather small range of variation (IRVING, PEYTON and MONSON, 1956). The heat transfer from the pig to its environment is determined by the heat loss, which is governed by evaporation (the insensible heat loss) and the three channels of sensible heat loss: radiation, convection and conduction. Some heat is needed for bringing up the temperature of feed and water to body temperature (2–10% of total heat). This aspect will, however, not be concerned in this study.

Insensible heat exchange

In all animals and also the pig, the evaporation of water at the surface of the body cools the animal. In some species of animals the transport of water to the surface can be increased by a special mechanism, i.e. sweating.

Determinations of the evaporative heat loss have been made by INGRAM (1964) with growing pigs of 3 months old. In these investigations he measured an evaporation of 7 g water/m^2. hour at -5 °C and 24 g water/m^2. hour at 35 °C. Compared with other farm animals (BLAXTER, 1962) this evaporative cooling is very poor. In sheep it may rise to 60 g/m^2. hour and in cattle to 70–140 g/m^2. hour. In the human it is even much higher. The capacity of heat loss by evaporation from a wet pig skin, however, is not known. After artificial wetting of the skin of the pig or smearing it with mud INGRAM (1964) found an evaporation nearly equal to the possible evaporation from the human skin i.e. 700 g/m^2. hour. This means that the transport of water to the surface of the body of the pig by sweating is very low.

MORRISON, BOND and HEITMAN (1967) investigated the evaporative heat loss in two Duroc gilts of 90 kg each and found that at temperatures of 16 °C to 29 °C with the same absolute humidity (dew point 10 °C) the heat loss from the skin doubled.

The other pathway along which water is vaporised is the respiratory tract. Studies from HOLMES (1966) showed correlation coefficients of 0.7 and 0.8 respectively between evaporative heat loss and respiratory rate at 30 °C. In the experiments of MORRISON, BOND and HEITMAN (1967) the evaporative heat loss from the respiratory tract tripled when the temperature rose from 16 °C to 29 °C at the same absolute humidity. Under warm conditions pigs seem to increase the respiratory evaporation rather than the evaporation from the skin and INGRAM (1964) could not find evidence that pigs do sweat under environmental conditions which induce sweating in other species.

Sensible heat exchange

The sensible heat exchange is characterized by the thermal gradients between the pig and the environment as it takes place through radiation, convection, and conduction. MOUNT (1968) discussed these three channels of heat loss. Radiation is determined by the absolute temperatures of the body, the surface of the body and the surroundings and by the emissivity of the body surface and the surroundings.

Convection depends on the surface temperature of the body, its shape, surface characteristics, size; temperature and velocity of the air surrounding the body.

Conduction heat is the heat loss from the body of the pig to the floor or wall with which the animals are in contact.

Insulation

According to MOUNT (1968, p. 192) heat transfer depends on the thermal insulation, both the specific insulation, i.e. the insulation per unit of surface area of the organism, and the overall insulation i.e. the insulation depending on body size, shape, posture and movement. This overall insulation of a pig governs for a given body-ambient temperature gradient its total non-evaporative heat-exchange with the environment.

In the pig being a bare-skinned animal the insulation of the core to the skin is considered as internal insulation and from skin to surface as external insulation. MOUNT (1968) has one objection using the terms internal and external insulation because they are proportional to surface area and this surface area is not the effective surface area for heat exchange by radiation, convection and conduction. These channels being effected by posture, he prefers to use overall insulation.

We might, however, distinguish between external and internal insulation because the calculation of overall insulation excludes the heat lost by evaporation from the skin.

Internal insulation

The internal insulation is the reciprocal of the conductance for heat transfer from the core of the body to the skin surface. If the heat transfer via respiration is excluded then the equation is:

Heat transfer $= A_S \times C_T (T_B - T_S)$ wherein
T_B = body temperature
T_S = skin temperature
A_S = skin surface in m^2.
C_T = conductance of the tissues in kcal/°C.m^2. hour

Due to the small losses of water vapour from the skin surface to the environment in cold conditions heat flows through body and skin surface will not differ very much.

In older mature pigs, animals which have been in the cold for a long time, also called acclimatised pigs, the internal insulation or insulation of the tissues has been investigated by IRVING, PEYTON and MONSON (1956). They found an insulation value of the tissues in the cold of about 0.21 °C.m^2. hour/kcal. Compared with other farm animals this internal insulation in the cold (at vasoconstriction) is rather high (BLAXTER, 1962, p. 130).

Internal insulation can be defined as:

$$\frac{\text{rectal temperature} - \text{mean skin temperature}}{\text{total non-respiratory heat loss in kcal/m}^2\text{. hour}}$$

MOUNT (1964) investigated this internal insulation in newborn pigs up to one week and INGRAM (1964) in pigs of 3 months of age. From their investigations it is clear that internal insulation varies with age and in piglets also with the temperatures. MOUNT (1964) found values of about 0.05 °C. hour m^2/kcal at 5 °C and 0.0 °C. hour m^2/kcal at 38 °C. In pigs of 3 months old INGRAM found values of 0.10, 0.11, 0.11, 0.085, and 0.063 °C. hour m^2/kcal at temperatures of – 5 °C, 10 °C, 25 °C, 30 °C and 35 °C. This is about twice as much as found in newborn pigs. The changes in internal insulation in the cold at various ages can partly be explained by the thermal circulation index, that is according to BURTON (1934).

$$\text{Index} = \frac{\text{skin temp.} - \text{environmental temperature}}{\text{rectal temperature} - \text{skin temperature}}$$

This thermal circulation is thus a measure of the ratio at which heat is transferred from the core to the surface of the body. Below 30 °C to 25 °C INGRAM (1964) found a nearly constant circulation index in pigs of 3 months of age. This indicated that vaso-constriction had occurred between 25 °C and 30 °C, and meant that the critical temperature of these Landrace pigs was between 25 °C and 30 °C.

At -5 °C, however, he noticed an increase due to increased skin blood flow. At low temperatures the temperatures of trunks and extremities can undergo cyclical changes by means of rapid vaso-dilatation and followed again by vaso-constriction. The temperatures thus rise quickly and decrease slowly (BLAXTER, 1962, p. 132). This mechanism prevents the animal from freezing or chilling.

External insulation

As the haircoat on piglets and fattening pigs is not very dense, the external insulation is almost completely due to the insulation of the air interface in the coat. According to BLAXTER (1962, p. 125) this can be visualized by representing the hair coat insulation by the insulation of a minute layer of very still air held at the surface by cohesive forces. External insulation can be defined as:

$$\frac{\text{effective environmental temperature} - \text{mean skin temp.}}{\text{total non-evaporative heat loss from skin in kcal/m}^2\text{ hour}}$$

The effective environmental temperature is defined as that temperature which determines with the skin temperature the heat loss through radiation, convection and conduction.

Because HOLMES (1966) has already reviewed the literature on this subject it will only be briefly discussed here. INGRAM (1964) investigated in his experiments the external insulation in pigs of 3 months old kept at different temperatures. He found it to be about 0.17 °C.m^2. hour/kcal at 5 °C to 0.07 °C. hour m^2 /kcal at 38 °C. According to the author this indicates that the pigs develope a change to a more bristle coat and the pigs tend to change their posture in order to reduce the effective area for heat loss and thus increase the insulation in the cold.

Overall insulation

The data on the overall maximum insulation found by IRVING, PEYTON and MONSON (1956) in Alaska were about twice as much as was found by INGRAM (1964) in pigs of three months old. The increase in maximum insulation in the cold with increasing age may be explained by the deposition of more subcutaneous fat as was found by SÖRENSEN and MOUSTGAARD (1961). Maximum insulation means that vaso-constriction has taken place.

Measurements on the insulation of pigs less than one week old made by MOUNT (1964) showed that both 5 °C and 30 °C were below the critical temperature, so that peripheral constriction was expected in both cases. However, there was a difference in insulation or conductance at these temperatures. He explains this phenomenon by a postural change at 5 °C and measurements on the effective radiating area supported his conclusion.

Another factor which might explain differences in insulation between 5 °C and 20 °C is the rate of heat loss to the floor. In the cold the animals adopted a more flexed tense posture. In young growing pigs, according to INGRAM (1964) and WINSLOW, HERRINGTON and GAGGE (1936) cited by HOLMES (1966), the total insulation is nearly equal to that of the human. In experiments with animals of 20 kg and 60 kg kept in a direct calorimeter at temperatures of 9 °C, 20 °C and 30 °C HOLMES (1966) noticed that the overall insulation of the pigs differed less between 9 °C and 20 °C than between 20 °C and 30 °C. He explained these differences in change of conductance above and below 20 °C by suggesting that the change above 20 °C was mainly due to vaso-motor activity. The change in conductance below 20 °C would be mainly due to posture changement. This, however, means that in both 20 kg and 60 kg pigs vaso-constriction has occurred close to 20 °C. If the vaso-constriction occurred just close to 20 °C then the change in conduction or insulation below 20 °C might be explained by a change in posture and or a change in resting on the floor so that the heat loss to the floor is reduced.

Generally we might conclude from the above mentioned literature that at the critical temperature maximum insulation not always has been reached. Pigs still may increase their insulation by changes in posture, way of lying on the floor as is shown by MOUNT. The change in maximum insulation in young piglets might be also partly explained by a change in external insulation. According to MOUNT (1963) the piglets in the cold seem to develop a coat with more bristle. With increasing age the external insulation does not vary much with the change in environmental temperature. But with vaso constriction the internal insulation and thus the total insulation increases a lot with lowering temperatures. Also with increasing age and with acclimatization there seems to be a considerable increase in overall insulation due to the deposition of subcutaneous fat. Compared with other farm animals the pig has little or no ability to sweat and the total insulation at maturation, consisting of the insulation of the tissues and the insulation of the air interface, is at least as high as in other farm animals.

2.3 HEAT PRODUCTION OR HEAT LOSS AND ZONE OF THERMONEUTRALITY

2.3.1. *Fasting heat production*

Although in practice no animals are kept in fasting conditions one can derive some information on the energy metabolism or heat production of pigs under practical conditions from fasting experiments. The first measurements of the fasting heat production of pigs were made by MEISSL (1886), who was cited by TANGL (1912). TANGL himself measured indirectly heat production of two animals weighing 50 kg and of two animals weighing 100–120 kg. The animals of 50 kg were of the Yorkshire breed and about 7 months of age and the heavier animals were of the Hungarian Mangalica breed and about 15 months of age. The animals were put in an indirect calorimeter and fasting heat production was measured at different temperatures. The lighter animals started to raise their heat production below 20 to 23 °C, and the heavier animals below 17 °C. Above these temperatures the heat production at the weights of 50 kg and 100–120 kg was 73 kcal/$W^{3/4}$. 24 hours and 64 kcal/$W^{3/4}$. 24 hours, resp. after the period of 5–9 days fasting. At 17 °C the heat production of 50 kg animals was found to be 27% more than at 23 °C. CAPSTICK and WOOD (1922), working with one mature Large White animal of 120–180 kg in a direct calorimeter noticed a critical temperature of about 21 °C and the heat loss above this temperature was about 54 kcal/$W^{3/4}$. 24 hours and at temperatures of 18 °C, 14 °C and 10 °C he found an extra heat loss of 6%, 22.7% and 46% respectively. This means an extra heat loss below the critical temperature which is nearly linear. DEIGHTON (1929) who performed fasting trials in a direct calorimeter with 2 Large White pigs and later on with 25 pigs of different breeds (1932, 1934, 1935, 1937) assumed or concluded somewhat prematurely the critical temperature of mature Large White animals to be near 16 °C. At this temperature one of his Large White animals lost about 65 kcal/$W^{3/4}$. 24 hours at 50 and 81 kg. The second pig was measured several times between 40 kg and 177 kg, age 218 and 702 days, resp., and lost 92 kcal/$W^{3/4}$. 24 hours and 55 kcal/$W^{3/4}$. 24 hours. Compared with the results of TANGL (1912) and CAPSTICK and WOOD (1922) these figures at 50 kg are rather high. From his other experiments a fasting heat loss of 84 kcal/$W^{3/4}$. day at 50 kg and 300 days of age and 73 kcal/$W^{3/4}$. day at 100 kg and 450 days of age was computed (VAN ES, in press). During the intervals between the experiments the animals were fed at a low feeding level. From the above mentioned investigations it can be concluded that the fasting heat production or heat loss of pigs seems to increase below 16 °C to 21 °C. However, there were differences in breeds of animals used and perhaps the kind of floor and also wall temperatures were different. These may have influenced the results obtained.

2.3.2. *Effect of air temperature on the heat production of fed animals kept singly*

One of the first investigations on this aspect may have been done by VON DER HEIDE and KLEIN (1913). They worked with pigs of 65–80 kg and put them separately in an indirect calorimeter. In these pigs, which were fed at maintenance level, i.e. not losing or gaining energy, they noticed an increase in heat production at 19 °C and 10 °C of 14% and 27% resp. as compared with 22 °C.

Recent investigations on the effect of air temperature on the heat production of single pigs have been performed by HOLMES (1966) and HOLMES (1968) with animals of 20 kg and 60 kg, and by PULLAR (1963) with pigs from 12 to 92 kg of weight. All these measurements have been done in direct calorimeters and were performed at least during some hours several times a day. It can be thought then, that the heat loss measured in these experiments is equal to the heat production. HOLMES (1966) measured the heat loss of growing animals kept singly at 9 °C, 20 °C and 30 °C in a direct calorimeter which has been described by MOUNT *et al* (1967). In this experiment the pigs of 20 kg received 0.83 kg food a day and the pigs of 60 kg received 1.83 kg food a day. Pigs of 20 and 60 kg which were kept at 9 °C lost 36% and 19% more heat than at 20 °C. Pigs of the same weight kept at 30 °C lost resp. 7% and 8% less than at 20 °C. Although the differences in heat losses at 30 °C and 20 °C were not significant, the possibility exists that the critical temperatures of the 20 kg pig might be sowewhat above 20 °C and also that 30 °C might be above the upper border of the thermoneutral zone for pigs of 60 kg. With pigs of 12–26 kg and in piglets of 1 to 8.6 kg MOUNT (1969) measured the oxygen consumption as an indication for heat production in a closed circuit respiratory metabolism apparatus, and he noticed that the single piglet produced more than 50% extra heat at 20 °C than at 30 °C. This means that 20 °C is far below the critical temperature of these piglets kept singly. PULLAR (1963) working with *ad libitum* fed animals in a gradient-layer calorimeter (PULLAR, 1958) did not notice significant differences in heat loss of animals kept at 20 °C or 30 °C both in pigs of 11.4 kg and 46 kg. From 46 kg to 92 kg the animals were fed restricted starting from 0.68 kg TDN at 48 kg to 1.1 kg TDN at 92 kg twice daily. At 10 °C, however, he found an increase of 48% in heat loss in pigs weighing 23 kg compared with 20 °C. These differences in heat loss between 10 °C and 20 °C decreased to 18% when the pigs were reaching bacon weight (92 kg). The total heat loss of the 92 kg pig at 20 °C or 30 °C was found to be 4300 kcal/day. He stated that the critical temperatures for pigs of 23 to 92 kg lie between 10 °C and 20 °C.

2.3.3. *Effect of air temperature on the heat production of fed animals kept in groups*

During their investigations with restricted fed animals (0.82 kg at 20 kg and 1.83 kg at 60 kg body weight) HOLMES (1966) and HOLMES and MOUNT (1968) did not notice significant differences in heat production in groups of pigs weighing 20 kg and kept at 20 °C or 30 °C in a direct calorimeter (MOUNT *et al*, 1967). The heat loss per pig in these groups of pigs at 20 °C was also nearly equal to the heat loss measured at 20 °C with single pigs. At 9 °C, however, both in one group of 20 kg and in two groups of 60 kg an increase was noticed of resp. 10% and 5% and 18% compared with 20 °C. And HOLMES (1966) stated: 'Under the conditions of these experiments 20 °C was within a range of ambient temperature in which minimal daily heat loss might be expected to occur from groups of pigs weighing 20 kg and 60 kg each regardless of the groups behaviour.'

Nevertheless he noticed in one group of 60 kg pigs a significant decrease in heat loss at 30 °C compared with 20 °C. In the other experiment the difference in heat loss between 20 °C and 30 °C did not differ significantly from zero.

In *ad libitum* fed animals BOND, KELLY and HEITMAN (1963) also noticed considerable differences in the heat output or heat production at different temperatures. In groups of 5 animals weighing 58–60 kg they found an increase in heat loss of 35% when the heat loss was measured at 10 °C instead of at 21.2 °C. Part of this extra heat loss may be caused by the higher feed intake at the lower temperature. Also in heavier animals this interaction of feed intake and temperatures may play an important role in thermoregulation. For instance in the above mentioned investigations of BOND, KELLY and HEITMAN (1963) one group of animals of 124 kg body weight lost 4626 kcal/day. animal at 21 °C and at 32 °C a group of 5 animals of the same weight had a total heat loss of 3984 kcal/animal. day.

Thus it is very difficult to examine at what temperature the *ad libitum* fed animals will start to produce or lose extra heat in order to maintain their body temperature. At low temperatures of 10 °C the above quoted Californian group of workers found an increase of 20 to 25%. BOND *et al* (1952) noticed an increase in heat loss of 10, 26 and 13% resp. when a group of *ad libitum* fed animals of 35, 45 and 135 kg kept in the Californian psyschrometric chamber at the University of Davis was exposed to 10 °C instead of 20 °C. All these investigations in the Californian psychrometric chamber have been done during test periods of one week. PULLAR (1963), working with groups of 4–6 small pigs from 1–2 kg and 3–6 kg kept together in the gradient layer calorimeter, noticed an increase in heat loss of nearly 100% when 15 °C was compared with 35 °C. MOUNT (1960) found that the group of 4 piglets (1–2 kg) produced about 25% more heat at 20 °C than at 30 °C. When the group size was 6 he noticed an increase in heat output of 14%.

MOUNT and WILLMOTT (1967) showed that a group of 4 mice lost about 140% more heat at 15 °C compared with 31 °C. Single mice produced 40% more extra heat above this 140% at the same conditions.

In pigs of 20 kg at 9 °C instead of 20 °C a group can save about 75% of the extra heat required (HOLMES, 1966). And a group of young piglets may save about 40% of the extra heat required (MOUNT, 1960). Huddling in groups thus seems to be an effective way of saving part of the extra heat required below the critical temperature.

Summarising the results from the influence of temperature on heat production or heat loss, it is clear that in general groups of pigs can save a lot of extra heat required at low temperatures compared with single animals.

2.3.4. *Effect of air movement on the heat production of pigs.*

Single pigs.

In single newborn pigs MOUNT (1966) measured the heat production in the closed circuit metabolism apparatus at Babraham. He found an increase in heat production of about 20 to 25% above heat production at 5 cm/sec. when the piglets were exposed to wind-speeds of 34, 82 and 158 cm/sec. at 30 °C. At temperatures of 30 °C the increase was about 10–15 % at 34 cm/sec. and 82 cm/sec. and 25 % at 158 cm/sec. This increase in convective heat loss was not equal to the square root of windspeed as found by WINSLOW, HERRINGTON and GAGGE (1936) in man between 8 and 35 cm/sec. MOUNT and INGRAM (1965) found that in older animals at a low temperature (15 °C) sensible heat loss from the animal's back due to increased wind speed (8, 35, 60 and 100 cm/sec.) was higher than at temperatures of 20 °C to 35 °C. They investigated the effect of windspeed on sensible heat loss by means of a heatflow disc. Landrace pigs from 3.4–5.8 kg, 20–25 kg and 60–70 kg were used. In younger pigs the slope of increase in sensible heat loss was steeper while in the older pigs the rate of increase showed a tendency to become progressively less steep.

At 20 °C the rise in sensible heat loss at the highest windspeed in pigs of 20 to 25 kg was about 86–90 kcal/m^2. hour. It was also found that changes in airspeed over the lower part of the range are more effective in changing heat loss than over the upper part of the air speed range. This was explained by the disproportionately disruptive effect on the boundery layer of air around the pig at different air speeds.

Groups

HOLMES (1966) and HOLMES and MOUNT (1967) compared the heat loss of a group of pigs between 20 and 50 kg at 12 °C and 20 °C. They measured the heat loss in the direct calorimeter at two levels of air velocity respectively 10 cm/sec. and 25 cm/sec. Pigs of 25 kg showed a 10 % higher heat loss during the first days at the higher level. After the initial period of 4–6 days, however, the increase in heat loss in the higher air speed decreased and the authors indicate the possibility that this decrease in heat production after the initial period of 4–6 days might be due to a behavioural adaptation on the part of the pigs. BOND, HEITMAN and KELLY (1965) compared heat output at different air velocities up to about 76 cm/sec. at 10 °C and 20 °C. In *ad libitum* fed animals of 65–70 kg they noticed a 12 % higher level of heat output at the highest air velocity at 10 °C and a 10 % higher level at 20 °C. Not only the total heat loss increased but the ratio of heat flow through the channels of heat flow i.e. radiation. convection and conduction, changed. Radiation heat flow decreased considerably while convective heat loss was nearly constant and evaporative heat loss increased considerably. If higher air velocities cause an increase in heat loss, than the lower border of the zone of thermoneutrality, i.e. the critical temperature will rise. The zone of thermoneutrality was found to be considerably smaller in young pigs when exposed to higher air velocities (SAINSBURY, 1954, cited by SMITH, 1964).

2.3.5. *Effect of different kinds of floors on the heat production*

MOUNT (1967) showed that conductive heat loss to different types of floors may be very different. He measured heat loss to different kinds of floors, i.e. concrete floors, wooden floors, expanded polystyrene floors, and a floor with one inch of straw on concrete.

To each of these types of floors the conductive heat loss doubled when the temperature was lowered from 30 °C to 20 °C. At 20 °C heat loss to the wood was nearly equal to the heat loss to concrete at 30 °C. Substituting wood for concrete was nearly equal to raising the floor temperature by 12 °C and one inch of straw reduced heat flow to the floor by 41 % being equivalent to a rise in floor temperature of 15 °C. Heat loss to the floor was estimated to increase to about 15 % of the total heat loss. This experiment, however, does not prove that total heat production of an animal on different floors is different. If one would measure O_2 consumption of piglets on these floors (STEPHENS, 1969) then an indication for differences in heat loss might be obtained.

STEPHENS noticed that, compared with the concrete floor, straw reduced O_2 consumption of a piglet on the floor by 10 % at 10 °C, 27 % at 20 °C and 12 % at 30 °C. Between 1 kg and 3.2 kg the body weight did not have influence on the ratios of O_2 consumption. OSINGA (1963) also showed that the heat flow from pigs or an artificial pig to the floor differed when much or litlle straw was on the floor. Also HAARTSEN (1967) noticed considerable differences in heat loss from an artificial pig to different floors.

2.3.6. *Effect of some other environmental factors on heat production or heat loss of pigs*

Relative humidity

In the literature investigations to show that relative humidity influences the heat loss between 10 °C and 25 °C in growing pigs could not be found.

Latent heat loss or evaporative heat loss of single pigs accounts for only 20 % to 25 % of the total heat loss. The evaporation heat does not differ much between different temperatures and different humidities below 20 °C. MORRISON, BOND and HEITMAN (1967) also HOLMES (1966) did not find big differences in evaporation heat at moderate temperatures of 9 °C and 20 °C. One might only expect an influence of high relative humidity on heat loss at high temperatures when the animals are going to pant very quickly in order to get rid of the heat. If the animals lie on a wet floor then of course the extra evaporation might be able to change the total heat loss. In fattening experiments there seems to be some influence of high humidity at temperatures of 24 °C on slaughter quality, SÖRENSEN (1961) and PFEIFFER (1962).

Light

Some investigations show that light does not have a great effect on the performance and growth of pigs. Experiments with pigs reared from 20–90 kg of BRAUDE *et. al.* (1958), showed that there is no or only a very small negative effect of complete darkness on growth and body composition.

NEUMANN and GRIEB (1968) cited investigations by KLOCKOVA and EMME (1961) who found that more hours light during the day (up to 18) increased the thyroxin content of the blood. No direct investigations, however, are known on the effect of light and light intensity on heat production; from the above mentioned investigations a big effect can hardly be expected. A small negative effect of complete darkness on growth might be explained by the findings of VAN PUTTEN (1968), who claimed that animals which were in complete darkness for some days did not sleep relaxed, as judged from their behaviour.

Generally it can be stated that environmental psychological influences, which cause an increase in activity compared with the normal activity, will also cause an increase in heat production, CAPSTICK and WOOD (1922) showed that standing or moving can increase heat loss of a pig in a direct calorimeter considerably. In practice, however, the activity or restlessness of pigs should be reduced, so that more energy is available for growth.

Composition of the air

The standard for allowed CO_2 vol. % in the air (DIN, 1966) is about 0.3 vol. %. There is, however, no evidence that higher CO_2 % are unfavourable to pigs.

THORBEK and NEERGAARD (1965) measured heat production of 8 pigs during 24 hours periods at various CO_2 % in the chamber from 0.4 to 1.0% and no relationship between CO_2 concentration in the outgoing air and heat production could be measured. With other gases such as NH_3 as far as known no measurements on the effects of concentration in the air on heat production have been made, though in experiments with growing pigs a negative effect of NH_3 % on feed intake has been noticed.

2.4 EFFECT OF LOW TEMPERATURES ON GROWTH AND FOOD CONVERSION

As this study deals mainly with the influence of low temperatures on the metabolism of growing pigs, only literature on the influence of low temperatures on growth and feed conversion will be reviewed here. Most investigations from the literature have been performed with *ad libitum* fed animals. A small number of experiments have been performed with restricted fed animals, SÖRENSEN (1961), SÖRENSEN and MOUSTGAARD (1961) and WÖHLBIER, KIRCHGESSNER and SCHNEIDER (1958).

SÖRENSEN (1961) showed that Danish pigs housed in groups without straw bedding at different constant temperatures of 3 °C, 8 °C, 15 °C with 70% relative humidity (R.H.) and at 23 °C and 24 °C with 50% R.H. respectively, performed best at 15 °C and 23 °C. The animals were fed according to Danish feeding standards. At 8 °C the feed conversion increased by 0.3 FU/kg gain and at 3 °C with 0.9 FU/kg gain. At 3 °C with straw bedding the animals had the same gain as animals housed at 8 °C without straw.

LUCAS and CALDER (1955) performed trials in piggeries at different temperatures and different feeding levels. They found that the differences in growth between the different temperatures were much lower in animals at a high feeding level. On the high feeding level the animals could withstand much worse conditions of low temperatures than at the low feeding level.

WÖHLBIER *et al* (1958) working with groups of 4 castrated pigs of the Schwäbisch Hällisch breed found the best growth at temperatures of 16 °C to 20 °C. The growth at 10 °C was decreased by about 16 g to 94 g/day. Animals with antibiotica supplemented to the food and housed at 10 °C showed a better digestion of protein under conditions of *ad libitum* feeding.

HEITMAN, KELLY and BOND (1958) noticed an optimum temperature of 23 °C in pigs of 35–70 kg and 16 °C in pigs of 80–125 kg. They kept a group of 5 during a test period of one week in the Californian psychometric chamber. KALICH (1961) showed that *ad libitum* fed animals from 40 to 80 kg had the highest weight increase at 20 °C and animals from 80 to 110 kg showed the highest increase at 15 °C.

The above mentioned investigations were done at constant temperatures. In practice, however, the temperature is not constant during such a long period and moreover it is difficult to distinguish between the effect of feeding level and feed intake. Some investigations have been done by SÖRENSEN and MOUSTGAARD (1961) to study the effect of a sudden change in ambient temperature. They noticed that a time of 14 days was needed before the animals had the same growth of animals kept at the constant temperature of 3 °C when the temperature was suddenly changed from 19 °C to 3 °C. Also after a sudden change from 3 °C to 19 °C the animals needed some time before the growth was the same as that of animals kept constantly at 19 °C.

BOND, KELLY and HEITMAN (1963) found that the daily weight gains and feed conversion rates were more favourable at a constant temperature of about 21 °C than when air temperature, although averaging 21 °C, cycled from about 15–16 °C to 30 °C or 5 °C to about 30 °C.

Results from several German analyses (SIEGL, 1960; COMBERG, WOLFERMANN and RUNDFELDT, 1967) from data of growth at different temperatures in *ad libitum* fed singly housed animals from 40–110 kg in selection fattening stations have shown that the temperature at which the pigs had the best growth in weight was between 15 °C and 22 °C.

Recent investigations of MANGOLD (1965) with *ad libitum* fed group-housed animals showed optimum temperatures from 10 °C to 21 °C. In the trials of HICKS (1966) with singly housed restricted fed pigs the critical temperatures were found to be about 8 °C in pigs up to 45 kg and 4,5 °C or lower in pigs above that weight. These low temperatures are even more remarkable because the pigs were housed on a concrete floor without straw.

COMBERG, WOLFERMANN and RUNDFELDT (1967) and also PFEIFFER (1962) and SIEGL (1960) noticed that there are some differences between breeds. The fat-type pigs did not show such decrease in growth at lower temperature as meat-type pigs.

It may be concluded from the above mentioned investigations that there are consistent differences in optimum temperatures. This might be due to differences in feeding, air velocity or movement, breed of animals, kind of floor, composition of the air, or wall temperatures. Often these conditions are not mentioned and also the breed of pigs is not even mentioned. Moreover, the results are difficult to compare because one part of the investigations deals with investigations under constant ambient temperatures and the other part consists of investigations from data which are obtained under more or less practical conditions of temperature fluctuation in fattening stations. The link between the results from investigations of this kind and the trials on the influence on heat production is difficult to make because several investigations have demonstrated differences in composition of growth at different conditions.

In the trials of SÖRENSEN (1961) with Danish pigs two carcasses of pigs of each group were dissected and analysed and the results showed that the reduction in weight increase at low temperatures was more due to the decrease in N-retention than to the reduction in fat growth. These findings are not in accordance with the results of a trial from PIATKOWSKI (1958), who found that fat deposition in the cold was more reduced than nitrogen retention. In *ad libitum* fed animals HOLME and COEY (1966), and also SEYMOUR, SPEER, HAYS, MANGOLD and HAZEN (1962) did not find differences in carcass composition at different temperatures. KALICH (1961), and GROSSE and PFEIFFER (1963) suggested that in *ad libitum* fed animals low temperatures can even have a beneficial effect towards more protein in the carcass. Pigs in the cold were found to deposite a different kind of outer backfat compared with pigs kept at higher temperatures as found by PFEIFFER (1962) and (1967), HICKS (1966) and also HOLME and COEY (1966). The iodine value of the fat in the cold was much higher than at higher temperatures and HOLME and COEY (1966) also found a shorter carcass length in animals raised in the cold.

Summarizing the results from the literature it may be stated that the temperatures, at which pigs will have the optimum growth, are not the same in all studies. But European investigations suggest that optimum temperatures of pigs of 30–110 kg are between 15°C to 22°C, where as American studies indicate an optimum temperature of 16°C to 23°C in some studies and also 4°C–8°C in another study.

The breed of pigs and the feeding level in the Danish investigations are more in accordance with practice in The Netherlands, so the Dutch pigs might be expected to react more or less like the Danish. An adequate interpretation of the results of this kind of experiments is thus very difficult.

3. EXPERIMENTAL

3.1. INTRODUCTION

To obtain characteristic and mutually comparable figures on the heat production and energy balances of growing pigs, the animals have to be in such a state, that the differences in the results obtained should only be due to differences in the treatment, e.g. weight, age, feed intake, temperature, kept singly or in groups, etc. Moreover, the animals will have to be very well accustomed to their surroundings in the chambers; this is the reason why the pigs were kept in the chambers throughout the entire growth period.

The rations given to the animals should contain adequate amounts of protein, minerals and vitamins. This to exclude the hazard of working with deficient animals. For that reason the rations which were used had the same composition as the food which is also normally being distributed to the farmers by the feed industry. By storing the feed in a room at 0–5 °C there is little risk that the composition of the rations changes during periods up to 3 months.

From the figures on heat production, energy balances and nitrogen balances of the animals it could be derived whether or not there is an increase in protein and fat deposition; by deposition of fat is meant deposition of fat and glycogen, the latter amount being very small. It is assumed that the heat production during the experiments of 24 h. or 48 h. is equal to the heat loss. The following definitions have been used:

Digestible energy = energy in feed – energy in faeces

Metabolisable energy = digestible energy – energy in urine – energy in methane produced

Energy balance = metabolisable energy – heat production

N balance = N in feed – N in faeces – N in urine (including also N lost from urine to the air as NH_3)

Most elements in these formulae can be determined directly.

The heat production is calculated as follows:

Heat production = $3.868 \times$ litres O_2 consumed $+ 1.200 \times$ litres CO_2 produced $- 0.518 \times$ litres CH_4 produced $- 1.431 \times$ gN excreted in the urine.

These constants used here and also other constants used are in accordance to the set of constants advised at the 3rd Symposium on Energy metabolism in Troon, (BROUWER, 1965).

3.2. METHODS

3.2.1. *General outline*

According to the general principle of indirect calorimetry the production of CO_2, CH_4 and NH_3 and the consumption of O_2 were measured in respiration chambers. These chambers are also climate chambers. Measurements of these items were made on single pigs with two together in one chamber, each in a metabolism cage and at the same time on a group of 4 or 5 animals kept in a pen in another chamber.

Inside the chambers the chosen temperature can be kept constant with a variation of plus and minus 0.3 °C. The range which can be covered by the installations is from 5 °C to 35 °C. The air velocity can be changed from about 10 cm/sec. to 80 cm/sec. and the relative humidity from 50% to 95% with an accuracy of about 5%. During the whole fattening period from 18–100 kg the animals stayed in the chambers to make sure that they were well accustomed to the environment of the chamber.

In order to get information about the digestibility and the content of metabolisable energy of the food, several trials were performed with both kinds of food.

It was thought that one determination in the beginning of the growth period and another just before 50 kg with the same food would also give enough information for the trials which were performed in the remaining part of the growth period from 20–50 kg. For the growth period 50–90 kg a ration with another composition was used and also one or two determinations of digestibility and metabolisability were made with animals in the growth period over 50 kg. It is thought that the data about these items would also apply to and therefore could also be used for the group of animals of the other chamber, which received the same ration and from which no faeces and urine were gathered. The animals in the group were littermates of the single animals or they had the same boar as father and their mothers were relatives. During the digestion trials, information was gathered on the quantity and composition (dry matter, crude protein, ash and kcal) of the food and the faeces and also on the quantity and composition (N and kcal) of the urine. When no digestion experiment was performed only information on the quantity and dry matter of the same food as used in the previous digestion trial was gathered.

It has been assumed that the composition of the food and the digestibility and metabolisability had not changed. The results of digestion trials with the same food at the beginning and the end of 3 months warranted this assumption.

For separate collection of urine and faeces the animals wore a harness (except in exp. VR 1) of the same type as described by DAMMERS (1964). The urine flowed through a gitter and funnel underneath the cage and then through a plastic tube (diametre 2.5 cm) into a 10 liter plastic container.

3.2.2. *Weighing and sampling*

Food

All rations were weighed with an ordinary balance with an error of less than 3 gr, with the exception of those used in exp. VR5 in which a balance with an error of about 5 gr was used. The ration in VR 5 was about 2.1 kg/day so that relatively the error made in this case was only 0.4%. All the day rations or halfday rations were weighed on the same day in the beginning of each experimental period of one or two weeks (climate studies) or of two weeks (digestion trials).

Before weighing the day or halfday ration a spoonfull of concentrate-mixture was put into a bottle with a tight fitting stopper to obtain a composite sample. This sampling was done in duplicate.

In the series experiments up to VR16 the feed sample was not dried at 60–70 °C and ground, but analysed as such for dry matter, crude protein, ash and calorific value. In some experiments, however, (VR17–VR18) the samples of the feed were not dry enough and had to be dried at 60–70 °C for 1–3 days. This drying was done because the analysis could not be done immediately. After cooling grinding was not necessary, and the sample was analysed.

As restricted feeding was used the animals did not leave feed residues.

Faeces

The faeces were collected twice a day by removing the light plastic bag, which was attached to the harness. The bags with the faeces were stored at 0–1 °C in a container with 10 ml formalin. At the end of the trials the faeces were weighed and again 10 ml formalin was added and faeces and formalin were thoroughly mixed. There after, immediately an analysis for dry matter and crude protein was done, while afterwards 500, 750 or 1000 g of the sample was dried at 60–70 °C for 2–4 days, weighed after cooling for 3 hours and ground.

In this ground sample analysis for dry matter, ash and calorific value were done.

Urine

The urine of each day was collected in a plastic container provided with 25 ml H_2SO_4 (25 %) as a preservative for losses of N. When small animals up to 30 kg were used the daily amount of urine was poured into a bigger container of 25 litre and this container was stored at 0–5 °C.

In this way all the urine during the whole digestion trial lasting 6–7 days was collected. When the animals were heavier a sample of about 20 % of the acidified urine + H_2SO_4 of each day was poured into the bigger container and stored at 0–5 °C.

At the end of the balance experiment the composite sample was mixed and immediately analysed for nitrogen. The stored sample was also analysed later on for calorific value.

Measurements of CH_4, NH_3 and heat production will be described in 3.3.

3.2.3. *Analytical*

All the analytical methods used to determine the dry matter content, ash and calorific value in the food and faeces have been described by VAN ES (1961) and NIJKAMP (1969). The determination of N was done with the KJELDAHL method and the determination of calorific value in the urine as described by NIJKAMP (1969).

3.2.4. *Correction for added preservatives*

The additions of H_2SO_4 to the urine resulted in a composition somewhat different from the original urine. No correction, however, was necessary if, at the end of the collection period, no additional H_2SO_4 was added to the sample, and all the urine produced during 6–7 days of the experiment was gathered with the H_2SO_4 in one container. Only the total amount of urine produced was somewhat different due to this addition of H_2SO_4 daily.

When, however, a 20% sample of the urine of each day was collected or when extra H_2SO_4 was added to the final sample a correction formula was established Also for the addition of formalin to the faeces some corrections had to be made. As done by VAN Es (1961) it was assumed that no loss of formalin occured during drying. Furthermore, the assumption was made, that the addition of 20 ml of formalin to the faeces, usually about 1 kg, did not alter the calorific value of the dry matter in the mixture of faeces and formalin. The dry matter content of this mixture was also thought to be the same. The calorific value of formalin is about 4 kcal/g, and does not differ much from the value of dry matter in faeces.

When we put:

U = quantity of daily produced urine + H_2SO_4 added daily, both in g.
U_1 = quantity of urine-H_2SO_4-mixture in composite sample + $H_2 SO_4$ added finally, both in g.
Z_1 = quantity of H_2SO_4 added to the composite sample (g)
F = quantity of faeces + added formalin (g)
q = quantity of formalin added to faeces (g)
n = % of nitrogen in F
un = % of nitrogen in U1
f = calorific value per g dry matter in F (kcal)
w = calorific value (kcal) per g mixture urine sample (U_1)
ash = % ash of dry matter in F
a = % of dry matter in F

Then
urinary energy $= w \times U \times U_1/(U_1 - Z_1)$
urinary N $= un \times 0.01 \times U_1/(U_1 - Z_1)$
faecal dry matter $= a \times (F\text{-}q) \times 0.01$
faecal N $= n \times F \times 0.01$
faecal ash $= ash \times a \times 0.0001 \times F$
faecal energy $= f \times$ faecal dry matter

From these above mentioned data the digestibilities of dry matter, crude protein, ash and kcal were computed and also the content of metabolisable energy. The last content still needs to be corrected for the amount of CH_4 produced.

For each litre of CH_4 9.45 kcal was substracted. The N-balance computed from N food, N faeces and N urine needs a correction when some NH_3 is lost from faeces and urine by way of the air. In such a case the N-balance was decreased correspondingly. It will be described in 3.3.1. how the daily amounts of CH_4 and NH_3 have been measured.

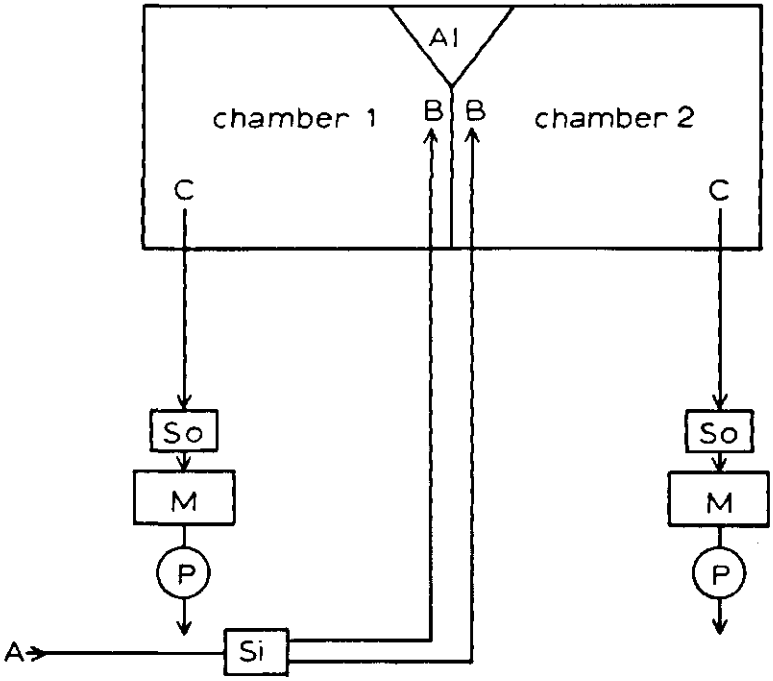


FIG. 1. Respiration chambers. A = inlet outdoor; B = inlet air in chamber; C = outlet air from chamber; chamber = respiration chamber; Si = sampling device ingoing air; So = sampling device outgoing air; M = dry Wilson gasmeter; P = centrifugal pump; Al = air lock.

3.3. EQUIPMENT AND ITS USE

3.3.1. *General*

Two new respiration chambers were used. Each had a floor surface of about 6 m^2 and a height of about 2 m. With the exception of some small modifications the chambers were identical to those described earlier by VAN ES (1961 and 1966). The two main modifications were:

1. The volume of the air leaving the chambers was not measured by wet gasmeters or by a piston pump but by dry gasmeters with a capacity of 30 m^3/hour. These were calibrated with a piston pump once every 3 months.
2. The negative pressure inside the chambers of 5–10 mm H_2O was regulated by means of a valve controlled by a Honeywell pressostate. By means of

separate membrane pumps gas from the inlet and outlet tubes, some 1 % of the total, was pumped to the gas sample collectors. These consisted of glass tubes one for the ingoing air and two for outgoing air, in which a piston covered with mercury gradually descended. In the beginning of a respiration experiment the mercury of the piston was at the upper end of the glass tube and it gradually descended in 48 hours operated by a synchronous motor. Only a small part of the gas from the membrane pump was drawn into the tube, the remainder was pumped back to the gasmeter through a plastic tube. For the analysis of the CO_2, O_2 and CH_4 content of the gas samples, a modified Sonden gas analysis-apparatus (VAN ES, 1958), an infrared CO_2 and CH_4 analyser (I.R.G.A., GRUBB and PARSONS, Ltd., SB_2) and a paramagnetic analyser (SERVOMEX, Ltd. type OA, 137) were used. The latter two instruments were calibrated by using air samples analysed with the Sonden. Before use, their correct functioning was checked by passing gas of known composition from a high pressure cylinder through it. All CH_4 analyses were done with the I.R.G.A. Up to experiment VR22 each of the two samples of outgoing air from the two chambers and also the sample of ingoing air were analysed once with the Sonden. Afterwards, only one of the samples of outgoing air was analysed in this way, both samples were then analysed with the I.R.G.A. and SERVOMEX, When, however, O_2 or CO_2 in one of the two samples from each chamber differed more than 0.01 vol. %, then also the other sample was analysed with the Sonden.

The computation of the CO_2 and CH_4 production and the O_2 consumption during a respiration trial from the volume of outgoing air and the composition of in and outgoing air and of the air in the chamber at the start and the end of the trial was done as follows. First the volume of the outgoing air measured with the dry gasmeter was converted to standard conditions (dry, 0°C and 760 mm Hg).

This may be done with the equation:

$$Vo = Vg \times Cg \times \frac{B - Pw}{760} \times \frac{273}{273 + tg} \qquad (1)$$

Vo = the reduced volume (0°C and 760 mm Hg dry)
Vg = volume measured with the gasmeter
Cg = calibration factor of the gasmeter determined with the mercury pump
B = average barometric pressure during the respiration experiment in mm Hg
tg = average temperature of dry gasmeter in °C
Pw = pressure of water vapour in the gasmeter.

It is assumed that the vapour pressure in the gasmeter is equal to that in the repiration chamber. The temperature of the gasmeter and the chamber do not differ more than some °C. If the difference would be 10-15°C as might happen in the summer then the difference in Pw would be less than 0.5 mm Hg. For the temperature between 5° and 30°C Pw may be computed with the following equation:

$$Pw = rch/100 \times (3.999 + 0.45547 \times tch + 0.001708 \times tch^2 + 0.000468 \times \times tch^3). \qquad (2)$$

In this formula rch = relative humidity in the chamber in % and tch = temperature in the chamber in °C.

The values of Pw found with this equation were also compared with the values obtained with the formula used in the experiments of JUST NIELSEN (1968):

$Pw = e^z$, in which

$$z = ([22.444 - 527.93/(tch + 310)]/(tch + 250) + 9.72 \times 10^{-6} \times tch - 0.0103) \times tch + 1.522 \qquad (3)$$

The differences found were less than 0.01 mm Hg.

The volume of the ingoing air at standard conditions will differ from the volume of the outgoing air at standard conditions, when the volumes of O_2 consumed and CH_4 and CO_2 produced are not equal. There is an indication that farm animals produce or fixate pure gases. COSTA, ULRICH, KANTOR and HOLLAND (1968) noticed that farm animals may produce some litres free nitrogen per day. This quantity, however, will not have a measurable influence on the computations of respiratory gaseous exchange of CO_2, CH_4 and O_2. The volume of ingoing air may thus be computed with

$$Vi = Vo\ (100 - Co - Oo - Mo)\ /\ (100 - Ci - Oi) \qquad (4)$$

In this formula (4) C, O and M are % CO_2, % O_2 and % CH_4 respectively and the suffixes i and o stand for ingoing and outgoing air.

Finally the computation of O_2 consumption, CO_2 production and CH_4 production is done in the following way:

litres CO_2 produced = $Co \times Vo - Ci \times Vi + (corr. - c)$
litres CH_4 produced = $Mo \times Vo$
litres O_2 consumed = $Oi \times Vi - Oo \times Vo + (corr. - o)$

in which (corr. – c) and (corr. – o) is the correction for composition of gas in the chamber at the start and at the end of the trial.

The correction of the CO_2 production and O_2 consumption is needed when the O_2 content and CO_2 content in the chamber at the start and at the end of a trial are not exactly the same. For a chamber with a content of 11 m^3 VAN ES (1961 p. 69) showed that the correction expressed in litres is equal to 100 times the difference of the CO_2 and O_2 content in % at the start and at the end.

Ammonia losses in the air from faeces and urine during digestion experiments were measured in two parts. One part of ammonia (NH_3) in the air could be found in the water, which condensed with the cooling of the air. This water was gathered in a 10 l container provided with 10 ml of H_2SO_4 (25%). In this condensation water nitrogen was determined with the KJELDAHL method. The other part of NH_3 in the air is leaving the chamber with the outgoing air. About 1% of this air is pumped through a bottle with a known equivalence of acid and by titration the NH_3 content absorbed to the acid is determined. Before passing the bottle this sample is pumped through a small dry gasmeter. The total amount of NH_3 lost in the air from urine and faeces can thus be computed from the amount in the condensation water and from the amount leaving the chamber. This method was also used to determine the content (%) of NH_3 in the air, and was found to be below 0.003 vol. % in all digestion experiments and during the respiration trials.

3.3.2. *Test experiments*

In the course of the experiments some tests were made to check for sources of errors. These tests were made while no animals were in the chamber. VAN ES (1961) has shown that these checks can be easily done with CO_2. If a CO_2 test gives good results then it can be concluded that the measurements of the volume of air leaving the chamber, the sampling of the air and analysis of CO_2 are correct. This does, however, not mean that the determination of O_2 consumption would be correct. This O_2 measurement can be tested by analysing O_2 from the ingoing air. If this gives good results then the analyses of O_2 would be satisfactory. Furthermore one must be sure that O_2 content of the sample does not change in time by leakage or diffusion of O_2 through the sampling tube. The constancy of O_2 and CO_2 content in the sample was tested by analysing the sample immediately after the end of a respiration trial with the Sonden and also after different days of storage of the sample in the closed sample tubes.

The tests showed that within some days after the end of the respiration trials no or only minor changes in composition of the sample could be detected. After the respiration experiments the samples were nearly always analysed within 48 hours after the end of sampling. Therefore, it was decided that if the analyses of the sample were done within one or two days these parts of the determinations were adequate. To test the measuring and sampling of the outgoing air, several CO_2 tests were performed prior to an experiment or after the animals had left the chambers.

A known volume of CO_2 was led into the chamber from a cylinder. Then an attempt was made to recover this gas in the same way as was done with the respiratory CO_2 of the animals. Prior to the test CO_2 was led into the chamber to produce a CO_2 content of the air in the chamber of 0.7% to 1.1%. Then the cylinder was weighed and the ventilation and sampling were started. Immediately after starting the sampling of the ventilation air CO_2 was released from the cylinder at a rate nearly equal to the CO_2 production of the animals.

The test usually lasted 16 to 24 hours or 40 to 48 hours. As the weight of the animals in the chamber varied very much, from 30 kg for the two pigs of 15 kg each at the beginning of the growth period, to 400 kg for 4 pigs of 100 kg at the end of the growth period, different rates of ventilation were used during the tests. The results of the tests were:

Chamber 1.

Date	Length (hours)	L CO_2 introduced	Recovery
17/4 - 19/4 - 1967	41	3193	99.1%
19/4 - 20/4 - 1967	19	1218	99.7%
10/10 - 11/10 - 1967	21	1508	98.8%
9/10 - 10/10 - 1968	23	600	99.3%
10/10 - 11/10 - 1968	22	1252	100.9%
20/1 - 21/1 - 1969	18	634	97.7%
21/1 - 22/1 - 1969	16	1202	98.6%

Chamber 2.

Date	Length (hours)	L CO_2 introduced	Recovery
17/4 - 19/4 - 1967	41	3796	98.8%
19/4 - 20/4 - 1967	19	1142	101.2%
30/11 - 2/12 - 1967	47	2901	100.3%
13/5 - 14/5 - 1968	22	1866	99.0%

The results of these tests show that there are only small differences between the measured CO_2 in the experiments and the amount of CO_2 really produced. Though the recovery in chamber 1 is slightly less than 100% it was concluded that no other test experiments with O_2 or N_2 were necessary.

3.4. ANIMALS

The animals used to study the effect of climate on the heat production, energy balance and nitrogen balance were pigs of the Dutch Landrace (NL), with the

TABLE 3.1. Survey of animals and chambers used for different experiments.

Chamber I

Exp.	Name of pigs used	Birth date	In the chamber from ... till ... (data)	Weight increase (kg)	Single or in group
VR 1	1 + 2 I	2-II -1967	28-IV / 6-VI -1967	30- 50	single
VR 2	1 + 2 I	2-II -1967	6-VI / 1-VII -1967	50- 70	single
VR 3	1 + 2 I	2-II -1967	9-VII /10-VIII-1967	70- 90	single
VR 4	1 + 2 I	2-II -1967	10-VIII/24-VIII-1967	90-104	single
VR 5	group I	26-VI-1967	1-IX /23-IX -1967	19- 26	group of 5
VR 6	group I	26-VI-1967	24-IX / 9-XI -1967	26- 51	group of 5[1]
VR 7	group I	26-VI-1967	9-XI /16-XII -1967	51- 75	group of 4
VR 8	group I	26-VI-1967	16-XII /28-XII -1967	75- 82	group of 4
VR 9	group I	26-VI-1967	28-XII /14-I -1968	82- 95	group of 4
VR10		chamber defect			
VR11	group II	23-XI-1967	28-I /19-III -1968	19- 41	group of 5
VR12	group II	23-XI-1967	19-III /10-IV -1968	41- 53	group of 5[2]
VR13	group II	23-XI-1967	10-IV /12-V -1968	53- 80	group of 4
VR14		chamber defect			
VR15		chamber defect			
VR16		chamber defect			
VR17		chamber defect			
VR18	9 + 10 II	9-V -1968	24-VI /20-VII -1968	16- 25	single
VR19	9 + 10 II	9-V -1968	20-VII / 2-VIII-1968	25- 34	single
VR20	9 + 10 III	16-VI-1968	26-VIII/24-IX -1968	18- 26	single
VR21		chamber defect			
VR22	1 + 2 II	3-XI -1968	21-I /23-II -1969	25- 39	single
VR23	1 + 2 III	unknown	1-III /15-III -1969	22- 27	single[3]
VR24	1 + 2 III	unknown	15-III / 4-IV -1969	27- 32	single[3]
VR25	1 + 2 IV	29-I -1969	5-IV /20-IV -1969	25- 32	single[3]
VR26	1 + 2 IV	29-I -1969	20-IV /15-V -1969	32- 40	single[3]
VR27	9 + 10 VI	28-II -1969	20-V /28-VII -1969	24- 70	single

exception of pigs no. 5 and 6 which were Large Whites. All pigs except these two were raised at the experimental farm of the Department of Animal Husbandry. As far as was possible all animals used in the same series were from the same litter and if not, they had the same boar as father and their mothers were relatives.

All pigs used for the experiments with singly housed animals were castrated male animals and except for two animals in group I and two in group II all the pigs in the groups were also castrated males. Before putting the animals into the chambers they were dewormed and treated for scabies. As far as was possible single pigs and groups were placed alternatively in chamber 1 or chamber 2. In order to prevent leg weakness, the animals in the cages were allowed to get some movement during some hours each week (exp. VR1 till VR12). In the remainder of the experiments (VR12 to VR19) the animals were used only during a part of the fattening period (from one month up to 8 weeks) and in that case the extra

Chamber II

Exp.	Name of pigs used	Birth date	In the chamber from ... till ... (data)	Weight increase (kg)	Single or in group
VR 1	3 + 4	2-II -1967	28-IV /18-V -1967	25–35	single
VR 2	5 + 6	4-IV-1967	6-VI /19-VII -1967	20–34	single
VR 3	5 + 6	4-IV-1967	21-VII /10-VIII-1967	34–50	single
VR 4	5 + 6	4-IV-1967	11-VIII/ 3-IX -1967	50–57	single
VR 5	5 + 6	4-IV-1967	4-IX /24-IX -1967	57–75	single
VR 6	5 + 6	4-IV-1967	24-IX /29-X -1967	75–95	single
VR 7	7 + 8	10-IX-1967	9-XI /14-XII -1967	20–32	single
VR 8	7 + 8	10-IX-1967	16-XII /28-XII -1967	32–40	single
VR 9	7 + 8	10-IX-1967	28-XII-67/10-I -1968	40–47	single
VR10	7 + 8	10-IX-1967	16-I /24-I -1968	47–57	single
VR11	7 + 8	10-IX-1967	25-I /14-III -1968	57–85	single
VR12		chamber defect			
VR13		chamber defect			
VR14	9 + 10 I	14-III-1968	26-IV /30-V -1968	17–25	single
VR15	9 + 10 I	14-III-1968	30-V / 6-VI -1968	25–32	single
VR16	9 + 10 I	14-III-1968	6-VI /20-VI -1968	32–42	single
VR17	group III	25-IV-1968	24-VI /19-VII -1968	20–26	group of 5
VR18		chamber defect			
VR19		chamber defect			
VR20		chamber defect			
VR21	group IV	18-VII-1968	26-IX /20-XI -1968	16–44	group of 4
VR22	group V	3-XI-1968	21-I /23-II -1969	25–38	group of 5
VR23	9 + 10 IV	unknown	1-III /15-III -1969	58–65	single[3]
VR24	9 + 10 IV	unknown	15-III / 4-IV -1969	65–75	single[3]
VR25	9 + 10 V	29-I -1969	5-IV /20-IV -1969	25–33	single[3]
VR26	9 + 10 V	29-I -1969	20-IV /15-V -1969	33–40	single[3]
VR27	group VI	28-II -1969	20-V /25-VI -1969	28–75	group of 4

Remarks: [1] at 7-XI-1967 one animal removed
[2] at 10-IV-1968 one animal removed
[3] no climate Exp.

movement was considered not to be necessary. From VR20 to VR22 and VR27 again some movement was allowed to the pigs during some hours each week.

During experiment VR1 till VR4 two pigs kept singly in a metabolism cage were placed in each chamber. From VR5 onwards, a group of pigs was placed in one chamber, in the chamber a pen was built.

A total of 50 pigs were used in this study. It was the intention that all pigs should stay as far as possible in the respiration chamber during their whole fattening period from 20–90 kg. When the chambers developed a defect the pigs had to be removed and new pigs were chosen to continue the investigations. The scheme of using the animals for different experiments is shown in table 3.1.

The animals were weighed once a week at the same time of the day (11.00 o'clock a.m. for practical reasons). If weighing could not be achieved at the same hour the weight found was corrected to that hour. A correction table has been composed by weighing animals of different ages at several times a day (see correction table 3.2.).

TABLE 3.2. Weight correction in kg for pigs weighed at different times, correction to 11.00 o'clock. (a.m.)

Weight/Time	10.00–11.00	12.00	14.00	16.00
20–30 kg	0	+0.2	+0.6	+0.8
30–40 kg	0	+0.3	+0.6	+0.9
40–50 kg	0	+0.4	+0.7	+0.9
50–60 kg	0	+0.5	+0.7	+1.0
60–70 kg	0	+0.6	+0.8	+1.1
70–80 kg	0	+0.7	+0.8	+1.2
80–90 kg	0	+0.7	+0.9	+1.3

The pigs were never weighed within some hours after a change of trials with decreasing temperature to trials with increasing temperature or vice versa, but always just before such a change, i.e. at the end of a period of trials with decreasing or increasing temperatures. This was done to avoid errors in determining the weight due to changes in live weight after a big change in temperature.

KASUBIEWICZ (1962) found a sudden decrease in weight after a change in temperature from room temperature to 3 °C. This might be due to an increase in urine production or in the defecation after a sudden change to low temperatures. Low temperatures were found to increase urine excretion in man (BADER *et al*, 1952).

3.5. TREATMENTS

3.5.1. *Feeding*

The animals were fed the rations of normal composition bought from a local feed factory. The pigs were fed restricted and the feeding level was as far as possible kept in accordance to the recommendations of the 'CENTRAAL VEE-

TABLE 3.3. Composition of rations (G) used for the growth period up to 50 kg and rations (F) used during the finishing period from 50–100 kg.

	g/1000 g					
Rations	G 1	G 2	G 3	G 4	F 1	F 2
Ingredients:						
maize	400	350	250	180	350	350
barley	115	100	180	100	100	100
milo		50			100	50
reye						100
coconut oilmeal	25				50	
soja oilmeal	125	155	125	120	120	135
sugar			50	70		
glutenfeed	50	100	100	135	100	100
peas	25				50	
fishmeal (ale)	40	30	30	30		
animal fat		10	20	20		10
wheat middlings (wheat mixed meal)	150				50	
pollards (pellets)		150	150	150		100
lucerne	40	25	50	50	50	25
wheat				100		
tankage			20	20		
min. fattening pigs	20	20	20	20	20	20
bicalcium phosfate	5	5			5	5
Almovit B_{10} AD_3	5	5	5	5	5	5

VOEDERBUREAU' (1965). The composition of the rations is given in table 3.3. During the first part of the growth period (15–50 kg) another kind of rations was used (Ration G) then in the period from 50–90 kg (Ration F). This in accordance to the feeding tables. In experiment VR11, VR21 and VR22 the animals received less food to study the influence of feeding level on the energy balance, and in experiment VR23 and VR24 the animals were fed 10% above or below these standards. During the growth period the amount of feed was changed each day according to the expected growth.

3.5.2. *Temperature*

The second aim is to evaluate the effect of different temperatures on the heat production of pigs. For that reason the temperature is one of the treatments. The treatments are schematicly shown in figure 2, 3 and 4. Due to disturbances in the equipment this scheme could not be always followed. Also during a digestion trial the temperatures were kept constant at 18 °C to 22 °C depending on the weight. During the digestion trials the temperature was above the critical one in any case.

In order to avoid adaptation as found by SÖRENSEN (1961) it was decided not to keep the temperature constant for a long time, but to change the temperature every 2–3 days. The changes were usually not more than 2 °C or 3 °C and were effected in two hours after the onset of the change in temperature.

When the animals were placed in the chamber at a weight of 15–25 kg a

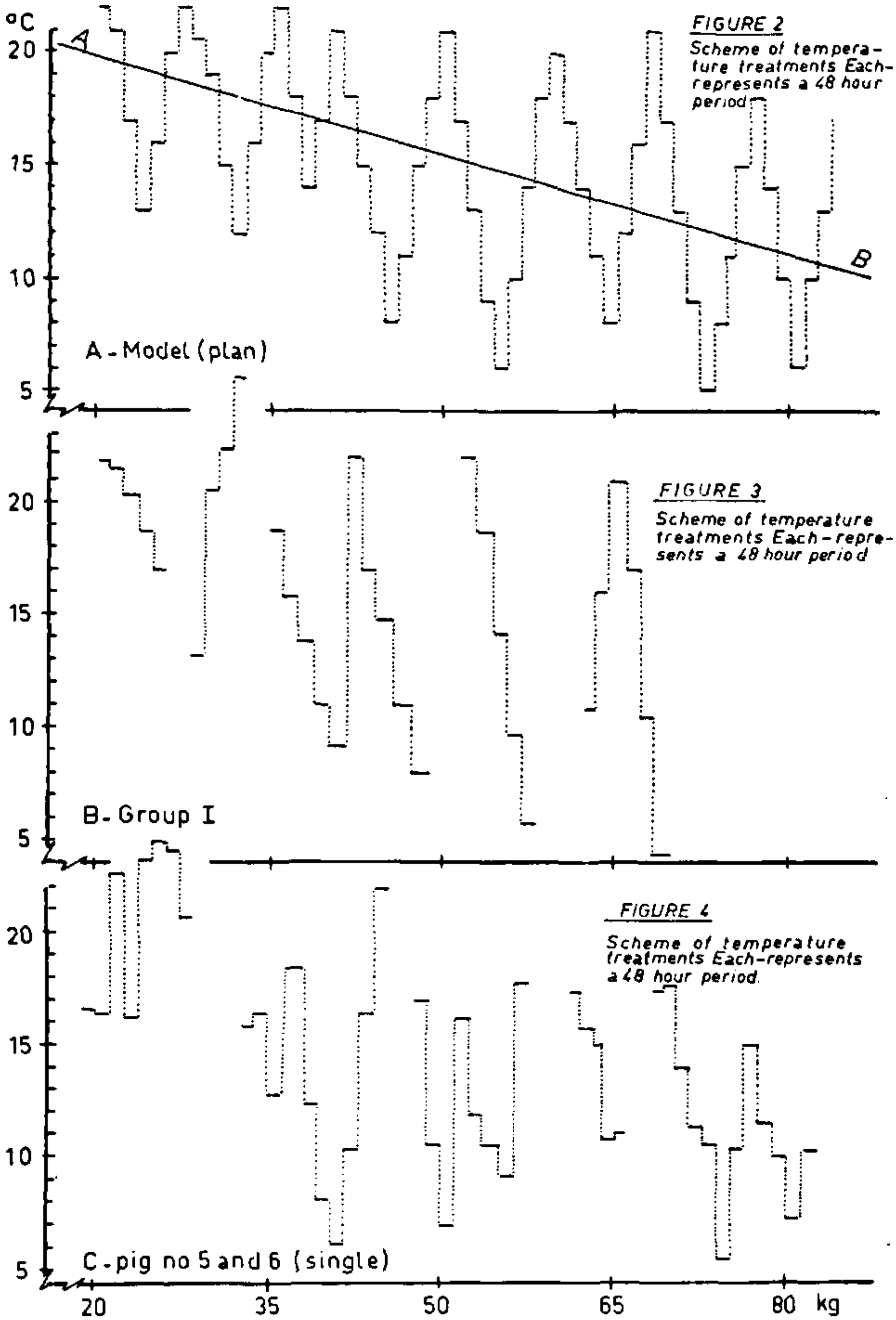


Fig. 2, 3 and 4. Schemes of climatic experiments.
A= plan; B= effectuated with group I; B= effectuated with animal 5+6.

temperature of 22 °C–24 °C was applied. In some experiments, VR3 and VR7 for single animals and VR5 and VR21 for a group of animals, heat production was measured on the second, third and fourth day after arrival of the pigs in the chambers. During these days the animals received the same amount of feed.

In Table 3.4. the results are given. From these measurements it was concluded that 4–6 days would be a safe period of acclimatisation and after this period the temperature was lowered by 2–3 °C and a few hours later the respiration experiment started and lasted exactly one or two days. On some occasions the time taken for animals to change heat production was determined in relation to the change in temperature.

By starting the measurement of the CO_2 production and O_2 consumption after half an hour, one hour, two hours, four hours and six hours and measuring during twenty-four hours no differences could be measured in the respiratory exchange of CO_2 and O_2. As a change in temperature of about 3 °C also happens under practical conditions within some hours it was thought that the heat production in the changed temperatures might be also adjusted at least within some 3–4 hours.

Moreover, it was found with continuous recording of CO_2 output of the chamber that the CO_2 content in the air leaving the chamber started to increase or decrease within 5–10 minutes after the temperatures had changed. This could be checked easily when the animals were asleep while changing the temperature and they stayed asleep during some time after the onset of temperature change. The change in CO_2 content could be detected on the I.R.G.A. with a delay of about 1 to 2 minutes in response after the content in the air leaving the chamber started to change.

TABLE 3.4. Heat production of pigs after arrival in the respiration chamber.

Exp.	Animals	Weight (kg) per animal	Day in chamber since arrival	Heat production kcal/an/day
VR3	5 + 6	20–30	2	1950
			3	1930
			4	1928
VR7	7 + 8	18–20	2	1650
			3	1610
			4	1660
			5	1680
VR5	group I	17–19	1[1]	1720
			2	1680
			3	1662
			4	1690
			5	1730
VR21	group V	16–17	2	1540
			3	1530
			4	1555

[1] Measuring started 5 hours after the arrival

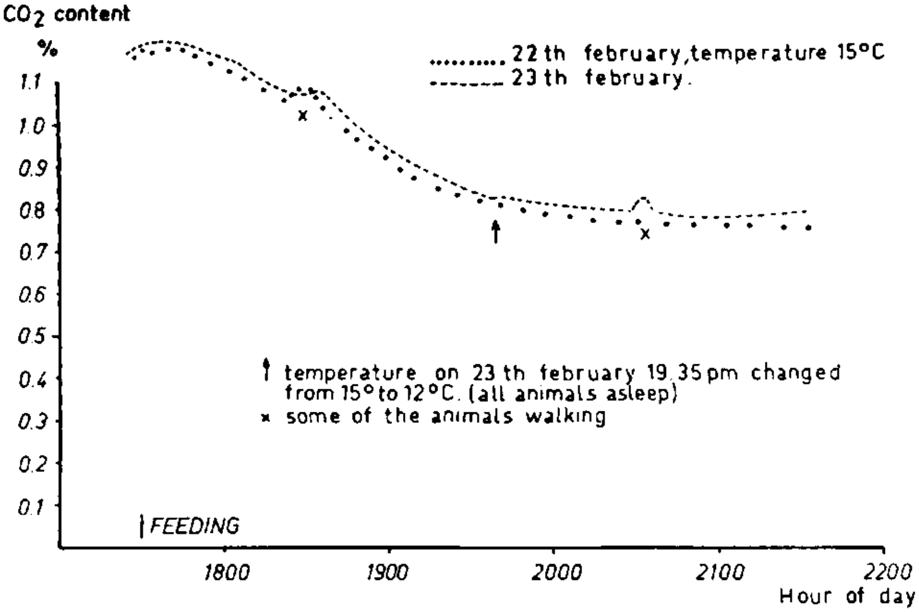


FIG. 5. The influence of temperature change to CO_2 content in the chamber. On 23th of February at 19.35 p.m. the temperature changed from 15°C to 12°C (↑).

In figure 5 an example has been given of the reaction of the animals to temperature changes on the basis of CO_2 production. The CO_2 content in the chamber after a temperature change, in comparison with the content on the preceding day, is presented. In the figure the CO_2 content of the air leaving the chamber, produced by sleeping animals is plotted for a number of hours. The ventilation rate was about 250 litres/minute. The measurements were performed with a group of 5 pigs weighing about 35 kg each.

After the experiment the temperature was again lowered 2–3°C and the respiration trials were performed again. This procedure was repeated till the temperature was about 8°C, after which the same treatments were applied in the opposite direction. The direction of the change was again reversed when a temperature of 19°C was reached, i.e. a temperature somewhat lower than 22–24°C, because the pigs in the meantime had grown, their critical temperature probably being lower. Again the temperature was lowered, etc.

In some pilot experiments the critical temperatures of single pigs were determined, being about 20°C for pigs of 20 kg, 17°C for pigs of 30 kg and 15–16°C for pigs of 50–55 kg. In these pilot experiments the feeding level was according to C.V.B. standards (CENTRAAL VEEVOEDERBUREAU, 1965).

The results from the tests are given in table 3.5. and the critical temperature (Tcr) is calculated according to KLEIBER (1961, fig. 15.1. p. 274).

In figure 2 the line A–B represents the expected critical temperatures of single pigs and it was decided to follow the same values for critical temperature

TABLE 3.5. Results of pilot experiments on critical temperatures (Tcr)

Weight	Temp.	Heat production	Tcr
20–25 kg	22°C	1600	
	16.2°C	1750	
	12.6°C	1902	20°C
about 30 kg	20°C	1960	
	16°C	2010	
	12°C	2140	17°C
50–55 kg	18°C	3100	
	14°C	3190	
	11°C	3390	15–16°C

of groups of pigs. Most research on the influence of temperature on the heat production is done with pigs which were kept constantly at either high or low temperatures.

SÖRENSEN and his coworkers (1961) found that after a big change in temperature (15°C) the animals needed several days of adaptation. In practice, however, the changes in temperature do not fluctuate in such a short time. It only changes some degrees in some hours. For that reason, the present scheme was chosen. It was thus tried to give the animals a temperature treatment which is more in accordance to what happens in practice. In fact the temperatures in our study were kept constant for two days and then changed, again kept constant at a certain level and again changed, etc.

In this way information on the heat production could be gathered during the whole fattening period of the same animals without allowing them to get adapted, since the exposure to a certain temperature lasted only two days.

It should be pointed out that the wall temperatures in the chambers were nearly equal to the air temperatures because of the good insulation of the wall. The relative humidity of the air was kept constant between 75–85% irrespective of the temperatures.

3.5.3. *Groups or single*

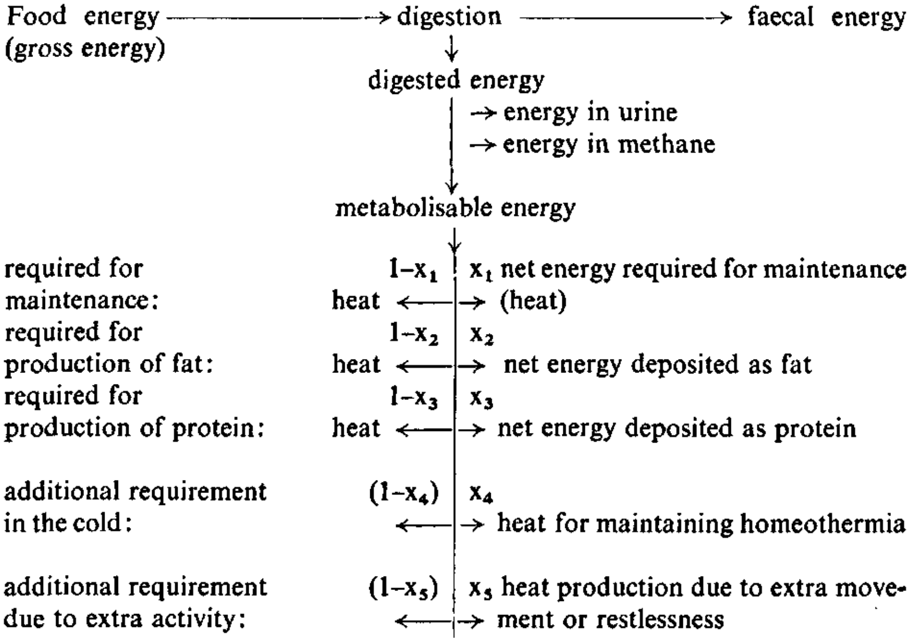
During the growth period the animals, in groups or single, had a wooden laying place and the faeces and urine were removed to avoid the floor getting wet. Once or twice a week the pen and cages were cleaned with water. After cleaning the chamber was dried and 6–10 hours afterwards the trials started again.

The animals in the groups were also group fed, the feeding trough, however, was provided with intercepts.

4. DEVELOPMENT OF A MODEL TO EXPLAIN THE HEAT PRODUCTION OF GROWING PIGS

4.1. General

Schematically the energy metabolism of pigs can be described in the following way:



In this scheme x_1, x_2, x_3, x_4, and x_5 are coefficients of the efficiency of conversion of metabolisable energy (ME) into net energy. Although physiologically the components in this scheme can not be seen as completely separate parts of metabolism, they can be considered statistically as separate. For simplicity the requirements for maintenance, for homeothermia and for increased activity together can be considered as 'maintenance'. Furthermore it can be assumed that the coefficients of the efficiencies x_4 and x_5, are equal to unity. This means that the animals convert all ME required for homeothermia and extra activity into heat. This extra activity or movement may be due to being kept singly or in groups and to changes in the climatic conditions. Besides this, interactions between the two main effects are possible: for instance animals kept in groups may spend more energy in looking for a good quiet place after a temperature change in their stall. Thus an effect above that of temperature as such may possibly be expected. Moreover it can be imagined that a group of animals in the zone of thermoneutrality may eventually spend more energy in walking and standing than an animal kept singly in a cage and which is not able to turn or to walk around.

The 'maintenance' heat production can be considered to depend on live weight, age, composition of the body, fill of digestive tract, composition of the ration, individuality, climatic environment, behaviour or activity. The experiments were designed in such a way that some of the factors mentioned were equal for the experimental groups of pigs used so that only weight, climatic environment and activity or behaviour were the important factors which influenced the so called 'maintenance' heat production of the animals used in this study.

One part of the heat production can be regarded as production heat equal to $(1\text{-}x_2)$ and $(1\text{-}x_3)$ times the metabolisable energy required for the production of fat gain and protein gain respectively. The coefficients x_2 and x_3 are usually below 1 due to the energy cost of synthesising fat and protein. In nearly mature animals the total energy gain consists of protein energy, for only a small part, the main part being fat energy. Usually protein and fat deposition are combined as energy gain and one efficiency figure for the conversion of metabolisable energy into this gain is used. In growing pigs from 20 kg onwards like those used in this study protein gain is relatively more important than in older animals. KOTARBINSKI and KIELANOWSKI (1967) and KIELANOWSKI (1965) and THORBEK (1969) determined from their experiments different values of efficiency for the conversion of ME into fat and into protein in piglets and pigs from 20–80 kg. Protein synthesis was found to require more ME than fat synthesis. In veal calves from 50 to 150 kg, fed a liquid milk replacer, VAN ES *et al*, (1969) however did not find significant differences in the efficiency of the conversion with varying ratios of protein gain to total energy gain, but in his trials these ratios varied less than in the Polish and Danish experiments.

In a pilot experiment with rats, growing differently due to various amounts of protein in the ration, SCHIEMANN, CHUDY and HERCOG (1969) recently found requirements of 2.18 and 1.43 kcal ME respectively for the deposition of one kcal of energy in protein and in fat. Their estimation of the maintenance requirement was 126.7 kcal ME/kg weight. They raised the possibility that the maintenance requirement might have been different during the periods in which different protein /energy ratios of the food resulted in different ratios of protein and fat being deposited.

Younger pigs are more active than older ones and they also deposit relatively more protein than fat. If, as is done in most computations, the same level of activity is assumed to exist in young as in older pigs, then a lower efficiency value will be found for protein synthesis. In the greater part of this study energy gain due to fat synthesis was far more important than energy gain due to protein synthesis. The evidence on the difference between the efficiencies of both processes is not yet convincing. In all experiments the level of feeding was kept fairly constant so that this level will not have increased the variation in the ratio of protein to fat deposition. Therefore, there seem to be no serious reasons against working with total energy gain rather than protein and fat gain separately. Even if this might introduce an error, this error would be largely compensated because live weight is being used as another independent variable and it is well known that live weight is correlated with the ratio of fat to protein deposition. Thus, it seems to be allowed to work with one value of the conversion of ME into energy deposition.

The possible influences of composition of the feed, metabolisability and feeding level on the efficiency can be regarded as unimportant because they are nearly constant within each set of experiments performed with each group or each pair of two single animals receiving the same ration. These considerations permit to simplify the schematically description of energy metabolism considerably.

4.2. MODEL

4.2.1. *Introduction*

The well known formula $H = k_1W^p$ in which

H = heat production at the maintenance feeding level in the thermoneutral zone in kcal/day;

k_1 = the maintenance part of the heat production in kcal per kg metabolic weight;

W = weight in kg;

p = power to which weight (W) is raised to express metabolic weight.

is extended to a formula which is also valid for higher levels of feeding i.e. like used in these studies

$$H = (1\text{–}a)\,(ME\text{–}k_1W^p) + k_1W^p = (1\text{–}a)ME + ak_1W^p \qquad (1)$$

in which

a = coefficient of the efficiency of the utilisation of metabolisable energy for energy deposition;

ME = feed intake in kcal metabolisable energy per day.

It should be pointed out here that k_1 in formula (1) does not necessarily have exactly the same value as k_1 in $H = k_1W^p$, as the maintenance requirement of an animal during production may be higher. However, it is assumed that within the range of feeding levels used in this study the maintenance requirement is independent of feeding level. Furthermore, it has been assumed for the same reason that the coefficient a is not affected by feeding level. This formula (1) is thought to be valid for animals fed above maintenance with rations which do not differ much in respect to composition and content of ME. As young animals usually have a higher activity and as animals in a group behave differently from those kept singly, it is better to perform separate computations for pigs below and above 50 kg and for pigs kept singly and in groups (classes).

To find out which is the correct value of p in formula (1) different values of p between 0.50 and 1.0 could be used in the computations. That value giving the lowest residual sum of squares will be closest to the real value of p.

If the use of different values of p results in small differences in the residual sum of squares, the value 3/4 might be used for p because this value is commonly accepted to apply to mature animals and is found to apply also to growing veal calves. Formula (1) will also be used for calculations with data from experiments described in the literature (see chapter 6).

Formula (1) is changed somewhat expressing intake of ME and heat production per unit of metabolic weight:

$$H/W^p = (1-a)ME/W^p + ak_1 \qquad (2)$$

and add weight as second independent variable. In this way the effect on heat production of lower activity at higher age or weight might be included trying to measure activity of the animals as another function of weight:

$$H/W^p = (1-a)\ ME/W^p + bW + ak_1 \qquad (3)$$

This formula (3) is only valid for the animals kept in the zone of thermoneutrality and has to be applied to each set of experiments separately, because the values of ak_1, determining the maintenance requirement (k_1), might differ due to between – animal variation. It should however be stated that all animals were closely related, as they all came from the herd of the Department of Animal Husbandry. The model developed in this part is thought to be valid for the prediction of heat production in the thermoneutral zone. As in the course of the experiments much more data have been gathered while the animals are near or below the critical temperature, it will be extended or changed into a model which can be used for temperatures below the critical temperature. This will be done in two ways (method A and method B).

In the first method (A) the model will be extended in such a way that it can be used for data obtained from conditions below the critical temperatures and in which the effect of being below the critical temperature can be estimated. In doing this it is assumed that the actual temperatures were below the critical temperatures but it is not known whether in all the experiments the temperatures have been indeed below the critical temperatures. In some cases the temperatures might have been just above the critical temperature. This may increase the residual variation.

In the second method (B) it will be tried to develop a model with which the critical temperature and the effect of being below the critical temperature both can be estimated. In this second model both items will be estimated when taking a thermoneutral heat production so high that all experiments with a higher measured heat production are certainly below the critical temperature. The consequence of doing so is, that part of the investigations can not be used for computations according to method B.

4.2.2. *Method A*

Most determinations of respiratory gaseous exchange in this study have been done below the lower critical temperature. The heat production of pigs below the critical temperatures will be equal to the thermoneutral heat production and the additional heat required to maintain homeothermia. This additional requirement will be dependent on the difference of actual temperature with the critical temperature. Moreover temperature change itself may have an influence on the additional heat due to a possible difference in activity of animals when the temperature will be lower or higher compared with the temperature during the two preceding days. Moreover being in group or single may have an influence on the heat production. Thus the heat production per kg metabolic weight may be described in a formula like (3) extended with a variable representing the influence of temperature change below the critical temperature.

$$H/W^p = (1-a)\ ME/W^p + bW + ak_1 + e(Tcr-T) + f\Delta t + gS \qquad (4)$$

in this formula

T = temperature in °C

Tcr = critical temperature

S = variable indicating whether the animals are kept singly or in a group

Δt = variable indicating whether the temperature in the two-day period of measurement is higher or lower than the temperature of the preceding two-day period.

a, b, k_1, e, f and g are coefficients.

In this formula (4) it is assumed that the increase in heat production per kg metabolic weight is linear with the difference between the actual temperature and the critical temperature according to KLEIBER (1961, p. 161). This critical temperature however is not known. From the literature data and from the pilot experiments (chapter 3) it is known that the critical temperature is dependent of body weight. In the rather small body weight ranges of the animals in the classes, i.e. 20–50 kg and 50–100 kg, it can be assumed that the critical temperature decreases linearly with increasing body weight.

Another factor which is known to influence the critical temperature is feeding level. Increasing the feeding level will decrease the critical temperature. It is thus clear that at temperatures below the critical temperature the difference between actual temperature and critical temperature will decrease with the increase of feeding level. Consequently at temperatures below the critical one increasing the feeding level will not alter the total heat production but will lead to an increase in energy gain, for it is only the environmental temperature which governs below the critical temperature the heat production. Applying this in formula (4) it follows that increasing the feeding level below the critical temperature with the e kcal in formula (4), i.e. the increase in heat production per kg metabolic weight per °C below the critical temperature, is equal to lowering the critical temperature with one °C. The reverse occurs when the feeding level will be decreased. Thus the influence of feeding level on critical temperature will be the reciprocal of the effect of temperatures on the heat production below the critical temperature.

The following equation may be written for Tcr:

$$Tcr = k_2 - cW - d\ ME/W^p \qquad (5)$$

wherein

Tcr = critical temperature in °C

W = body weight in kg

Tcr = critical temperature in °C

W = body weight in kg

ME/W^p = metabolisable energy in kcal per kg metabolic weight.

k_2, c and d are coefficients.

For d also 1/e may be used.

Substituting (5) in (4) results in:

$$H/W^p = (1-a-ed)ME/W^p + (b-ec)W - eT + f\Delta t + gS + ak_1 + ek_2 \quad (6)$$

In this model (1–a–ed) = -a because e and d are reciprocal.

The possibility exists that for the whole material all variation due to pigs kept singly or in groups can not be accounted for by the independent variable S alone. The other coefficients may also be different for singly and group-housed animals. An additional separate treatment of the data of pigs kept in each of the two manners seems advisable, especially, because the data of the single animals and groups of animals are average values of 2 and 4–5 animals respectively. In doing so S has to be omitted.

Finally it should be pointed out that in formula (6) critical temperature itself may not be estimated so well, because ak_1 and ek_2 are computed together. It is thought that the effect of being below the critical temperature can be estimated very well with this equation (6).

4.2.3. *Method B*

In this part a model will be developed which is also based on KLEIBER (1961, p. 161). It does not differ basically from method A but some prerequisites are made so that only part of the data can be used according to this model. As mentioned before the heat production is independent of feed intake below the critical temperature. The heat production is just only dependent on environmental temperature and possibly also on temperature change and on being in group or singly. Therefore it is allowed to regress the heat production below the critical temperature on the difference of actual temperature with critical temperature, temperature change and the variable indicating whether the animals are in group or singly. From the computations all data in which feeding level might have an influence on total heat production are excluded by using only data in which heat production has been higher than the highest thermoneutral heat production. The criterion indicating whether an experiment will be used for treatment according to this method or not is a heat production per kg metabolic weight above for instance 160 kcal/$W^{3/4}$.

As said in method A, S will be omitted because the results of both housing systems will be treated separately. The model will be then:

$$H/W^p = e\,(Tcr - T) + f\Delta t + k_3 \quad (7)$$

wherein k_3 is a constant representing a heat production per kg metabolic weight, which is equal to the highest noticed thermoneutral heat production (i.e. 160 kcal/$W^{3/4}$). This model thus gives a description of heat production above 160 kcal/$W^{3/4}$ in dependency of temperature change and the difference of actual temperature with the critical temperature. The critical temperature is not the same as the one in method A. It will be surely lower because in this method it is based on a much higher thermoneutral heat production. The critical temperature itself can be described now as

$$Tcr = k_2 - cW \quad (8)$$

The critical temperature according to (8) may be substituted in formula (7).

But the critical temperatures may be also computed by using different combinations of k_2 and c. The critical temperature with which in formula (7) the lowest residual standard deviation is reached is thought to give a good estimation of critical temperature at different weights. From the literature and the pilot experiments (see table 3.5.) k_2 can be assumed to be somewhere between 23 and 17 and c may be 0.1 or 0.15. Thus instead of critical temperature we may write $k_2 - cW$, k_2 varying from 23 to 17 and c being 0.1 or 0.15. This method of approach will be compared with method A in order to investigate whether the estimation of the effects of being below the critical temperature on heat production are differently or not. That combination of k_2 and c which gives the lowest residual sum of squares is expected to give the best estimation for the critical temperature and of the effect on heat production per °C below the critical temperature. Moreover it will be tested whether Δt being a positive change from a lower to a higher temperature or a negative in reverse direction has a significant effect on these items.

It can now also be tested if the addition of weight as independent variable will cause a better fitting of the model in the data in the weight range of 20–50 kg and also of 50–90 kg.

5. RESULTS

5.1. GENERAL

As mentioned before 50 pigs were involved in this study and a total of 366 respiration experiments have been performed; respectively 134 with singly housed pigs weighing less than 50 kg, 96 with animals of this weight category kept in groups of 4–5, a number of 88 with individual and 48 with groups of

TABLE 5.1. Coefficients of apparent digestibility of the components in the rations and metabolisability of energy and loss of energy in urine in % of gross energy.

Exp.	Animal	Weight (kg)	Ration	Digestibility				ME/GE	En.urine in % of GE
				D.M.	C.P.	O.M.	Kcal.		
VR 1[1]	2	37	G 1	78.11	74.79	80.16	77.16	74.28	2.88
VR 1[1]	3	38	G 1	79.58	77.45	81.73	78.80	75.49	3.31
VR 1[1]	4	37	G 1	76.29	73.14	78.83	75.68	71.72	3.96
VR 2	5	19	G 1	75.48	73.99	77.89	74.35	71.34	3.01
VR 2	6	19	G 1	76.37	74.10	78.43	74.94	72.76	2.18
VR 8	7	34	G 2	79.68	77.64	81.62	78.56	75.13	3.43
VR 8	8	36	G 2	77.12	76.16	79.29	76.10	72.56	3.54
VR 9	7	47	G 2	79.03	79.73	81.49	78.87	75.51	3.36
VR 9	8	53	G 2	77.02	79.71	79.74	77.12	74.10	3.02
VR14[2]	9 I	24	G 2	78.97	78.02	80.07	77.93	74.23	3.70
VR14[2]	10 I	25	G 2	78.53	78.83	80.81	77.44	73.41	4.03
VR15	9 I	33	G 2	79.23	80.11	81.41	78.64	75.00	3.64
VR15	10 I	34	G 2	79.57	81.39	81.86	79.02	76.73	2.29
VR18[3]	9 II	22	G 2	78.07	74.17	78.76	74.89	71.98	2.91
VR18[3]	10 II	21	G 2	78.25	78.20	80.00	77.45	74.22	3.23
VR19	9 II	27	G 3	78.06	76.70	79.65	76.87	73.80	3.07
VR19	10 II	27	G 3	78.09	76.74	79.84	76.91	74.33	2.58
VR22	1 I	32	G 4	78.00	81.19	80.26	78.52	75.66	2.86
VR22	2 II	34	G 4	80.37	82.67	82.05	81.10	78.35	2.75
VR23	1 III	25	G 4	78.02	77.94	79.82	77.70	74.49	3.21
VR23	2 III	25	G 4	75.89	74.14	77.85	75.42	72.49	2.93
VR24	1 III	30	G 4	78.74	78.33	79.63	78.35	74.24	4.11
VR24	2 III	30	G 4	76.85	76.03	78.82	76.32	72.35	3.97
VR 2	1	50	F 1	78.86	74.62	80.97	78.21	75.74	2.47
VR 2	2	67	F 1	80.06	76.03	82.22	79.37	76.08	2.29
VR 3	1	81	F 1	80.51	78.15	82.71	80.24	78.32	1.92
VR 3	2	98	F 1	82.81	80.46	85.14	82.51	80.69	1.82
VR10	7	53	F 2	82.81	82.34	84.92	81.59	78.10	3.49
VR10	8	54	F 2	77.94	76.23	80.22	76.80	73.20	3.60
VR11	7	63	F 2	80.16	77.15	82.21	79.39	75.76	3.63
VR11	8	64	F 2	79.56	78.20	81.80	79.13	74.23	4.90

[1] Animals did not wear a harness in this digestion experiments.

[2], [3] Feed was only analysed on dry matter and kcal. The components in dry matter were considered to be the same as in VR9[2] and VR15[3].

TABLE 5.2. Results of the no. of respiration and digestion experiments which have been done during the different trials.

Year	Data	An.	Exp.	Digestion Exp.	Ration	Respiration experimentsy[1]) Number	Respiration experimentsy[1]) climatic	Respiration experimentsy[1]) in thermoneutral zone
Single animals								
67	28/ 4- 6/ 6	1 + 2	VR 1	+	G 1	15	+	+
67	28/ 4-18/ 5	3 + 4	VR 1	+	G 1	7	+	+
67	6/ 6- 9/ 7	1 + 2	VR 2	+	F 1	10	–	+
67	6/ 8-19/ 7	5 + 6	VR 2	+	G 1	10	+	+
67	9/ 7-10/ 8	1 + 2	VR 3	+	F 1	1	–	+
67	21/ 7-10/ 8	5 + 6	VR 3	–	G 1	8	+	–
67	10/ 8-29/ 8	1 + 2	VR 4	–	F 1	4	+	–
67	12/ 8- 3/ 9	5 + 6	VR 4	–	F 1	8	+	–
67	4/ 9-24/ 9	5 + 6	VR 5	–	F 1	8	+	–
67	24/ 9-29/10	5 + 6	VR 6	–	F 1	11	+	–
67	9/11-19/12	7 + 8	VR 7	–	G 1	10	+	–
67	16/12-28/12	7 + 8	VR 8	+	G 2	5	–	+
68	1/ 1-10/ 1	7 + 8	VR 9	+	G 2	4	–	+
68	16/ 1-24/ 1	7 + 8	VR 10	+	F 2	4	–	+
68	25/ 1-19/ 3	7 + 8	VR 11	+	F 2	17	+	+
68	26/ 4-30/ 5	9 + 10 I	VR 14	+	G 2	4	–	+
68	30/ 5- 6/ 6	9 + 10 I	VR 15	+	G 2	3	–	+
68	6/ 6-20/ 6	9 + 10 I	VR 16	–	G 2	4	–	+
68	21/ 6-20/ 7	9 + 10 II	VR 18	+	G 2	8	+	+
68	20/ 7- 2/ 8	9 + 10 II	VR 19	+	G 3	11	+	+
68	26/ 8-29/ 9	9 + 10 III	VR 20	–	G 3	14	+	–
69	21/ 1-23/ 2	1 + 2 II	VR 22	+	G 4	9	+	–
69	1/ 3-15/ 3	1 + 2 III	VR 23	+	G 4	3	+	+
69	1/ 3-15/ 3	9 + 10 IV	VR 23	–	F 2	3	–	+
69	15/ 3- 4/ 4	1 + 2 III	VR 24	+	G 4	4	–	+
69	15/ 3- 4/ 4	9 + 10 IV	VR 24	–	F 2	4	–	+
69	20/ 5-25/ 6	9 + 10 VI	VR 27	–	G 4	24	+	–
Groups of animals								
67	1/ 9-23/ 9	group I	VR 5		G 1	10	+	+
67	24/ 9- 9/11	group I	VR 6		G 1	15	+	–
67	9/11-16/12	group I	VR 7		F 1	13	+	–
67	16/12-18/12	group I	VR 8		F 1	5	+	–
67/68	28/12-14/ 1	group I	VR 9		F 1	6	+	–
68	28/ 1-19/ 3	group II	VR 11		G 2	17	+	–
68	19/ 3-10/ 4	group II	VR 12		G 2	9	+	–
68	10/ 4-12/ 5	group II	VR 13		F 2	7	+	–
68	24/ 6-19/ 7	group III	VR 17		G 2	4	+	–
68	26/ 9-20/11	group IV	VR 21		G 3	25	+	+
69	21/ 1-23/ 1	group V	VR 22		G 4	9	+	–
69	20/ 5-25/ 6	group VI	VR 27		G 4	24	+	–

1) + or – indicating wether in the experiments (VR) a serie of temperature treatments and a serie of experiments in the thermoneutral zone have been performed.

animals above 50 kg. Thirty-one experiments have been performed to examine digestibility and metabolisability. The results of the respiration and balance experiments have been listed in the appendix and those of the digestion experiments in Table 5.1. In some trials also N-balances have been carried out; these data are given in the Table 5.8. and 5.9. The use of the chambers for different pairs of single animals and groups of animals is given in Table 3.1 (chapter3). The data of climatic experiments, digestion experiments and the rations used during the experiments have been given in the Tables 3.1, 3.3 and 5.2 and in the Figures 3 and 4.

Due to difficulties in the airconditioning equipment of the chambers the temperature treatments have not been the same in all experiments. The temperature treatments were significantly different between the various pairs of single animals and between the groups. Therefore it was decided to establish different classes of data in which the temperature treatments in a part of the growth period were more comparable. For average temperatures see Table 5.3.

TABLE 5.3. Temperatures treatments applied in animals within different trials. Average temperatures and standard deviations.

animals	Av. temp. °C	SD of temp.
Class I:		
An 1 + 2	16.7	1.3
3 + 4	16.1	3.7
5 + 6	17.7	4.5
7 + 8	15.4	3.3
9 + 10 I	19.6	2.3
9 + 10 II	17.3	4.1
9 + 10 III	17.5	3.9
9 + 10 IV	13.1	3.6
9 + 10 V	14.4	3.2
Class II:		
Group I	14.4	4.6
II	14.8	2.9
III	15.3	4.0
IV	17.4	3.1
V	15.4	3.6
VI	16.2	2.4
Class III:		
An 1 + 2	15.4	5.5
5 + 6	12.7	6.0
7 + 8	14.8	2.7
9 + 10 V	14.7	2.2
Class IV:		
Group I	11.8	3.9
II	15.1	2.8
VI	15.2	3.0

Therefore as a result of the temperature differences four classes have been made:

class I : Individually housed animals weighing less than 50 kg;
class II : Animals housed in groups weighing less than 50 kg;
class III: Individually housed animals weighing more than 50 kg;
class IV: Animals housed in groups weighing more than 50 kg.

Four different rations G were used and two different rations F. The feeding level was in accordance to the C.V.B. tables, equivalent to 230–260 kcal metabolisable energy (ME) per kg metabolic weight ($W^{3/4}$). The metabolisability of the rations, ME in % of gross energy, was 73 to 77% (see Table 5.1) and this % ME is somewhat higher in the finishing rations (F). For the benefit of the reader the metabolic weights (kg $W^{3/4}$) which belong to the weights in kg are given in Table 5.4.

TABLE 5.4. Metabolic weights of various weights.

weight (kg)	20	30	40	50	60	70	80	90	100
metabolic weight (kg)	9.5	12.8	15.9	18.8	21.6	24.2	26.7	29.2	31.6

The ammonia content in the chamber air during the respiration experiments was measured regularly. In all cases less than 0.003 vol % was found and this is far below the highest level of ammonia (NH_3), which can be tolerated (DIN 1966).

The growth of the animals during the experimental period was considered to be satisfactory, especially when the averages of the different temperature treatments were taken into account (see Table 5.2). The animals which have been in the chamber till about 80–100 kg had an average growth of about 550 to 600 g a day. The growth data and feed conversion data of the animals are given in Table 5.5. Only the growth of the animals which have been in the chamber during the period 20–80 kg and longer for the greater part of the fattening periods has been given. These data show that the feed conversion is very low in most animals. Concerning these data it must be kept in mind that the data obtained from these animals are comparable to the level which is normal in

TABLE 5.5. Growth and feed conversion of animals in the experiments.

Animals	Weight (kg) at Start	Weight (kg) at End	Growth g/day	kg feed/kg growth
1 + 21	25	95	587	3.40
5 + 6	19	94	548	2.93
7 + 8	20	88	578	3.15
Group I	18	98	553	3.02
Group II	18	80	584	2.54
Group VI	32	80	552	3.01

practice and also the heat production at the higher temperatures (between 20 and 23 °C) can be considered to be at least not above the minimum heat production under practical conditions.

5.2. COMMENTS

5.2.1. *Some remarks on digestion experiments*

At least two digestion experiments were performed with each ration. In each experiment two animals together in one chamber were used. In most experiments the digestibility of dry matter, organic matter, protein and kcal in dry matter was measured. In some other experiments usually only the digestibility of dry matter and sometimes of kcal were determined to reduce the amount of analytical work (see Table 5.1).

No difficulties occured except in one trial, which had to be discarded due to rectal prolapse occuring in the two young animals (13 and 14 kg). The root for this trouble was not known, perhaps the animals were too small to wear a harness. The differences in composition between the two separate samples A and B of the ration fed were very small. The standard deviations and variation-coefficients of the average composition computed from sample A and B of rations C and F are given in Table 5.6.

TABLE 5.6. Standard deviation in amounts of individual components in concentrate samples A and B.

Standard deviation	D.M.	in dry matter			
		C.P.	O.M.	Kcal	
SD	0.14	0.14	0.14	16	Ration G (20–50 kg)
$SD/\sqrt{2}$	0.09	0.10	0.10	11	
VC %	0.10	0.48	0.09	0.2	
SD	0.11	0.12	0.19	7	Ration F (50–100 kg)
$SD/\sqrt{2}$	0.08	0.08	0.14	5	
VC %	0.10	0.40	0.16	0.1	

On the basis of Table 5.6 the conclusion can be drawn that there is little objection against applying the digestibility data of the two digestion experiments to other experiments in which the same ration was used.

5.2.2. *Some remarks on the estimation of energy losses with urine and methane*

Metabolisable energy was determined during a digestion experiment when also urine was gathered. From the digestible energy the energy in the urine was subtracted and also the energy in the methane. Methane production of young pigs is generally thought to be of minor importance. However in trials with young pigs of 20 kg already some CH_4 could be detected. CH_4 production was 1–2. 5 litre/day/animal in young pigs and 13–15 litre/day/animal in older pigs (Table 5.7). These data indicate that the CH_4 production per animal increases markedly with weight and this means that young pigs of 20 kg lose about 0.5 % of their gross energy intake as CH_4 whereas in older animals up to a body weight

TABLE 5.7. Results of CH_4 measurements (averages of 3 values)

Weight (kg)	20	40	60	80	90–100
single animals: 9 + 10 II					
CH_4 litres per animal per day	1.8	4.6	7.6		
single animals: 5 + 6					
CH_4 litres per animal per day				11.1	15.0
group of animals: group II					
CH_4 litres per animal per day	2.3	4.1	9.4	14.0	
group of animals: group I					
CH_4 litres per animal per day					13.6

of 80–100 kg this loss increases to about 1% of the gross energy intake. The methane production was measured during most determinations of gaseous exchange from experiment VR 6 onwards. In all further computations it was assumed that in the other determinations amounts of CH_4 of similar size were produced.

During digestion experiments also losses of energy in the urine were measured. In Table 5.1 the results of these determinations are given in % of gross energy (GE). About 2–4% of gross energy is lost as urinary energy. In some experiments rather high values were found, which possibly was due to contamination of urine with faeces.

These two somewhat exceptional values however, did not influence the metabolisability of gross energy (ME) much as Table 5.1 shows. With ration F1 lower losses of energy in the urine were found. The reason for these low values is not known, possibly it was due to an undetected error, like incomplete collection of the urine.

5.2.3. *Some remarks on the correction of N-balance due to losses of NH_3 into the air*

During the digestion trials (except during VR1, VR3 and VR2) the losses of NH_3 from animal's faeces and urine into the air were determined. A part of these losses consisted of ammonia which was dissolved in the water at the condensor of the cooling system inside the respiration chamber. The other part of this NH_3 left the chamber with the ventilation air. By leading a proportional sample of this air (about 1.2 litres per minute) through a bottle filled with a known amount of acid and determining what was left of the acid after some time the content of NH_3 could be determined. When respiration trials with groups of pigs were done also NH_3 content was measured regularly in a similar way. The N-balance was computed by subtracting N in faeces, in urine and in NH_3 from N in the feed. It was considered that from the N-balances obtained in this way more reliable data on protein gain would be obtained. The correction for NH_3 – N amounted to 5–8% of the N-balance. About 1.8% of the N-intake was lost as NH_3 in the water of the condensor and 0.2% into the air. In all further computations N-balance was corrected for NH_3 losses.

5.3. ENERGY AND N-BALANCES

5.3.1. *Energy balances in protein and fat during balance trials*

During the experiments to determine digestibility and metabolisability, energy balances and N-balances were measured. Energy balances were obtained by subtracting heat production from metabolisable energy. The results are given in Table 5.8. From this table it can be seen that especially animals 7 + 8 have a rather constant gain in protein during the period 33 to 65 kg amounting to about 650–700 kcal per day. This means a gain of about 130 g protein/day. In the smaller animals 9 + 10I, 9 + 10II and 1 + 2II and 1 + 2 III this gain was lower. A similar range of protein gain was found by OSLAGE *et al* (1965).

TABLE 5.8. Energy balances of animals during digestion trials (7 days).

Exp	Animals	Av. Weight	per animal/day			
			ME (Kcal)	En balance (Kcal)	En Prot (Kcal)	En Fat (Kcal)
VR 1	3 + 4	42.4	3966	1550	475[1]	1075
VR 2	5 + 6	25.2	2798	1082	406[1]	674
VR 2	1 + 2 I	61.3	6214	2606	878[1]	1728
VR 3	1 + 2 I	98.7	7269	3293	840[1]	2453
VR 8	7 + 8	33.4	3968	1435	652	782
VR 9	7 + 8	46.1	4410	1453	650	803
VR10	7 + 8	54.1	5242	1774	666	1108
VR11	7 + 8	65.2	6060	2118	711	1409
VR14	9 + 10 I	23.9	2744	911	366	545
VR15	9 + 10 I	30.5	2204	357	273	84
VR18	9 + 10 II	21.5	2217	676	368	308
VR19	9 + 10 II	27.8	2839	952	448	504
VR22	1 + 2 II	33.1	2877	712	348	365
VR23	1 + 2 III	25.0	3886	1655	627[1]	1027
VR24	1 + 2 III	30.2	3281	1018	396[1]	622

[1] not corrected for losses of N with ammonia in the air.

When the data in exp. VR1 to VR3 and VR23 and VR24 are corrected for the N-losses in the air measured in other experiments: about 0.5 to 1.5 gN/day/animal, the protein gains in these experiments will be closer to the results of the other animals. Generally it can be stated that the gain in protein seems to vary much less than fat gain, during the growth period, the latter of course is easily affected by feeding level and environmental temperature.

5.3.2. *Some remarks on the estimation of N-balances during experiments at low temperatures*

In two series with single animals losses of N with the urine were measured during the respiration trials at different temperatures. The trials lasted 48 hours each. The assumption has been made that the digestibility of protein was the same at low and thermoneutral temperatures. To obtain the nitrogen balances, the amount of N excreted in the urine and N lost with NH_3 into the air were subtracted from the amount of digested N. The collection of the urine started immediately after the temperature had been changed and lasted 48 hours. Usually, a change to a low temperature (e.g. to below 18 °C – 15 °C for pigs of 20 kg) was followed by an increase in the quantity of urine voided by the pigs during the next day.

The possibility exists that with this increased quantity of urine more N was lost than under ordinary circumstances, with a result that too low estimated N-balances were obtained after a decrease of the temperature. Perhaps also a too high estimation of N-balance after an increase in temperature was obtained.

5.3.3. *Influence of temperature on protein and fat gain in animals housed singly*

During the trials with single animals in two series (VR17 and VR22) the energy gain, computed from metabolisable energy intake minus heat production was partitioned in protein gain and fat gain. From the N-balance determinations described in the experimental part and the data on NH_3 losses (see paragraph 5.2.3) the N-balances were estimated during the two–day experiments. The deposition of fat was computed by subtracting from the energy balance the

TABLE 5.9. Heat production and energy balance in fat and protein of young pigs, when kept successivily at different temperatures.

Animal	Weight (kg)	Temp. °C	ME intake kcal/animal/day	N in food g/an/day	N balance g/an/day	Energy deposition in kcal/an/day			
						Total	Fat	Protein	Heat production
9 + 10	20.8	23.5	2224	21.3	13.2	800	330	470	1424
	21.1	19.6	2220	21.3	10.3	680	312	368	1540
	21.4	15.3	2219	21.3	9.4	586	252	334	1713
	21.8	11.4	2213	21.3	9.3	226	–193	329	1987
	22.3	17.1	2260	22.5	7.4	557	295	262	1703
	23.0	19.6	2343	28.2	9.3	634	308	326	1709
	24.1	15.7	2849	28.2	12.6	849	401	448	1990
	25.2	11.9	2822	28.2	11.5	423	13	410	2399
	25.9	8.4	2847	28.2	14.2	306	–198	504	2541
	26.8	12.1	2853	28.2	13.3	478	4	474	2375
	27.9	16.8	2851	28.2	15.8	716	159	557	2135
	29.9	20.5	2936	28.6	13.3	858	382	476	1978
1 + 2 II	19.4	20.1	2320	22.9	11.7	786	392	394	1544
	20.1	16.5	2261	22.9	10.3	556	190	366	1705
	20.9	11.4	2127	22.9	11.4	153	–250	403	1974
	21.6	8.3	2175	22.9	7.4	–23	–282	259	2198
	22.2	12.2	2244	22.9	8.4	112	–186	298	2132
	23.5	19.2	2394	22.9	9.3	464	148	316	1930
	24.1	19.5	2208	22.9	8.4	678	366	312	1530

energy deposited as protein. In Table 5.9 the amount of kcal deposited in fat and protein are given. From this table it can be seen that lowering the temperature some degrees influences fat gain much more pronounced than protein gain.

Protein gain as far as this could be measured with sufficient accuracy under these circumstances (see 5.3.2) appears only slightly to be influenced. It can be seen from Table 5.9 that young animals can have a negative energy balance and still gain weight due to the protein gain.

This means that animals tend to reduce fat gain in order to produce the extra heat required at low temperatures, rather than reducing protein gain. As a result cold conditions will influence weight increase of young animals to a smaller extent than could be expected on the basis of the extra heat production measured.

5.4. ACCURACY OF DETERMINATIONS

5.4.1. *General*

To judge the model used and to conclude if it is necessary to improve techniques and or to improve the model it is essential to gather information on that part of the residual standard deviation (RSD) of the model that is due to inaccuracy of the determinations.

The determination on the digestibility and metabolisability of the feed given to the animals have been done during 6–day periods. During the respiration experiments, which lasted two days, the data on digestibility and metabolisability from these 6–day determinations have been applied. In doing so the dry matter content of the feed was always determined and the assumption has been made that the composition of the feed did not change during a short time (some weeks) after the digestion trial. First the errors made during the 6-day trials and afterwards will be taken into consideration will be computed what consequences there may be in the accuracy of estimation of metabolisable energy during the two-day respiration experiments.

5.4.1.1. Accuracy of the determinations of the quantity and composition of feed, faeces and urine during the digestion trials

The determinations during the 6–day periods will be dependent on the following items and their errors which are presented schematically in Table 5.10.

The daily amount of feed was weighed on a balance with an error of about 3 g. (W_F). The daily ration was stored in a paper bag and hardly any feed was left after emptying. Moreover no feed residues were left. Thus the ration weighed and given to the animal can be thought to be no subject of further error. The only feed given to the animals were concentrates and these were sampled in duplicate. The standard deviations of the results due to sampling (S_F) and analytical error (A_F) could be computed from the difference in composition between the two samples A and B. The result of the computations of the analytical errors made (A_F, A_M and A_U) is given in Table 5.11. Sampling errors include sampling

TABLE 5.10. Sources of error in quantity and composition of feed faeces and urine.

	sources of error	sources	Ration SD(g)	G + F cal[1]
Quantity of feed:	weighing (W_F)	W_F	3	
Composition of feed (energy):	sampling (S_F) and analysis (A_F)	$S_F + A_F$		11
Quantity of faeces:	weighing (W_M)	W_M	8	
Composition of faeces (energy):	sampling (S_M) and analysis (A_M)	$S_M + A_M$		31
Quantity of urine:	weighing (W_U)	W_U	8	
Composition of urine (energy):	sampling (S_U) and analysis (A_U)	$S_U + A_U$		0.26[2]

[2] cal/100 g urine. [1] cal per g dry matter.

TABLE 5.11. Analytical errors in feed, faeces and urine; D.M. = dry matter; P = protein; O.M. = organic matter.

	D.M. %	in dry matter			gN/100g urine	cal/100 g urine
		C.P. %	O.M. %	cal.[1]		
Feed .S.D of mean	0.09	0.03	0.09	9.8		
C.V. %	0.10	0.40	0.10	0.22		
Faeces S.D. of mean	0.09	0.03	0.08	14.5		
C.V. %	0.35	0.15	0.17	0.31		
Urine S.D.					0.017	0.26
C.V. %					0.7	0.7

[1] cal. in 1 g dry matter.

and analytical errors and the results have already been given in Table 5.6. The average results from samples A and B were used for further calculations. The SD of the quantities of the components in the feed given daily to the animals may be computed from weight, the composition of the ration and the SD's of weighing sampling and analysing the feed.

The quantities of faeces and urine obtained from the animals during the 6–day periods were weighed on a balance with an accuracy of 20 g. This means a SD of 8 g due to weighing error for the average daily output (W_M and W_U). The analytical errors (A_M and A_U) in the determination of composition of faeces and urine were given in Table 5.11. Because no replicate experiments were made with the same animals, due to the fact that rapidly growing pigs were used. The errors made in sampling could not be calculated. The analysis, however, was done in various sub-samples and will thus include some sampling variation (S_M and S_U). It should be noted that therefore the SD's mentioned in the Table 5.10 may be underestimated.

5.4.1.2. Accuracy of the determination of digestible energy and metabolisable energy intake from components in feed, faeces and urine during the digestion experiments

The accuracy of the determinations of digestible energy intake depends on the SD's of the quantity and composition of feed and faeces. And the determination of metabolisable energy intake depends on the SD of determination of digestible energy and energy in the urine. The SD of the digestible energy can be computed from de SD's of the separate components in the equation; digestible energy = feed energy – faecal energy and metabolisable energy = digestible energy – energy in urine.

TABLE 5.12. Coefficients of variation of the amounts of components in the rations fed daily to the animals when 800 g of food was given.

		D.M.	C.P.	O.M.	cal.
a) weight of ration (g)	800[1])				
b) dry matter content in ration %		87.68			
c) composition of dry matter			20.13	93.18	4410[2]
standard deviation of a) (g)	3				
b) (%)		0.09			
c) (%)			0.10	0.10	11
coeff. of variation a) %	0.38				
b) %		0.10			
c) %			0.50	0.11	0.25
coeff. of variation of amount of component fed %		0.39	0.63	0.40	0.46

[1] As the daily quantity of feed will change with the weight of the animals a small ration of 800 g (G 1) is taken as example.

[2] cal, in 1 g dry matter

TABLE 5.13. Coefficients of variation of faecal components per day.

		D.M.	C.P.	O.M.	cal. g. (d.m.)
amount of faeces day (g) a)	700				
dry matter content of faeces (%) b)		26.0			
composition of D.M. (%) c)			22.17	86.89	4584
S.D. of a) (g)	8				
analytical S.D. of b) %		0.13			
analytical S.D. of c) %			0.08	0.09	31
C.V. of a) %	1.2				
b) %		0.50			
c) %			0.03	0.09	0.8
coefficient of variation of daily faecal components		1.1	1.2	1.1	1.1

The computations for components in the feed are given in Table 5.12 and in Table 5.13 for faeces. The standard deviations expressed as coefficients of variation in the components of feed and faeces per day are also given in Table 5.13 and 5.12. From these items the SD's of digestible energy, metabolisable energy and also for N have been computed and in Table 5.14 they are given.

TABLE 5.14. Standard deviation of various items.

	Kcal	N × 6.25
SD feed	14	1
SD faeces	108	12.1
SD urine	14	2.5
SD digestible energy	110	
SD metabolisable energy	111	

5.4.1.3. Accuracy of the determination of the apparent digestibility and the metabolisability during 6-day periods

The accuracy of the determination of apparent digestibility can be computed from the errors in the determination of the daily feed components and of the amounts of daily faecal components. By making the assumption that the errors

TABLE 5.15. Results of computation of the standard deviation in % DE and % ME from weighing, sampling and analytical errors and results from calculation of SD from within-animal and between-animal data on % DE and % ME (Ration G).

	Pig A chamber 1 1st trial live weight 20 kg app 800 g feed % DE ± 1.2% % ME ± 1.3%	Pig B chamber 1 1st trial live weight 20 kg app 800 g feed % DE ± 1.2% % ME ± 1.3%	average results of animal in the same trial and the same chamber includes additionally between-animal variation % ME ± 1.35%
	Temperature trials		
	Pig A chamber 1 2nd trial live weight 40 kg app 1500 g feed % DE ± 1.2% % ME ± 1.3%	Pig B chamber 1 2nd trial live weight 40 kg app 1500 g feed % DE ± 1.2% % ME ± 1.3%	average results of animals in the same trial and the same chamber includes additionally between-animal variation % ME ± 1.35%
average results of repeated trials includes additionally within-animal and periodical variation	% DE ± 0.64% % ME ± 0.93%	% DE ± 0.64% % ME ± 0.93%	

in the determination of feed and faeces are independent we may try the formula $SD = 100\ y/x \sqrt{C^2_x + C^2_y}$ which was derived by van Es (1961, p. 77). In this formula y and x are the average daily amounts of a component in the feed and faeces whereas C_x and C_y stand for the coefficients of variation in components in the feed and faeces. For this calculation the data in Table 5.10 and in Table 5.12 and Table 5.13 were used and computed for the rations F and G. The SD of digestibility calculated in this way is about 1.2% and of %ME about 1.3%. The computations are given in Table 5.15. The calculated SD in the determination of digestibility and metabolisability is the SD regarding only weighing, sampling and analytical errors. Two animals were in the chamber each in his metabolism cage and then the SD of results of digestion experiments depends on the errors made in the estimations. Schematically the different SD's of digestibility (% DE) and metabolisability (% ME) due to between-animal and within – animal variation are given in Table 5.15.

The same computation as in Table 5.15 can be made for trials with rations F used for animals 50–90 kg. For rations F the SD of % DE and % ME computed from weighing, sampling and analytical error are respectively 1.2% and 1.3% i.e. the same like SD in rations G. From the repeated trial with the same animals the SD's in % ME were found to be 1.76 and 2.02% (Table 5.16) respectively. Computed from the trials performed at the same time with animals of nearly equal weight kept in the same chamber these SD's were % DE ± 1.76% and % ME ± 2.04% (Table 5.17). It will therefore depend on the results used in further computation which will be the SD of the data used.

TABLE 5.16. Within-animal variation (SD) in digestibility coefficients and % ME.

component	dm	cp	om	kcal	% ME
Rations G SD (%)	0.51	1.52	0.55	0.64	0.93
Rations F SD (%)	1.50	2.80	0.92	1.76	2.02

Because respiration experiments were performed during two days this has some consequences on the accuracy of determination of metabolisable energy in these days. Moreover the averages of digestibility and metabolisability determinations with the two animals in one chamber at the same time were applied to the same animals in the further course of their growth (during some weeks) and to other animals. The time difference will cause an additional error in the estimation of metabolisable energy. This within-animal variation includes periodical and physiological variation. With periodical variation is meant variation in metabolisability due to undetected small changes in composition of the feed. Physiological variation means variation due to a non-optimal functioning of digestion and variation due to changes in conversion to metabolisability. Moreover this error includes possible variation in digestibility as the animals increase in weight. Part of the periodical and physiological variation may be computed from the comparison of results of two digestion experiments with the same

TABLE 5.17. Metabolisibility in % ME and SD of this % ME computed from the values obtained with both of the two animals in a digestion trial.

Exp.	Animals	Ration	% ME	SD (%)
VR 1	2 + 3 + 4	G 1	73.83	
VR 2	5 + 6	G 1	72.05	1.61 %
VR 8	7 + 8	G 2	73.84	
VR 9	7 + 8	G 2	74.80	
VR14	9 + 10 I	G 2	73.82	
VR15	9 + 10 I	G 2	75.86	
VR18	9 + 10 II	G 2	73.10	1.31 %
VR19	9 + 10 II	G 3	74.06	0.37 %
VR22	1 + 2 II	G 4	77.00	
VR23	1 + 2 III	G 4	73.49	
VR24	1 + 2 III	G 4	73.30	1.54 %
				all rations G 1.35 %
VR 2	1 + 2 I	F 1	75.91	
VR 3	1 + 2 I	F 1	79.50	1.40 %
VR10	7 + 8	F 2	75.65	
VR11	7 + 8	F 2	75.00	2.61 %
				all rations F 2.04 %

animal and the same food in the beginning and at the end of the period 20–50 kg and also in the period 50–90 kg. This may be called within – animal variation. This error is considered to be purely accidental. The SD of determination of metabolisable energy can thus be computed from within-animal variation and from the determination of between-animal variation.

As the average of the determinations with two animals is used the SD of between-animal variation has to be divided by $\sqrt{2}$. Thus the total SD of digestibility and metabolisability may be computed from within-animal variation and between-animal variation, of course the latter part divided by $\sqrt{2}$. The results obtained with 6–day periods were applied to two–day periods and therefore the SD's will have to be multiplied by $\sqrt{3}$. This gives a SD of estimation of metabolisability with rations G of 2.01 % and with rations F of 4.3 % for determination of metabolisability during a two-day period. This only holds true for animals kept singly, when groups of animals are concerned we should have to divide the between-animal variation with $\sqrt{4}$ or $\sqrt{5}$ and then composing the SD of estimation of metabolisability in these experiments from within- and between-animal variation. As it is not known whether the variation in digestibility and metabolisability for a group is the same as for the animals kept singly the same value for groups as for the animals kept singly is taken.

Summarising the sources of errors in the determinations of metabolisable energy and metabolisability it is obvious that analytical and weighing errors of feed, faeces and urine give a rather unimportant contribution to the error in the estimation of metabolisable energy intake and metabolisability. Working with SD of % ME in the feed intake on the ME intake gives very different values as the amounts of ME are different in the course of the growth period. Therefore it seems to be justified to use the data from Table 5.16 and 5.17 to recompute them for a two-day period. The most important error seems to be present in the determination of digestibility of the feed because metabolisability gives only a slight increase in error. It can be seen from paragraph 5.2.2 that the energy in CH_4 is relatively small in pigs, usually less than 1% of the gross energy. Its error, therefore, can only be of minor influence on the accuracy of estimation of metabolisable energy intake. From the determinations this SD of determinations of metabolisability can be regarded as being about 1–2% for 6–day periods and 2% and 4.3% for rations G and F respectively during two-day periods. As the number of determinations with rations F are much lower the value obtained for ration G will be used and the RSD of the regression equations will show whether the value obtained from the animals which received rations F is higher or not. This SD in rations G will result in a C.V. of about 2.3% in % of average percentage of metabolisability (% ME).

5.4.1.4. Some remarks about making use of the results from the digestion experiments for the computation of the intake of digestible energy during the other experiments

As pointed out previously the results of the digestion trials were used to calculate the intake of digestible and metabolisable energy during the other trials with animals kept singly and also during the trials with groups of animals. In both sets of trials only the content of dry matter of the feed was determined. In doing so some assumptions have been made; the first one was that the digestibility of a ration will remain constant during the time required for the growth of the animal from 20 to 50 kg or from 50 to 90 kg.

From the results of the digestibility experiments, given in Table 5.1, and the computed within-animal and between-animal variation it is clear that digestibility and composition of the feed remain fairly constant.

Therefore the average of the data of the digestion experiment with two animals was used in the temperature experiments during the first weeks after this digestion experiment. The same data were used until some weeks before a new digestion experiment was performed or until a new ration was used. Ration G and ration F contained low amounts of crude fibre (less than 7%). An improvement of ability to digest crude fibre as mentioned by DAMMERS (1964) could therefore not influence digestibility. Furthermore it was assumed that pigs kept together digest their feed to the same extent as animals kept singly. It is well known that the digestion process seldom is influenced by external factors. This assumption might not be completely justified but no figures on digestibility from groups of pigs compared with single animals are known from the literature.

The same holds true for another assumption, that the digestibility of the feed at lower temperatures would be the same as in trials at temperatures above the critical temperature. Results from the experiments of PIATKOWSKI (1958) indicated that there were no differences in digestibility of energy and protein at temperatures from 3°C to 7°C compared with 18°C. HICKS (1966) however noticed a significant lower digestibility of the energy at 4.5°C compared with 10°C and a significant lower digestibility of protein at 14.5°C compared with 10°C and 4.5°C. The feed intake however was not completely the same in the animals in Hick's experiments.

Hick's results on the digestibility of energy and protein were obtained with the C_2O_3 indicator method and not with the more accurate total collection method which is normally used to determine digestibility. Therefore the SD's given in the previous part and computed for a two-day period can be considered as being the SD of digestible energy intake during the two-day period. This SD being about 1.5–2% in animals below 50 kg receiving rations G and 4% in animals above 50 kg, receiving rations F.

5.4.1.5. Estimation of metabolisable energy intake during respiration experiments at different temperatures.

There is some indication from the literature, KASUBIEWICZ (1962) and BADER (1952) that metabolisability data may vary with environmental temperature, possibly due to increase in urine output and that therefore data obtained at one temperature may not be applied to trials performed at other temperatures. At lower temperatures the excretion of N in the urine might be different from the N excretion at higher temperatures. Moreover there might be differences in the percentage of the digested N which is retained with increasing age so that relatively more N in the form of urea is voided with the urine at higher body weights. By analysing the urine it was found that there existed a high correlation between its content of N and of energy ($r=0.98$).

During some series of experiments with single animals at different temperatures the urine was collected and analysed for N-content. In most trials N-content of urine was not determined. In those it was assumed that the increase of N at the lower temperatures was equal to these in which urine-N had been measured and the same corrections were thus applied to the data of these trials. In groups of animals it was impossible to determine the N-excretion in the urine. It was assumed that within the thermoneutral zone the N-excretion in urine was the same in groups of pigs as in single animals of the same weight. It was assumed furthermore that at lower temperatures there was a smaller increase in N in the urine compared with single animals as also the extra heat production due to low temperatures in groups of pigs was lower. The extra heat production at low temperatures (determined in the pilot experiments) was about 3–4 times as high in animals kept singly as in groups of animals.

When working with groups of animals the increase in N-excretion in the urine in the cold was thought to be equivalent to the increase in heat production in groups of pigs of the same weight as in single animals which was estimated to be nearly 1/4–1/3 of the increase of heat production in singly housed animals as measured in the pilot experiments (see chapter 3).

From the data obtained during the CH_4 measurement and with the increase in N-excretion in urine, measured at low temperatures the metabolisable energy intakes determined during digestion experiments and applied during respiration experiments were corrected. For the estimation of metabolisable energy intake during these temperature the SD can be considered as being about 2% in animals receiving rations G and 4.3% in animals receiving rations F (see 5.4.1.3).

5.4.1.6. Some remarks on deviation in weight and metabolic weight of animals in one chamber

In the experiments two or more animals were in the chambers. There are two sources of error, concerned with the metabolic weight of the two or more pigs used during a determination of heat production, which influence the accuracy of the figures, heat production per kg metabolic weight (H/W^p) and metabolisable energy per kg metabolic weight (ME/W^p). The first consists of the error made by weighing the animal and the error which results by interpolating from actual weighings to obtain the weight during the determination. This error is thought to be about 2% in animals of 20 kg and 1% in animals of 50 kg. The second error consists of differences in weight of the animals in the chamber. The heat production has been measured for all animals together, as a consequence that also the metabolic weights should be added together.

Averaging the metabolic weights and expressing heat production per metabolic weight gives the average of an animal of average metabolic weight. If both animals got the same amount of ME, then the heavier pig had a lower feeding level than the supposed hypothetical average animal. Therefore this animal was more sensitive to low temperatures due to its higher critical temperature value. The reverse holds true for the lighter animals, which having most likely a lower critical temperature and therefore be in or closer to the thermoneutral zone during this temperature treatment might even have no increase in heat production at all. If, however, the feeding level (ME/W^p) was kept constant for both the lighter and heavier pigs, then a temperature treatment would not alter their heat production in a different way then the heat production of the hypothetic average animal.

In the experiments both sources of error may play a role. As to the second in the two animals kept singly, the differences in body weight were small and the same amount of feed was fed to each, so that their feeding levels differed only slightly. The animals in groups were group-fed, so that the feeding level of each was not known. Their body weights varied more than those of the animals kept singly.

5.4.2. *Accuracy of determination of heat production per kg metabolic weight*

The measurements of gaseous exchange from which data the production was derived apply to rapidly growing animals which have a daily increasing heat production. No replicate measurements are available to compute the accuracy of the determination of heat production per pair or group of animals.

The experiments in which known volumes of CO_2 were led into the chamber with the aim to recover these volumes can give partly information (see ch. 3) about the accuracy. VAN ES (personal communication) has the experience that O_2-volumes can be recovered with nearly equal accuracy as CO_2-volumes, provided that the O_2-analyses of outdoor air with the gasanalysis equipment gives constant and normal results. Therefore the variation coefficient of heat production due to technical and analytical errors of gaseous exchange measurements will be in the order of 1–2%. The same will apply to the values of heat production computed from gaseous exchange. The equation used for this computation includes a term 1.431 × N urine. Compared to the total heat production the contribution of this term is less than 1% so that the rather small technical and analytical errors made while determining N-urine cannot have increased this error. As pointed out before the error of measuring gaseous exchange is not the only cause of error in the determination of heat production. There may be also some physiological and periodical variation.

From experiments with cows VAN ES (1961, p. 72) found that the CV of heat production increased with the length of the intervals between the measurements. From experiments with intervals of 14 days he computed CV's of gaseous exchange of 2.2–3.7%. This kind of variation may be also present in our data because in these experiments the periods, during which heat production measurements are performed, are even much longer. If the error due to technical physiological and periodical variation is assumed to be the same as VAN ES found in cows this leads to an increase in SD of heat production expressed per kg metabolic weight. The CV of heat production per kg metabolic weight will be then 3.1%, because the CV of weight measurement due to errors in weighing is considered to be 2% in animals of 20 kg and 1% in animals above 50 kg. As the average metabolic weight has some variation, some additional error is introduced by expressing total heat production as:

$$(\frac{H}{W_1P + W_2P}) \text{ in stead of } \tfrac{1}{2}\,(\frac{H_1}{W_1P} + \frac{H_2}{W_2P}) \text{ and}$$

$$(\frac{H}{W_1P + W_2P \ldots W_nP}) \text{ in stead of } \frac{1}{n}\,(\frac{H_1}{W_1P} + \frac{H_2}{W_2P} \cdots \frac{H_n}{W_nP})$$

Let x = heat production of the animal in the chambers and the standard deviation SD_x, ($CV = C_x$)

w = average metabolic weight of the animal in the chambers and the standard deviation SD_w : ($CV = C_y$)

We use

$$\frac{x_1 + x_2 \ldots + x_n}{w_1 + w_2 \ldots + w_n} = \text{instead of } \frac{1}{n}\,(\frac{x_1}{w_1} + \frac{x_2}{w_2} + \ldots + \frac{x_n}{w_n})$$

When n = 2 the difference between these terms can be computed from the difference with $\frac{x}{w}$

analysing per term in the right hand formula gives

$$\frac{x + SD_x}{w + SD_w} = \frac{x + SD_x}{w\,(1 + \frac{SD_w}{w})} \text{ if } \frac{SD_w}{w} \text{ is small then it follows}$$

$$\frac{x + SD_x}{w\,(1 + \frac{SD_w}{w})} = \frac{x + SD_x}{w}\,(1 - \frac{SD_w}{w}) = \frac{x + SD_x}{w} \times \frac{w - SD_w}{w} = \frac{x}{w}(1 + \frac{SD_w}{x} - \frac{SD_w}{w} - \frac{SD_xSD_w}{wx})$$

and the other term gives

$\frac{x - SD_x}{w - SD_w} = \frac{x}{w}\,(1 - \frac{SD_x}{x} + \frac{SD_w}{w} - \frac{SD_xSD_w}{wx})$ and it follows that

$$\tfrac{1}{2}\,(\frac{x + SD_x}{w + SD_w} + \frac{x - SD_x}{w - SD_w}) = \frac{x}{w}\,(1 - \frac{SD_x}{x} \times \frac{SD_w}{w}) = \frac{x}{w}\,(1 - C_xC_y)$$

and the difference with

$\frac{x_1 + x_2}{w_1 + w_2}$ is $- \alpha\beta \frac{x}{w}$ and this is an overestimation.

When n is more than two, the same difference is computed because the addition of all $\frac{SD_x}{x}$'s and $\frac{SD_w}{w}$'s in the terms results in zero.

From the calculations on different pairs of animals the highest CV of metabolic weight was 6% in animal 1 + 2 weighing less than 50 kg and in group I also below 50 kg this CV was 3%. The CV of heat production of the animals within one chamber in the same trial is thought to be nearly the same because heat production will vary with metabolic weight and intake of metabolisable energy (ME). Of course the same kind of error would be valid for the expression of metabolisable energy per kg metabolic weight in groups of animals, because the feed intake per animal in these groups is not known. If the variation coefficients of the measurement of gaseous exchange of one animal of a group or of a pair are considered to be of the same order as variation coefficients of average metabolic weight then it follows that the additional error in expressing heat production in this way is very small. The overestimation of heat production per kg W^p is maximal 0.36% in the case of pigs kept in pairs and 0.09% in the case of the groups of animals.

The error in the prediction of H/W^p from ME/W^p will partly be caused by the errors of ME/W^p and partly by the model being an oversimplification.

$$H/W^p = (1 - a)\ ME/W^p + ak_1$$

Thus the effect of an error in ME/W^p on H/W^p can be computed. This may be calculated in the following way:

Let y = heat production per kg metabolic weight (H/W^p),
x = metabolisable energy in kcal per kg metabolic weight (ME/W^p),
d = metabolic weight per animal (W^p)
z = coefficient of regression of increase in heat production on increase in metabolisable energy intake (1-a).

x, d and z are thought to be averages of experiments per animal or group of animals. In this computation it is thought that the accidental error of z is very low. The conversion coefficient z can be regarded as a physiological constant for a certain ration and for pigs within a small part of the growth period, 20–50 kg as well as 50–100 kg. According to the formula

$$y = z\,(x/d) + ak \text{ and } \operatorname{var} y = \operatorname{var}(z \times x/d)$$

then it follows

$$SD_y = 1/d\,\sqrt{z^2 \operatorname{var} x + (z^2x^2/d^2) \operatorname{var} d}$$

In this formula it is assumed that cov $z\,\frac{x}{d}$ and cov x d are very small and omitting them does at least not give an underestimation of SD_y.

TABLE 5.18. Standard deviation and variation coefficient in the prediction of heat production/$W^{3/4}$ due to determination error in $ME/W^{3/4}$, $H/W^{3/4}$ predicted from $H/W^{3/4} = (1-a)\,ME/W^{3/4} + ak_t$.

animals	SD kcal/$W^{3/4}$	av $H/W^{3/4}$ kcal/an./day	CV (%)
Individuals less than 50 kg (*class I*)			
1 + 2	3.20	158.1	2.0
5 + 6	3.60	154.5	2.3
7 + 8	4.00	173.4	2.3
9 + 10 I	4.20	163.0	2.6
9 + 10 II	3.70	145.1	2.5
9 + 10 III	3.60	151.5	2.4
Groups less than 50 kg (*class II*)			
group I	1.52	158.6	1.0
group II	1.30	158.8	0.8
Individuals above 50 kg (*class III*)			
1 + 2	3.97	155.6	2.6
5 + 6	3.95	152.7	2.6
7 + 8	4.16	173.0	2.4
9 + 10 V	3.96	181.3	2.2
Groups above 50 kg (*class IV*)			
group I	2.95	158.8	1.9
group II	2.87	162.1	1.8
group VI	2.10	159.3	1.3

The SD computed from this formula consists of deviation in predicting H/W^p from $(1-a)\,ME/W^p + ak_t$ and due to errors in the determination of ME/W^p. This SD is computed to be about 1.0 to 2.6 kcal/$W^{3/4}$ (see Table 5.18) and is computed from all trials above the critical temperature and the data have been obtained before and after low temperature trials.

The total determination error in $H/W^{3/4}$ consists of several sources of error and can be composed of the following parts:

1) The above mentioned error in predicting $H/W^{3/4}$ from $ME/W^{3/4}$ due to variation in $ME/W^{3/4}$, this also includes periodical and physiological variation as it has been computed from all data from respiration experiments above the critical temperature per pair or group of animals within the four classes during the whole part of the growth period.

2) Variation in heat production per kg metabolic weight due to error in determination of gaseous exchange and deviation in metabolic weight. This can be computed in the same way as digestibility (see 5.4.1.3). The assumption has been made that both sources of error are independent and the CV of this composed error in heat production ($H/W^{3/4}$) is about 3.5–4.5% for single pigs and 2.5–3% for groups of pigs. When average heat production per kg metabolic weight is about 160 then the SD of the determinations will be about 6.4 kcal $H/W^{3/4}$ in single pigs and 4–4.8 kcal $H/W^{3/4}$ in groups of pigs.

5.5. APPLICATION OF THE MODEL OUTLINED IN 4.2

5.5.1. *General*

In the following paragraph we will deal with the comparison of the residual standard deviations computed by using the models outlined in § 4.2 and the standard deviations due to determination of the various items in this model. Before these comparisons are made it should be pointed out again that variation in heat production of physiological and between-animal origin will decrease with the number of animals within one group. Thus this variation will be less for the determinations with groups than with the pairs of animals. Periodical variation was thought to be included in within-animal variation, (see Table 5.15 in §5.4.1.3) but the residual standard deviation of the regression computations will include it. Furthermore it is assumed that no correlation exists between treatment and period in the experiments with one pair or group of animals.

As stated before, periodical variation, i.e. gradually changes in metabolisability (and of course also digestibility) due to e.g. an unnoticed infection or changes in composition etc., is regarded to be purely accidental. The same can be said about physiological variation, which gives changes in requirement for maintenance. Speaking about treatment variation the following considerations can be made. If a treatment leads to a higher maintenance requirement (= treatment variation) but at the same time leads to a non-optimal conversion of metabolisable energy due to, for instance, a sub-clinical infection then we should honestly speak about interaction. No distinction between interaction and treatment variation can be made. Therefore it might be better to consider all extra variation due to a treatment e.g. low temperatures, as treatment and neglect the interaction. The treatment variation e.g. variation in feeding level, weight and temperature is thought to be explained by the model. Taking these interactions as treatment however might give some increase in residual standard deviation (RSD) of the model computed from all date per pair or group.

5.5.2. *Goodnes of fit of the model*

Results of computations according to the equation (1)

$H = (1-a)\ ME + ak_1W^p$ and (2) $H/W^p = (1-a)\ ME/W^p +$
$+\ ak_1$ ..... (with $p = 0.75$).

This equation (1) which is derived in chapter 4 is applied to all data obtained above the critical temperature from each pair of two animals or from each group of animals. In order to see wether this formula fits in the results, different values of p were used in the calculation. In Table 5.19 a survey is given of the results with that value of p which gives the lowest residual sum of squares in equation (1). Table 5.19 gives the regression coefficients and their standard deviations as well as, in the last columns, the residual standard deviation (RSD), the variation coefficient (CV) and the value of R^2 when $p = 0.75$. The regression equations were computed separately for animals kept in groups and kept singly and also above and below 50 kg, i.e. for the four classes of animals, both between and within the animals of each class. The results indicate that the RSD as a percentage of the average heat production (CV) is about 5 to 6% in the single animals and 3.5 to 4% in groups of animals.

Part of the RSD found is due to errors made during the determination of metabolisable energy, metabolic weight and heat production, moreover part of it may be due to the fact that the model does not completely apply to the results obtained. For two reasons these sources of errors will be discussed in the next part: if it can be demonstrated that the former source of error is more important, more confidence can be given to the model used and ways could be found to improve techniques which result in smaller errors of this kind. If the other source of error predominates, then it is necessary to improve the model.

As in further computations we worked with heat production expressed per kg metabolic weight (H/W^p) and also metabolisable energy expressed as kcal per kg metabolic weight (ME/W^p), the regression equation has also been computed according to formula (2). Then a better comparison of the RSD of this formula with error computed for one determination of H/W^p and for predicting H/W^p from ME/W^p can be made. In Table 6.4 (page 71) the computations according to this formula have been performed and it can be seen that the RSD of computations with data from single animals are higher (up to 10 kcal/$W^{3/4}$) than with the data from groups of animals (up to 6 kcal/$W^{3/4}$). Compared with the SD of determinations (computed from rations G) 6.4 kcal per $W^{3/4}$ in animals kept singly and 4–4.8 kcal per $W^{3/4}$ in groups of animals the model fits rather well, the differences between RSD of the model and SD of the determinations being between 1–6.5 kcal per $W^{3/4}$. That part of residual variation, that is explained by determination variation, i.e. $(SD)^2/RSD^2$, is about 0.70 to 0.95.

The RSD of computations from data of animals which received ration F (class III and IV) were not higher than from the animals which received ration G (class I and II). Therefore it was thought that the SD of determinations computed from the animals with rations G might also be used for animals which received rations F. If the SD computed from rations F would be the real SD of determination than the part of $(RSD)^2$ explained by determination error would

TABLE 5.19. Results of regression of heat production (H) on metabolisable energy intake (ME) and metabolic weight (W^p) with p that gives the highest R^2 and R^2 when p = 0.75 according to $H = (1-a)\ ME + ak_1W^p + q$[1]

Animals	average weight (kg)	no of exp.	(1–a)	SD of 1–a	ak_1	SD of ak_1	p	RSD	CV = $(\frac{RSD}{H} \times 100)$	R^2	R^2 with p = 0.75
Class I											
1 + 2	46.2	9	0.39	0.18	225.23	189.52	0.55	255.51	4.6	0.95	0.95
5 + 6	36.8	12	0.18	0.42	73.38	73.05	0.85	442.52	9.6	0.89	0.89
7 + 8	33.9	6	0.37	0.08	75.07	22.60	0.75	78.68	1.6	0.99	0.99
9 + 10 I	27.3	7	0.28	0.05	170.03	47.35	0.55	142.73	3.8	0.96	0.96
9 + 10 II	29.7	10	0.30	0.07	111.09	41.28	0.55	121.41	3.3	0.85	0.85
9 + 10 III	22.9	10	0.28	0.10	194.57	60.94	0.65	206.62	6.5	0.65	0.63
all together	33.1		0.28	0.04	45.79	9.37	0.85	298.70	6.9	0.93	0.93
within animals	33.1		0.30	0.05	53.67	8.96	0.85	254.20	5.9	0.91	0.91
Class III											
1 + 2	76.8	12	1.02	0.74	–208.63	338.30	0.55	497.90	6.3	0.75	0.75
5 + 6	78.1	9	0.52	0.25	60.77	172.71	0.55	294.10	3.7	0.93	0.93
7 + 8	72.6	11	1.09	0.56	–414.27	502.94	0.55	527.50	6.9	0.85	0.85
9 + 10 V	60.3	4	–0.60	0.92	789.40	647.58	0.55	194.80	4.1	0.99	0.99
all together	74.0		0.63	0.20	–64.90	130.62	0.55	597.50	7.7	0.85	0.85
within animals	74.0		0.68	0.14	–46.26	67.08	0.55	426.40	5.5	0.86	0.86
Class II											
group I	34.2	5	0.61	0.08	–50.02	87.55	0.55	207.50	2.0	0.99	0.99
group IV	28.0	9	0.21	0.11	181.69	125.57	0.55	445.70	4.6	0.70	0.70
all together	31.6		0.22	0.08	67.38	15.53	0.85	376.30	3.7	0.97	0.97
within animals	31.6		0.16	0.07	75.37	14.02	0.85	377.10	3.7	0.97	0.97
Class IV											
group I	71.9	6	–0.28	0.24	436.71	135.94	0.55	140.90	1.9	0.99	0.99
group II	64.7	4	–5.41	3.19	3463.56	1798.94	0.65	666.70	3.8	0.95	0.85
group VI	69.2	10	1.45	2.37	80.22	101.96	0.75	358.80	2.4	0.92	0.92
all together	69.1		–0.01	0.14	363.86	87.16	0.55	586.31	3.7	0.88	0.84
within animals	69.1		–0.10	0.20	394.22	104.58	0.55	608.37	3.8	0.84	0.79

---

[1] Intercept q not in table

be higher up to nearly 1. It may be concluded that the model computed with formula (2) (and with $p = 0.75$) fits satisfactorily in the data obtained above the critical temperature. The fact that R^2 of the model (1) usually was between 0.85 and 0.99 also shows that the formulae derived in chapter 4 can be used to compute the relation of metabolic weight to heat production.

6. STATISTICAL TREATMENTS

6.1. STATISTICAL TREATMENTS OF RESULTS FROM THE LITERATURE

6.1.1. *General*

In the beginning of this century many energy balance trials with pigs have been performed by FINGERLING and his coworkers (1912–1941) and also some by KNIBBE (1936) at the institute where Oscar Kellner initiated suchs trials with cattle. (NEHRING and WERNER (1953) and SCHIEMANN (1953)) The purpose of these trials was to measure the energetic feeding value of feedstuffs. The pigs used were mature or nearly mature animals. In 1960 NEHRING and his coworkers published the results of 133 trials with 18 animals of about 80 to 170 kg to study the effect of increasing feed intake on net energy content of the feed. They measured the energy balances of their animals when a basal ration and also when in addition to this basal ration various quantities of a test feed were fed.

With pigs weighing 20–90 kg many series of experiments have been performed by LUND (1938), BREIREM (1935), LUDVIGSEN and THORBEK (1953) and JUST NIELSEN (1968) in Copenhagen and by OSLAGE (1965) in Braunschweig-Völkenrode to determine the energy requirements of young growing pigs. In most of these studies the energy balances were measured during trials which lasted one week up to 10 days. All experiments were performed at temperatures in the thermoneutral zone. Various feeding levels were used so that the results may give information on the influence of feeding level on energy balance and therefore also on heat production.

Studies with young growing animals from 20–90 kg give results which can be compared with the results of the animals used in this study which were also young growing animals. Therefore it was decided to treat these data from the literature statistically, but only those trials were used, which were comparable with this work, i.e. the trials with a positive energy balance. As it was interesting to compare young and mature pigs, the results obtained with the young animals as well as those with the older ones were treated separately. It is clear that the former animals, also with regard to composition of the gain, can be compared better with our experimental animals. All trials described in the literature were performed with animals kept in metabolism cages, the environment of the animals was therefore comparable with the environment of these pigs kept singly in comparable cages. It is likely however, that these results are not completely comparable with trials with pigs kept in groups.

6.1.2. *Material*

With grown-up animals FINGERLING and coworkers (1912–1941) have performed quite a number of balance trials with older pigs weighing from 80 to 150 kg. In some of the trials the animals received a basal ration mainly consisting of barley and fishmeal. On this ration the animals had a small positive energy balance. In other trials the animals received again the basal ration but in addition a test feed. In both kinds of trials the energy balances were measured.

From the differences of the energy balances the energetic feeding value, the so called starch value of the test feed could be derived. The results of 240 trials with 58 animals of their work will be used in the calculations.

NEHRING and coworkers (1960) also worked with older animals weighing 80–170 kg and performed 133 trials with 18 animals, partly difference trials like those of FINGERLING, partly trials with different feeding levels. Besides these experiments a great number of balance trials have been performed in the Dyrefysiologisk Laboratorium at Copenhagen, Denmark. The first results have been published by BREIREM (1935). These were obtained in 43 experiments with 8 animals receiving a high – or low-protein diet. LUND (1938) reported on 56 trials. LUDVIGSEN and THORBEK (1953) published the results of 44 experiments with 8 animals. All animals received a diet of skimmilk and barley and 4 of the animals were given some aureomycin. OSLAGE (1965) also worked with growing animals, 3 or 4 experiments with each 13 animals were done. In all trials the assumption has been made that the pigs were in the zone of thermoneutrality.

In the trials various methods or constants for computing the results had been used. In 1964 ,at the EAAP-conference at Troon, Scotland, on Energy Metabolism of Farm Animals a new coherent set of formulae and constants for computing results of balance experiments proposed by a working group was recommended for general use (BROUWER, 1965). When it was considered necessary the heat production data of the trials were recomputed according to these recommendation, using the figures for CO_2 production and O_2 consumption given by the authors. In the trials described in the literature with younger animals the methane production was assumed to increase from a value of 0.5% of the gross energy in pigs weighing 20 kg to a value of 1% in animals of 100 kg, as was found in the own trials (see chapter 5 Table 5.7) .In older pigs above 100 kg also a value of 1% was taken for CH_4 production. A similar value was found by BREIREM (1935) and FINGERLING (1914) in experiments with older pigs.

When the corrections had not been taken into consideration by the authors, in the trials with young animals and with the older ones, metabolisable energy was corrected for this assumed CH_4 production. Such recomputations of heat production from the gaseous exchange and of metabolisable energy were made with the data of LUND (1938), BREIREM (1935), LUDVIGSEN and THORBEK (1953) and NEHRING (1960).

Another recomputation concerned the trials of FINGERLING (1912–1941) in which heat production was computed by subtracting energy gain from metabolisable energy. Metabolisable energy was first corrected for CH_4 production. During a part of his trials (up to 1930), FINGERLING measured the methane production and used these data computing the C- and energy balances. In the trials after 1930 this was no longer done and therefore the C-balances were corrected assuming a CH_4 production of 1% of the gross energy. This resulted finally in slightly changed C-balances and energy balances. Then finally production was computed by subtracting this recomputed energy balance from metabolisable energy. In the above cited trials with young animals heat production figures were obtained from gaseous exchange. FINGERLING measured only CO_2-, C-and sometimes CH_4-production and heat production had to be computed indirectly from C- and N-balances.

6.1.3. *The relation between heat production, metabolisable energy and metabolic weight in the literature data.*

In the collected data heat production was regressed on metabolisable energy and metabolic weight using the equation $H = (1-a)\ ME + ak_1\ W^p$. Metabolic weight was expressed in different ways, W^p, with $p = 0.50$ up to $p = 0.95$ in steps of 0.05. The regression was computed within-animals as well as for all animals together. In the latter case the residual standard deviation (RSD) includes variation due to differences between animals. In Table 6.1 the R^2's of the different computations are given.

In the data of FINGERLING *et al* the value $p = 0.50$ to $p = 0.70$ gives the highest R^2, but the difference with $p = 0.75$ is very small. In NEHRING'S trials hardly any differences can be noticed between $p = 0.50$ and $p = 0.95$. This might be due to the relatively small range in W^p. Furthermore there are significant differences in R^2 when computed from within-animals compared with all data together in NEHRING'S trials. With the younger animals used in the trials of LUND, BREIREM, LUDVIGSEN and THORBEK the values $p = 0.95$, $p = 0.65$ to $p = 0.90$ and $p = 0.85$ to $p = 0.95$ respectively seem to fit best to the model, lower values of p giving a higher residual variance. Regressing heat production on ME and $W^{3/4}$ does seem to fit reasonably well in young animals though a somewhat higher value of p might be better. On the whole the RSD increases only very slightly when the value $p = 3/4$ is used.

At the Troon Symposium (KLEIBER, 1965) the value $p = 3/4$ was advised for general use. Since the literature results hardly gave any improvement when another value was used, it was decided also to follow that advice in this work.

TABLE 6.1. Goodness of fit (R^2) of regressing heat production on metabolisable energy and metabolic weight W^p for different values of p.

author	No. of Exp.	No. of An.	value of p									
			0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
Lund	56		0.921	0.920	0.921	0.923	0.924	0.925	0.926	0.927	0.928	0.928
Breirem	43[1]	8	0.970	0.970	0.970	0.971	0.971	0.971	0.971	0.971	0.971	0.971
within animals			0.979	0.980	0.981	0.982	0.982	0.982	0.982	0.982	0.982	0.982
Ludvigsen and Thorbek	44[1]	8	0.943	0.945	0.946	0.945	0.946	0.947	0.948	0.948	0.949	0.949
within animals			0.968	0.968	0.970	0.970	0.970	0.971	0.971	0.972	0.972	0.972
Nehring	133[1]	18	0.786	0.787	0.787	0.788	0.788	0.787	0.788	0.788	0.788	0.788
within animals			0.899	0.898	0.899	0.899	0.900	0.900	0.900	0.900	0.900	0.900
Fingerling	240[1]	58	0.835	0.835	0.835	0.835	0.835	0.834	0.834	0.834	0.843	0.833
within animals			0.846	0.845	0.845	0.844	0.842	0.841	0.840	0.838	0.837	0.835

[1] all data used together.

In the investigations of which the results led to the Troon advice, however, nearly always mature animals were used. For young animals it was considered well to allow for possible deviations from the general rule. Therefore, in the regression computations with such animals age will be added to the model as additional independent variable.

6.1.4. *The relation between heat production and metabolisable energy both expressed per kg metabolic weight computed from the literature data.*

In the material taken from the literature we regressed heat production per kg metabolic weight $ME/W^{3/4}$ and a constant according to the equation $H/W^{3/4} = ME/W^{3/4} + ak_1$ (formula 2) and with data from young animals also according to the equation, $H/W^{3/4} = (1-a)\ ME/W^{3/4} + b\ \text{age} + ak_1$ being a small modification of formula (3). Age is taken as variable instead of weight because the animals in the literature trials can not be compared with normally growing pigs.

In accordance with the considerations in the preceding section the young animals used in the Danish studies also age was added as an additional independent variable in order to correct for possible non-fitting of $p = 3/4$ in all weight ranges from 20 to 90 kg to the model. From Table 6.2 it can be seen that the increase of heat production with increasing food intake in the experiments of different authors varies from about 0.06 to 0.64 kcal heat per kcal $ME/W^{3/4}$. These values cover a big range. There are however also differences of considerable size of feeding level in the data, the SD of $ME/W^{3/4}$ being 35.1, 28.2, 21.9, 14.5 and 17.8 kcal/$W^{3/4}$ in the experiments of Nehring, Fingerling, Lund, Breirem and Thorbek respectively. The conversion of metabolisable energy for

Table 6.2. Regression of heat production per metabolic weight on intake of metabolisable energy per metabolic weight and animal's age using 2) $H/W^{3/4} = (1-a)\ ME/W^{3/4} + ak_1$ 3) $H/W^{3/4} = (1-a)\ ME/W^{3/4} + b\ \text{age} + ak_1$.

Literature	Formula 2			value of k_1 if a = 0.70	Formula 3		
	1–a	ak_1	k_1		1–a	b	ak_1
Lund	0.22[2]	96.7	123	123	0.20[2]	–0.10[3]	112.8
Breirem	0.59	– 4.1	10	108	0.29	–0.20	106.8
within animals	0.64	–17.4	47	108	0.21	–0.22	131.4
Ludvigsen and Thorbek	–0.54	311.4	202	104	–0.12	–0.25[2]	222.8
within animals	–0.57[2]	320.0	204	104	–0.04	–0.29	206.6
Fingerling	0.38	41.9	67	76			
within animals	0.35[2]	46.5	72	76			
Nehring	0.34[2]	58.6	89	91			
within animals	0.30[2]	63.9	90	91			
Oslage[1]	0.06	111.9	119	65			

[1] From 13 averages of approximately 4 trials each

[2] $P < 0.01$

[3] $P < 0.05$

energy gain and heat production can be computed more accurately from experiments with the highest SD in feeding level.

Young growing animals are normally fed according to body weight and the feeding level ME/$W^{3/4}$ will be rather constant. By doing so the feeding level of young animals of 20 kg will be somewhat lower than in the older animals of 50 kg and the estimation of efficiency from this deviation will be not so reliable. The slope of the line can be computed from the data from NEHRING *et al.* with less error than from the data of the other authors. Therefore it seems likely that 0.30, the value of NEHRING's data, is most reliable. This value has nearly the lowest standard deviation (SD = 0.019 while these SD's were 0.128, 0.08, 0.100 and 0.012 in the trials of BREIREM, LUND, LUDVIGSEN and THORBEK and FINGERLING respectively.

An efficiency of 70% is also said to be valid when considered biochemically and can be concluded from the literature .For that reason we may accept this efficiency of 70% and look whether the maintenance part of total heat production in the various trials differs. The results of these computations are given in column 4 of Table 6.2. According to this way of computation the young pigs of the experiments of LUND, BREIREM, LUDVIGSEN and THORBEK have a higher maintenance requirement than the older pigs, being between 100 and 110 kcal ME/$W^{3/4}$ for animals between 20 and 90 kg and being below 100 kcal ME/$W^{3/4}$ for the older pigs (see also VAN ES in press). From the data of the experiments of OSLAGE (1965) VAN ES computed a maintenance requirement of 65 kcal metabolisable per kg if the efficiency for gain (a) was assumed to be 0.70. The efficiency computed with formula 2 from the averages of 13 experiments, each consisting of approximately 4 trials, was 0.94 and the maintenance requirement about 119 kcal ME/$W^{3/4}$. OSLAGE assumed a maintenance requirement of 196.3 kcal ME/$W^{0.56}$ and he found an efficiency value of 0.61 to 0.62.

It should be pointed out that the value for efficiency of conversion of ME into net energy and the value for maintenance requirement can not be regarded separately. For the average value of heat production per kg metabolic weight and the average feeding level every value for efficiency and the maintenance requirement derived there from will give the same energy gain and heat production.

The results show that there seems to exist some indications that the maintenance requirement if computed assuming a production efficiency of 0.70 is somewhat higher in the young animals. In the treatments of the results of the Danish experiments age was used instead of weight in formula (3) and the results indicate that in the experiments of LUND and LUDVIGSEN and THORBEK increasing age gave a significant reduction of heat production per kg metabolic weight. Perhaps the animals were more active in the metabolism cage when they were younger. This might explain why the computed maintenance requirement in the younger animals (with an efficiency of 0.70) was somewhat higher. Except for the results from the experiments of OSLAGE these results show that there exists some indications that the maintenance requirement if computed assuming a production efficiency of 0.70 is somewhat higher in the young animals.

6.2. STATISTICAL TREATMENTS OF RESULTS OF THE EXPERIMENTS CONDUCTED AT WAGENINGEN

6.2.1. *The relation between heat production and metabolic weight*

From results of experiments above the critical temperature the heat production is regressed on metabolisable energy intake and metabolic weight (W^p). In the material marked with 1) in the appendix the formula (1) $H = (1\text{-}a)\ ME + ak_t\ W^p$ was calculated for $p = 0.50$ up to $p = 0.85$ in steps of 0.05. In Table 6.3 the R^2's from the different calculations with $p = 0.50$ up to $p = 0.85$ are given for each pair or group of animals below and above 50 kg. The calculations have also been done from the within-variance of each pair or group within a class and from all data in one class together. Table 6.3 shows that it does not matter much which value of p is used though a value of $p = 0.85$ fits

TABLE 6.3. Goodness of fit expressed as R^2 after regressing heat production on metabolisable energy and metabolic weight using different values of p in $H = (1\text{-}a)\ ME + ak_1W^p + q$ (q = intercept).

animals	n	p=0.55	p=0.60	p=0.65	p=0.70	p=0.75	p=0.80	p=0.85
Class I								
1 + 2	9	0.9521	0.9520	0.9520	0.9521	0.9527[1]	0.9527	0.9526
5 + 6	12	0.8864	0.8866	0.8870	0.8871	0.8876	0.8876	0.8877[1]
7 + 8	6	0.9971	0.9972	0.9972	0.9972	0.9972[1]	0.9972	0.9972
9 + 10 I	7	0.9957[1]	0.9952	0.9953	0.9952	0.9952	0.9951	0.9950
9 + 10 II	10	0.8511[1]	0.8501	0.8490	0.8484	0.8486	0.8465	0.8458
9 + 10 III	10	0.6321	0.6307	0.6339[1]	0.6330	0.6330	0.6325	0.6320
within an.		0.9075	0.9077	0.9081	0.9083	0.9085	0.9088	0.9090[1]
all data together		0.9281	0.9283	0.9286	0.9288	0.9291	0.9293	0.9295[1]
Class II								
group I	5	0.9964[1]	0.9964	0.9963	0.9962	0.9961	0.9959	0.9958
group IV	9	0.7044[1]	0.7041	0.7038	0.7036	0.7033	0.7032	0.7031
within an.		0.9541	0.9576	0.9606	0.9631	0.9652	0.9668	0.9681[1]
all data together		0.9571	0.9601	0.9626	0.9644	0.9645	0.9659	0.9659[1]
Class III								
1 + 2	12	0.7496[1]	0.7495	0.7492	0.7490	0.7488	0.7486	0.7484
5 + 6	9	0.9321[1]	0.9320	0.9319	0.9319	0.9318	0.9317	0.9316
7 + 8	11	0.8494[1]	0.8492	0.8488	0.8487	0.8483	0.8480	0.8476
9 + 10 V	4	0.9919	0.9927	0.9931	0.9936	0.9939	0.9942	0.9944[1]
within an.		0.8494[1]	0.8484	0.8477	0.8472	0.8469	0.8467	0.8465
all data together		0.8542[1]	0.8539	0.8537	0.8535	0.8534	0.8533	0.8533
Class IV								
group I	6	0.9955[1]	0.9954	0.9953	0.9952	0.9951	0.9950	0.9949
group II	4	0.7927	0.8068	0.9553[1]	0.8735	0.8516	0.8427	0.8376
group VI	10	0.9188	0.9188[1]	0.9187	0.9187	0.9188[1]	0.9188	0.9188
within an.		0.8378[1]	0.8241	0.8115	0.8004	0.7908	0.7826	0.7756
all data together		0.8809[1]	0.8670	0.8547	0.8443	0.8360	0.8291	0.8234

[1] highest R^2

slightly better for younger animals and a value of $p = 0.55$ for older animals. It is clear that the goodness of fit (R^2) hardly changes with the value of p chosen. Therefore it is allowed to use the value $p = 3/4$ in all further calculations, in order to be able to compare the present results with the results of trials from the literature. As done in the treatment of the literature data another variable, live weight instead of age, was added as independent variable to improve the model, (formula 3). As the range of weight between 20–50 kg and 50–90 kg is rather small, and as feeding level expressed in kcal/W^p does not vary much it can be easily understood that using different powers to express metabolic weight does not make much difference.

The results of the computations show that the values of p which give the highest R^2 do not differ much from the value which gave the best results in the computations of the data from experiments in the literature. And the results of the own trials with animals below 50 kg do confirm most results of the literature with animals of 20–80 kg, which showed that for these growing animals the best value of p might be somewhat higher than 3/4. The results of calculations from the own experiments with animals above 50 kg give the highest R^2 with p below 3/4. Perhaps the animals below 50 kg are more active than the older animals.

6.2.2. *The relation between heat production and metabolisable energy both expressed per kg metabolic weight*

During 2 experiments (VR 16 with single animals (9 + 10 I) and VR 21 with groups (group IV) the level of feed intake expressed as kcal ME/$W^{3/4}$ was changed within a short time. During one week the amount of feed was reduced daily with 20 g per animal per day i.e. about 3% per day. In the next week it was increased again with 20 g per animal per day. In the course of these two weeks 6 measurements of gaseous exchange during two days each were made.

The environment of the chamber was kept as quiet as possible in order to prevent walking around of the animals, which due to the feed restriction showed an increased activity at the slightest sound. Even so, it is still questionable whether this way of reducing the feed intake and comparing heat production at different days allows a correct estimation of the real effect of increasing or lowering metabolisable energy intake on heat production or not. The results of computations of the data (formula 3) with these animals were:

9 + 10 I (VR 16): $H/W^{3/4} = 0.323\ (\pm\ 0.07)\ ME/W^{3/4} + 86.7$ RSD 7.8 kcal
group IV (VR 21): $H/W^{3/4} = 0.210\ (\pm\ 0.11)\ ME/W^{3/4} + 109.7$ RSD 7.5 kcal

These data will also be included in the further calculations.

As rapidly growing animals are concerned it would be very difficult to get such growing animals still normal and comparable to animals fed at a higher feeding level. For that reason in two experiments (VR 23 and VR 24) 2 animals of 25 kg and 2 of 50 kg were kept singly at a feeding level 10% above and 10% below the Dutch feeding standards (C.V.B., 1965) during periods of 10 days each.

These results are not included in the further calculations but they are given below.

$1 + 2\ \mathrm{III}\ H/W^{3/4} = 0.236\ (\pm 0.088)\ ME/W^{3/4} + 111$ R.S.D. 6.4 kcal
$9 + 10\ \mathrm{IV}\ H/W^{3/4} = 0.270\ (\pm 0.030)\ ME/W^{3/4} + 123$ R.S.D. 7.2 kcal
(OGINK, 1969)

In both these experiments and in the other experiments with animals above the critical temperature the heat production was regressed on feed intake both expressed per kg metabolic weight (Table 6.4). The maintenance requirement in kcal ME per kg metabolic weight was derived from this regression by dividing ak_1 by a. From the results of these computations it may be said that 1–a will be in the near of 0.30 although in Table 6.4 many other value swere found. The value of (1–a) from the experiments with the highest variation in feeding level is in the near of 0.30 and 0.25.

As already pointed out in 6.1.4 the estimation of 1–a can be done more accurately in experiments with a higher variation in $ME/W^{3/4}$. For the computation of maintenance requirement at the average feeding level a value of 0.30 or 0.25 for 1–a can be accepted. The maintenance requirement expressed in kcal $ME/W^{3/4}$ was computed assuming the regression coefficient (1–a) to be 0.30 or 0.25. As can be seen from this Table 6.4 the average maintenance figures between classes of animals do not differ very much, however in some pairs of singly housed animals weighing less than 50 kg higher figures were found (7 + 8, 9 + 10 I and 9 + 10 III). The data used for these computations have also been plotted in Figure 6 and Figure 7. The results are comparable to those of the literature data for growing animals given in Table 6.2. With 1–a is 0.30 they are in the neighbourhood or close to 110–120 kcal ME per kg metabolic weight. There is a tendency toward a slightly (2–3 %, not significant) higher maintenance requirement in animals below 50 kg. The data of the groups of animals also do not differ much from those of the singly housed animals.

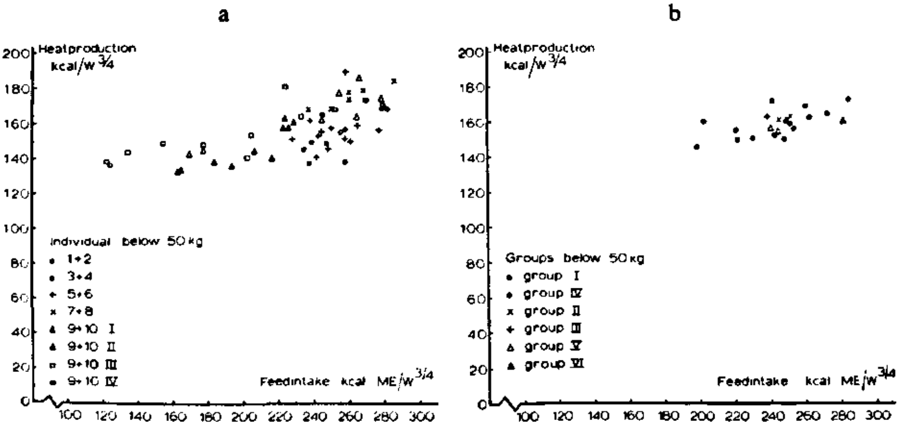


FIG. 6. Relationship between intake of metabolisable energy and heat production. *a.* Pigs weighing less than 50 kg and housed individually; *b.* Pigs weighing less than 50 kg and housed in groups.

TABLE 6.4. Results of regression of heat production ($H/W^{3/4}$) on metabolisable energy ($ME/W^{3/4}$), computed maintenance requirement in kcal $ME/W^{3/4}$ assuming different coefficients a. Formula $H/W^{3/4} = (1-a)\ ME/W^{3/4} + ak_1$ has been used.

Animals	No	average weight (kg)	1–a	SD of 1–a	ak_1	RSD	R^2	F-value	Maintenance requirement if the value of a was:		
									as found	0.70	0.75
Class I											
1 + 2	9	45.5	0.458	0.18	37.80	9.0	0.48		71	113	123
5 + 6	12	36.8	0.210	0.28	101.92	12.3	0.06		127	114	123
7 + 8	6	33.0	0.342	0.06	84.69	2.1	0.90		129	136	145
9 + 10 I	7	29.3	0.323	0.07	86.74	7.8	0.80		128	132	139
9 + 10 II	10	27.7	0.419	0.08	60.37	6.2	0.76		104	120	126
9 + 10 III	10	22.5	0.241	0.06	107.50	9.1	0.64		144	138	141
within an.[1]			0.301	0.04		8.7	0.52	F = 1.80	123	123	130
all data tog.[2]			0.229	0.04	102.70	10.9	0.42	F = 3.90**	133	123	130
Class II											
group I	5	35.4	0.435	0.09	46.21	3.6	0.90		82	116	125
group IV	9	26.7	0.210	0.11	109.70	7.5	0.34		139	126	134
within an.[1]			0.254	0.08		6.2	0.45	F = 0.29	130	122	130
all data tog.[2]			0.186	0.06	113.60	6.0	0.33	F = 0.69	139	122	130
Class III											
1 + 2	12	77.2	0.612	0.10	–8.88	8.0	0.77		–23	107	118
5 + 6	9	76.1	0.441	0.16	34.55	5.7	0.50		60	103	114
7 + 8	11	71.3	0.983	0.50	–90.57	10.2	0.30		–4500	132	141
9 + 10 V	4	59.5	0.048	0.15	168.43	5.2	0.05		177	145	153
within an.[1]			0.527	0.09		8.6	0.51	F = 2.1	48	118	128
all data tog.[2]			0.500	0.15	28.90	13.9	0.25	F = 11.7**	58	118	128
Class IV											
group I	6	73.8	0.828	0.12	–52.40	3.9	0.93		–300	117	127
group II	4	64.7	0.650	0.66	– 9.67	9.5	0.33		–27	118	128
group VI	10	66.5	0.086	0.07	137.85	3.5	0.15			121	129
within an.[1]			0.339	0.11		6.9	0.35	F = 7.2**	112	119	128
all data tog.[2]			0.309	0.10	81.25	6.6	0.34	F = 3.8*	118	119	128

[1] Test if 1–a is the same when ak_1 is thought to be different (F-value)

[2] Test if for the coefficients, 1–a and ak_1, the same values can be used for all pairs and groups within one class (F-value)

** $P < 0.01$

* $P < 0.05$

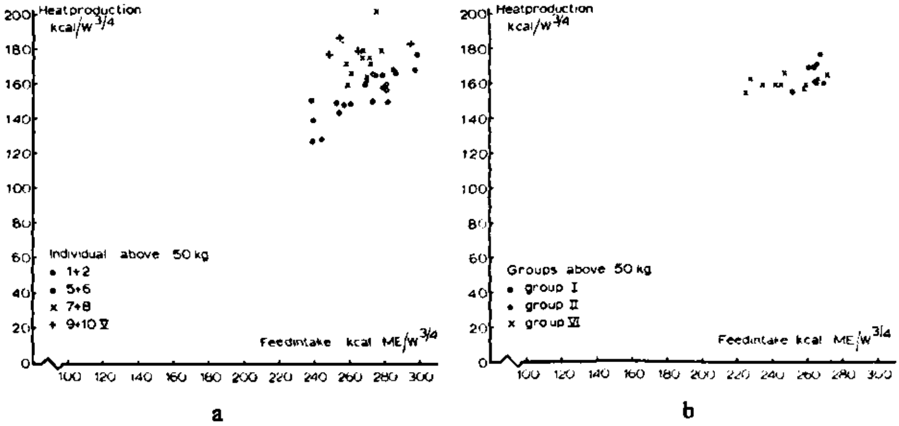


FIG. 7. Relationship between intake of metabolisable energy and heat production. *a.* Pigs weighing between 50–90 kg and housed individually. *b.* Pigs weighing between 50–90 kg and housed in groups.

As stated before the animals of a group were group-fed, the other pigs were fed individually. The unmeasured losses of feed will be in any case somewhat higher with the group then with the pigs housed individually. This would suggest that the maintenance requirement found is somewhat too low in groups of animals. Therefore the total heat production in groups of animals probably is slightly higher at the same feeding level compared with the singly housed animals. Adding weight to the formula did not give any improvement of the model except in one case, i.e. animals 1 + 2 below 50 kg. As this is the only set of data

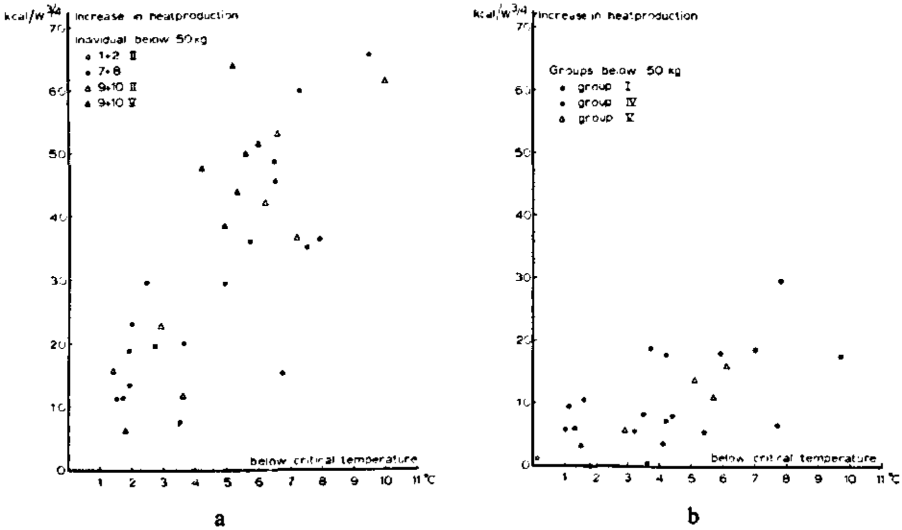


FIG. 8. Relationship between heat production increase and difference between computed critical temperature and ambient temperature. *a.* Pigs weighing less than 50 kg and housed individually; *b.* Pigs weighing less than 50 kg and housed in groups. See text page 84 and 85.

in which weight had a significant influence the results are not included in Table 6.4.

Tests to determine whether various coefficients (1–a)'s and ak_i's were different between animals showed that except in the groups below 50 kg these coefficients may not be regarded to be the same between animals in one class. Testing if ak_i differs significantly between animals within one class while keeping 1–a constant, by comparing computations per pair with the total within-pair or within-group computations (see Table 6.4), shows that this hypothesis is only rejected in groups above 50 kg (class IV). In the other three classes the values (1–a) are not significantly different between pairs or groups of animals if different values of ak_i's are considered per pair and per group of animals.

When comparing the results from these experiments with the results from the literature, it is clear that in the results of these experiments the goodness of fit after regressing is slightly lower than in the literature trials. In the literature data the R^2's were above 0.75 whereas in these results they were sometimes below 0.75. This might be due to several reasons. In this study two-day periods were used and the ME data on intake of ME from dry matter intake during the two-day periods were predicted from metabolisability determined during digestion trials before and after these periods. The literature results are based on trials lasting 6–10 days during which the ME intake was measured as well as heat production. Nevertheless, in this material the R^2-values are only slightly lower, perhaps caused by the fact that the pigs were continuously in the respiration chambers while in the literature trials they were usually elsewhere except for the actual respiration trials.

The value of p which gives the highest R^2 is in these experiments generally lower (class III and IV) than in the experiments with growing animals from the literature. This might be due to the fact that in this study the animals were weighed at 11 o'clock whereas in the literature the animals were usually weighed at another time of the day i.e. some times before the morning feeding. Due to differences in fill of digestive tract an animal at 11.00 o'clock weighs slightly more than before the morning feeding .This time of weighing seems to be nearer to the average weight during the day than weighing before the morning feeding.

Summarising the computations with results of this study obtained above the critical temperature and expressing metabolic weight as W^p it can be stated that $p = 0.75$ fits reasonably well in the data but $p = 0.80 - 0.85$ may give slightly better results for animals below 50 kg and $p = 0.55$ for animals above 50 kg. The maintenance heat production, equal to the requirement for maintenance in ME, may be in the order of 110–120 kcal/$W^{3/4}$ i.e. somewhat higher than the results computed from the literature data.

6.2.3. *The relation between heat production and temperature*

6.2.3.1. Estimation of critical temperature

As stated in chapter 4 some assumptions have to be made regarding the computations to estimate the critical temperature values. First of all the heat production above the critical temperature is assumed to be independent of temperature, provided that this temperature is not too high e.g. less than 25 °C. The heat production above this critical temperature but below 25 °C is only dependent of feed intake, metabolic weight and probably of the fact whether the animals are housed singly or in groups. The critical temperature is thought to be dependent of feeding level, weight and perhaps some other factors, for instance, the fact whether the pigs are kept being singly or in groups and the temperature change itself. The explanation has already been given in § 4.2.3. The effect of feeding level is taken into account in a special way. The heat production per metabolic weight within the thermoneutral zone is raised to a constant level by applying a constant feeding level per pair or per group of animals. This thermoneutral heat production (i.e. heat production in the thermoneutral zone) might be different due to between-animal variation in maintenance heat production (see § 6.2.2.) Applying the same feeding level to all animals would therefore give different values of thermoneutral heat production. Therefore this difficulty has been avoided by taking one thermoneutral heat production e.g. 160 kcal/$W^{3/4}$ only in the trials with a heat production above 160 kcal/$W^{3/4}$ and the increase in heat production above this 160 was regressed on the difference with various assumed critical temperatures. Instead of values above 160 also values above 165 and 170 kcal/$W^{3/4}$ were used and regressed on the same variables.

This way of computing can give information on the question whether the critical temperatures decreases linearly with the higher thermoneutral heat production in the same animals, which is in fact only due to a higher feeding level. For example an animal of 30 kg body weight at a temperature of 5 °C, a temperature surely below the critical temperature, a feeding level of 200 kcal ME/$W^{3/4}$ and a heat production of 180 kcal/$W^{3/4}$ is taken into consideration. First one should be sure that the heat production above the critical temperature would have been below or equal to 160. It can be assumed that with an efficiency of conversion of ME into net energy of 0.70 and a maintenance heat production of 130 kcal/$W^{3/4}$ the heat production would be: $(1-a)(ME-k_1W^{3/4}) + k_1W^{3/4} = 0.30\,(200-130) + 130 = 151$ kcal/$W^{3/4}$. As 151 is lower than 160 it is taken as being 160 and $(180-160) = 20$ kcal/$W^{3/4}$ is used as the increase in heat production above 160 kcal/$W^{3/4}$.

The thermoneutral heat production computed with the above quoted formula was below or equal to 160 kcal/$W^{3/4}$ i.e. the highest value at the temperatures and therefore this is regarded to be 160. One should however be sure that the heat production at the lower temperatures taken into account would be the minimum heat production needed to meet the requirement of the animal to maintain its body temperature. In other words the animal should be below the critical temperature. The thermoneutral heat production data found have been nearly always below 160 kcal and therefore it was decided to take this value as upper limit of thermoneutral heat production. Doing this, includes therefore working with heat production data independently of feed intake. Moreover if thermoneutral heat production in the example had been 162 then also it would have been allowed to take 160 as the upper limit because in this case the heat production at 5 °C would be at least 180 kcal/$W^{3/4}$.

The feeding level in the data of which the thermoneutral heat production was computed has however been in the same range as in the temperature trials (see appendix). Thus it can be assumed that animals with a heat production above 160 kcal/$W^{3/4}$ were below the thermoneutral zone. Therefore it was decided that this way of computing would give information on the critical temperature at different weights when the thermoneutral heat production has been taken as 160, 165 or 170 kcal/$W^{3/4}$. The results will show whether the critical temperatures decrease linearly with the increase in thermoneutral heat production or not. This can be seen in the following way: If the difference in critical temperatures estimated from a thermoneutral heat production of 160 and 165 is equal to the difference in Tcr's computed from 165 and 170 kcal/$W^{3/4}$, then Tcr decreases linearly with increasing thermoneutral heat production.

The computation of critical temperature and the effect per °C below this temperature can also give information on the effects per °C below Tcr on the energy balance. This can be done by comparing the thermoneutral heat production and the actual heat production and also what should have been the feed intake to cover the need of heat for maintaining body temperature. The disadvantage of doing this is that part of the data which might give information on the critical temperature itself or of the effect per °C below the critical temperature can not be used for the estimation of critical temperature, because they were lower than 160 kcal/$W^{3/4}$. The more this is true when 165 and 170 kcal/$W^{3/4}$ are used.

All the various regressions of differences between actual heat production and a thermoneutral heat production at high feeding level of 160, 165 or 170 kcal/$W^{3/4}$ on differences between actual temperature and the assumed critical temperature and weight were computed. The critical temperatures were expressed as linear functions of weight. These functions are based on some pilot experiments (Table 3.5) and the critical temperatures are thought to be linearly related to body weight at the same feeding level, i.e. the same thermoneutral heat production (see model in 4.2.3). The range of temperatures is rather small mostly covering 10 to 20°C so that a non-linear function very probably will not give a better relationship. The following functions of Tcr were tried:

Tcr = 23°C − 0.1 × W(Tcr = 23/0.1)
22°C − 0.1 × W(Tcr = 22/0.1)
21°C − 0.1 × W(Tcr = 21/0.1)
20°C − 0.1 × W(Tcr = 20/0.1)
19°C − 0.1 × W(Tcr = 19/0.1)
18°C − 0.1 × W(Tcr = 18/0.1)
17°C − 0.1 × W(Tcr = 17/0.1)

22°C − 0.15 × W(Tcr = 22/0.15)
21°C − 0.15 × W(Tcr = 21/0.15)
20°C − 0.15 × W(Tcr = 20/0.15)
19°C − 0.15 × W(Tcr = 19/0.15)
18°C − 0.15 × W(Tcr = 18/0.15)
17°C − 0.15 × W(Tcr = 17/0.15)

Thus:

$H/W^{3/4} - 160 = e(23 - 0.1\ W\text{-}T)$ and $H/W^{3/4} - 160 = e(22 - 0.15\ W\text{-}T)$
etc. $(22 - 0.1\ W\text{-}T)$ etc. $(21 - 0.15\ W\text{-}T)$
$(21 - 0.1\ W\text{-}T)$ $(20 - 0.15\ W\text{-}T)$
etc. etc.

TABLE 6.5. Estimation of critical temperature when thermoneutral heat production would be 160 kcal/$W^{3/4}$, 165 kcal/$W^{3/4}$ or 170 kcal/$W^{3/4}$ and corrected for weight if necessary.

Animals	Av. weight (kg)	Tcr equation[2]	Critical temperature of average weight with thermoneutral heat production of		
			160 kcal/$W^{3/4}$ T_{cr} of Av. weight °C	165kcal/$W^{3/4}$ T_{cr} of Av. weight °C	170kcal/$W^{3/4}$ T_{cr} of Av. weight °C
Class I					
1 + 2 I	42.3	21/0.1	16.4[1]		
1 + 2 II	35.4	21/0.1	17.5		
3 + 4	42.3	21/0.1	16.8		
5 + 6	36.8	21/0.1	17.3		
7 + 8	33.0	21/0.1	17.7	16.7	15.7
9 + 10 I	29.3	20/0.1	17.1		
9 + 10 II	27.7	21/0.1	18.2	17.2	16.2
9 + 10 IV	22.5	21/0.1	18.7	17.7	17.6
9 + 10 V	32.2	21/0.15	16.2		
Class II					
Group I	35.4	20/0.15	14.7		
Group II	33.4	19/0.15	13.7		
Group III	19.7	18/0.15	14.5		
Group IV	26.7	21/0.1	18.3[1]	17.3	17.0
Group V	30.0	21/0.15	16.5		
Group VI	44.7	21/0.1	16.5		
Class III					
1 + 2	77.2	21/0.15/18/0.1	10.1[1]	9.3	
5 + 6	76.1	21/0.1	10.4	9.4	
7 + 8	71.3	21/0.1	13.4	12.4	11.4
9 + 10 V	59.5	21/0.1	15.1	14.1	13.1
Class IV					
Group I	73.8	18/0.1	10.6[1]		
Group II	63.4	18/0.1	11.7		
Group VI	66.5	20/0.15	10.0		

[1] corrected for weight influence

[2] See page 75

Moreover weight was added to the variables in order to test if the effect of temperatures below the critical one was also dependent of weight differences within each set of trials. The extra heat production due to low temperature might be also influenced by 'age' differences i.e. differences in weight.

In Table 6.5 some results of the computations are given. In this table the estimation of the critical temperature obtained with that functions, of the possible 13, giving the lowest residual sum of squares are given for the average weight. It can be seen that the critical temperatures for the animals are very close to the values found in the pilot trials given in table 3.5 i.e. a critical temperature of 20°C for animals of 20–25 kg, 17°C at 30 kg and 15–16°C at 50–55 kg body weight. At an average thermoneutral heat production of 160 kcal/$W^{3/4}$ and assuming a maintenance requirement of 120 kcal ME/$W^{3/4}$ and an efficiency of the conversion of ME into gain of 70% as derived in § 6.2.2, this means a feed-intake of 254 kcal ME/$W^{3/4}$. The critical temperature can be estimated very well in animals housed singly below 50 kg with 21°C–0.1W. In the groups below 50 kg Tcr was found to be the same or 0.5–0.1°C lower. In individually housed animals above 50 kg the best estimates were obtained with the same equation 21°C–0.1 W and furthermore with 21°C–0.15 W. In groups of animals above 50 kg the best estimations of critical temperatures were obtained with 20°C–0.1 W and 20°C–0.15 W.

If the thermoneutral heat production was fixed at 165 kcal/$W^{3/4}$ or 170 kcal/$W^{3/4}$, in some sets of trials no differences could be noted between the different possible critical temperatures due to the small numbers of data at lower temperatures. It is however evident from the calculations that a higher feeding level, i.e. 270 and 285 kcal ME/$W^{3/4}$ which would give respectively 165 and 170 kcal as thermoneutral heat production ,would reduce the critical temperatures. Taking 165 and 170 reduces the number of data below the critical temperatures and therefore in several pairs of groups of animals the estimation of Tcr could not be done because no data below the critical temperature were obtained. Also the critical temperatures of groups of animals seem to be only slightly less or almost equal to the ones found in singly housed animals of the same weight.

6.2.3.2. Effect of temperatures below the critical temperature on heat production and energy balance (method A)

In this part we will deal with the effect of temperatures below the critical temperatures on the heat production computed according to formula (6), $H/W^{3/4} = (1-a-ed)\,ME/W^{3/4} + (b-ec)\,W + f\Delta t - eT + gS + ak_1 + ek_2$. This will be done separately for positive and negative values of Δt, Δt being the change in temperature compared from the preceding 48-hour measurement period to the period under study. Moreover the interaction of temperature and weight and temperature and Δt were added as variables.

Due to the small number of experiments with each pair or each group of animals with either a negative or a positive temperature change, the equation according to (6) was computed within pairs or groups of animals in every class so that S, the variable indicating whether the animals were kept in groups or singly, could be omitted. As the interactions, which were also computed did not give a significant improvement in any of the pairs or groups of animals they were omitted.

In Table 6.6 the results of the computations are given. From this table it is clear that the average effect of being below the critical temperature (value of e) in single animals is much higher than in groups of animals. The RSD's of the regression equations are nearly equal to those obtained for the equations to express the thermoneutral heat production. This means that the model fits as well

TABLE 6.6. Results of regression of heat production on metabolisable energy intake, weight, temperature and temperature change below the critica temperature; computed according to formula (6)

$$\frac{H}{W^{3/4}} = (1-a-ed).\frac{ME}{W^{3/4}} + (b-ec)\,W - eT + f\Delta t + ak_1 + ek_2 \text{ (intercept } ak_1 + ek_2 \text{ not in table)}$$

	1-a-ed	SD of 1-a-ed	(b-ec)	SD of b-ec	e	SD of e	f	SD of f	RSD	VC	R^2
						Δt positive					
single below 50 kg[1]	0.19	0.13	-0.11	0.47	4.41**	1.1	-1.10	1.20	11.4	6.7	0.66
groups below 50 kg[2]	0.25**	0.12	0.04	0.21	0.74*	0.43	-1.00	0.98	5.6	3.5	0.55
single above 50 kg[3]	-0.16	0.26	-0.40**	0.21	3.11**	0.75	-0.0002*	0.0001	10.1	6.3	0.96
groups above 50 kg[4]	-0.19	0.25	-0.56	0.51	0.97*	0.49	0.64	0.81	2.3	1.6	0.70
						Δt negative					
single below 50 kg[1]	0.35**	0.13	-0.45**	0.22	3.75**	0.52	1.46	1.10	8.7	4.8	0.74
groups below 50 kg[2]	-0.03	0.11	-0.18	0.16	1.02**	0.31	2.45**	0.56	5.4	3.2	0.56
single above 50 kg[3]	0.42**	0.19	-0.44*	0.20	3.27**	0.57	0.17	0.17	8.9	5.2	0.83
groups above 50 kg[4]	-0.15	0.19	-0.73**	0.24	1.17**	0.42	0.47	0.47	4.9	3.1	0.77

* $P < 0.05$

** $P < 0.01$

Computed from withinanimal of data of

[1] 1 + 2, 1 + 2 II, 3 + 4, 5 + 6, 7 + 8, 9 + 10 II, 9 + 10 V

[2] group I, II, III, IV, V.

[3] 1 + 2 I, 5 + 6, 7 + 8, 9 + 10 V.

[4] group I, II, VI.

in these data as the model for the thermoneutral heat production in the data in the thermoneutral zone does. The obtained R^2's given in Table 6.6 are between 0.55 to 0.96 and are even higher than those concerning the thermoneutral heat production given in Table 6.4. The variation in feeding level is however very small, i.e. the SD's of feeding level expressed as kcal $ME/W^{3/4}$ in the four classes are 16.4, 9.2, 18.6 and 14.4 respectively and it is obvious that the higher variation in temperature will cause this better goodness of fit. Especially in animals above 50 kg housed singly the model fits very well. There are only small differences in effects below the critical temperatures, the value of e between the classes of single animals below and above 50 kg and between the classes of groups of animals below and above 50 kg.

The size of temperature change had no significant influence except in single animals above 50 kg, in which the size of temperature change was found to give a significant improvement to the model. However the regression coefficient f is nearly o, therefore this is of no importance. However weight seems to be an important factor, and weight increase seems to reduce the heat production. This may be caused partly by a higher activity or restlessness of younger animals at rather low temperatures, and of course the relation weight and critical temperature is also important.

The results indicate that animals housed individually being kept r °C below the critical temperature increase their heat production per $W^{3/4}$ by 3. – 4.5 times r kcal. In the case of groups of pigs it is only 0.7–1.2 times r kcal. This indicates that a group of pigs can save about 60% to 80% of the extra heat needed below the critical temperatures merely by huddling.

In § 6.2.2 it was found that weight was not an important factor to explain thermoneutral heat production, this means that b in the equation $H/W^{3/4} = (1-a)\, ME/W^{3/4} + bW + ak_t$ is equal to zero. The decrease of Tcr with increase in weight in formula (6) would be $\frac{b\text{-}ec}{e}$ °C per kg live weight increase and applying this in the equations in Table 6.6 in which b – ec is significant, this gives a decrease of critical temperature with $\frac{-ec}{e}$, i.e. 0.12, 0.12, 0.13 and 0.52 °C respectively per kg live weight increase for single animals above 50 kg with positive temperature change, and with negative temperature change for single housed animals below 50 kg, single housed animals above 50 kg and groups of animals above 50 kg respectively. The computed results are given in Table 6.6. This however is only valid if weight itself has no influence on heat production per kg $W^{3/4}$ above the critical temperature. Most of the data about the decrease of critical temperature in °C with an increase in weight of 1 kg as given in Table 6.6 do not differ much in general from the relationships by which the critical temperatures were estimated, except the last figure of 0.52 for groups of animals above 50 kg.

TABLE 6.7. Results of regression of heat production ($H/W^{3/4}$) on differences with Tcr in °C and weight. Thermoneutral heat production assumed to the 160 kcal $H/W^{3/4}$. Regression according to the formula ($H/W^{3/4} = e\,(Tcr\text{-}T) + bW + q$ (intercept q not in table).

Animals	Tcr	e	SD of e	b	SD of b	RSD	CV	R^2	F-value
class I									
1 + 2	21/0.1	–0.25	1.24	0.27*	0.14	3.6	2.0	0.26	
1 + 2 II	21/0.1	7.50**	0.73	–1.03	1.11	5.1	2.7	0.96	
3 + 4	21/0.1	3.57**	0.39	–0.29	0.37	1.6	1.0	0.98	
5 + 6	18/0.15	7.82**	2.62	0.15	0.16	7.0	4.2	0.38	
7 + 8	21/0.1	3.10**	0.71	0.36	0.22	7.9	4.4	0.57	
9 + 10 I	20/0.1	8.70	2.84	–0.78	0.52	8.2	4.9	0.31	
9 + 10 II	21/0.1	6.26**	0.05	0.24	0.36	5.5	3.1	0.94	
9 + 10 III	21/0.1	5.52**	0.52	–0.29	0.72	6.5	6.5	0.92	
9 + 10 V	20/0.15	9.46*	4.14	1.07	1.12	13.0	6.5	0.70	
within an.	20/0.15	5.80**	0.37	0.23	0.12	8.3	4.8	0.70	F 3.62*
all data together	21/0.1	5.21**	0.35	–0.06	0.10	10.4	6.0	0.67	F 6.36**
class II									
group I	19/0.15	1.02*	0.43	0.13	0.10	4.9	2.7	0.30	
group II	17/0.1	0.70*	0.32	0.02	0.03	1.3	0.8	0.32	
group IV	21/0.1	2.18**	0.51	0.43*	0.18	4.9	2.9	0.60	
group V	20/0.15	4.38**	0.51	–0.21	0.40	1.9	1.2	0.96	
group VI	21/0.1	5.74*	1.58	0.27	0.60	4.2	2.5	0.87	
within an.	21/0.1	0.83**	0.24	0.05	0.07	5.1	3.4	0.31	F 2.53*
all data together	21/0.1	1.07**	0.22	0.12	0.08	5.0	3.0	0.16	F 3.89**
class III									
1 + 2	18/0.1	7.70**	0.51	–0.17**	0.05	3.8	2.3	0.96	
5 + 6	18/0.1	3.49**	0.68	0.04	0.10	6.7	4.0	0.59	
7 + 8	21/0.1	1.87	2.28	0.12	0.21	10.3	5.9	0.05	
9 + 10 V	21/0.1	5.86	3.31	0.38	0.47	10.4	5.5	0.37	
within an.	18/0.1	5.08**	0.72	–0.04	0.08	8.9	5.1	0.47	F 3. 84*
all data together	19/0.1	4.08	1.11	–0.28**	0.10	12.3	7.1	0.26	F 13.47**
class IV									
group I	18/0.1	0.77*	0.36	–0.23**	0.05	2.4	1.4	0.67	
group II	no significant value								
group VI									
within an.	19/0.1	0.69	0.42	–0.21**	0.06	3.5	2.1	0.34	F 4.2**
all data together	19/0.1	0.89*	0.41	-0.18**	0.06	3.6	2.2	0.30	F 2.81*

* $P < 0.05$
** $P < 0.01$

TABLE 6.8. Results of regression of heat production above 160 Kcal/$W^{3/4}$ on differences with critical temperatures and size of temperature change; $H/W^{3/4} = e(Tcr - T) + f\Delta t + q$. (Intercept q not in table)

Animals	n	Tcr	SD of e	f	SD of f	e	RSD	CV	R^2	F-value
Class I										
1 + 2	15	21/0.1	-1.08	1.25			3.55	2.17	0.05	
1 + 2 II	9	21/0.1	6.94**	0.51			4.88	2.54	0.96	
3 + 4	7	20/0.1	3.46**	0.30	-0.61*	0.30	1.26	0.76	0.98	
5 + 6	22	18/0.15	7.92**	2.54			6.83	4.15	0.32	
7 + 8	18	21/0.1	2.85**	0.72			8.34	4.61	0.49	
9 + 10 II	18	21/0.1	6.42**	0.40	1.01*	0.57	4.87	2.81	0.95	
9 + 10 V	8	21/0.1	8.66**	1.57	4.37**	1.54	8.90	4.48	0.86	
within an.		20/0.1	5.51**	0.43	0.70*	0.33	8.38	4.80	0.67	7.90**
all data together		21/0.1	5.66**	0.44	0.89*	0.42	10.56	6.05	0.66	11.86**
Class II										
group I	28	21/0.15	1.15**	0.30	0.34*	0.18	3.92	2.40	0.37	
group II	18	17/0.1	0.34	0.26			1.32	0.82	0.09	
group III	4	18/0.15	4.53**	0.54			5.80	1.00	0.97	
group IV	22	21/0.1	2.17**	0.50			6.42	3.82	0.48	
group V	9	21/0.1	2.45**	0.82	1.54*	0.66	4.89	2.96	0.60	
group VI	5	21/0.1	5.74**	1.36			3.60	2.13	0.86	
within an.		21/0.1	1.25**	0.22	0.34*	0.19	5.24	3.18	0.30	4.67*
all data together		21/0.1	0.93**	0.22			6.02	3.66	0.18	5.91**
Class III										
1 + 2	15	21/0.15	8.40**	0.66			4.84	2.84	0.93	
5 + 6	9	21/0.1	5.66**	3.21			10.08	5.34	0.31	
7 + 8	23	18/0.1	3.47**	0.63			6.36	3.85	0.59	
9 + 10 V	19	21/0.1	1.58	2.18			10.10	5.78	0.08	
within an.		18/0.1	5.13**	0.70			8.83	5.12	0.47	3.80*
all data together		20/0.15	4.74**	1.26			12.76	7.41	0.18	16.37**
Class IV										
group I	16	19/0.1	0.58	0.47			3.75	2.29	0.10	
group II	6	21/0.1	0.96	1.90			6.94	4.20	0.06	
group VI	14	20/0.15	175.73**	34.43			1.99	1.23	0.68	
within an.		21/0.15	0.55	0.76	-0.46*	0.25	8.94	2.41	0.16	0.38
all data together		21/0.15	0.54	0.72	-0.48*	0.24	3.93	2.40	0.17	0.64

** $P < 0.01$
* $P < 0.05$

6.2.3.3. The effect of temperatures below the critical temperature on heat production and energy balance (method B)

In the preceding paragraph the critical temperatures have been estimated from the data of groups of animals and pairs of single animals. If these critical temperatures are known then the effect of being below this temperature on heat production and energy balances can be estimated by plotting the heat production above the thermoneutral heat production against the temperature difference. However, this effect can not be seen separately from the value of the estimated critical temperature itself. In the Tables 6.7 and 6.8 the results from the regression of heat production above the thermoneutral heat production on differences with the estimated critical temperatures and weight or size of temperature change are given. The variable weight, however, has no significant influence in the computations per animal except I + 2 I below 50 kg, I + 2 I above 50 kg and group I above 50 kg and also in the within-animal computations from groups of animals above 50 kg.

The computations have been made with the value of the temperature change added as independent variable and Table 6.7 and Table 6.8 show that this value of temperature change was found to have no significant influence in animals above 50 kg. In some of these animals the weight was a significant variable. The size of temperature change itself may have an influence on heat production below the critical temperature in young animals below 50 kg. The hypothesis that the effects (regression-coefficients) of different variables on heat production, of 1) pairs of single animals and 2) groups within classes, were the same, was rejected (see F values).

The difficulties in the climatic regulation equipment may however partly have caused these different effects. As the number of trials within each group and with negative or positive temperature change itself were low, the equations with all variables have been computed from within-animal data in each class.

In the classes the average effects on heat production/$W^{3/4}$, due to the fact that the animals were below the critical temperatures, computed from within-animals in each class are given in Table 6.9.This Table 6.9 shows that the increase in heat production per °C below the critical temperatures in singly housed animals are about 3–4 times as high as in groups of animals and the latter can save about 75–80% of the extra heat required below the critical temperatures compared with animals housed singly.

TABLE 6.9. Critical temperatures and average effects of lower temperatures.

animals	critical temperature estimated from	Increase in heat production in kcal/$W^{3/4}$ below Tcr.
class I (single below 50 kg)	21 – 0.1 W	5.66 (± 0.15)
class II (groups below 50 kg)	21 – 0.1 W	1.15 (± 0.26)
class III (single above 50 kg)	21 – 0.15 W	5.15 (± 1.40)
class IV (groups above 50 kg)	21 – 0.15 W	1.10 (± 0.65)

TABLE 6.10. Regression of heat production above 160 kcal/$w^{3/4}$ on difference with Tcr, weight and temperature change according to formula (8): $(H/_{w}{}^{3/4} - 160) = e\,(Tcr - Temp) + b\,W + f_{pos}(\Delta t) + f_{neg}\Delta t$

	n	e	SD of e	b	SD of b	f_{pos}	SD of f	f_{neg}	SD of f	RSD	R^2
single below 50 kg[1]	82[1]	4.77**	0.42	0.17	0.1	6.55**	2.7	0.76	2.5	8.8	0.70
groups below 50 kg[2]	50[2]	1.01**	0.30	0.04	0.1	3.76**	2.0	4.10*	2.0	5.6	0.41
single above 50 kg[3]	41[3]	5.86**	0.98	-0.09	1.0	1.68	3.5	3.55	3.4	8.7	0.58
groups above 50 kg[4]	36[4]	0.60	0.63	-0.21**	0.06	-0.89	1.7	2.12*	1.5	3.4	0.43

[1] From within-animal data of 1 + 2 II, 3 + 4, 5 + 6, 7 + 8, 9 + 10 II and 9 + 10 V (Tcr = 21/0.1)

[2] From within-animal data of group I, II, III, IV and VI (Tcr = 21/0.1)

[3] From within-animal data of 1 + 2 I, 9 + 10 V and 5 + 6 (Tcr = 20/0.15)

[4] From within-animal data of group I, II and VI (Tcr = 21/0.15)

* $P < 0.05$

** $P < 0.01$

TABLE 6.11. Regression of heat production above 160 kcal/$W^{3/4}$ on difference with Tcr, and weight apartly for Δt positive and negative: $(H/W^{3/4}-160) = e\ (Tcr-T) + b\ W)$

	n	Tcr	e	SD of e	b	SD of b	RSD	R^2
				Δt negative				
single below 50 kg	39[1]	21/0.1	4,35**	0.58	0.32	0.22	9.0	0.70
groups below 50 kg	35[2]	21/0.1	1.09**	0.31	–0.05	0.11	5.0	0.32
single above 50 kg	23[3]	20/0.15	7.94**	1.20	–0.10	0.15	7.7	0.78
groups above 50 kg	17[4]	21/0.15	0.92	0.71	–0.22**	0.08	3.5	0.46
				Δt positive				
single below 50 kg	19[1]	21/0.1	6.18**	1.44	0.47**	0.37	8.3	0.66
groups below 50 kg	24[2]	21/0.1	0.52	0.40	0.25**	0.09	3.8	0.34
single above 50 kg			no significant value					
groups above 50 kg	11[4]	21/0.1	0.41	0.42	–0.09*	0.05	1.1	0.39

** $P < 0.01$

* $P < 0.05$

[1] From within animal data of 1 + 2 II, 3 + 4, 5 + 6, 7 + 8, 9 + 10 II and 9 + 10 V

[2] From within animal data of group I, II, III, IV and VI

[3] From within animal data of 1 + 2 I, 9 + 10 V and 5 + 6

[4] *From within animal data of group I, II and VI*

The results of some pairs of animals and some groups of animals (from Tables 6.10 and 6.11 in which the model fits best are plotted in figure 8. Moreover heat production above the thermoneutral heat production was regressed on weight and on two variables, positive t and negative t, being 1 if the temperature change was positive or negative and 0 if not positive or not negative (Table 6.10) Moreover heat production below Tcr was computed separately from data obtained after a decrease or increase of the temperatures (see Table 6.11). From these computations it is clear that heat production is influenced in some cases, e.g. in young animals below 50 kg both in groups and pairs of animals, by temperature change itself. In both cases this temperature change has a positive effect on heat production above the value for temperature itself and in some cases it gives a significant improvement of the reduction of variance in heat production.

The computed effects of being below the critical temperature are not much different when animals above and below 50 kg are compared. However between groups and pairs of singly housed animals the effects of low temperatures are different. From Table 6.8 it is clear that in some cases an effect of the size of temperature change will be present. In some animals temperature change itself is also significant, see Table 6.10.

Weight influence is only significant in groups of animals above 50 kg. However in total the results given in Table 6.10 and Table 6.11 show that the model does not fit as good in the obtained data as the separate computations for rising or falling temperatures do (see Table 6.6). The variation in heat production however was also lower if only heat production figures below the critical temperature and above 160 kcal/$W^{3/4}$ are taken into account. The RSD from the equations computed in Tables 6.10 and 6.11 were also somewhat higher compared to those computed in Table 6.6.

A fall of the temperature is found to increase the heat production only in groups of animals. On the other hand a rise of the temperature causes a significant increase in heat production in two classes i.e. in animals below 50 kg both group-housed and housed individually. Using the two different methods of computations (method A and method B), established in chapter 5, the effect of temperatures on the heat production of the pigs has been estimated to be on average between 4.5 and 5.8 kcal/$W^{3/4}$ for singly housed animals and about 0.6–1.2 kcal/$W^{3/4}$ for groups of animals. Though in using method B the model was applied to data which were corrected to thermoneutral heat production, the RSD was even higher (see Table 6.10 and 6.11) than with the values obtained with computations according to method A. With the data from animals above 50 kg the regression equations were computed from within-animal data without adding negative T or positive T as independent variables, this gave:

groups:
$H/W^{3/4} = 0.89\ (\pm\ 0.62)\ (Tcr\text{-}T) - 0.18\ (\pm\ 0.06)\ W$ RSD 3.6 kcal/$W^{3/4}$;
individual:
$H/W^{3/4} = 4.08\ (\pm\ 0.42)\ (Tcr\text{-}T) - 0.28\ (\pm\ 0.10)\ W$ RSD 7.1 kcal/$W^{3/4}$.

The residual standard deviation (RSD) of the equations derived from within-animal data below the critical temperatures were about the same as those obtained from data above the critical temperature. It is therefore obvious that the heat production expressed per kg $W^{3/4}$ of animals kept at temperatures up to 10°C below the thermoneutral zone can be predicted with about the same accuracy as the heat production of animals kept within this zone. It is also clear that animal weight and temperature change should be taken into account while predicting heat production when working with young growing animals kept singly or in groups. Moreover there may be between-animal differences in the effects of temperature and of weight on the heat production of pigs kept in experiments which are done in a temperature range similar to the range found under practical conditions in a piggery, which is not climaticly conditionned.

6.2.3.4. The effect of temperatures below the critical temperature on energy balances

As stated in paragraph 6.2.4 one can compute the reduction in energy gain of pigs kept at lower temperatures beneath the critical temperatures. In Table 6.12 the effects of low temperatures on the energy balances are given in kcal/$W^{3/4}$ °C. These data are calculated while assuming two possible different efficiencies of conversion of metabolisable energy into net energy and it is also assumed that the effect of the differences between and critical temperatures on the reduction of energy gain is linear. The data in table 6.12 are calculated by multiplying the extra heat production required per °C below the critical temperature with the assumed efficiency of conversion of ME into net energy. The

TABLE 6.12. Average effects of low temperatures in kcal/$W^{3/4}$ per °C on energy gain at assumed efficiences of conversion of ME into NE of 70% and 75%. (a = 0.70 and a = 0.75)

	Method A				Method B	
	positive Δt		negative Δt			
	a = 0.70	a = 0.75	a = 0.70	a = 0.75	a = 0.70	a = 0.75
single animals below 50 kg (class I)	3.08	3.31	2.62	2.81	3.34	3.58
groups of animals below 50 kg (class II)	0.52	0.55	0.71	0.77	0.71	0.76
single animals above 50 kg (class III)	2.18	2.33	2.29	2.45	3.90	4.20
groups of animals above 50 kg (class IV)	0.70	0.73	0.82	0.88	0.42	0.45

data indicate that the depression of energy gain due to low temperatures is about 3–4% per °C below Tcr in single animals and about 0.5–1% in groups of animals with nearly the same feeding level. The thermoneutral energy gain is about 100–110 kcal/$W^{3/4}$ at a feeding level of 250–260 ME/$W^{3/4}$.

As shown in Table 6.7 the effect of temperatures below the critical one on heat production is different between the animals in one class. In the four classes the range of the effects in kcal/$W^{3/4}$ per °C below Tcr were respectively between 3.1 and 9.5, 0.7 and 5.7, 3.5 and 7.7 and between 0.77 and 0.89 kcal/$W^{3/4}$°C.

The cause of these different effects is not known. Between-animal variation in effect may exist and the difficulties in climatic regulation equipment sometimes previously to a set of experiments may have partly contributed to these differences. The same can be said to the significant influence of weight and temperature change on heat production which was sometimes found. The differences in effect of temperature on heat production between the classes will be caused firstly by the huddling of the animals in group. The other variables, i.e. weight and temperature change, may be influenced by a difference in activity between the animals.

The increase in heat production and thus decrease in energy gain, during experiments two days after decreasing the temperature, which was found in groups of animals (Table 6.10) may be caused by a change in behaviour due to looking for a better position in the huddling group. The opposite effect was sometimes noticed after a rise in temperature. This also might be explained by a change in behaviour. Summarising the effects of the various variables on the heat production and thus energy balances at low temperatures it can be stated that the main effect is due to the temperature and this is evident in all animals (except 1 + 2 I in class I). Besides this effect of temperature there are other factors which may influence the behaviour. Their influence on energy metabolism however is much less than the influence of low temperatures. Thus the low temperature is the main factor and the study of the influence of this factor has been one of the aims of these experiments.

6.3. PRACTICAL APPLICATION OF THE RESULTS OF THE COMPUTATIONS

In Table 6.13 a survey of the metabolisable energy and net energy which is required to maintain a constant and to decrease the critical temperature with 1 °C has been given. The general way of the necessary calculations was as follows. In 4.2.1 the formula for the predition of the thermoneutral heat production for animals below 50 kg and above 50 kg has been described. The thermoneutral heat production could be predicted from the formula $H = (1-a)\,ME + ak_1W^{3/4}$ this gave:

below 50 kg (av. weight 30 kg) $H = 0.3\ ME + 86\ W^{3/4}$
above 50 kg (av. weight 60 kg) $H = 0.3\ ME + 83\ W^{3/4}$

These formulae suggest that the maintenance heat production decreases gradually with increasing weight and consequently ak_1 decreases with 1 unit per 10 kg body weight increase.

To compute e.g. the required metabolisable energy and net energy at low temperatures for an animal of 20 kg then firstly the ME which is needed to obtain a thermoneutral heat production of 160 kcal/$W^{3/4}$ is calculated. For this animal of 20 kg 160 kcal/$W^{3/4}$ is equal to $160 \times 9.46 = 1514$ kcal (metabolic weight of 20 kg is $(20)^{3/4} = 9.46$). This heat originates from $0.3\ ME + 87 \times 9.46$ this gives $ME = 2340$ kcal. When the efficiency of conversion of ME into net energy is 0.7 then the net energy is 1631 kcal.

The critical temperature of this animal at a thermoneutral heat production of 160 kcal/$W^{3/4}$ was found to be 19 °C and below this temperature 4.8 kcal/$W^{3/4}$ extra heat/°C were produced, when the animal is housed singly. This gives a total extra production of $4.8 \times 9.46 = 45.4$ kcal production originating from 45.4 kcal ME, i.e. 31.7 kcal net energy per °C below Tcr. For an animal of 20 kg belonging to a group of 4–5 animals this extra heat is about 1 kcal/$W^{3/4}$ this is 95 kcal heat production increase, i.e. 6.7 kcal net energy.

Now the question arises with how much feed, ME or net energy, the thermoneutral zone can be lowered with 1 °C. This happens for an animal of 20 kg housed singly when extra ME is given to such extent, that 0.3 ME equals to the extra heat required i.e. 45.4 kcal. Thus $0.3\ ME = 45.4$ kcal and ME equals to 151 kcal. The critical temperature i.e. lower limit of the thermoneutral zone in this animal can be decreased with 1 °C by giving 151 kcal ME or 106 kcal net energy. When considering an animal in a group, this extra feed required to reduce the critical temperature with one degree °C has to be 31.7 kcal ME or 22 kcal net energy.

The same computations can be made with older animals and for the extra heat production the data computed with method B are taken i.e. 4.8 kcal/$W^{3/4}$ extra per °C below the critical temperature for single housed animals below 50 kg and 5.8 kcal/$W^{3/4}$ for singly housed animals above 50 kg. When an animal of 50 kg is concerned the average of 4.8 and 5.8 kcal/$W^{3/4}$ °C is taken. For groups of animals below and above 50 kg 1 kcal/$W^{3/4}$ increase in heat production per °C below the critical temperature is taken. In Table 6.13 also the computations have been made with the other weights of animals. It should how-

TABLE 6.13. Metabolisable and net energy required to maintain the same gain and also to decrease the lower border of thermoneutrality with one °C.

Weight (kg)	Kcal ME to produce 160 kcal $H/W^{3/4}$ at thermoneutrality	Net energy	T_{cr}	Normal heat production	extra heat in kcal per °C below Tcr**		Net energy required per °C below Tcr		Required for maintaining thermoneutrality at one °C lower temp.			
									ME kcal		Net energy kcal	
					single	groups	single	groups	single	groups	single	groups
20 kg	2340	1631	19°C	1514	45.4	9.5	31.7	6.7	15.1	31.7	106	22
30 kg	3153	2207	18°C	2048	61.4	12.8	43.0	9.0	20.5	42.7	144	30
40 kg	3900	2730	17°C	2544	76.3	15.9	53.4	11.1	25.4	53.0	178	37
50 kg	4762	3333	16°C	3008	100.0	18.8	70.2	13.3	33.3	66.0	233	46
60 kg	5536	3875	14°C	3456	125.3	21.6	87.7	15.1	41.4	72.0	290	50
70 kg	6292	4404	13°C	3872	140.4	24.2	99.0	16.9	47.8	80.6	335	56
80 kg	7050	4935	12°C	4272	154.9	26.7	108.4	19.7	51.6	89.0	361	62
90 kg	7788	5452	11°C	4672	161.4	29.2	113.0	20.4	53.8	94.0	377	66
100 kg	8532	5972	10°C	5056	183.3	31.6	128.3	22.1	161.1	105.3	428	74

* Normal heat production predicted from 0.3 ME + 87 × $W^{3/4}$ kcal for animals of 20 kg and 87 is gradually decreasing with 1 unit per 10 kg weight increase.

** *Extra heat production* Single below 50 kg 4.8 kcal/$W^{3/4}$ per °C below Tcr
Single just 50 kg 5.3 kcal/$W^{3/4}$ per °C below Tcr
Single above 50 kg 5.8 kcal/$W^{3/4}$ per °C below Tcr
Groups both below and above 50 kg 1 kcal/$w^{3/4}$ per °C below Tcr.

ever be pointed out here that the animals were kept on a wooden floor and moreover wall temperatures were about the same as the ambient temperatures. Before the data of the groups can be applied to conditions in practice, such data on animals kept on concrete, slatted floors and straw-bedding should be gathered also.

7. DISCUSSION

1. *Determination of heat production and energy balances*

In chapter 5 the SD's of the various parameters which were used to determine heat production per kg metabolic weight are given. From the determinations it is clear that technical errors i.e. analytical errors, are rather small.

The SD of the determination of metabolisability was estimated to be 2.0% in rations G and 4.3% in rations F when data obtained during 6-day experiments were applied to the two day periods during which the respiration experiments were carried out. This SD includes between-animal and within-animal period variation for animals in one chamber. When working with two-day periods this accuracy is considered to be sufficient for the purpose of these investigations.

Expressing heat production and metabolisable energy per metabolic weight in singly housed animals and in group housed animals causes some increase of the SD if the weights of the pigs in one chamber, of which the heat production is measured together, are not exactly the same. Especially when working with two animals, which differ considerably in weight the SD of the expression of heat production per kg metabolic weight will increase due to the fact that it has been computed as total heat production divided by total metabolic weight and not by averaging the heat productions expressed in kcal per kg metabolic weight per animal. This could not be done in another way because gaseous exchange was measured of all animals together in one chamber and the same was done with the metabolisable energy (ME) intake in the groups of animals.

The CV of heat production expressed per kg metabolic weight, due to the error of measuring heat production and metabolisable energy and to the variation in weight of animals which were together in one chamber is about 3% in groups and about 6–8% in singly housed animals HOLMES (1966) found in his experiments with a direct calorimeter a variation coefficient in heat production measurement of 2.3% when working with animals of the same weight.

Temperature treatments could be only applied to parts of the growth period of some animals due to failures in the air-conditioning equipment of the chambers. In order to be able to compare the results from different animals and to compute relationships of heat production with other parameters the experiments were divided in four classes; singly housed animals below and above 50 kg (class I and III respectively) and group-housed animals below and above 50 kg (class II and IV respectively). The use of the model $H/W^p = (1-a)\ ME/W^p + ak_1$ per class (see 5.6.1 and Table 5.19) showed that the residual standard deviation was higher than the SD due to the determination of H/W^p. The goodness of fit of $H = (1-a)\ ME + ak_1W^p$ expressed as R^2 was usually between 0.70 and 0.99.

Compared with the results from the literature (derived from trials with periods of 6–10 days) the R^2's of the here reported trials within the thermoneutral zone are only slightly lower and this is the more remarkable as in these studies only small weight ranges (20–50 kg and 50–90 kg) were applied and also ME intake per kg metabolic weight did not vary much. Moreover, the number of ME determinations was reduced. The ME intake in the other trials was computed from actual dry matter content in the feed and metabolisability data from the preceding balance experiment. The R^2's of the computations according to the model concerning heat production in the thermoneutral zone are nearly the same in trials from the literature and in these experiments. It shows that this experimental procedure is satisfactory and it also shows that within-animal variation of the metabolisability, % ME of the gross energy, in the feed has been unimportant.

2. *The relation between metabolic weight and heat production*

From the computations according to the model derived in chapter 4 and applied to the literature data and to the results from the trials in Wageningen the value of 3/4 for p in W^p is not in all cases the value which gives the lowest residual error. From data of the literature, reported by BREIREM (1935), LUND (1938), LUDVIGSEN and THORBEK (1953), FINGERLING (1912–1941) and NEHRING (1960) the relation of heat production to metabolisable energy (ME) and metabolic weight (W^p) was studied: $H = (1-a)\,ME + ak_1\,W^p$. Computations with different values of p show that in the young animals perhaps a somewhat higher value i.e. $p = 0.85$ fits slightly better than $p = 3/4$. In the older animals a somewhat lower value of p was found to fit better than $p = 3/4$.

In the computations with the material of this study (Table 6.3) with small weight ranges $p = 0.55$ gives the best results for animals above 50 kg, whereas $p = 0.85$ is found to fit better for animals below 50 kg. However, the differences in R^2 when using various values of p, e.g. $p = 0.55$ and $p = 0.85$, are very small and one might use $p = 3/4$ to express metabolic weight in young singly housed animals and group housed animals. An incomplete fit when using $p = 3/4$ in the equation due to difference in activity of the pigs may be compensated in adding weight as additional independent variable. Probably because the weight range was small, this addition of weight did not give any significant improvement, except in one pair of animals. It should be noticed here that in these experiments the animals were weighed at another time of the day then was done in the above mentioned literature trials. Due to differences in fill of digestive tract at different times of the day the weights and thus also metabolic weights may not be comparable and another value of p might be found when the weight had been determined at another time of the day.

3. *Relation of heat production and intake of metabolisable energy*

From the literature trials in which feeding level was varied in order to study the efficiency of metabolisable energy for energy gain (NEHRING 1960) an efficiency coefficient of 0.70 was found. The efficiency value computed for the other literature trials was less accurate as the feeding level expressed in kcal metabolisable energy ($ME/W^{3/4}$) per kg metabolic weight did not vary so much. If an efficiency (a) of 0.70 was also assumed to apply to the other trials the maintenance requirement which can be derived is higher in young animals below 100 kg (about 100–110 kcal $ME/W^{3/4}$; Lund (1938), Breirem (1935), Ludvigsen and Thorbek (1953)), than in the older animals (60–80 kcal $ME/W^{3/4}$; Fingerling (1912–1941) and Nehring (1960)) (see Table 6.2). In the trials with older animals the heat production can be computed from:

$H = 0.30\ ME + 64\ W^{3/4}$ Nehring et al (1960)
$H = 0.30\ ME + 53\ W^{3/4}$ Fingerling (1912–1941)
whereas in the younger animals these equations are:
$H = 0.30\ ME + 74\ W^{3/4}$ Breirem (1935), Ludvigsen and Thorbek (1953)
$H = 0.30\ ME + 86\ W^{3/4}$ Lund (1938)
From Oslages experiments (1965) with another kind of ration the equation was:
$H = 0.30\ ME + 47\ W^{3/4}$
From the trials described here the heat production can be computed from:
$H = 0.30\ ME + 86\ W^{3/4}$ animals below 50 kg (groups and single)
$H = 0.30\ ME + 83\ W^{3/4}$ animals above 50 kg (groups and single).

The reason for these big differences between the results from Oslages trials and the results from the Danish trials is not known. Probably it was due to the high digestibility of the ration used by Oslage whose pigs were also somewhat heavier.

From the two equations computed from this material the maintenance requirement was respectively 123 and 119 kcal $ME/W^{3/4}$. When doing this and using the equations derived per animal there are however differences in computed maintenance requirement between the different animals ranging from 103 up to 145 kcal $ME/W^{3/4}$. It is still questionable whether or not the higher maintenance requirement computed in this way is due to the temperature treatments preceding the trials performed within the thermoneutral zone or to differences between the animals (see figures 2,3. and 4). The hypothesis that there were differences in maintenance requirement between the animals but that the efficience of conversion of ME for net energy was the same could be accepted in all classes, except in groups of animals above 50 kg (Table 6.4). If it is assumed that there is a gradual change in ak, in the formula for the prediction of heat productiondue to a change in maintenance requirement then the formula $H = 0.30\ ME + 86\ W^{3/4}$ for animals of about 30 kg till $H = 0.30\ ME + 83\ W^{3/4}$ for animals of 60 kg will be for the other weights:

20 kg animals: $H = 0.30\ ME + 87\ W^{3/4}$
30 kg „ : $H = 0.30\ ME + 86\ W^{3/4}$
40 kg „ : $H = 0.30\ ME + 85\ W^{3/4}$
50 kg „ : $H = 0.30\ ME + 84\ W^{3/4}$
60 kg animals: $H = 0.30\ ME + 83\ W^{3/4}$
70 kg „ : $H = 0.30\ ME + 82\ W^{3/4}$
80 kg „ : $H = 0.30\ ME + 81\ W^{3/4}$
90 kg „ : $H = 0.30\ ME + 80\ W^{3/4}$

It should be pointed out that the relations for group housed animals were computed disregarding the unmeasured waste of feed. According to the applied equations it seems therefore probable that the maintenance heat production (= maintenance requirement = k_1) in groups, will be calculated somewhat too low if feed is wasted. The data obtained from groups can probably be compared with practical conditions as the feeding level and temperatures were rather close to the practical conditions. The lowest maintenance heat production found in single animals was 103 kcal ME/$W^{3/4}$ i.e. very close to the results obtained from the literature and in groups of animals 116 kcal ME/$W^{3/4}$ was found as lowest maintenance heat production.

4. *Relation between heat production and temperature*

Critical temperature.

The estimation of critical temperature is done according to the model derived in chapter 4. It was assumed that the heat production in the zone of thermoneutrality below 25 °C at a given feeding level is constant and that in this zone merely the ratio of the heat quantities leaving the body through the various possible channels changes. Moreover it was assumed that below the critical temperature the extra heat required and produced by the animal in order to maintain the body temperature increases linearly with the difference between ambient and critical temperature at least in the temperature range applied in this study i.e. 5° to 25 °C. It was found that the critical temperature could be estimated using the equation k_2-cW, in which k_2 and c are constants and W is body weight. Values of 21 for k_2 and 0.1 for c gave a lower residual variance than values of k_2 between 17 and 23 other then 21 or a value 0.15 for c. These estimations were made assuming a constant thermoneutral heat production of 160 kcal/$W^{3/4}$ (see Table 6.5). The value 160 is taken because this heat production in the thermoneutral zone originates from one of the highest feeding levels noticed.

The critical temperature at a higher or lower thermoneutral heat production depends on the extra heat required per °C below the critical temperature. The hypothesis that the critical temperatures decrease linearly with increasing feed intake could be maintained, although the number of data in which the thermoneutral heat production could be fixed at such a high level of 165 or 175 kcal/$W^{3/4}$ was lower due to the fact that the feeding level was not always high enough to cause such heat production figures. There were also differences in estimated critical temperatures between the various pairs of animals. In some pairs of singly housed animals the critical temperature at 160 kcal/$W^{3/4}$ was found to be 1 to 2 °C lower than in other pairs. In groups of animals below 50 kg the critical temperature was about 1 °C lower than estimated from 21–0.1 W. This may have been due to the fact that at temperatures slightly above the critical temperature the animals start resting close to each other so that the surface by which heat is dissipated gets smaller which results in a lower critical temperature. About the same equation, 21–0.1 W fitted in data of singly housed animals above 50 kg but also the equation 21–0.15 W did. In groups of animals above 50 kg again the critical temperature was about 1 °C lower, probably due to huddling. The finding that 0.15 W could be used as well as 0.1 W in some animals above 50 kg may suggest that at advancing age due to a higher content of subcutaneous fat the heat conductivity of the tissues decreases, which results in a lower critical temperature. This might be in accordance with the findings of the research team in Cambridge (MOUNT, INGRAM (1968) (see chapter 2).

5. *Relation between temperature, heat production and energy balances*

In chapter 4 the model by which the data on heat production and energy balance can be described was discussed and in chapter 6 some computations with this model have been given. It is clear that the influence of various variables, e.g. temperature, weight and temperature change, are different in respect to the class to which the data belong, i.e. single or in groups and below or above 50 kg. The increase of heat production at low temperatures is much more pronounced in singly housed animals than in groups of animals. HOLMES (1966) found about the same increase. The results also confirm the findings of MOUNT (1960) who showed that huddling of piglets can save a lot of extra heat lost at low temperatures by piglets when kept singly. However the saving of required extra heat in Mount's trials by huddling was about 40%, whereas in these trials about 70–80% less extra heat was found in groups compared with singly housed pigs.

For a thermoneutral heat production of 160 kcal/$W^{3/4}$ the increase of heat production per °C below the critical temperatures was computed to be about 2.3 to 3.3% in single animals and 0.6 to 0.9% in groups of animals. This resulted in a smaller energy gain. To obtain no change of energy gain the intake of ME had to be increased by the same amount as the increase in heat production i.e. about 1.4 to 1.9% in single animals and by 0.7–0.9% in groups of animals if the normal feed intake is considered to be 260–270 kcal ME/$W^{3/4}$.

Theoretically, one could try to lower the critical temperature of the animals with one °C by increasing their feeding level. Provided the pigs would eat the amount needed, this would of course result in an increased energy gain.

As to the net energy content of the feed i.e. the energy which could have been deposited if all the metabolisable energy was available for production this content can be computed by multiplying the content of metabolisable energy with 0.70, because the efficiency of the utilisation of ME for fat production can be regarded to be 0.70 (NEHRING, 1960). In Table 6.13 the net energy required to maintain the same gain is given and also the net energy required to maintain thermoneutrality at that temperature which is 1 °C below the critical temperature.

It can be concluded that experiments with groups of pigs will be of much value to investigate the influence of environmental conditions in practical circumstances, because their reactions are quite different from singly housed animals. In this study the animals were housed on a wooden floor, and therefore, the effects of low temperature on heat production and the heights of the critical temperature should also be studied when animals are kept in groups on other floors e.g. concrete, slatted or strawbedding floors.

6. *Temperature and gain*

The growth of the animals in this study was as an average between 550 and 600 g per day, with a rather good feedconversion (Table 5.6). This might suggest that animals can withstand changing temperatures rather well and can still grow efficiently. When the energy balances in protein and fat at normal temperatures (see Table 5.8) and with pigs of 20–50 kg at low temperatures (see Table

5.9) are considered separately then rather big differences can be noted. The energy gain in protein decreased only very little at lower temperatures whereas fat gain decreased or increased considerably with rising or lowering of the temperature. The protein gain measured in this study at low decreasing temperatures will at least not have been overestimated since KASUBIEWEZ (1962) noticed a sudden decrease in weight when animals where placed in the cold which was probably due to an increase in urine output as found by BADER (1952) with men after a sudden decrease in temperature. Protein is related to less energy per g gain than fat and moreover protein is accompanied by much more water than fat gain.

The lower influence of temperature found on protein gain may be in accordance with the investigations of PIATKOWSKI (1958) and probably also FULLER (1964) who found also a low reduction or none at all in N-balance at low temperatures. FULLER (1964) has the opinion that when eating *ad lib* the young pigs consume enough food for protein metabolism to be unaffected by temperatures down to 10°C. SÖRENSEN (1961) found a considerable decrease in N-retention at low temperatures when fattening the animals at constant low or high temperatures.

The results of the experiments in this study however do not exclude the possibility that in a further stage of the growth period the protein gain might be reduced at low temperatures.

8. CONCLUSIONS

1. Measurement of heat production in a two-day period and computation of metabolisable energy from dry matter intake and previously measured metabolisibility is found to be an adequate method of measuring possible effects of temperature and feeding level on heat production and energy gain.
2. The power of p used to raise body weight to metabolic weight (W^p) may be higher than p = 3/4 in animals below 50 kg and lower than 3/4 in heavier animals
3. The heat production of growing pigs kept in the thermoneutral zone could be computed from feedintake in kcal metabolisable energy and metabolic weight.
4. Differences were found in computed maintenance requirement between the various pairs and between the various groups of animals in the growth period of 20–50 and 50–90 kg.
5. Comparing animals housed in groups with animals kept individually at equal feed intake and weight in the zone of thermoneutrality, showed that about the same amount of heat was produced.
6. The critical temperatures of pigs housed in groups compared to those individually housed were found to differ not significantly. These temperatures decreased linearly with increasing weights.
7. In animals of 50–90 kg this decrease in critical temperature with increasing weight is slightly faster than in younger animals of 20–50 kg.
8. The increase of heat production below the critical temperature in singly housed pigs was found to be 3–4% per °C i.e. 3–4 times as high as in pigs housed in groups.
9. Between single pigs and also between groups of pigs consistent differences in increase of heat production per °C below the critical temperatures were found.
10. Below the critical temperature the raise or fall of temperature can influence the extra heat production in groups of animals.
11. Body weight gain in single housed animals of 20–50 kg was much less influenced by temperatures below the critical temperature then heat production, because at low temperatures, protein gain was only slightly decreased whereas fat gain was nearly proportional to the reduced amount of feed available for production.

9. SUMMARY

During the last years increasing attention has been paid to ventilation in piggeries and to the influence of climatic factors in the piggery on the growth of fattening pigs. It was necessary to accumulate more information on the heat and water vapour production of pigs in order to enable the construction of piggeries with climatic conditions for optimal production. For that reason an investigation into the influence of different temperatures on the heat production of growing pigs was started. The animals were kept singly with two pigs each in a metabolism cage or in groups of 4–5 pigs in one chamber. The experiments were performed in two new climatic chambers of the department of Animal Physiology of the Agricultural University at Wageningen. These chambers were constructed for respiration trials. These investigations were performed in a close cooperation between this Department and the Department of Animal Husbandry. In order to obtain data on the energy metabolism of pigs which could be compared as much as possible with conditions in husbandry practice, the animals stayed inside the respiration-climatic chamber during their whole fattening period from about 20 to 100 kg.

To investigate the temperature influence the following scheme was designed. After arrival the pigs were allowed to become accustomed to the chamber at 23–24 °C during a period of about 5–6 days and then a measurement of gaseous exchange was performed during a period of two days. After this period the temperature was lowered (usually 2–3 °C) and a new period of gaseous exchange determination followed after an adjustment period of 2–3 hours. The 2–3 hours were found to be adequate for the animals to produce the heat required under the new established temperature. The temperature was lowered again after the end of the two-day period and gaseous measurement started after 2–3 hours. This procedure was repeated until the temperature was about 8 °C, and after the period of declining temperatures the same trials were performed with temperatures changing in a reverse direction, up to 18–19 °C because in the meantime the animals had grown and had a lower limit of the thermoneutrality traject and therefore required a relatively lower temperature. The whole sequence was repeated until the animals weighed 80–100 kg. By following this experimental scheme a cyclical change in environmental temperature was achieved to avoid possible adaptation to cold conditions. In the literature these adaptations to cold conditions have been described. The cyclical change is more or less in accordance with the temperature fluctuations within 24 hours in practice. The animals were fed according to the normal feeding standards in usual use in The Netherlands (CENTRAAL VEEVOEDER BUREAU).

The singly housed animals were kept in metabolism cages of which two were placed together in one respiration chamber, whereas the group of 4–5 animals was housed in a pen built inside the chamber. Both housing systems had a wooden floor.

To obtain information on the energy balances the digestibility and metabolisability of the feed was determined 3 or 4 times with the single housed animals at 18–20 °C during periods of one week each in the course of the fattening period. The results of these determinations were applied to the other periods with single housed pigs and also to the experiments with groups of animals. The pigs in the groups were of the same weight and received the same amount of the same feed. The determination of metabolisable energy with groups of pigs was, of course, hardly possible and because of this reason the results obtained with the single housed animals were used.

Analysis of the errors made in the determination showed that this procedure of reducing the number of metabolisability determinations only slightly increases the inaccuracy of the results of balance trials provided that dry matter of the same feed was determined for every ration the animals received. Therefore during each part of the fattening period (20–50 kg and 50–90 kg) the feed was the same.

Since in the literature many balance experiments with grown-up pigs (FINGERLING, NEHRING) and growing pigs housed singly (LUND, BREIREM, LUDVIGSEN and THORBEK) are recorded it was decided also to use these data in the computations on the relation between heat production, feed-intake and metabolic weight in the zone of the thermoneutrality with such equations as

$$H = (1-a)\ ME + ak_1W^p \qquad (1)$$

$$H/W^p = (1-a)\ ME/W^p + ak_1 + bW \qquad (2)$$

In these equations:

H = heat production in kcal/animal. day;

ME = metabolisable energy intake in kcal/animal. day;

W = body weight in kg;

a, b, p and k_1 are coefficients;

k_1 represents the maintenance heat production and is calculated from $\frac{ak_1}{a}$

The computations with the equation (see Chapter 6) showed that the best value of p in these trials could be found between 0.50 and 0.70 for pigs above 50 kg and between 0.80 and 0.90 for animals below 50 kg. The differences in goodness of fit (R^2) with $p = 3/4$, however, were very small.

The computations of the literature trials also suggested that p may be lower than 3/4 in mature animals and 3/4 or higher in growing animals of 20–100 kg. In general R^2 from equation (1) was between 0.77 and 0.99 in the results of these trials and between 0.85 and 0.99 in results of trials from the literature. It was concluded that $p = 3/4$ can be used without much hazard to express metabolic weight, especially when small weight ranges are concerned. Further the computations show a significant influence of age which in some of the literature trials had been taken as the variable instead of weight. No influence of weight (except in one case) in the present material for 20–50 kg or 50–90 kg was found. From those literature data which had a varying amount of $ME/W^{3/4}$ (NEHRING)

1–a was found to be 0.30 and this value was also used in the other trials from the literature in which a much smaller variation in feeding level was present. The by this method computed maintenance requirement (= maintenance heat production computed from ak_1/a) was between 60 and 92 kcal $ME/W^{3/4}$ for animals above 100 kg and between 100–110 kcal $ME/W^{3/4}$ for animals between 20 and 90 kg. From the results obtained with formula (2) without the term bW 1–a was found also to be about 0.30 in the trials with the highest variation in feeding level ($ME/W^{3/4}$).

When again 1–a was assumed to be 0.30 the computed maintenance requirement was slightly higher than in the literature trials. This value however was the same in trials with single pigs and in those with groups of animals. Although there were consistent differences in these values between the various pairs of singly housed animals and also between the various groups of animals, the average for animals of 20–50 kg was about 122 kcal $ME/W^{3/4}$ and for animals of 50–90 kg about 116 kcal $ME/W^{3/4}$.

Most of the presented experiments, however, were carried out at temperatures below the thermoneutral zone. Hypothetically a linear relationship between critical temperature of an animal and the weight and feedintake could be expected. Moreover the increase of heat production below the critical temperatures was assumed to be linear with the deviation from the critical temperature. To compute this relation the following regression equations were used:

$$H/W^p = (1-a)\ ME/W^p + bW + e(Tcr-T) + f\Delta t + ak_1 \quad (3)$$

$$H/W^p = bW + e(Tcr - T) + f\Delta t + ak_1 + 160 \quad (4)$$

and

$$Tcr = k_2 - cW - d\ ME/W^p \qquad \text{(for formula (3))}$$

$$Tcr = k_2 - cW \quad \text{(for formula (4))}$$

in which H, W and ME represent heat production per day in kcal, body weight in kg and metabolisable energy in kcal respectively; Tcr = critical temperature in °C, T = temperature in °C and t is temperature difference in °C between the actual temperature in the chamber and the temperature in the chamber during the preceding two days. k_1, k_2, b, d, a, c, e and f are coefficients. The value 160 refers to the heat production within the zone of thermoneutrality at the highest feeding level (about 250–270 kcal $ME/W^{3/4}$) found.

In the experiments belonging to this kind of temperature trial the feeding level was kept as constant as possible. Therefore the results obtained with equation (3) and (4) were compared. Regression equations according to (3) and (4) were computed from data obtained with each pair and each group of animals, when using different values of k_2 and c in Tcr for formula (4). It was found that in animals below 50 kg the lowest residual standard deviations were obtained with $k_2 = 21$ and $c = 0.1$. This indicated that the critical temperature at a constant feeding level i.e. a level giving a thermoneutral heat production of 160 kcal/$W^{3/4}$, could be computed with 21–0.1 W for animals housed singly. With groups of pigs 20–0.1 W fitted as well as 21–0.1 W. Therefore the critical temperature in groups may be equal or only slightly less than in single animals.

In pigs from 50–90 kg also the values 20 and 21 for k_2 were found to give the best results with groups and singly housed pigs and c could be considered to be somewhat higher than 0.1 i.e. 0.15.

So probably the decrease in Tcr with decreasing body weight is somewhat faster in the animals above 50 kg. No significant influence of weight in equation (4) was found. Further the value of e in (3) and (4) refers to the effect of temperature below the critical level on heat production an effect which differed considerably between pigs housed singly or in groups. Between the different pairs of single pigs and groups significant different values of e were also obtained. As an average the single housed animals produced about 3.5–5 kcal $H/W^{3/4}$ extra per °C below the critical whereas in groups this effect was 0.8–1 kcal $H/W^{3/4}$. This means that groups of pigs, kept in this way, saved about 70–80% of the extra heat required below the critical temperature compared with the single housed animals merely by huddling.

From computations with equation (3) and (4) it was found that the direction of temperature change had in some cases a significant influence. Especially in pigs kept in groups the heat production increased with decreasing temperatures. Animals kept in groups produced below the critical temperature often more heat at the same temperature when they had been kept during the preceding two day period at a higher temperature than when they had been kept that preceding two-day period at a lower temperature. Perhaps this resulted from the fact that the animals were somewhat more restless due to looking for a better place in the huddled group.

The energy gain of the single animals measured with animals weighing 20–50 kg and at different temperatures was distinguished as fat and protein. The low temperatures hardly affected the protein deposition of single animals of 20–50 kg but considerably reduced their fat deposition. The animals obviously mobilised body reserves to meet the required heat production while they still gained protein.

In the discussion it has been pointed out that the amount of feed required to meet the extra heat necessary at low temperatures should be determined with animals kept in groups. Determination of critical temperature, however, can be made with singly-housed animals. Furthermore investigations will be necessary to study the influence of temperature on heat production of groups of pigs under different housing systems e.g. floors. The influence of temperature on the composition of body weight gain in groups of pigs has also to be investigated further.

SAMENVATTING

De laatste jaren wordt steeds meer aandacht gevraagd voor de ventilatie in varkensmeststallen en voor de invloed van het stalklimaat op de groei van mestvarkens. De kennis over de warmte- en waterdampproduktie en over de invloed van de temperatuur op de groei van mestvarkens is echter nog lang niet volledig. Om in deze materie meer inzicht te krijgen werd met behulp van twee nieuwe respiratieklimaatcellen op de afdeling Fysiologie der Dieren van de Landbouwhogeschool onderzoek gedaan naar de invloed van de temperatuur op de energiestofwisseling van groeiende mestvarkens. Deze dieren werden, hetzij individueel in een verteringsbox en met 2 boxen in een cel, hetzij in een groep van 4 à 5 in een hok in de respiratiecel geplaatst.

Het onderzoek werd verricht op de afdelingen Fysiologie der Dieren en veeteelt van de Landbouwhogeschool. De dieren in de respiratiecel werden gedurende de gehele mestperiode (van 20–90 kg) gehouden onder omstandigheden die zoveel mogelijk op praktijkomstandigheden werden afgestemd. Aan het begin van de proef werden de varkens in de cel geplaatst.

Na een gewenningsperiode van 5 à 6 dagen bij 23°–24°C werd begonnen met de bepaling van de warmteproduktie, door middel van de meting van CO_2 en CH_4 produktie en O_2 konsumptie, welke metingen steeds gedurende twee dagen werden gedaan. Na de eerste meetperiode van 2 dagen werd de temperatuur 2–3°C verlaagd en na enkele uren van aanpassing (2 à 3 uur) werd opnieuw gestart met de metingen. Na 2 dagen werd opnieuw de temperatuur verlaagd, etc. Deze procedure werd vervolgd tot een temperatuur van 8°C was bereikt. Na de proefperiode bij 8°C werden dezelfde metingen verricht na temperatuursstijgingen van 2 à 3°C. Bij 18 à 19°C en niet bij 23°C à 24°C werd weer begonnen met metingen bij dalende temperatuur omdat de dieren intussen zwaarder waren geworden en dus ook de kritieke temperatuur lager was geworden. De metingen op deze manier werden voortgezet tot de dieren 80 à 100 kg wogen. De laagste temperatuur werd nu echter ook iets lager nl. tot 5°C en de hogere temperatuur ongeveer 17–18°C.

De korte proefperioden van 2 dagen en de overgang van enkele uren werden aangehouden om te voorkomen dat de dieren zich op langere termijn zouden aanpassen en omdat ook in de praktijk temperatuursveranderingen van enkele °C in de stallen in enkele uren kunnen voorkomen. De dieren werden gevoerd volgens de normen van het centraal veevoederbureau (C.V.B.).

Beide categorieën dieren, alleen of in de groep, ontvingen bij gelijk gewicht dezelfde hoeveelheid van hetzelfde voer. Om informatie te verkrijgen over de verteerbaarheid en beschikbaarheid van de bruto energie in het voer werden in verteringsboxen balansproeven uitgevoerd. Met elk dier werd aan het begin en het einde van de periode 20–50 kg en ook tijdens de periode 50–90 kg bij temperaturen van 18°–20°C gedurende een week in de verteringsboxen deze balansen gemeten. De resultaten van deze balansproeven, i.c. beschikbaarheid van energie in het voer, werden gebruikt voor de berekening van de opname aan beschikbare energie tijdens de temperatuursproeven welke in de periode die volgde op de energie-balansproef werden gedaan. De gegevens werden ook gebruikt voor de proeven met groepen dieren, die hetzelfde voer ontvingen en waarmee de bepaling van beschikbaarheid van de energie in het voer moeilijk uitvoerbaar is. Wel werd steeds voor elke proef het droge-stof gehalte van het voer bepaald.

In de literatuur worden vele balansproeven vermeld met oudere dieren (FINGERLING en NEHRING) en met groeiende dieren, die alleen in een box gehuisvest waren (LUND, BREIREM, LUDVIGSEN en THORBEK). Op de resultaten van de proeven werd een statistische bewerking toegepast, aan de hand van hetzelfde model dat ook voor de resultaten van de eigen proeven werd gebruikt, om de relatie tussen warmteproduktie, voeropname en metabolisch gewicht weer te geven. Voor de berekeningen werd uitgegaan van:

$$H = (1-a)(ME - k_1W^p) + k_1W^p$$

dit is gelijk aan:

$$H = (1-a)\,ME + ak_1W^p \tag{1}$$

en

$$H/W^p = (1-a)\,ME/W^p + ak_1 + bW \tag{2}$$

waarin H = warmteproduktie in kcal/dag;
ME = beschikbare energie in kcal/dag;
W = gewicht in kg;
W^p = metabolisch gewicht in kg;
a, b, k_1, p zijn coëfficiënten.

In formule (1) is k_1 de onderhoudswarmte (is onderhoudsbehoefte) per kg W^p en $(1-a)(ME - k_1W^p)$ de produktiewarmte. In formule (2) werd gewicht als variabele toegevoegd om na te gaan of gewicht invloed heeft op de warmteproduktie per metabolisch gewicht door verschil in activiteit e.d. Uit de berekening met formule (1) volgde, dat de beste waarde van p voor de eigen proeven met dieren boven de 50 kg tussen 0.5 en 0.7 lag en een waarde groter dan 0.75 voor dieren beneden 50 kg. Uit de berekeningen met cijfers uit de literatuur blijkt ook dat p voor jonge dieren mogelijk hoger is dan voor oudere dieren.

De verschillen in restspreiding van H na berekening met formule (1) bij verschillende waarden van p waren echter klein, hetgeen op grond van het kleine gewichtstraject tussen 20 en 50 kg of tussen 50 en 90 kg ook wel verwacht kon worden. In de berekening van de warmteproduktie uit de literatuurcijfers volgens formule (1) was R^2 (mate van aanpassing van regressie) meestal tussen 0.85 en 0.99, terwijl bij het eigen materiaal R^2 tussen 0.77 en 0.99 lag. Uit deze berekeningen werd geconcludeerd dat $p = 3/4$ zonder veel bezwaar kan worden gebruikt om het metabolisch gewicht voor dieren van 20-50 en van 50-90 kg gewicht weer te geven in W^p, vooral ook omdat het gaat om een vrij klein gewichtstraject.

Bij de berekeningen met cijfers uit de literatuur volgens formule (2) werd een significante invloed van gewicht op de warmteproduktie per kg metabolisch gewicht gevonden in een gewichtstraject van 20-100 kg. De warmteproduktie per kg metabolisch gewicht ($W^{3/4}$) werd lager met toenemend gewicht (leeftijd) van de dieren bij gelijke voederopname in kcal beschikbare energie per kg metabolisch gewicht ($ME/W^{3/4}$).

In het eigen onderzoek werd geen invloed van gewicht op de warmteproduktie per kg metabolisch gewicht gevonden in de gewichtstrajecten 20–50 en 50–90 kg, behalve bij enkele dieren.

Uit de proeven van NEHRING, waarbij het voederniveau erg varieerde, werd voor (1–a), dit is de toename in warmteproduktie per kcal ME boven onderhoud, een waarde gevonden van 0.30. Deze waarde werd ook gebruikt in andere proeven uit de literatuur waarbij 1–a zelf veel onnauwkeuriger kon worden geschat omdat het voederniveau minder varieerde.

Voor de berekeningen werd voor 1–a de waarde 0.30 aangenomen, dat wil zeggen dat de efficientie van beschikbare energie voor produktie 0.70 is. Uit de literatuurcijfers betreffende oudere dieren boven 80–100 kg werd met $k_1 = \frac{ak_1}{a}$ een onderhoudsbehoefte berekend tussen 60 en 92 kcal $ME/W^{3/4}$. Uit de cijfers welke in de literatuur met jongere dieren van 20–100 kg werden verkregen werd een onderhoudsbehoefte van 100–110 kcal $ME/W^{3/4}$ berekend.

Uit de cijfers van het eigen onderzoek werden bij de proeven met de grootste spreiding in voederniveau ($ME/W^{3/4}$) voor 1–a ook waarden in de buurt van 0.30 gevonden. Voor alle proeven werd daarom een constante waarde van 0.30 aangenomen. De met deze 0.30 berekende waarden voor de onderhoudsbehoefte lag wat hoger (115–123 kcal $ME/W^{3/4}$) dan bij de proeven uit de literatuur met de jongere dieren. De aldus berekende onderhoudsbehoeften waren voor groepen dieren en individueel gehuisveste dieren gelijk. Evenwel werden tussen de paren individuele dieren en tussen de groepen dieren duidelijke verschillen waargenomen. Gemiddeld was de onderhoudswarmte (= onderhoudsbehoefte) voor dieren beneden 50 kg 122 kcal $ME/W^{3/4}$ en voor dieren boven 50 kg was deze waarde 116 kcal $ME/W^{3/4}$.

Het grootste deel van de hier beschreven proeven werd uitgevoerd bij omgevingstemperaturen beneden de thermoneutrale zone, dit is beneden de onderste kritieke temperatuur. Deze kritieke temperatuur daalt met toenemend gewicht van de dieren. Bovendien zal de extra warmteproduktie per °C onder deze kritieke temperatuur evenredig zijn met het verschil van de kritieke temperatuur met de omgevingstemperatuur.

Voor de berekening van de extra warmteproduktie beneden de kritieke temperatuur werden de volgende formules gebruikt:

$$H/W^{3/4} = (1-a)\ ME/W^{3/4} + bW + e\,(Tcr\text{-}T) + f\Delta t + ak_1 \tag{3}$$

$$H/W^{3/4} = bW + e(Tcr\text{-}T) + f\Delta t + ak_1 + 160 \tag{4}$$

$$Tcr = k_2 - cW \text{ (voor formule 4)}$$

$$Tcr = k_2 - cW - d\ ME/W^{3/4} \text{ (voor formule 3)}$$

In deze formules zijn H, W en ME respectievelijk warmteproduktie in kcal, lichaamsgewicht in kg en beschikbare energie opname in het voer in kcal per dag, $W^{3/4}$ is kg metabolisch gewicht, Tcr is kritieke temperatuur in °C, T = celtemperatuur in °C, Δt is temperatuursverschil tussen twee opeenvolgende warmtemetingen, k_1, k_2, a, b, c, d, e en f zijn coefficienten. Formule (4) werd toegepast om de kritieke temperatuur en het effect van temperaturen beneden de kritieke temperatuur op de warmteproduktie te schatten. Deze schatting is onafhankelijk van het voederniveau maar wel werden de berekeningen verricht uitgaande van een konstante bepaalde thermoneutrale warmteproduktie (160 kcal/$W^{3/4}$). Het getal 160 geeft dus aan dat voor berekeningen met deze formule (4) alleen resultaten van warmtemetingen boven 160 kcal/$W^{3/4}$ zullen worden gebruikt. Dit getal is de thermoneutrale warmteproduktie die behoort bij de hoogste voederopnamen (260–270 kcal ME/$W^{3/4}$). Of het voederniveau invloed heeft op de extra warmteproduktie bij lage temperatuur in deze proeven werd vergeleken door de waarden van de coefficienten uit berekeningen via formule (3) en (4) na te gaan.

Bij de berekeningen met formule (3) werden alle proefgegevens gebruikt die beneden de kritieke temperatuur werden verzameld en hiermee kon na substitutie van de Tcr alleen het effect van temperaturen beneden de kritieke temperatuur worden berekend. Berekeningen volgens beide formules werden uitgevoerd voor de proeven bij lage temperatuur elk paar of groep dieren apart en ook nog afzonderlijk voor alle dieren boven en onder de 50 kg.

In berekeningen met formule (4) werden voor de waarde van Tcr verschillende waarden voor k_2 en c ingevuld. Die waarden voor k_2 en c die de laagste restfout gaven werden geacht de beste schatting te geven voor de kritieke temperatuur. Bij dieren beneden 50 kg bleken $k_2 = 21$ en $c = 0{,}1$ het beste de kritieke temperatuur weer te geven. Dit betekende dat de kritieke temperatuur bij een thermoneutrale warmteproduktie van 160 kcal/$W^{3/4}$ berekend kan worden uit $21-0{,}1$ W voor dieren die individueel gehuisvest zijn en lichter zijn dan 50 kg. Bij groepen varkens beneden 50 kg gaf $20-0{,}1$ W een gelijk resultaat. De kritieke temperatuur van groepen dieren zal dan ook slechts weinig lager zijn dan van dieren alleen in boxen. Uit berekeningen met de proefresultaten verkregen van varkens van 50–90 kg werd gevonden dat voor k_2 zowel 20 als 21 een gelijke restspreiding gaven, terwijl c nu wat hoger was nl. 0,15. Mogelijk daalt de kritieke temperatuur van dieren boven de 50 kg iets sneller met de toename in gewicht dan beneden de 50 kg. Met berekeningen volgens formule (4) werd geen significante invloed gevonden van gewicht op warmteproduktie.

Het effect van temperaturen beneden de kritieke temperatuur op de warmteproduktie kan worden weergegeven door de waarde e in formule (3) en (4). De waarde van e uit de berekeningen volgens formule (3) en (4) was niet erg verschillend. Uit de berekeningen blijken wel erg grote verschillen in effect van temperaturen beneden de kritieke temperatuur op de warmteproduktie te bestaan wanneer groepen dieren en alleen gehuisveste dieren worden vergeleken. Gemiddeld produceerden dieren die alleen werden gehuisvest 3,5–5 kcal H/$W^{3/4}$ extra per °C onder de kritieke temperatuur, dit is 2–3 % van de thermoneutrale warmteproduktie. Bij groepen was deze waarde 0,8–1 kcal H/$W^{3/4}$ of wel 0,5–0,8 % van de thermoneutrale warmteproduktie. Dit betekent dat groepen varkens ongeveer 70–80 % kunnen besparen van de extra warmteproduktie die de dieren nodig hebben wanneer ze alleen in een verteringsbox gehuisvest zijn.

De temperatuursverandering zelf, Δt in formule (3) en (4), bleek bij sommige groepen dieren een significante invloed op de warmteproduktie te hebben. Wanneer Δt negatief was werd bij groepen dieren gemiddeld een hogere warmteproduktie gevonden dan bij een positieve Δt en bij gelijke temperatuur. Mogelijk zijn de dieren na temperatuursdaling iets minder rustig.

De energieaanzet in vet en eiwit werd bij de dieren in de box bij verschillende temperaturen apart bepaald. Lage temperaturen hadden nauwelijks invloed op de eiwitaanzet maar wel op de vetgroei. De dieren mobiliseerden lichaamsreserves om voldoende warmte te kunnen produceren, terwijl de eiwitgroei ondertussen doorging.

In de discussie is gesteld dat proeven om de extra voederkosten bij lage temperatuur onder praktijkomstandigheden te bepalen behoren te geschieden met groepen dieren omdat de effekten bij individuele gehuisveste dieren heel anders zijn. De kritieke temperatuur kan echter wel met individuele dieren worden bepaald. Onderzoek is noodzakelijk om de invloed van de temperatuur bij varkens na te gaan op verschillende soorten vloeren. Het is ook wenselijk dat wordt nagegaan hoe de invloed is van de temperatuur op de samenstelling van de groei bij groepen dieren.

REFERENCES

BADER R. A., J. W. ELIOT and D. E. BASS. Hormonal and renal mechanisms of cold diuresis. J. Appl. Physiol. **4** (1952) 649.

BLAXTER K. L., The energy metabolism of ruminants. London, 1962. Hutchinson and Co Ltd.

BOND T. E., C. F. KELLY and H. HEITMAN Jr. Heat and moisture loss from swince. Agric. Engrs. **33** (1952) 148-152.

BOND T. E., C. F. KELLY and H. HEITMAN Jr. Effect of diurnal temperature on heat loss and well-being of swine. Trans. Am. Soc. agric. Engrs. **6** (1963) 132-135.

BOND T. E., H. HEITMAN Jr. and C. F. KELLY. Effects of increased air velocities on heat and moisture loss and growth of swine. Trans. Am. Soc. agric. Engrs. **8** (1965) 167-169.

BRAUDE R. G., K. G. MITSCHELL, P. FINN-CELSEY and V. M. OWEN. The effect of light on fattening pigs. Proc. Nutr. Soc. **17** (1958) 38.

BREIREM K. Under søgelser over væksten hos svin II. Energie omsætningen hos svin. 162 Beretning forsøgslaboriet., København (1935) 277 p.p.

BRODY S. Bioenergetics and growth. Reinhold Publ., New York 1945.

BROUWER E. Report of sub-committee on constants and factors. 3rd symposium on energy metabolism, Troon, Scotland. EAAP publ. **11** (1965) 441-443.

BURTON A. C. The application of the theory of heat flow to the study of energy metabolism. J. Nutrition **7** (1934) 497.

CAPSTICK J. W. and T. B. WOOD. The effect of change of temperature on the basal metabolism of swine. J. Agric. Sci., Camb. **12** (1922) 257-268.

CENTRAAL VEEVOEDER BUREAU IN NEDERLAND: Voedernormen voor de landbouwhuisdieren en voederwaarde der veevoeders. 24th. ed. 1965.

COMBERG G., H. F. WOLFERMANN und H. RUNDFELDT. Der Einfluss von Temperatur und relativer Luftfeuchtigkeit auf Gewichtszunahme und Futterverwertung bei Mastschweinen. Zeitschr. f. Tierz. u. Zücht. Biol. **83** (1967) 240-259.

COSTA G., L. ULRICH, F. KANTOR and J. F. HOLLAND. Production of elemental nitrogen by certain mammals including man. Nature, Lond., **218** (1968) 546-551.

DAMMERS J. Verteringsstudies bij het varken. Thesis University of Leuven 1964.

DEIGHTON T. A study of the metabolism of two breeds of pig. J. Agric. Sci., Camb. **19** (1929) 140-184

DEIGHTON T. The determination of the surface area of swine and other animals. J. Agric. Sci., Camb **22** (1932) 418-449.

DEIGHTON T. A study of the fasting metabolism of various breeds of hog. I. Introductory, age, weight and length data. J. Agric. Sci., Camb. **24** (1934) 321-334.

DEIGHTON T. A study of the fasting metabolism of various breeds of hog. II. Body, temperature measurements. J. Agric. Sci., Camb. **25** (1935) 180-191.

DEIGHTON T. A study of the fasting metabolism of various breeds of hog. III. Metabolism and surface area measurements. J. Agric. Sci., Camb. **27** (1937) 317-331.

DIN., 18910 from Stall klima; Planung Grundlagen, Berechnungs- und Bemessungs Grundlagen. Einfluss von Tierbesatz und Raumgrösse. ALB Schriftenreihe **27** (1966) 137 p.p.

Es A. J. H. van. Gas analysis in open circuit respiration chambers. I symp. on energy metabolism Wageningen. EAAP publ. **8** (1958) 132-137.

Es A. J. H. van. Between-animal variation in the amount of metabolisable energy required for the maintenance of cows. Versl. Landbouwk. Onderz. 67.5 (1961).

Es A. J. H. van. Labour-saving methods for energy balance experiments with cattle; description of equipment and methods used. Neth. J. Agric. Sci. **14** (1966) 32-46.

Es, A. J. H. van, H. J. NIJKAMP, E. J. van WEERDEN and K. K. van HELLEMOND Energy, Carbon and Nitrogen Balance Experiments with Veal Calves. 4th Symp. on Energy Metabolism, Warsaw. EAAP publ. **12** (1969) 197-202.

Es A. J. H. van. Handbuch der Tierernährung Band II Parey, Berlin in press.

FINGERLING G., A. KÖHLER, Fr. REINHARDT und R. DIETRICH. Untersuchungen über den Stoff- und Energieumsatz wachsender Schweine. Die Landw. Versuchsstat. **84** (1914) 149-230.

FINGERLING G. Untersuchungen über den Stoff- und Energieumsatz wachsender Schweine Die Landw. Versuchstat. **113** (1932) 273–318.

FINGERLING G. Der Nährwert der Zuckerrüben. Die Landw. Verscuhsstat. **113** (1932) 1–68.

FINGERLING G. Die Stärkewert des Gerstensschrotes. Die Landw. Versuchsstat. **116** (1933) 1–63.

FINGERLING G., F. HONCAMP. Uber den Wert der Holzzuckerhefe als Futtermittel. Die Landw. Versuchsstat. **118** (1935) 263–353.

FINGERLING G. Die Nährwirkung der Runkelrüben beim Schwein. Die Landw. Versuchsstat. **121** (1934) 34–141.

FINGERLING G. Untersuchungen über den Stoff- und Energieumsatz wachsender Schweine. Zeischr. Tierern. Futtermittelk. **1** (1938) 193–240.

FINGERLING G., P. EISENKOLBE, Br. HIENTZSCH, M. JUST und G. KNAUT. Untersuchungen über den Stoff- und Energieumsatz wachsender Schweine. Zeitschr. Tierern. Futtermittlk. **1** (1938) 13–40.

FINGERLING G., P. EISENKOLBE, Br. HIENTZSCH, M. JUST und G. KNAUT. Untersuchungen über den Stoff- und Energieumsatz wachsender Schweine. Zeitschr. Tierern. Futtermittelk. **6** (1943) 196–221.

FINGERLING G., P. EISENKOLBE, Br. HIENTZSCH, M. JUST, G. KNAUT und K. REIFGERST. Der Nährwert der Gehaltsrüben in Vergleich der Maisenrüben. Zeitschr. Tierern. Futtermittelk. **7** (1944) 22–103.

FINGERLING, G., Br. HIENTZSCH, K. REIFGERST, G. KNAUT und H. KUNZE. Der Nährwirkung des Maisschrotes beim Schwein. Zeitschr. Tierern. Futtermittelk. **8** (1944) 1–24.

FINGERLING G., Br. HIENTZSCH, K. REIFGERST, G. KNAUT und H. KUNZE. Der Nährwert von Topinamburknollen beim Schwein. Zeitschr. Tierern. Futtermittelk. **8** (1944) 122–211.

FULLER M. F. The effect of environmental temperature on the nitrogen metabolism and growth of the young pig. Br. J. Nutr. **19** (1965) 531–546.

GROSSE F. und H. PFEIFFER. Der Einfluss der Umgebungstemperatur auf der Ansatzleistung, der Futterverbrauch und die Energieverwertung beim Schwein. Archiv für Tierernährung **13** (1963) 1–7.

HAARTSEN P. L. De isolatie van stalvloeren. I.L.B. publ. no. 35 Wageningen (1967).

HICKS A. M. Physiological responses of growing swine to low temperatures. Univ. of Saskatchewan 1966 Ph. D. Thesis.

HEITMAN H. Jr., C. F. KELLY and T. E. BOND. Ambient air temperature and weight gain in swine. J. Anim. Sci. **17** (1958) 62–67.

HOLME D. W. and W. E. COEY. The effects of temperature and method of feeding on the performance of bacon pigs. Anim. Prod. **8** (1966) 360–365.

HOLMES C. W. Studies on the effects of environment on heat losses from pigs. Queens Univ. of Belfast 1966 Ph. D. Thesis.

HOLMES C. W. and L. E. MOUNT. Heat loss from groups of growing pigs under various conditions of environmental temperature and air movement. Anim. Prod. **9** (1967) 435–452.

HOLMES C. W. Heat losses from young pigs at three environmental temperatures, measured in a direct calorimeter. Anim. Prod **10** (1968) 135–147.

INGRAM D. L. Evaporative cooling in the pig. Nature, London **207** (1965) 415–416.

INGRAM D. L. The effect of environmental temperature on heat loss and thermal insulation in the young pig. Res. Vet. Sci. **5** (1964) 357–364.

IRVING L., L. J. PEYTON and M. MONSON. Metabolism and insulation of swine as bare-skinned mammals. J. Appl. Physiol. **9** (1956) 421–426.

KALICH J. Bedeutung der Wärme für die Ferkelaufzucht und Schweinemast. Bayrisches Landw. Jahrbuch 39 (1961) 41–52.

KASUBIEWICZ C. Reaction and adaption of pigs to the cold. Med. Wet. **19** (1962) 422.

KIELANOWSKI J. Estimates of the energy cost of protein deposition in growing animals. 3rd symposium on energy metabolism, Troon, EAAP publ. **11** (1965) 13–20.

KLEIBER M. The fire of life. An introduction into animal energetics. John Wiley and sons inc. New York, London 1961 454 p.p.

KLEIBER, M. Metabolic body size. 3rd Symposium on energy metabolism, Troon, Scotland. EAAP publ. **11** (1965) 427–435.

KLOČKOVA, A. J. und A. M. EMME. Der Einfluss der photoperiodischen Bedingungen auf Schweine. 1961 cited by NEUMANN and GRIEB (1968).

KNIBBE, R. Der Nährwert der Nacktgersten im Vergleich zu bespelzten Gersten beim Schwein. Die Landw. Versuchsstat. **117** (1933) 131–216.

KOTARBINSKI, M. and J. KIELANOWSKI. Energy balance studies with growing pigs by the comparative slaughter technique. 4th symposium on energy metabolism, Warsaw. EAAP publ. **12** (1969) 299–310.

LUCAS, J. A. M. and A. F. C. CALDER. The interaction between environment and level of feeding for pigs from weaning to bacon weight. J. Agric. Sci., Camb. **46** (1955) 56–73.

LUDVIGSEN, J. and G. THORBEK. Virkingen af aureomycin på stofskiftet hos svin og stofskiftet hos galte og sogrise. Varme productionen hos svin på forskellige alderstrin med saerlig henblick på staldventilation. 283 Beretning forsøgslaboriet København (1955) 1–110.

LUND, A. Experimentelle undersøgelser vedrørende svinets avitaminose A. 180 Beretning forsøgslaboriet København (1938) 1–304.

MORRISON, S. R., T. E. BOND and H. HEITMAN. Skin and lung moisture loss from swine. Trans. Am. Soc. agric. Engrs. **10** (1967) 691–692.

MOUNT, L. E. The metabolic rate of the new born pig in relation to environmental temperature and to age. J. Physiol. Lond. **147** (1959) 333–345.

MOUNT, L. E. The influence of huddling and body size on the metabolic rate of the young pig. J. agric. sci., Camb. 55 (1960) 101–105.

MOUNT, L. E. The thermal insulation of the newborn pig. J. Physiol. Lond. **168** (1963) 698–705.

MOUNT, L. E. The tissue and air components of thermal insulation in the newborn pig. J. Physiol. Lond. **170** (1964) 286–295.

MOUNT, L. E. and D. L. INGRAM. The effects of ambient temperature and air movement on localised sensible heat loss from the pig. Res. vet. Sci. **6** (1965) 84–91.

MOUNT, L. E. The effect of wind-speed on heat production in the newborn pig. Q. J. Exp. Physiol. **51** (1966) 18–26.

MOUNT, L. E. The heat loss from newborn pigs to the floor. Res. Vet. Sci. **8** (1967) 175–186.

MOUNT, L. E., C. W. HOLMES, I. B. START and A. J. LEGGE. A. direct calorimeter for the continous recording of heat loss from groups of growing pigs over long periods. J. agric. Sci., Camb. **68** (1967) 47–55.

MOUNT, L. E. and Jane V. WILLMOTT. The relation between spontaneous activity, metabolic rate and the 24-hour cycle in mice at different environmental temperatures. J. Physiol., Lond. **190** (1967) 371–380.

MOUNT, L. E. The Climatic Physiology of the Pig. Monographs of the Physiological Society no. 18, 1968 London.

MANGOLD, D. W. Effect of air temperature on energy utilisation of growing finishing swine. Iowa State University Science and Technology 1965 Ph. D. Thesis.

NEHRING, K. und A. WERNER. Festschrift Möckern I Wiss. Abt. Deutschen Akad. Landw. Berlin Bd 5/1 (1953) p.p. 350.

NEHRING, K., R. SCHIEMANN, L. HOFFMANN und W. KLIPPEL. Die Verwertung der Futterenergie in Abhängigkeit vom Ernährungsniveau. Versuche met Schweine. Arch. Tierernähr. **10** (1960) 275–320.

NEUMANN, W. und G. GRIEB. Einfluss der Dunkelstallhaltung auf die Mast van Schweinen und Rindern sowie auf einige Leistungen von Zuchtschweinen. Tierzucht **22** (1968) 354–359.

NIELSEN, A. JUST. Experiences with application of computer processing in physiological investigations. International Summer School on biomathematics and data processing in animal experiments, Elsinore 1968 13 p.p.

NIJKAMP, H. J. Determination of urinary energy- and carbon output in balance trials. Z. Tierphysiol. Tierernähr. u. Futtermitt. **25** (1969) 1–9.

OGINK, G. J. A. De invloed, bij groeiende mestvarkens ,van het voederniveau op de verteerbaarheid van het voeder, de energie benutting en de netto formule van Nehring. Scriptie

Fys. d. Dieren, Wageningen (1969) 31 p.p.

OSINGA, A. Het meten van de isolerende waarde van vloerconstructies en de warmteafgifte van varkens aan de ligplaats. Landb. k. Tijdschr. **75** (1963) 901–912.

OSLAGE, H. J. Untersuchungen zum Stoff- und Energieansatz wachsender Schweine. Landbauforsch., Völkenrode **15** (1965) 107–138.

PFEIFFER, H. Die Beeinflüssung der Mast und Schlachtleistungen verschiedener Schweinerassen durch Temperatur, relative Luftfeuchtigkeit und Luftdruck. Kühn-archiv (1962) no. 76 pp. 347–423.

PFEIFFER, H. Die Quantitative und Qualitative Schlachtkörperzusammensetzung sowie der Nährstoffansatz bei Schweinen unter verschiedenen Haltungsbedingungen. Kühn-archiv (1968) no. 82 pp. 1–68.

PIATKOWSKI, B. Untersuchungen über den Einfluss niedriger Umgebungstemperaturen auf den Stoffwechsel wachsender Schweine. Archiv für Tierernährung **8** (1958) 161–181.

PULLAR, J. C. Direct calorimetry of animals by the gradient layer principle. 1st Symposium Energy Metabolism EAAP publ. **8** (1958) 95–101.

PULLAR, J. D. Energy metabolism, in Progress, in Nutrition and Allied Sciences. ed. D. P. Cuthbertson (1963) 187–197, Oliver and Boyd Edinburgh.

PUTTEN, G. van. Een onderzoek naar staartbijten bij mestvarkens. Amsterdam, 1968, Thesis.

SAINSBURY, D. W. B. Studies on the environment in pighouses. University of London Ph. D. Thesis 1954 cited by Smith, 1964.

SCHIEMANN, R. Restschrift Möckern III Wiss. Abh. Deutschen Akad. Landw. Berlin Bd 5/3 (1953) 129 p.p.

SCHIEMANN, R., A. CHUDY und O. HERCOG. Der Energieaufwand für die Bildung von Körperprotein beim Wachstum nach Modellversuchen an Ratten I mitt. Versuche mit Vollei als Nährungsprotein. Arch. Tierernähr. **19** (1969) 395–407.

SEYMOUR, E. W., V. C. SPEER, D. W. MANGOLD, T. E. HAZEN and MCCALL. Effect of protein and environmental temperature on performance and carcas quality of swine. J. Anim. Sci. **21** (1962) 1013.

SIEGL, O. Untersuchungen über die Beziehungen zwischen Stalltemperatur und Mastleistungen bei Schweinen unter besonderer Berücksichtigung der in der Mastprüfungsanstalt Knau erzielten Ergebnisse II Mitteilung. Archiv für Tierzucht **3** (1960) 88–216.

SMITH, C. V. A quantitative relationship between environment comfort and animal productivity. Agr. Meteorol., **1** (1964) 249–270.

SÖRENSEN, P. H. and J. MOUSTGAARD. Der Einfluss des Stallklimas auf das Wachstum, die Futterverwertung und Schlachtqualität von Schweinen. Diskussionsbeiträge. VIII Int. Tierzuchtcongress, Hamburg 1961, vol III; 104–115.

SÖRENSEN, P. H. Influence of climatic environment on pig performance. in Nutrition of pigs and poultry. Proc. Univ. of Nottingham, 1961, 8th Easter School in Agric. Sci, Butterworths London p.p. 88–103.

STEPHENS, D. B. Oxygen consumption of piglets on concrete and straw floors at various ambient temperatures. Anim. Prod. **11** (1969) 289.

TANGL, F. Die minimale Erhaltungsarbeit des Schweines. (Stoff- und Energie umsatz in Hunger) Biochem. Z. **44** (1912) 252–278.

THORBEK, G. and L. NEERGAARD. Some remarks about instruments and methods applied to an open-circuit respiration apparatus for pigs. 3rd Symp. on Energy Metabolism, Troon Scotland EAAP publ. **11** (1965) 179–181.

THORBEK, G. Studies on the energy metabolism of growing pigs. 4th Symp. on Energy Metabolism, Warsaw EAAP publ. **12** (1969) 281–290.

VON DER HEIDE, R. und W. KLEIN. Stoff und Energie Umsatz des Schweines bei Wachtsum und Mast. Biochem. Z. **55** (1913) 195–215.

WÖHLBIER, W., M. KIRCHGESSNER und W. SCHNEIDER. Der Einfluss verschiedener Lufttemperaturen auf die Gewichtszunahme und Futterverwertung von Schweine bei der Getreideschnellmast. Archiv. für Tierernährung **8** (1958) 32–40.

WINSLOW, C. E. A., L. P. HERRINGTON and A. P. GAGGE. The determination of radiation and convection exchanges by partitional calorimetry. Am. J. Physiol. **116** (1936) 669–684.

Appendix. Results of two-day respiration experiments.

			Animals			Conditions in chamber		Kcal/animal.day				
Exp.	Number	Name	Age (days)	Weight (kg)	Metabolic weight	Temp. °C	Relative Humidity (%)	Gross energy	Metabolisable energy	Heat production	Energy gain	code*
VR 1	2	3+4	92	37.8	15.2	20.1	82	4833.5	3610.0	2069.0	1540.5	1)
VR 1	2	"	98	40.7	16.1	18.6	80	5336.6	3971.9	2375.4	1596.5	1)
VR 1	2	"	99	41.5	16.3	16.3	56	5336.6	3966.6	2674.6	1292.1	0)
VR 1	2	"	100	42.5	16.6	19.4	75	5336.6	3961.2	2458.0	1503.2	1)
VR 1	2	"	104	44.0	17.1	14.7	70	5336.6	3960.9	2837.4	1123.4	0)
VR 1	2	"	105	44.8	17.3	13.7	66	5336.6	3957.2	2882.9	1074.3	0)
VR 1	2	"	106	45.3	17.4	9.7	62	5336.6	3957.9	3201.5	756.4	0)
VR 1	2	1+2	89	32.2	13.5	20.0	82	4640.6	3463.7	1842.5	1621.1	1)
VR 1	2	"	97	35.1	14.4	18.8	86	4737.2	3519.1	2354.6	1164.5	1)
VR 1	2	"	101	36.8	14.9	14.4	80	4737.2	3511.8	2402.6	1109.2	0)
VR 1	2	"	108	42.5	16.6	17.1	85	5220.6	3879.6	2390.8	1488.8	1)
VR 1	2	"	109	43.4	16.9	16.2	89	5220.6	3877.7	2486.2	1391.5	0)
VR 1	2	"	112	45.2	17.4	16.2	80	6380.8	4739.9	2932.6	1807.3	0)
VR 1	2	"	113	46.0	17.6	15.8	87	6380.8	4741.4	2899.9	1841.5	0)
VR 1	2	"	114	47.3	18.0	15.6	82	6380.8	4737.0	2905.9	1831.2	0)
VR 1	2	"	115	48.3	18.3	16.1	78	6380.8	4732.0	3047.9	1684.1	0)
VR 1	2	"	116	49.0	18.5	17.7	79	6380.8	4733.3	2866.5	1866.8	1)
VR 1	2	"	117	49.8	18.7	16.8	84	6380.8	4740.9	2865.1	1875.8	1)
VR 1	2	"	119	50.8	19.0	16.5	72	7125.2	5288.3	3203.8	2084.5	1)
VR 1	2	"	120	51.1	19.1	16.3	77	7221.9	5362.0	3172.4	2189.5	1)
VR 1	2	"	121	52.7	19.5	16.1	79	7318.5	5431.1	3259.9	2171.2	1)
VR 1	2	"	122	53.2	19.6	17.0	84	7395.9	5486.8	3289.9	2197.0	
VR 2	2	"	127	55.0	20.2	17.6	80	7863.6	5982.0	3380.5	2601.5	1)
VR 2	2	"	128	56.2	20.5	17.5	78	8009.4	6087.2	3613.4	2473.8	1)
VR 2	2	"	135	60.9	21.8	17.6	86	8202.2	6227.1	3606.8	2620.3	1)
VR 2	2	"	137	62.1	22.1	16.9	83	8202.2	6212.9	3538.6	2674.3	1)
VR 2	2	"	138	63.0	22.3	17.1	84	8202.2	6214.1	3680.4	2533.8	1)
VR 2	2	"	142	64.2	22.6	7.4	88	8374.9	6345.6	4581.4	1764.2	0)
VR 2	2	"	145	66.4	23.2	4.3	79	8719.3	6611.0	5058.8	1552.3	0)
VR 2	2	"	148	69.0	23.9	20.3	81	8853.6	6707.3	3747.0	2960.3	1)
VR 2	2	"	152	73.1	25.0	22.2	86	9064.6	6849.8	4125.5	2724.3	1)
VR 2	2	"	155	76.0	25.7	16.5	53	9218.1	6995.2	4256.8	2738.3	1)
VR 3	2	"	186	98.8	31.3	22.1	82	9904.3	7269.5	3975.9	3293.6	1)
VR 4	2	"	189	100.3	31.7	18.9	85	10077.6	7684.1	4044.6	3639.5	1)
VR 4	2	"	193	103.2	32.3	15.3	80	10143.9	7692.1	4507.2	3184.9	1)
VR 4	2	"	197	104.8	32.7	11.1	79	10229.1	7750.7	4921.5	2829.2	1)
VR 4	2	"	201	105.5	32.9	7.0	87	10303.0	7815.5	5382.7	2432.8	0)
VR 2	2	5+6	75	19.9	9.4	17.7	84	2602.9	1987.6	1498.8	488.7	0)
VR 2	2	"	85	23.7	10.7	21.8	82	3277.7	2503.0	1612.1	890.9	1)
VR 2	2	"	88	24.6	11.0	21.5	73	3663.4	2799.5	1589.1	1210.3	1)
VR 2	2	"	90	25.4	11.3	20.3	73	3663.4	2797.2	1710.8	1086.4	1)
VR 2	2	"	92	26.0	11.5	18.8	75	3663.4	2796.7	1847.2	949.5	1)
VR 2	2	"	95	26.7	11.7	16.9	72	4049.0	3086.6	2002.3	1084.3	
VR 2	2	"	99	29.0	12.5	13.2	86	4049.0	3084.6	2164.2	920.4	0)
VR 2	2	"	102	30.8	13.1	20.5	61	4646.7	3550.8	1916.1	1634.7	
VR 2	2	"	103	32.1	13.5	22.4	64	4666.0	3561.2	2023.0	1538.2	1)
VR 2	2	"	105	33.9	14.0	26.5	78	4693.0	3591.8	2193.4	1398.4	1)
VR 3	2	"	109	35.6	14.6	18.8	64	5404.8	4120.7	2255.9	1864.8	1)
VR 3	2	"	111	37.2	15.0	15.8	75	5404.8	4110.2	2424.9	1685.2	0)
VR 3	2	"	115	38.6	15.5	13.8	72	5404.8	4108.8	2635.8	1473.1	0)
VR 3	2	"	117	39.8	15.8	11.1	68	5404.8	4104.3	2734.5	1369.8	0)
VR 3	2	"	120	41.2	16.3	9.2	79	5404.8	4112.2	2960.6	1151.6	0)
VR 3	2	"	122	42.7	16.7	22.1	75	5404.8	4129.0	2333.0	1796.1	1)
VR 3	2	"	123	43.7	17.0	17.1	76	5551.5	4241.8	2616.7	1625.1	1)
VR 3	2	"	127	45.3	17.5	14.9	73	5893.1	4460.9	2728.2	1732.7	0)
VR 4	2	"	129	46.4	17.8	11.0	70	6085.9	4511.6	2832.7	1679.0	0)
VR 4	2	"	133	48.1	18.3	17.4	81	6357.3	4709.3	3438.5	1270.7	1)
VR 4	2	"	137	51.2	19.1	22.1	67	6706.2	4979.8	2830.2	2149.6	1)
VR 4	2	"	141	52.9	19.6	18.7	68	6977.5	5178.3	3089.1	2089.3	1)
VR 4	2	"	144	54.4	20.0	14.3	70	7136.4	5366.8	3132.0	2237.8	0)
VR 4	2	"	147	55.4	20.3	9.7	75	7201.6	5455.8	3276.7	2179.1	0)
VR 4	2	"	148	56.2	20.5	5.7	73	7353.2	5609.6	3715.6	1893.9	0)
VR 4	2	"	151	57.8	20.9	25.1	73	7694.4	5884.5	3132.1	2752.4	1)
VR 5	2	"	157	62.6	22.2	10.8	68	8437.7	6256.5	3899.7	2356.8	0)
VR 5	2	"	159	64.0	22.6	16.0	68	8475.8	6296.3	3798.5	2497.8	1)
VR 5	2	"	162	66.5	23.3	21.0	67	8523.4	6334.6	3668.7	2665.9	1)
VR 5	2	"	164	68.9	23.9	15.9	67	7961.6	5910.0	3567.1	2342.9	1)

*) 1) = above critical temp.
0) = below critical temp.

			Animals			Conditions in chamber		Kcal/animals.day				
Exp.	Number	Name	Age (days)	Weight (kg)	Metabolic weight	Temp. °C	Relative Humidity (%)	Gross energy	Metabolisable energy	Heat production	Energy gain	code*
VR 5	2	,,	165	69.9	24.2	10.4	78	8113.9	6014.3	3821.7	2192.5	0)
VR 5	2	,,	166	70.4	24.3	10.4	78	8228.2	6100.3	3772.2	2328.2	0)
VR 5	2	,,	169	73.3	25.1	4.4	74	8571.1	6357.5	4441.0	1916.6	0)
VR 5	2	,,	171	75.1	25.5	23.4	76	9028.2	6694.7	3624.5	3070.2	
VR 6	2	,,	178	79.3	26.6	20.3	72	9513.7	7244.7	3992.2	3252.5	1)
VR 6	2	,,	185	84.6	27.9	9.9	78	9623.6	7304.3	4686.5	2617.8	0)
VR 6	2	,,	187	85.1	28.0	6.9	93	9659.6	7314.0	4780.3	2533.6	0)
VR 6	2	,,	190	86.1	28.3	3.9	90	9703.2	7360.2	5624.4	1735.8	0)
VR 6	2	,,	192	87.0	28.5	10.2	84	10120.2	7709.5	4711.6	2998.0	0)
VR 6	2	,,	194	88.4	28.8	17.4	80	10120.2	7722.8	4601.9	3121.0	1)
VR 6	2	,,	197	91.3	29.5	20.4	82	10120.2	7709.2	4390.2	3319.0	1)
VR 6	2	,,	200	92.7	29.9	13.1	78	10120.2	7682.9	4427.9	3255.0	1)
VR 6	2	,,	203	93.2	30.0	9.2	80	10120.2	7709.9	4759.7	2950.2	0)
VR 6	2	,,	205	93.9	30.2	6.0	85	10120.2	7672.8	4740.4	2932.5	0)
VR 6	2	,,	207	94.7	30.3	18.6	68	10120.2	7717.2	4350.9	3366.3	1)
VR 7	2	7+8	63	20.3	9.5	21.5	86	3020.2	2248.1	1588.7	659.3	1)
VR 7	2	,,	66	21.5	10.0	17.0	82	3337.1	2491.8	1733.7	758.1	0)
VR 7	2	,,	68	22.6	10.4	16.2	86	3490.0	2603.9	1735.5	868.3	0)
VR 7	2	,,	70	23.1	10.6	12.0	81	3641.0	2717.0	1847.2	869.9	0)
VR 7	2	,,	73	24.3	11.0	19.3	85	3821.8	2841.7	1886.2	955.5	1)
VR 7	2	,,	80	27.1	11.9	13.4	79	4493.0	3338.2	2247.4	1090.8	0)
VR 7	2	,,	83	28.0	12.2	13.6	83	4642.1	3452.5	2330.5	1122.0	
VR 7	2	,,	85	29.1	12.5	10.6	78	4828.5	3593.5	2440.7	1152.8	0)
VR 7	2	,,	87	30.1	12.9	10.1	68	4977.7	3705.7	2522.4	1183.3	0)
VR 7	2	,,	90	31.8	13.4	15.4	69	5169.7	3844.0	2538.0	1306.0	0)
VR 8	2	,,	94	33.5	13.9	18.4	85	5362.3	3968.7	2533.3	1435.5	1)
VR 8	2	,,	97	35.8	14.6	15.4	66	5362.3	3973.6	2679.9	1293.7	0)
VR 8	2	,,	99	36.5	14.8	18.6	90	5362.3	3968.2	2626.1	1342.3	1)
VR 8	2	,,	101	38.1	15.3	14.0	87	5362.3	3948.7	2941.4	1007.1	0)
VR 8	2	,,	104	39.2	15.7	10.6	87	5362.3	3947.1	3218.3	728.8	0)
VR 9	2	,,	110	43.6	17.0	18.3	84	5907.9	4391.0	2981.3	1409.7	1)
VR 9	2	,,	113	45.5	17.5	14.8	85	5907.9	4401.9	3145.0	1256.9	0)
VR 9	2	,,	115	46.2	17.7	17.7	84	5909.9	4409.7	2957.9	1451.8	1)
VR 9	2	,,	117	46.8	17.9	14.6	76	5909.9	4403.8	3069.8	1334.0	0)
VR 10	2	,,	125	51.7	19.3	14.5	76	6845.6	5231.6	3416.7	1814.9	0)
VR 10	2	,,	127	52.9	19.6	17.6	79	6845.6	5246.7	3423.9	1822.8	1)
VR 10	2	,,	129	54.3	20.0	13.2	80	6845.6	5236.2	3519.4	1716.8	0)
VR 10	2	,,	131	55.5	20.3	17.8	85	6845.6	5236.9	3484.4	1752.4	1)
VR 11	2	,,	141	63.4	22.5	18.4	78	8046.4	6054.4	3675.7	2378.7	1)
VR 11	2	,,	143	65.3	23.0	12.8	78	8046.4	6071.3	3898.2	2173.1	0)
VR 11	2	,,	145	66.9	23.4	17.3	80	8046.4	6065.0	3738.2	2326.8	1)
VR 11	2	,,	149	69.3	24.0	10.1	82	8460.2	6379.3	4271.0	2108.3	0)
VR 11	2	,,	152	71.0	24.5	15.2	85	8920.0	6738.5	4934.3	1804.2	1)
VR 11	2	,,	156	72.7	24.9	12.6	85	9310.8	7003.5	4263.6	2740.0	0)
VR 11	2	,,	159	74.2	25.3	13.3	84	9425.8	7091.8	4491.0	2600.8	0)
VR 11	2	,,	162	76.0	25.7	15.5	88	9579.1	7190.1	4880.9	2309.2	
VR 11	2	,,	164	77.1	26.0	18.6	76	9579.1	7230.5	4655.0	2575.5	1)
VR 11	2	,,	166	78.2	26.3	14.6	86	9579.1	7159.9	4485.1	2674.8	1)
VR 11	2	,,	168	79.2	26.5	19.2	82	9579.1	7165.3	4302.6	2862.7	1)
VR 11	2	,,	171	81.1	27.0	14.6	80	9732.3	7324.7	4735.9	2588.8	1)
VR 11	2	,,	173	82.1	27.3	14.7	88	9797.5	7388.3	4929.5	2458.9	
VR 11	2	,,	175	83.9	27.7	11.6	66	9897.1	7436.7	4799.7	2637.0	0)
VR 11	2	,,	178	85.2	28.0	11.0	83	9981.4	7493.7	5419.6	2074.1	0)
VR 11	2	,,	181	86.5	28.4	14.4	73	10104.0	7586.1	5083.2	2502.9	1)
VR 11	2	,,	184	87.5	28.6	15.1	79	9962.2	7470.4	4735.9	2734.5	1)
VR 14	2	9 + 10I	55	21.3	9.9	21.8	83	3698.0	2740.2	1707.8	1032.4	1)
VR 14	2	,,	57	22.6	10.4	21.8	83	3698.0	2748.0	1908.2	839.8	1)
VR 14	2	,,	59	23.9	10.8	22.0	87	3698.0	2744.8	1896.7	848.0	
VR 14	2	,,	61	25.2	11.2	19.3	89	3698.0	2745.6	1814.4	931.2	1)
VR 15	2	,,	64	28.8	12.4	19.6	91	2997.7	2202.7	1790.6	412.1	1)
VR 15	2	,,	66	30.5	13.0	19.6	91	2997.7	2201.3	1839.0	362.3	1)
VR 15	2	,,	68	32.4	13.6	16.5	85	2997.7	2202.6	1911.4	291.2	0)
VR 16	2	,,	75	39.0	15.6	20.3	89	5305.0	4119.0	2536.3	1582.7	1)
VR 16	2	,,	77	40.0	15.9	15.7	84	5305.0	4103.3	2644.2	1459.1	0)
VR 16	2	,,	80	41.4	16.3	13.2	87	5411.1	4174.6	2806.4	1368.2	
VR 16	2	,,	82	42.2	16.6	7.5	83	5721.8	4412.2	3349.4	1062.8	
VR 18	2	9 + 10II	64	20.9	9.8	23.5	73	2942.0	2222.7	1424.8	797.9	
VR 18	2	,,	66	21.2	9.9	19.6	71	2951.5	2216.8	1540.0	676.8	1)
VR 18	2	,,	69	21.5	10.0	15.3	82	2951.5	2219.5	1713.2	506.2	0)
VR 18	2	,,	71	21.9	10.1	11.4	74	2949.8	2214.2	1987.2	226.9	0)

			Animals			Conditions in chamber		Kcal/animals.day				
Exp.	Number	Name	Age (days)	Weight (kg)	Metabolic weight	Temp. °C	Relative Humidity (%)	Gross energy	Metabolisable energy	Heat production	Energy gain	code*
VR 18	2	,,	73	22.4	10.3	17.1	81	3006.5	2261.3	1703.4	557.9	
VR 18	2	,,	75	23.1	10.5	19.6	86	3123.8	2348.1	1709.4	638.7	1)
VR 18	2	,,	79	24.1	10.9	15.7	83	3869.2	2839.2	1990.2	849.0	0)
VR 18	2	,,	81	25.3	11.3	11.9	85	3869.2	2822.3	2399.3	423.0	0)
VR 19	2	,,	83	26.0	11.5	8.4	74	3902.4	2847.7	2541.4	306.3	0)
VR 19	2	,,	85	26.9	11.8	12.1	80	3902.4	2854.3	2375.3	479.0	0)
VR 19	2	,,	87	28.0	12.2	16.8	82	3902.4	2853.2	2135.3	717.9	0)
VR 19	2	,,	89	28.8	12.4	20.5	82	3902.4	2836.2	1977.8	858.4	1)
VR 19	2	,,	91	29.9	12.8	20.5	82	3902.4	2842.9	1996.5	846.3	1)
VR 19	2	,,	94	30.9	13.1	20.3	78	3689.1	2702.2	1884.3	817.9	1)
VR 19	2	,,	96	31.5	13.3	20.4	77	3335.9	2440.3	1817.5	622.8	1)
VR 19	2	,,	98	32.1	13.5	20.6	79	3029.7	2208.5	1779.7	428.8	1)
VR 19	2	,,	100	32.7	13.7	20.5	78	3061.1	2232.3	1800.2	432.1	1)
VR 19	2	,,	102	33.5	13.9	20.5	80	3689.1	2694.7	1877.0	817.8	1)
VR 19	2	,,	103	33.9	14.1	20.5	80	4167.9	3044.5	1957.4	1087.1	1)
VR 20	2	9 + 10III	72	18.3	8.9	20.3	79	2467.2	1809.0	1357.5	451.5	1)
VR 20	2	,,	75	19.0	9.1	20.5	80	2888.1	2119.1	1482.6	636.5	1)
VR 20	2	,,	77	19.5	9.3	20.1	82	3172.1	2332.6	1544.4	788.2	1)
VR 20	2	,,	79	20.2	9.5	16.5	86	3093.7	2271.5	1705.2	566.2	0)
VR 20	2	,,	81	20.9	9.8	11.4	81	2899.9	2127.9	1974.4	153.4	0)
VR 20	2	,,	83	21.6	10.0	8.3	86	2969.2	2174.6	2197.8	–23.2	0)
VR 20	2	,,	85	22.2	10.2	12.2	85	3066.9	2244.8	2132.8	112.0	0)
VR 20	2	,,	88	23.6	10.7	19.2	81	3262.2	2395.1	1930.8	464.2	1)
VR 20	2	,,	89	24.2	10.9	19.5	84	3014.0	2208.3	1530.0	678.4	1)
VR 20	2	,,	92	24.9	11.1	18.8	81	2693.9	1968.8	1640.8	328.0	1)
VR 20	2	,,	94	25.4	11.3	19.3	81	2381.5	1740.7	1673.1	67.6	1)
VR 20	2	,,	96	25.4	11.3	19.6	87	2082.9	1515.3	1621.1	–105.9	1)
VR 20	2	,,	98	25.1	11.2	19.5	89	1918.9	1394.1	1529.3	–135.2	1)
VR 20	2	,,	99	25.0	11.2	19.2	87	1874.0	1364.2	1538.8	–174.5	1)
VR 22	2	1 + 2II	86	32.0	13.5	18.2	74	3739.6	2842.1	2212.9	629.2	
VR 22	2	,,	88	32.5	13.6	18.6	75	3830.7	2877.3	2164.4	712.9	1)
VR 22	2	,,	91	33.4	13.9	15.8	78	3937.5	2959.7	2484.5	475.1	0)
VR 22	2	,,	93	34.2	14.2	11.9	80	4024.6	3025.9	2772.9	253.0	0)
VR 22	2	,,	95	34.8	14.3	10.2	70	4082.0	3071.6	3147.9	–76.3	0)
VR 22	2	,,	98	35.8	14.6	10.9	80	4214.5	3168.8	3050.2	118.6	0)
VR 22	2	,,	100	36.6	14.9	13.7	71	4319.4	3252.4	2673.9	578.6	0)
VR 22	2	,,	102	37.1	15.0	15.8	71	4418.9	3329.9	2578.1	751.7	0)
VR 22	2	,,	109	39.1	15.6	7.7	57	5069.8	3816.0	3519.8	296.2	0)
VR 23	2	1 + 2III	92	25.8	11.4	9.4	67	5208.5	3794.2	2115.4	1678.8	1)
VR 23	2	,,	94	26.8	11.8	18.3	83	5340.5	3886.8	2240.5	1646.2	1)
VR 23	2	,,	96	28.0	12.2	18.4	82	5468.5	3977.7	2337.1	1640.7	1)
VR 24	2	,,	109	34.1	14.1	18.6	80	4430.4	3221.0	2269.5	951.5	1)
VR 24	2	,,	111	34.7	14.3	18.2	84	4509.3	3279.4	2249.5	1029.9	1)
VR 24	2	,,	113	35.1	14.4	18.5	82	4594.1	3342.5	2269.2	1073.3	1)
VR 24	2	,,	114	35.5	14.5	10.6	87	4674.9	3380.0	2725.7	654.3	1)
VR 23	2	9 + 10IV	148	61.9	22.1	20.7	81	7020.2	4972.7	3509.8	1462.9	1)
VR 23	2	,,	150	62.9	22.3	18.5	77	7079.3	5011.5	3738.4	1273.2	1)
VR 23	2	,,	152	63.9	22.6	18.6	82	7154.1	5064.4	3684.1	1380.3	1)
VR 24	2	,,	167	73.6	25.1	16.2	80	10600.0	7700.0	4896.7	2803.3	1)
VR 24	2	,,	169	75.0	25.5	16.2	79	10745.9	7808.3	4635.5	3172.9	1)
VR 24	2	,,	171	76.3	25.8	16.2	76	10893.7	7911.4	4783.4	3128.0	1)
VR 24	2	,,	172	77.2	26.0	19.5	63	11041.6	8006.7	5508.8	2497.8	1)
VR 27	2	9 + 10VI	120	26.3	11.6	20.2	73	4305.0	3115.4	1986.1	1129.4	1)
VR 27	2	,,	122	27.1	11.9	16.5	81	4617.2	3345.1	1972.8	1372.3	0)
VR 27	2	,,	124	28.1	12.2	12.9	79	4925.5	3560.5	2490.6	1070.0	0)
VR 27	2	,,	127	29.7	12.7	12.8	77	5313.3	3839.9	2752.9	1087.0	0)
VR 27	2	,,	129	30.8	13.1	12.7	83	5613.9	4059.9	2927.3	1132.6	0)
VR 27	2	,,	131	32.2	13.5	16.9	80	5901.7	4271.6	2680.6	1591.0	0)
VR 27	2	,,	133	33.6	14.0	16.9	77	6088.0	4404.0	2830.2	1573.8	1)
VR 27	2	,,	135	34.9	14.4	13.3	72	6391.9	4627.5	2979.8	1674.7	0)
VR 27	2	,,	138	37.5	15.1	11.3	76	6764.4	4897.0	3186.7	1710.3	0)
VR 27	2	,,	140	39.1	15.6	11.4	76	7087.9	5132.6	3373.7	1758.9	0)
VR 27	2	,,	142	40.8	16.1	11.3	71	7274.2	5262.5	3388.1	1874.4	0)
VR 27	2	,,	145	43.3	16.9	14.0	77	7397.3	5341.5	3332.0	2009.4	0)
VR 27	2	,,	147	45.1	17.4	17.4	77	7397.3	5349.9	3252.6	2097.3	1)
VR 27	2	,,	149	47.0	17.9	17.4	77	7430.6	5280.7	3284.5	1996.2	1)
VR 27	2	,,	151	48.5	18.4	14.6	76	7529.4	5350.5	3418.3	1932.2	0)
VR 27	1	,,	159	56.2	20.5	12.7	67	7865.6	5565.2	3867.4	1697.8	0)
VR 27	1	,,	163	58.5	21.2	18.2	82	7917.4	5615.1	3774.0	1841.1	1)
VR 27	1	,,	167	60.4	21.7	15.3	88	7983.4	5663.9	3841.8	1822.2	

			Animals			Conditions in chamber		Kcal/animal.day				
Exp.	Number	Name	Age (days)	Weight (kg)	Metabolic weight	Temp. °C	Relative Humidity (%)	Gross energy	Metabolisable energy	Heat production	Energy gain	code*
VR 27	1	„	168	61.5	22.0	12.7	79	8037.7	5694.1	4407.0	1287.1	0)
VR 27	1	„	171	62.8	22.3	12.7	79	8126.7	5760.1	4172.7	1587.4	0)
VR 27	1	„	175	65.5	23.0	12.8	72	8390.9	5943.7	4906.5	1037.3	0)
VR 27	1	„	177	67.0	23.4	14.4	76	8390.9	5945.9	4368.7	1577.2	1)
VR 27	1	„	180	69.0	23.9	16.4	74	8390.9	5945.9	4239.1	1706.8	1)
VR 27	1	„	181	69.6	24.1	16.5	80	8390.9	5947.2	3998.2	1948.9	
VR 5	5	Group I	72	19.6	9.3	16.7	85	3013.8	2225.5	1547.0	678.5	0)
VR 5	5	„	74	20.8	9.7	16.5	85	3099.0	2282.4	1480.1	802.3	0)
VR 5	5	„	76	21.5	10.0	22.7	85	3114.5	2301.4	1499.8	801.7	1)
VR 5	5	„	79	22.2	10.2	16.2	85	3133.9	2309.2	1610.7	698.4	0)
VR 5	5	„	81	23.4	10.6	23.2	78	3277.2	2420.8	1515.2	905.6	
VR 5	5	„	83	24.3	11.0	24.0	80	3463.1	2566.1	1720.3	845.8	
VR 5	5	„	82	24.1	10.9	24.0	80	3416.6	2534.0	1695.4	838.7	
VR 5	5	„	86	25.6	11.4	23.7	84	3695.6	2743.2	1793.0	950.1	
VR 5	5	„	87	26.8	11.8	20.3	84	3904.7	2902.7	1812.6	1090.1	
VR 5	5	„	88	27.1	11.9	20.3	84	3966.7	2949.2	1779.9	1169.3	
VR 6	5	„	94	29.9	12.8	15.7	81	4617.5	3439.6	2029.5	1410.1	0)
VR 6	5	„	95	30.1	12.9	16.2	81	4619.3	3441.2	2010.9	1430.2	0)
VR 6	5	„	97	31.6	13.3	12.8	86	4650.2	3460.0	2239.4	1220.6	0)
VR 6	5	„	100	32.9	13.7	18.5	82	4689.0	3485.8	2137.9	1348.0	1)
VR 6	5	„	102	33.7	14.0	12.3	80	4758.7	3521.4	2243.7	1277.6	0)
VR 6	5	„	104	34.1	14.1	8.2	95	4890.3	3608.8	2345.0	1263.9	0)
VR 6	5	„	107	34.3	14.2	6.2	92	5087.8	3768.4	2518.7	1249.8	0)
VR 6	5	„	109	35.1	14.4	10.4	87	5277.5	3922.1	2386.0	1536.1	0)
VR 6	5	„	111	36.3	14.8	16.5	80	5432.4	4033.0	2491.3	1541.6	1)
VR 6	5	„	114	37.8	15.2	21.9	84	5626.0	4161.0	2507.2	1653.8	1)
VR 6	5	„	118	40.0	15.9	16.9	81	5808.0	4298.0	2508.9	1789.1	1)
VR 6	5	„	120	41.9	16.5	10.6	75	5869.9	4336.6	2805.0	1531.6	0)
VR 6	5	„	122	43.0	16.8	7.0	74	5959.0	4400.9	2662.1	1738.8	0)
VR 6	5	„	124	44.7	17.3	16.2	68	6121.6	4531.8	2724.9	1806.9	1)
VR 6	5	„	127	46.2	17.7	11.9	73	6183.6	4571.0	2854.1	1716.8	0)
VR 6	4	„	130	48.9	18.5	10.5	83	5616.7	4160.7	2448.1	1712.6	0)
VR 6	4	„	132	50.8	19.0	9.2	74	7235.8	5390.5	3179.0	2211.4	0)
VR 6	4	„	135	52.1	19.4	17.8	84	7477.8	5528.9	3347.5	2181.4	1)
VR 7	4	„	141	57.0	20.7	17.4	86	7276.5	5517.2	3513.6	2003.6	1)
VR 7	4	„	145	58.6	21.2	15.7	82	7385.4	5604.4	3556.7	2047.7	0)
VR 7	4	„	147	60.3	21.6	15.0	85	7458.9	5662.2	3641.8	2020.4	0)
VR 7	4	„	149	61.6	22.0	10.8	88	7532.4	5724.5	3701.7	2022.8	0)
VR 7	4	„	152	63.2	22.4	11.0	84	7673.0	5854.7	3748.6	2106.1	0)
VR 7	4	„	156	64.8	22.8	17.4	84	7984.2	6050.9	3667.3	2383.6	1)
VR 7	4	„	158	66.1	23.2	17.5	86	8025.1	6053.7	3745.4	2308.3	
VR 7	4	„	160	67.4	23.5	14.1	87	8133.9	6114.7	3700.3	2414.4	
VR 7	4	„	163	68.6	23.8	11.3	87	8272.8	6293.2	3912.9	2380.3	
VR 7	4	„	165	70.3	24.3	10.6	78	8404.3	6398.2	3965.2	2433.0	
VR 7	4	„	167	71.9	24.7	5.6	91	8515.0	6491.3	4094.3	2397.0	0)
VR 7	4	„	170	74.4	25.3	10.5	82	8658.4	6585.6	4078.6	2507.0	0)
VR 7	4	„	172	76.1	25.8	15.1	83	8739.1	6614.3	4011.7	2602.7	
VR 8	4	„	174	77.2	26.0	11.7	84	8778.1	6653.2	4057.1	2596.1	0)
VR 8	4	„	177	79.5	26.6	10.1	83	8823.5	6678.8	4174.0	2504.9	1)
VR 8	4	„	179	81.0	27.0	7.4	85	8864.3	6703.8	4474.8	2229.0	0)
VR 8	4	„	181	82.9	27.5	5.0	89	8898.1	6699.3	4539.0	2160.3	0)
VR 8	4	„	184	84.5	27.9	10.5	89	8950.5	6745.7	4410.6	2335.0	0)
VR 9	4	„	190	89.4	29.1	16.4	85	9601.9	7186.9	4580.8	2606.0	
VR 9	4	„	193	92.0	29.7	8.5	85	9645.1	7191.8	4663.5	2528.3	
VR 9	4	„	195	92.5	29.8	4.2	87	9645.1	7214.5	5191.9	2022.7	
VR 9	4	„	197	93.3	30.0	18.5	82	9645.1	7228.1	4409.8	2818.3	
VR 9	4	„	199	94.6	30.3	15.3	80	9645.1	7203.0	4384.5	2818.5	1)
VR 9	4	„	201	96.6	30.8	13.5	84	9645.1	7240.9	4363.0	2877.9	1)
VR 11	5	Group II	73	18.9	9.1	20.4	78	3941.4	2955.8	1844.9	1110.9	
VR 11	5	„	75	19.9	9.4	18.4	80	3153.1	2339.7	1517.5	822.2	0)
VR 11	5	„	79	21.3	9.9	20.3	81	3280.0	2434.1	1589.7	844.4	1)
VR 11	5	„	82	22.6	10.3	15.0	88	3464.7	2580.5	1650.7	929.9	0)
VR 11	5	„	86	24.2	10.9	12.6	85	3708.7	2764.0	1787.0	977.0	0)
VR 11	5	„	89	25.4	11.3	14.7	85	3798.8	2828.4	1809.9	1018.5	0)
VR 11	5	„	92	27.1	11.9	11.8	78	3860.4	2870.6	1904.3	966.3	0)
VR 11	5	„	94	28.2	12.2	18.6	76	3897.9	2908.1	1528.5	1379.6	
VR 11	5	„	96	29.2	12.5	9.4	84	3929.4	2912.9	1950.9	962.0	
VR 11	5	„	98	30.0	12.8	11.0	78	3967.7	2938.0	2066.6	871.4	
VR 11	5	„	103	31.4	13.3	14.2	89	4241.7	3169.4	2115.2	1054.2	0)
VR 11	5	„	105	32.4	13.6	15.6	83	4390.4	3281.3	2102.5	1178.8	0)

			Animals			Conditions in chamber		Kcal/animal.day				
Exp.	Number	Name	Age (days)	Weight (kg)	Metabolic weight	Temp. °C	Relative Humidity (%)	Gross energy	Metabolisable energy	Heat production	Energy gain	code*
VR 11	5	,,	108	34.0	14.1	17.4	87	4537.5	3352.7	2114.7	1238.0	0)
VR 11	5	,,	111	35.3	14.5	14.4	73	4722.2	3481.3	2310.5	1170.9	0)
VR 11	5	,,	114	36.8	14.9	18.0	74	4954.2	3654.3	2396.7	1257.6	1)
VR 11	5	,,	116	37.9	15.3	10.0	73	5103.6	3781.2	2624.7	1156.4	0)
VR 12	5	,,	119	39.8	15.8	9.7	71	5330.6	3951.8	2512.9	1438.9	0)
VR 12	5	,,	122	41.3	16.3	15.9	65	5520.5	4094.6	2548.8	1545.8	0)
VR 12	5	,,	125	42.8	16.7	13.0	71	5747.9	4230.7	2692.3	1538.4	0)
VR 12	5	,,	127	44.8	17.3	9.3	62	5963.3	4417.0	2823.4	1593.6	0)
VR 12	5	,,	129	46.3	17.7	9.0	77	6081.9	4512.7	2982.9	1529.8	0)
VR 12	5	,,	131	47.9	18.2	12.7	85	6233.6	4622.9	2873.8	1749.1	0)
VR 12	5	,,	134	49.8	18.8	17.2	70	6466.2	4737.1	3062.7	1674.3	1)
VR 12	5	,,	136	51.3	19.2	17.8	76	6616.3	4944.7	3117.6	1827.1	1)
VR 12	5	,,	138	52.7	19.5	13.6	70	6768.7	5017.1	3055.8	1961.3	0)
VR 13	5	,,	146	57.2	20.8	17.0	78	7411.7	5540.2	3316.5	2223.8	1)
VR 13	5	,,	148	58.9	21.3	17.4	76	7602.6	5645.9	3046.2	2599.6	
VR 13	5	,,	150	60.4	21.7	12.5	59	7755.3	5771.9	3560.2	2211.8	
VR 13	5	,,	153	61.6	22.0	11.3	66	7984.5	5945.7	3703.4	2242.2	
VR 13	5	,,	155	62.9	22.3	18.6	75	8079.9	6029.3	3551.8	2477.5	1)
VR 13	5	,,	157	64.0	22.6	15.2	57	8141.0	6077.5	3976.7	2100.8	1)
VR 13	4	,,	170	74.7	25.4	16.0	81	6851.9	5119.9	3133.6	1986.3	1)
VR 17	5	Group III	67	18.6	8.9	23.3	78	3622.5	2696.7	1710.5	986.2	
VR 17	5	,,	69	19.1	9.1	19.3	81	2924.2	2178.5	1485.7	692.7	0)
VR 17	5	,,	72	19.7	9.3	15.2	83	2924.2	2177.8	1489.2	688.6	0)
VR 17	5	,,	74	20.4	9.6	11.4	83	2950.5	2189.9	1696.9	493.0	0)
VR 21	5	Group IV	71	15.8	7.9	16.8	96	2817.3	2078.1	1200.5	877.6	0)
VR 21	5	,,	73	16.3	8.1	16.6	96	2883.4	2124.2	1323.8	800.4	0)
VR 21	5	,,	79	18.8	9.0	19.8	72	3069.9	2256.6	1445.5	811.1	
VR 21	5	,,	81	19.6	9.3	16.4	78	3135.2	2305.1	1587.3	717.8	1)
VR 21	5	,,	83	20.5	9.6	12.1	75	3213.7	2363.8	1713.9	649.8	1)
VR 21	5	,,	85	21.7	10.0	9.9	79	3281.4	2410.6	1902.1	508.5	
VR 21	5	,,	87	22.4	10.3	13.3	72	3390.7	2488.8	1730.0	758.8	1)
VR 21	5	,,	89	23.4	10.6	17.5	57	3582.1	2624.0	1804.8	819.2	0)
VR 21	5	,,	91	24.4	11.0	20.1	76	3769.7	2760.3	1745.9	1014.4	1)
VR 21	5	,,	93	25.1	11.2	20.1	76	3959.5	2901.2	1547.1	1354.1	
VR 21	5	,,	95	25.4	11.3	20.1	75	4148.6	3041.5	1961.5	1080.0	
VR 21	5	,,	97	25.9	11.5	20.1	74	4073.2	2986.3	1935.7	1050.6	1)
VR 21	5	,,	99	26.3	11.6	20.1	69	3823.5	2804.8	2001.8	803.1	1)
VR 21	5	,,	101	26.9	11.8	20.1	74	3573.8	2620.1	1768.0	852.2	1)
VR 21	5	,,	103	27.5	12.0	20.0	73	3324.1	2435.4	1930.8	504.6	1)
VR 21	5	,,	105	28.4	12.3	20.1	73	3355.3	2447.1	1802.7	644.3	1)
VR 21	5	,,	107	29.7	12.7	20.0	74	3854.7	2817.6	1978.3	839.2	1)
VR 21	5	,,	109	30.9	13.1	20.0	74	4354.1	3188.1	1999.1	1189.0	1)
VR 21	5	,,	111	32.2	13.5	20.0	75	4853.5	3558.4	2199.5	1358.9	1)
VR 21	5	,,	114	33.8	14.0	15.6	76	5234.7	3827.9	2466.4	1361.5	0)
VR 21	5	,,	116	35.0	14.4	15.6	79	5250.3	3840.2	2531.1	1309.0	
VR 21	5	,,	118	36.0	14.7	12.8	74	5289.2	3869.3	2613.3	1256.0	
VR 21	5	,,	119	36.8	14.9	11.3	67	5320.4	3892.6	2667.9	1224.8	0)
VR 21	5	,,	123	38.7	15.5	11.2	69	5374.9	3934.9	2453.6	1481.3	
VR 21	5	,,	125	39.9	15.9	13.3	70	5406.1	3948.6	2836.6	1112.0	0)
VR 22	5	Group V	86	26.5	11.7	17.6	85	3751.5	2863.8	1776.2	1087.6	
VR 22	5	,,	88	27.2	11.9	20.4	80	3838.6	2919.7	1847.0	1072.7	1)
VR 22	5	,,	91	28.4	12.3	16.2	82	3937.5	2987.3	1903.5	1083.8	0)
VR 22	5	,,	93	29.3	12.6	13.0	81	4020.6	3046.1	2186.4	859.6	0)
VR 22	5	,,	95	30.1	12.8	11.9	71	4107.7	3113.3	2261.8	851.5	0)
VR 22	5	,,	98	31.5	13.3	12.2	77	4214.5	3195.7	2269.0	926.7	0)
VR 22	5	,,	100	32.5	13.6	14.9	72	4293.7	3252.8	2250.9	1001.9	0)
VR 22	5	,,	102	33.5	13.9	18.5	69	4418.9	3355.8	2184.5	1171.2	1)
VR 22	5	,,	109	36.3	14.8	7.9	88	5069.8	3849.7	2139.5	1710.2	
VR 27	4	Group VI	120	41.1	16.2	19.7	88	4498.9	3254.8	2085.0	1169.8	1)
VR 27	4	,,	122	42.2	16.6	16.0	78	5934.8	4296.7	2784.2	1512.5	0)
VR 27	4	,,	124	43.8	17.0	13.5	89	6244.1	4517.6	3016.0	1501.6	0)
VR 27	4	,,	127	46.0	17.7	14.2	84	6632.0	4801.5	3113.0	1688.5	
VR 27	4	,,	129	47.6	18.1	14.5	76	6932.5	5021.9	3208.5	1813.4	0)
VR 27	4	,,	131	49.1	18.6	17.1	72	7225.2	5236.6	2981.7	2255.0	1)
VR 27	4	,,	133	50.0	18.8	16.7	75	7425.2	5285.0	3227.3	2057.7	
VR 27	4	,,	135	51.6	19.2	13.5	69	7572.9	5391.5	3172.7	2218.9	0)
VR 27	4	,,	138	53.6	19.8	11.9	74	7779.7	5537.4	3405.9	2131.5	0)
VR 27	4	,,	140	55.2	20.2	11.1	80	7937.2	5647.5	3517.4	2130.1	
VR 27	4	,,	142	56.6	20.6	11.6	70	8094.8	5760.5	3182.5	2578.0	0)
VR 27	4	,,	145	59.4	21.4	15.9	67	8221.1	5833.8	3500.9	2333.0	1)

			Animals			Conditions in chamber		Kcal/animal.day				
Exp.	Number	Name	Age (days)	Weight (kg)	Metabolic weight	Temp. °C	Relative Humidity (%)	Gross energy	Metabolisable energy	Heat production	Energy gain	code*
VR 27	4	,,	147	61.3	21.9	17.8	67	8221.1	5842.1	3530.5	2311.5	1)
VR 27	4	,,	149	63.4	22.5	17.9	68	8221.1	5842.0	3541.1	2300.9	1)
VR 27	4	,,	151	64.5	22.8	16.4	70	8290.3	5890.8	3544.8	2345.9	1)
VR 27	4	,,	159	68.9	23.9	14.2	86	8354.1	5929.9	3956.2	1973.7	1)
VR 27	4	,,	161	69.9	24.2	15.5	67	8388.0	5955.5	3822.4	2133.2	1)
VR 27	4	,,	163	71.1	24.5	18.6	71	8402.6	5964.6	3870.6	2094.1	1)
VR 27	4	,,	167	73.7	25.2	15.7	79	8436.5	5988.6	3786.2	2202.4	
VR 27	4	,,	168	75.0	25.5	13.8	71	8460.8	6006.2	4024.6	1981.6	1)
VR 27	4	,,	171	76.0	25.7	13.9	72	8511.3	6029.4	4111.7	1917.7	
VR 27	4	,,	173	77.0	26.0	9.6	87	8526.8	6039.3	4177.3	1862.0	0)
VR 27	4	,,	175	77.9	26.2	14.7	80	8526.8	6040.7	4132.4	1908.3	
VR 27	4	,,	177	78.9	26.5	17.0	78	8526.8	6041.6	4271.0	1770.6	0)
VR 27	4	,,	180	80.3	26.8	19.8	70	8526.8	6040.9	4118.1	1922.8	0)
VR 27	4	,,	181	80.8	26.9	16.3	80	8526.8	6030.7	4425.7	1605.0	

* 1) = above critical temp.
0) = below critical temp.