636:591.12.084.1

MEDEDELINGEN LANDBOUWHOGESCHOOL
WAGENINGEN NEDERLAND 71-16 (1971)

AN INDIRECT CALORIMETER FOR THE MEASUREMENT OF THE HEAT PRODUCTION OF LARGE GROUPS OF ANIMALS KEPT TOGETHER

M. W. A. VERSTEGEN, W. VAN DER HEL
Department of Animal Husbandry,
Agricultural University, Wageningen, The Netherlands

R. KOPPE,
Technical and Physical Engineering Research Service,
Ministery of Agricultural and Fisheries, Wageningen, The Netherlands

A. J. H. VAN ES,
Department of Animal Physiology,
Agricultural University, Wageningen, The Netherlands

(Received 1-IV-1971)

INTRODUCTION

The influence of different climatic conditions on growing animals is often studied by the measurement of the rate of growth, or other production traits, under the different climatic conditions. When working with pigs the parameters measured are then live weight increase, feed conversion and slaughter quality. Mostly the results obtained resulted from exposure to a constant or fluctuating condition during a rather long period i.e. from one week up to several months. Due to the fact that the body composition may be dependent on temperature (SÖRENSEN (1961), PFEIFFER (1968) and HICKS (1966)), and the fact that body weight gain includes not only tissues but also intestine contents etc. the results of such experiments are difficult to interpret. Moreover such experiments require a rather long time before eventually effects on weight can be noticed due to errors in determining the weight of the animals or their tissues.

Measurements of heat exchange have the advantage that they provide the possibility of the investigation of a quantitative effect resulting from small changes in climate, e.g. temperature, relative humidity, air velocity during short periods.

Sometimes an effect can be measured within some minutes (or hours). If the

technical equipment provides the possibility of changing the climate more or less similarly to the changes occurring in a practical housing system (piggery), it may be possible to detect differences in energy metabolism (heat production) when the temperatures change during each day or parts of a day.

Results of determinations of the effect of climatic conditions on the metabolism of pigs can only be applied under practical conditions with confidence, if the animals are kept in groups. HOLMES and MOUNT (1967) and VERSTEGEN (1971) have shown the importance of including groups in the investigations.

Therefore a large indirect calorimeter has been constructed.

In this calorimeter animals, e.g. pigs, can be housed under conditions which are close to the practical conditions during the whole period of growing or fattening.

Different systems of housing can be installed in the chamber, e.g. different floors and pens of different size; also experiments can be done with different group size and with individual or group feeding.

The climatic equipment can provide a desired climate with temperatures between 5° and 35°C, relative humidities between 50 and 90% and different air velocities of 0.10–0.20 m/sec, 0.20–0.30 m/sec, 0.40–0.50 m/sec and 0.60–0.80 m/sec all independent from each other. The heat production is measured indirectly by means of determining respiratory gaseous exchange according to the Pettenkofer system. The measurement is done in the same way as in the respiration chambers in use for more than 10 years at the Department of Animal Physiology of the Agricultural University. (VAN ES 1961 and 1969).

TECHNICAL DESCRIPTION AND DIMENSIONS OF THE CHAMBER

The chamber has an inner room of 6 m × 3.8 m × 1.9 m. This room can be used by the pigs. Thus it is large enough to contain two pens of normal size. In each pen 8–10 pigs or a proportional number of other animals can be housed during several months. Various floor systems for pigs can be installed in the chamber, i.e. concrete, straw on concrete and slatted floors, on top of the permanent floor structure. See text figure 1.

The climate respiration chamber has external dimensions of 6.2 m × 4.8 m × 2.0 m and is constructed from 1.5 mm and 2 mm sheet steel suitably stiffened. The chamber is insulated with 100 mm glasswool which is covered with 1.5 mm aluminium sheet.

The chamber floor consists of 35 mm non toxic asphalt wich covers a layer of 80 mm foam glass imbedded in a concrete floor.

The feeding is done with two feeding devices outside the chamber from which tubes lead through the wall to a trough from which the lid can be opened from the outside of the chamber by means of a hand crank lever.

In the ceiling of the chamber two emergency covers of 0.7 m × 0.7 m each act as safety lids. These are sealed by keeping their rims in an oil or water filled groove. The covers are counter-weighted in such a way that they open when the

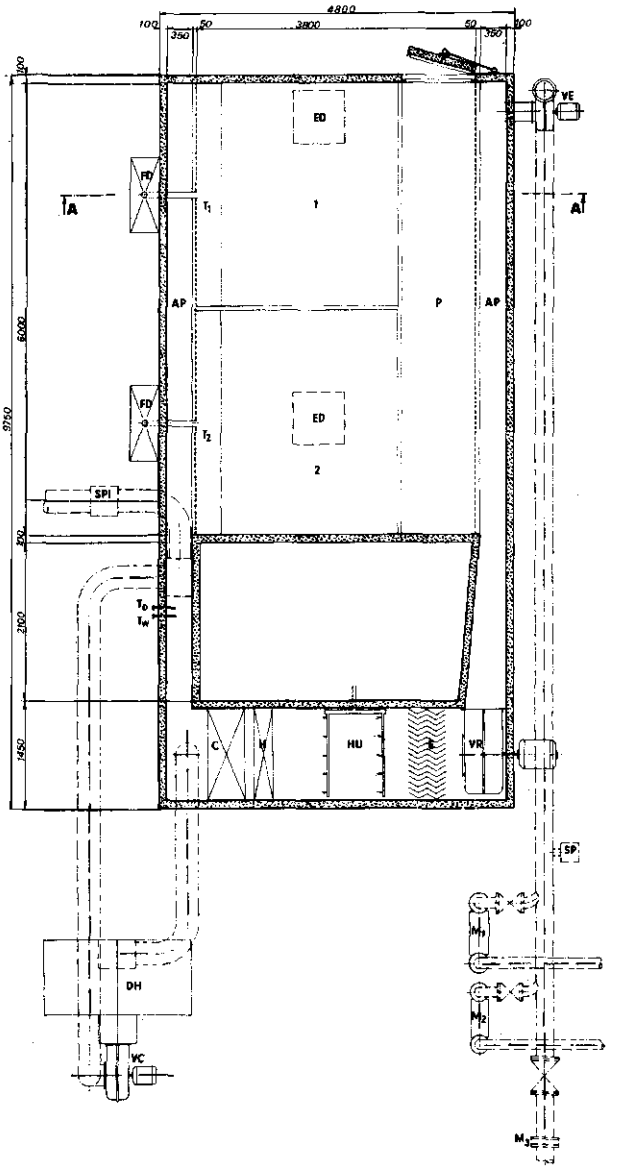

FIG. 1. Sketch of the climate-respiration chamber. Dimensions given in this figure are in mm: ED = emergency covers; P = passage; AP = air plenum; 1 and 2-pens for pigs; T_1 and T_2 = troughs for pen 1 and 2; FD = feeding device; VE = exhaust fan; SPi = sampling pump ingoing air; TD = dry bulb thermometer; TW = wet bulb thermometer; C = cooling coil; H = electric heater; Hu = humidifier; E = droplet eliminators; VR = recirculation fan; DH = dehumidifier; SP = sampling pump for air leaving the chamber; M_1 = dry Wilson gasmeter, capacity 0–120 m^3/hr; M_2 = dry Wilson gasmeter, capacity 0–60 m^3/hr; M_3 = standard orifice.

catches holding them down are released by signals from the low or high safety thermostat or by the safety pressostat. The safety pressostat acts when the pressure in the chambers rises above the desired level which is approximately 5 to 10 mm water column below atmospheric. The door to the chamber is sealed off by neoprene strips. The door is tightened with lever locks.

The whole equipment including the machinery is placed in an old poorly insulated wooden building.

Mode of operation

Air conditioning and chamber pressure

Air is exhausted from the chamber by means of a centrifugal fan. This air quantity can be adjusted at values between 0 m^3/h and 500 m^3/h. The exhausted air quantity is replaced by outside air. The outside air is admitted to the air conditioning circuit through a motorised valve. The valve opening is regulated by the chamber pressure controller.

The chamber is completely air conditioned in order to maintain the desired chamber temperature and humidity. The layout of the air conditioning system is schematically shown in text figure 2.

In the main air circuit air is drawn from the chamber and recirculated through the air conditioning unit with the chilled water cooling coil, electric heaters, sprays and recirculation fan and then back to the respiration chamber.

The cooling coil in the air conditioning unit is fed with chilled water which is maintained at a temperature of 1–2 °C below the desired chamber temperature in a separate circuit. Dry and wet bulb chamber temperature control is on-off, the dry bulb controller switching the chilled water pump and the electric heaters and the wet bulb controller the cooling compressor for the dehumidification direct expansion coils and the sprays.

The total air volume of the chamber and air circulation circuits is approximately 70 m^3.

As a high CO_2 level is to be maintained in the chamber the ventilation rate should be rather low.

Before entering the air conditioning unit, part of the recirculating air, mixed with outside air, is drawn alternatingly through either one of the two direct expansion coils of the dehumidification circuit. After leaving the dehumidification unit the dried air is brought back into the main circulation circuit.

As the indirect calorimetry system has been selected it is required to measure all CO_2 and CH_4 produced and O_2 consumed by the animals in the chamber. It should be pointed out that it is for this reason that in the two parts inside the air conditioning unit were overpressure might be present, i.e. just after the recirculation fan and after the fan in the dehumidification circuit, the casing should be absolutely air tight. Keeping the chamber pressure below atmospheric reduces errors in the determination of gaseous exchange because it prevents leakage of respiratory gas out of the chamber. No chamber air may leave the chamber or air conditioning unit in any other way then through the exhaust fan.

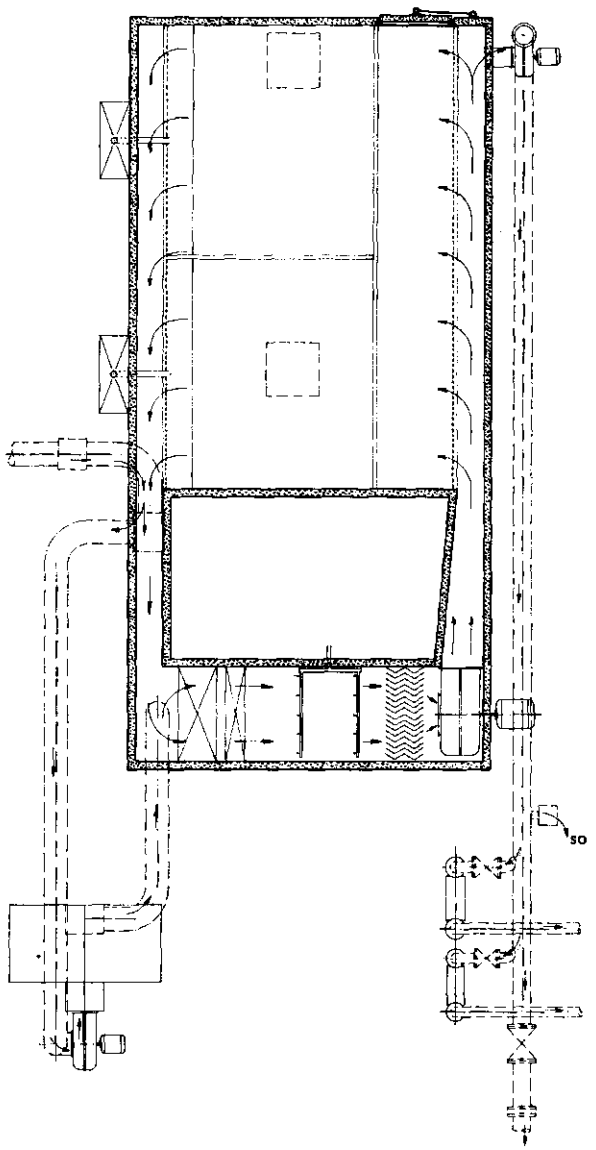

FIG. 2. Scheme of air flow in the chamber and air conditioning unit: For explanation see text figure 1; So = sampling outgoing air.

Measurement of the exhausted air quantity and air composition

The air quantity exhausted from the chamber is measured with dry gasmeters. Two gasmeters are used in parallel, one to measure a ventilation rate between 0–60 m^3/h and the other one for measuring between 0–120 m^3/h and used

together air quantities up to 180 m^3/h can be measured. If a higher ventilation rate is required e.g. up to 500 m^3/h, this air quantity is measured with a standard orifice while leaving the chamber.

Just before entering the gasmeter, the air is sampled in duplicate with two small membrane pumps.

One sampling pump takes about 1–2 litres/minute and part of this air is collected in recipients of glass (containing about 1–1.5 litres each) during periods of 24 hours or 48 hours.

In the recipients pistons covered with mercury are gradually lowered by a synchronous motor. The remainder of the sampling air goes back to the gasmeter in a tube around the plastic tube which leads the air to the sampling unit.

This sampling is in accordance with the procedure described by VAN ES (1961 and 1968).

Moreover part of the sampling air is continuously drawn through a CO_2 and an O_2 analyser and the CO_2 and O_2 contents are recorded.

At the end of a 24 or 48 hours period the sample in the recipients is analysed on a SERVOMEX 137 A O_2 analyser and a SB_2 IRGA CO_2 analyser (GRUBB and PARSONS). These two instruments are calibrated with air of a known composition from a high pressure cylinder. The composition of the air in the cylinder is analysed with the modified Sonden apparatus described by VAN ES (1958).

All data on CO_2, O_2 contents, temperature and humidity of the air entering the chamber as well as temperatures of the gasmeter are recorded on a 24 channel recorder. These data on temperature, humidity, air volume and air composition with barometric pressure are required to compute the amounts of CO_2 and CH_4 produced and O_2 consumed by the animals.

Computation of CO_2 production and O_2 consumption from these data is done as described by VAN ES and VERSTEGEN (1968).

Computation of respiratory gaseous exchange and water vapour production

The computation of CO_2 production, O_2 consumption, CH_4 production and H_2O production (H_2O production = water vapour production) is carried out as follows:

First the measured volume of air is converted into standard conditions (dry, 0 °C and 760 mmHg).

This is done with the equation

$$V_o = V_g \times \frac{B - P_w}{760} \times \frac{273}{273 + t_g} \qquad (1)$$

in wich

V_o = reduced volume (0 °C, dry and 760 mmHg) (litres),
V_g = volume measured with gasmeters (litres),
B = average barometric pressure,
t_g = average temperature of gasmeter (°C),
P_w = pressure of water vapour.

It is assumed that P_w in the gasmeters is equal to that in the chamber since the temperatures in the chamber and gasmeter do not differ much, only some °C.

P_w is computed with the following equation derived by BROUWER (see VAN ES (1961)).

$$P_w = r_{ch}/100 \times (3.999 \times 0.45547\ t_{ch} + 0.001708\ t_{ch}^2 + 0.000468\ t_{ch}^3) \quad (2)$$

in this formula 2:

r_{ch} = relative humidity in the chamber,

t_{ch} = temperature in chamber.

The volume of ingoing air at standard conditions will differ from that of outgoing air at standard conditions when the volumes of CO_2 consumed and of CO_2 produced are not equal.

Furthermore it is assumed that the production of N_2 by the animals as said to be found by COSTA, KANTOR, ULRICH and HOLLAND (1968) is so small that it has no influence on the computation of CO_2, CH_4 and O_2.

The volume of ingoing air at standard conditions can be computed from

$$V_i = V_o \times (100 - C_o - O_o - M_o)\ (100 - C_i - O_i) \quad (3)$$

In this formula 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.

A correction factor which is important to know, is the difference in content of CO_2 and O_2 of the chamber at the beginning and end of the measuring period.

Finally O_2 consumption and CO_2 and CH_4 production of the animals are calculated in the following way:

$$\text{litres } CO_2 \text{ produced} = C_o \times V_o - C_i \times V_i + 7x\ (\text{corr} - C) \quad (4)$$

$$\text{litres } CH_4 \text{ produced} = M_o \times V_o \quad (5)$$

$$\text{litres } O_2 \text{ consumed} = O_i \times V_i - O_o \times V_o + 7x\ (\text{corr} - 0) \quad (6)$$

in which (corr − C) and (corr − 0) is the correction for the difference in CO_2 and O_2 content in the chamber at the start and at the end of the experiment. The correction amounts to 7 litres for each 0.01 vol % difference in contents of O_2 and CO_2 at start and end because the chamber content is about 70 m^3.

Heat production can be computed from the data on gaseous exchange and N-excretion with the urine using the formula of BROUWER (1965). Heat production in kcal $= 3.866\ O_2 + 1.200\ CO_2 - 0.518\ CH_4 - 1.431\ N$ (7) where O_2, CO_2 and CH_4 represent volumes consumed or produced (litres) and N is urinary nitrogen (g). When expressed in kJ the heat production in kcal has to be multiplied with 4.184.

Water vapour production is computed as H_2O leaving the chamber plus water collected from the dehumidifier minus H_2O entering the chamber.

Water vapour leaving the chamber (H_2O_1) with the air in grammes is:

$$H_2O_1 = V_o \times 0.8036 \times P_w/(B_g - P_w) \quad (8)$$

When substituting relative humidity and temperature of ingoing air in formula (3) the water entering the chamber (H_2O_e) can be computed as

$$H_2O_e = V_i \times 0.8036 \times P_{wi}/(B_g - P_w) \quad (9)$$

Substracting the H_2O_i from H_2O_e and correcting this with the H_2O gathered from the dehumidifier gives H_2O production inside the chamber.

HOUSING OF THE ANIMALS

When used for pigs two pens can be built inside the chamber. Each pen can contain 8–10 animals.

Feeding is done from outside and as group housing is applied also group feeding has been chosen. During the respiration experiments of 24 of 48 hours the chamber must not be entered. Therefore the animals are fed from outside through a funnel from which a tube leads to the trough (see text figure 3). 'Wet mash' is put in the funnel and when a plug in the funnel is opened the mash flows through the tube into the trough. With some extra water the funnel is emptied and the lid of the trough is opened from the outside.

Removal of dung

The floor has a fall of about 2% and the urine flows underneath the trough into a gutter.

At the end of a measuring period of two days the floor can be easily cleaned with water. The mixture of water, faeces, urine and feed residues outside the trough is also collected in the gutter. From this gutter it can be pumped over

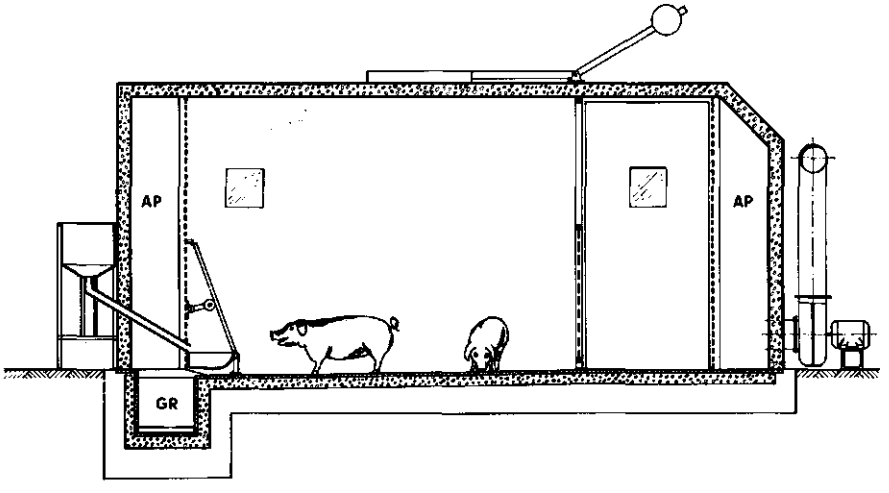

FIG. 3. Section A-A (see figure 1).
AP = air plenum; GR = gutter for gathering dung.

into a tank in which it can be weighed and sampled. When the data on N-content in the mixture from the gutter are known and when N is determined in the condens water which is collected from the dehumidification section and also in the air leaving the chamber, these data can be used to compute N balances.

TECHNICAL TESTS OF THE SYSTEM

The air conditioning unit can maintain a constant climate in the chamber with temperatures adjustable between 10 °C and 35 °C in the summer and between 5 °C and 30 °C in the winter.

KOOYMAN (1970) noticed that the temperature within an experimental period did not deviate more than 0.5 °C from the desired value. Relative humidity can be adjusted in the range between 40 to 90% and the deviation from the desired value is about 5%.

Pigs are sensitive to draught and high air velocities and therefore the normal (low) velocity may not be too high. The air velocity in the room can be adjusted between 0.10–0.20 m/sec, 0.20–0.30 m/sec, 0.40–0.50 m/sec and between 0.60–0.80 m/sec. For an example of one plan of air velocities in the chamber see table 1.

TABLE 1. Air velocities inside the chamber in m/sec at a height of 0.20 m above the floor with a low circulating air quantity. Origin near the door (see figure 1).
b,l = distances, in m, from long and short wall respectively.

b	l= .10	1.00	2.00	3.00	4.00	5.00	5.90
.10		.18	.10	.10	.10	.10	.5
.50	.19	.18	.10	.10	.10	.10	.5
1.00	.18	.15	.12	.8	.12	.10	.10
1.50	.10	.14	.10	.12	.12	.12	.8
2.00	.10	.12	.12	.10	.12	.12	.8
2.50	.11	.8	.8	.10	.10	.10	.8
3.00	.10	.5	.10	.10	.10	.12	.10
3.50	.9	.5	.8	.10	.10	.12	.10

Leakage test

As respiration experiments require the measurement of all CO_2 and CH_4 produced and of all O_2 consumed no air from the chamber should leave the chamber except through the exhaust fan and gas measuring unit. Moreover leakages from outside to the chamber should be reduced since also at the minimum ventilation rate the pressure should be maintained at 5–7 mm water column below atmospheric.

In table 2 the results of one test are given.

TABLE 2. Leakage into the chamber in m^3/hour at various pressures.

pressure in mm H_2O below atmospheric	5	7.5	10	12.8	15.3	14.0	11.4	9.0	6.5	4.2
leakage in m^3/hour	9	15	21.0	30	39	35.4	25.8	18	14.0	8.9

Calibration

The respiration chamber has been tested both in respect with leakage of air and the recovery of CO_2.

Test experiments with CO_2

In order to find whether with the equipment reproducible measurements of CO_2 could be done before and at the end of an experiment with animals, CO_2 is released into the chamber from high pressure cylinders at such a rate as can be expected from animals. As the experiments are done with animals of different weights the tests are also carried out with a release of various amounts of CO_2. At the start of a test experiment CO_2 is released from the cylinder until the CO_2 contents in the chamber is 0.7 to 1.3%. Then the cylinder is weighed. Together with the start of ventilation the release of CO_2 from the cylinder and the gas sampling are started. At the end of the CO_2 test usually lasting 20–40 hours the cylinder is weighed and the gas sample is analysed for CO_2.

The amount of CO_2 released in the chamber is also measured in the same way as the CO_2 production of the animals. When the same quantity of CO_2 is recovered in this way as was released, the volume measurement of the air leaving the chamber, the gas sampling and the CO_2 analysis are correct. The correctness of the O_2 analysis is verified by analysing outdoor air, having a constant composition and gases of known contents stored in high pressure cylinders. A simular procedure is in use at the Department of Animal Physiology. The CO_2, CH_4 and O_2 analysis apparatus is calibrated by passing calibration gas of a known composition through it.

The samples in the cylinder are analysed on a Sonden described by VAN ES (1958). The other parts of the calibration curve for each analysis are also tested by analysing air with various contents of CO_2 and O_2 on the IRGA and SERVOMEX and also on the Sonden. The results of the CO_2 tests are given in table 3.

TABLE 3. Test experiments with CO_2.

CO_2 released from cylinder in litres	Length in hours	Recovery (%)
11.371	17	99.4%
13.739	19½	95 %
18.440	21	98.5%
18.640	19	97.4%
24.640	29	98.9%

As the recoveries given in table 3 are close to 100% it was thought that no further tests with O_2 (or burning alcohol) are necessary. Moreover the measurement of gaseous exchange is made during periods of 24 or 48 hours and the intervals between two measurement periods is only some hours. The error made in these measurements and in the comparison is considered to be mainly accidentally.

When longterm experiments are performed a recovery which is systematically too low will influence the accuracy of comparison made between two measurements which differ a long time. Some results of an experiment (K6) with pigs on straw are given in table 4.

TABLE 4. Heat production of a group of animals of 40–45 kg body weight at various temperatures in kcal/$W^{3}/_{4}$/24 hours. Feed intake constant at about 93 g/$W^{3}/_{4}$ (about 3 kcal metabolisable energy/g feed).

Weight (kg)	Heat production (kcal/$W^{3}/_{4}$)	Temperature
40.9	156.0	19.4°C
42.7	155.5	16.8°C
44.0	163.9	14.0°C
46.1	163.4	11.0°C
47.4	166.7	8.2°C
49.6	169.2	5.6°C

The data (given in table 4) show that at decreasing temperatures there is a rise in heat production. Experiments are in progress to measure the heat production of growing pigs at various temperatures. The experiments are done with pigs housed on concrete, straw and slatted floors to determine the lower critical temperature of pigs fed at normal levels at the various conditions and to determine the effects of being below this critical temperature on the heat production.

The critical temperature can be defined as that temperature below which pigs of a certain weight, fed a certain amount of feed and housed under certain conditions, will increase their heat production in order to maintain their body temperature, this temperature is also called the lowest border of the thermoneutral zone.

MAINTENANCE

The experience sofar has shown that the chamber and the associated equipment need careful maintenance in order to assure the correct functioning of the installation.

Regular inspections and preventive maintenance are carried out according to predetermined schedules by the laboratory personnel and the engineering staff.

The installation has been running continuously for more than two years now

and only small disturbances of one or two days each month have been experienced.

Acknowledgement

The respiration chamber has been designed by Mr. A. M. Bransen, T.F.D.L. The air conditioning equipment has been supplied by Messrs Machine- en Apparatenfabriek van Kempen N.V. Tiel.

Summary

A description has been given of a large respiration climatic chamber. The gaseous exchange of groups of pigs can be measured at various temperatures, relative humidities and air velocities from which their heat production can be derived. Also the housing system i.e. the floor, pen size etc. can be changed. The preliminary results show a satisfactorily recovery of CO_2 in the system. The desired climatic conditions can be easily adjusted and are reached within a few hours.

Samenvatting

Op de Afdeling Veeteelt van de Landbouwhogeschool is een grote respiratieklimaatkamer gebouwd. Met deze klimaatkamer kunnen metingen van de gaswisseling worden verricht bij groepen dieren welke onder verschillende klimaatomstandigheden, zoals temperatuur, relatieve vochtigheid en luchtsnelheid worden gehouden. De gewenste klimaatomstandigheden kunnen in enkele uren worden bereikt. Er kunnen ook verschillende huisvestingssystemen in de cel worden aangebracht. De nauwkeurigheid van de gaswisselingsmetingen blijkt aan de gestelde eisen te voldoen. De gehele apparatuur werkt sinds 2 jaar vrijwel continu en zonder storingen.

References

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

Costa, G. L., Ulrich, F. Kantor and J. F. Holland. Production of elemental nitrogen by certain mammals including man. Nature, London, **218** (1968) 546–551

Hicks, A. M. Physiological responses of growing swine to low temperatures. Univ. of Sashatchewan (1966) Ph. D. Thesis.

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 and under various conditions of environmental temperature and air movement. Anim. Prod. **9** (1967) 435–451

Kooyman, J. Meetrapport klimaatrespiratiecel. T. F. D. L. Wageningen. (1970) 43 pp.

Pfeiffer, H. Die Quantitative und Qualitative Schlachtkörperzusammensetzung sowie der

Nährstoffansatz bei Schweinen unter verschiedenen Haltungsbedingungen. Kühn-Archiv (1968) no. 82 pp. 1–68.

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, pp. 88–103.

ES, A. J. H. VAN, Gas analysis in open circuit respiration chambers. 1st symposium on energy metabolism Copenhagen. EAAP publ. **8** (1958) 132–137

ES, A. J. H. VAN, Between-animalvariation in the amount of metabolisable energy required for the maintenance of cows. Publ. 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 and M. W. A. VERSTEGEN. Data processing in physiology experiments. Int. Summer School on biomathematics and data processing in animals experiments. Elsinore, Denmark (1968) 8 pp.

VERSTEGEN, M. W. A. Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups. Meded. Landbouwhogeschool Wageningen, (1971) 71–2.