Netherlands Journal of Agricultural Science 34 (1986) 173-184

The effect of ambient temperature and activity on the daily variation in heat production of growing pigs kept in groups*

W. van der Hel[1], R. Duijghuisen[1] and M. W. A. Verstegen[1,2]

[1] Department of Animal Husbandry, Agricultural University, Zodiac, Marijkeweg 40, 6709 PG Wageningen, Netherlands
[2] Department of Animal Nutrition, Agricultural University, Haagsteeg 4, 6708 PM Wageningen, Netherlands

Received 1 August 1985; accepted 12 December 1985

Key words: pigs, ambient temperature, diurnal variation, thermal demand

Abstract

The effect of ambient temperature on metabolic rate at various times of the day in relation to activity was studied in two experiments with pigs housed in a group. For both experiments two climate-controlled respiration chambers were used, each containing two pens with 8 pigs each. The experiments were done with animals in the weight range from about 20 kg initial weight to 35 kg final weight. Feeding level was kept constant at 93 g of feed $kg^{-0.75}$ d^{-1} during Experiment 1 and at 83 g $kg^{-0.75}$ d^{-1} during Experiment 2. Feed contained about 12 kJ of metabolizable energy per g. After a 7-day adaptation period at 24 °C the animals were exposed to temperature treatments which lasted 3 days each. The temperatures applied were subsequently 24, 20, 16, 12, 8, 8, 12, 16, 20 and 24 °C. At each temperature treatment, after an acclimation period of 18 hours, metabolic rate and activity were measured continuously during 48 hours.

Lower temperature increased 24-h heat production but not 24-h activity. Moreover, main activity periods shifted from before and after feeding to after feeding, especially in the afternoon.

During the afternoon (12h00-16h00) activity had decreased at the lower ambient temperatures whereas metabolic rate remained constant. It is concluded that the effect of ambient temperature on metabolic rate depends on the time of the day.

Introduction

Pigs are animals having a diurnal rhythm of metabolism. They have a higher metabolic rate and level of activity during day time than during night time (Ingram &

* Part of this research was carried out as an undergraduate of Animal Science of one of the authors (R.D.).

Legge, 1970; Mount, 1979; van der Hel et al., 1984). Activity in pigs may be regarded as one of the main factors affecting the variation in metabolic rate between periods of the day (Charlet-Lery, 1976; Hörnicke, 1970). The ambient temperature may affect this diurnal rhythm in activity as well as in heat production of pigs kept in groups (van der Hel et al., 1984).

It is important to analyse this influence of ambient temperature on diurnal rhythm in metabolic rate because such an influence may indicate that there is a diurnal variation in thermal demand. This may have consequences for assessment of the optimum temperature for feeder pigs. The present experiments were carried out to quantify further the influence of environmental temperature on heat production during different periods of the day in relation to the level of activity of the animals.

Material and methods

Two experiments were carried out with 16 castrated pigs each. The pigs, crossbreds of Large White & Landrace, were housed in a climate-controlled open-circuit respiration chamber (Verstegen et al., 1986). Each of the two chambers used has a volume of 80 m^3. In each chamber there are two pens with a floor space of 9 m^2. The floor consists of 25 mm non-toxic asphalt embedded in foam glass. In each pen 8 animals were housed together in a group. Pigs were fed individually in two equal portions daily at 08h00 and 16h00. Feed contained about 12 kJ of metabolizable energy (ME) per g and 16 % of crude protein. Composition of the feed was similar to the feed normally used in progeny testing stations (Cöp, 1974). Feeding level was 93 g $kg^{-0.75}$ d^{-1} during the first experiment and 83 g $kg^{-0.75}$ d^{-1} during the second experiment. All animals within one experiment received equal amounts of feed based on the mean body weight of the animals in both pens in one chamber.

Temperature

In both experiments the animals were exposed to the same temperature treatments. There was a 7-day period of adaptation to the chambers at 22-24 °C before the experiments started. After each temperature treatment, which lasted three days, the temperature was changed by 4 degrees Kelvin (K). The temperature treatments were subsequently 24, 20, 16, 12, 8, 8, 12, 16, 20 and 24 °C. This procedure was adopted to avoid a long period of adaptation and to be more in line with farm conditions where temperature fluctuates during and between days (Verstegen & van der Hel, 1974). Relative humidity averaged about 70 % (between 65 and 75 %). Water was available from 16h00 to 09h00. The light schedule was 12 h light (07h00 to 19h00) and 12 h dark.

In Fig. 1 the experimental procedures are presented.

Measurements

Animals were weighed at the end of each temperature treatment. During the two experiments of 30 days each the mean live weight of the animals increased from 20 to 33 kg during Experiment 1 and from 20 to 31 kg during Experiment 2.

Heat production. Heat production was determined from measurements of the CO_2

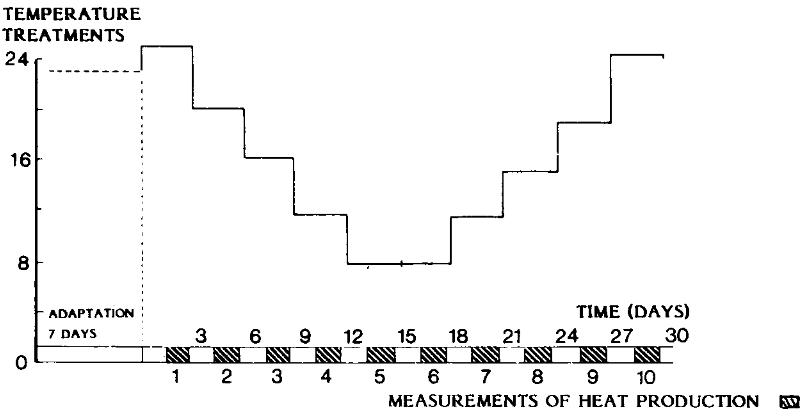

Fig. 1. Temperature treatments and measurements of heat production.

production and O_2 consumption over successive 18-minute periods throughout 48 hours in each temperature treatment (Verstegen et al., 1986). Before the measurements of the gaseous exchange started, the animals were allowed an adaptation period of 18 hours before each temperature treatment.

Activity. Physical activity was measured during successive 6-minute periods in each pen in each chamber. The measurement is based on the Dóppler effect of ultrasound waves as used in a burglar device. Westerterp (1968) has shown that in fasting rats there is a linear relation between activity measured in this way and metabolic rate. The same conclusion has been drawn by Wenk & van Es (1977) for chickens. In a previous experiment this technique was also used (van der Hel et al., 1984).

Calculations

Activity in groups of pigs is related to metabolic rate in two ways. Activity is related to metabolism by means of increased metabolic rate due to increased activity itself. Additionally activity at lower temperatures is related to extra thermoregulatory heat production by its effect on the way of huddling of the pigs (Duijghuisen, 1984, unpublished; Boon, 1982).

It was assumed that at thermoneutrality and at a given feeding level increased metabolic rate is related to physical activity itself. Therefore the relation between activity and heat production was calculated at thermoneutrality according to the formula:

$$H_i = u + b_1 x_{1_i} + b_2 x_{2_i} + e_{ij} \qquad (1)$$

where: H_i = heat production in kJ per $kg^{0.75}$ per 18 minutes at thermoneutrality

x_{1_i}, x_{2_i} = activity counts per 18 minutes (at thermoneutrality) of the two activity meters
b_1, b_2 = regression coefficients at thermoneutrality
e_{ij} = error term

Activity-related heat production (H_{ac}) at different subthermoneutral temperatures was derived by multiplying b_1 and b_2 at thermoneutrality with the respective counts of activity meter 1 and 2 in each chamber (x_1 and x_2) at different temperatures as:

$$H(\mathrm{ac}_i) = b_1 x_{1_i} + b_2 x_{2_i} \qquad (2)$$

in which $H(\mathrm{ac}_i)$ = activity related heat production at temperature i
x_{1_i} and x_{2_i} = activity counts measured at temperature i
b_1 and b_2 = increase in heat production with increase in activity at thermoneutrality as calculated from Eq. 1.

This is thought justified since on an average subthermoneutral temperatures were applied at the same mean age and weight as the thermoneutral conditions.

Energy balances

Energy balances (EB) were determined from intake of metabolizable energy (ME) and metabolic rate. ME was calculated from energy in feed, faeces and urine. Energy content of feed, faeces and urine was determined with a bomb calorimeter. For the energy balances the data of the two treatments at the same temperature in each experiment at the increasing and decreasing temperature treatment scale were pooled to obtain similar mean weights at each of the temperatures.

Results

Table 1 gives data on mean ambient temperatures, metabolizable energy intake, heat production and energy gain expressed per day. The metabolizable energy intake was on an average 1111 kJ $kg^{-0.75}$ d^{-1} in Exp. 1 and 995 kJ $kg^{-0.75}$ d^{-1} in Exp. 2. In Exp. 1 the heat production varied from 765 kJ $kg^{-0.75}$ d^{-1} at the highest temperature to 904 kJ $kg^{-0.75}$ d^{-1} at the lowest temperature level. In Exp. 2 the heat production varied from 716 kJ $kg^{-0.75}$ d^{-1} at the highest temperature level to 845 kJ $kg^{-0.75}$

Table 1. Temperature, metabolizable energy intake (ME), heat production (H) and energy balance (EB) (in kJ $kg^{-0.75}$ d^{-1}).

Exp. 1				Exp. 2			
temperature (°C)	ME	H	EB	temperature (°C)	ME	H	EB
23.8	1112	765	347	24.6	991	716	275
20.5	1112	770	342	20.6	1004	733	271
15.8	1110	814	296	16.4	996	786	210
11.7	1108	872	236	12.6	991	811	180
8.3	1113	904	209	8.7	992	845	147

Table 2. Activity-related heat production (H_{ac}) (in kJ $kg^{-0.75}$ d^{-1}) at different temperatures.

Exp. 1		Exp. 2	
temperature (°C)	H_{ac}	temperature (°C)	H_{ac}
23.8	136	24.6	116
20.5	136	20.6	100
15.8	141	16.4	97
11.7	160	12.6	109
8.3	146	8.7	102

d^{-1} at the lowest temperature level. In Exp. 1 heat production was increased at ambient temperatures below 20 °C and in Exp. 2 below 24 °C. To determine the relation between activity and heat production, in Exp. 1 it was assumed that the 24 and 20 °C treatments were at thermoneutrality whereas in Exp. 2 it was assumed that only the 24 °C treatment was at thermoneutrality.

Table 2 gives data on activity-related heat production. The mean activity-related heat production was 144 kJ $kg^{-0.75}$ d^{-1} in Exp. 1 and 105 kJ $kg^{-0.75}$ d^{-1} in Exp. 2 as calculated with Eq. 2.

In Figs. 2 to 5 heat production and activity at different ambient temperatures at subsequent times of the day are plotted. The figures indicate a clear relation of time of day with heat production and activity depending on ambient temperatures. There were maxima in heat production and activity around feeding time. A low level of heat production and activity were measured during the late night (04h00-07h00). Heat production was increased at lower temperatures except during a part of the afternoon (13h00-16h00). At this period of the day and also from 00h00-

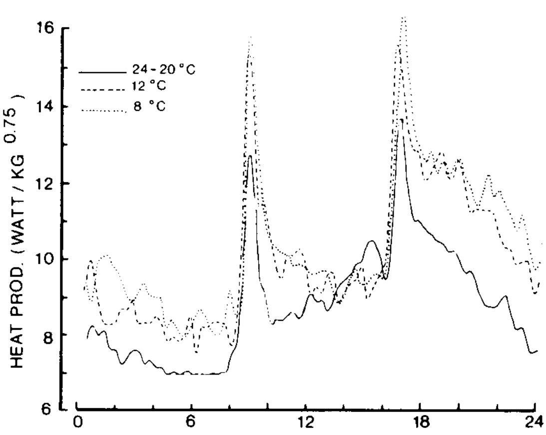

Fig. 2. Heat production pattern over the day at different temperature levels, Experiment 1 (in W/$kg^{0.75}$).

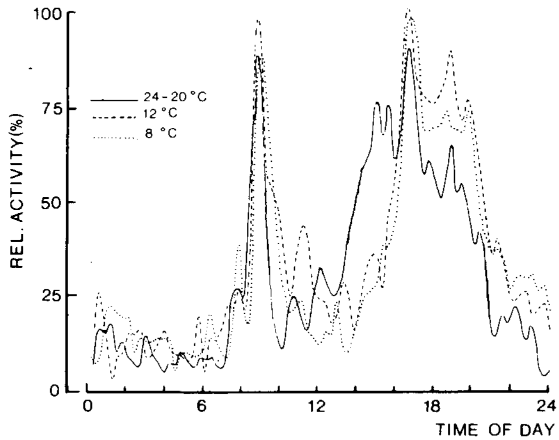

Fig. 3. Activity pattern over the day at different temperature levels, Experiment 1.

08h00 in Exp. 2 activity was decreased somewhat at lower temperatures. During the night (00h00-07h00) there was not much difference in activity of pigs housed at thermoneutral and low temperatures. During the morning (08h00-12h00) and the evening (16h00-24h00) activity was mostly increased when temperatures were low (below thermoneutrality). Therefore average activity on a daily basis hardly changed but its distribution over the day shifted to other hours.

Heat production of pigs in Exp. 2 at 20 °C increased somewhat compared to 24 °C. Since the increase is rather small it was decided in further calculations to

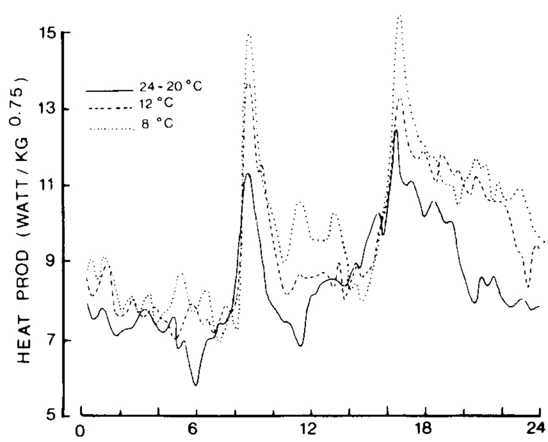

Fig. 4. Heat production pattern over the day at different temperature levels, Experiment 2 (in $W/kg^{0.75}$).

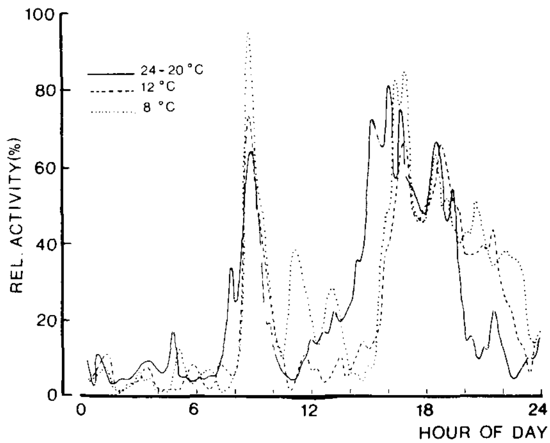

Fig. 5. Activity pattern over the day at different temperature levels, Experiment 2.

combine 24 °C and 20 °C as done for Exp. 1. To quantify this further heat production per hour during the day at thermoneutrality has been subtracted from the heat production measured at 12 and 8 °C. The results are presented in Figs. 6 and 7 for different hours of the day. The increase in heat production at 12 and 8 °C with respect to the mean of 24 and 20 °C is evident from these results. It appeared that the increase in heat production with decrease in temperature was highest during the evening hours (16h00-24h00) and during some hours of the morning (08h00-12h00).

It is thus clear from the results presented in Figs. 6 and 7 that animals do not react in a similar way to temperature during different parts of the day. On basis of the activity pattern and heat production pattern over the 24-hour day at different temperatures as described in Figs. 2 to 5, data on various hours were grouped together per experiment. From Figs. 2 and 4 at thermoneutrality we decided to choose 4 periods

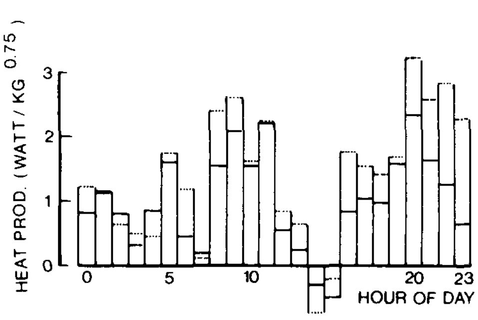

Fig. 6. Difference in heat production at 12 (–) and 8 (·····) °C with respect to the mean heat production at 24 and 20 °C for different hours of the day, Experiment 1 (in $W/kg^{0.75}$).

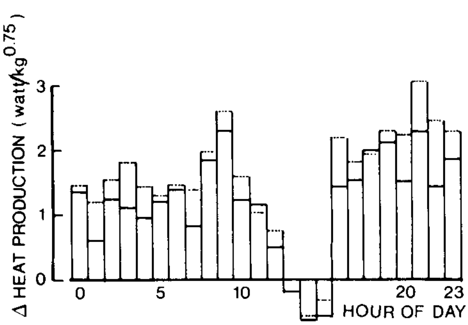

Fig. 7. Increase in heat production at 12 (–) and 8 (·····) °C with respect to the mean heat production at 24 and 20 °C for different hours of the day, Experiment 2 (in W/kg$^{0.75}$).

which represented the periods after feeding in the morning (08h00-12h00) and evening (16h00-24h00) and the periods before feeding in the morning (00h00-08h00) and afternoon (12h00-16h00). Figs. 2 to 5 show that these periods are adequate for thermoneutral conditions. For the lower temperature treatments these periods have a different meaning because Table 3 gives data on heat production at 3 temperature levels and at these different periods of the day. The mean increase in heat production from data of Exp. 1 and 2 between the two highest (24 and 20 °C) and the two lowest (12 and 8 °C) temperature levels was for the morning (08h00-12h00), afternoon (12h00-16h00), evening (16h00-24h00) and night (00h00-08h00) 1.88, –0.03, 1.89 and 1.08 W kg$^{-0.75}$ respectively. Increase in heat production in the cold is most clear in early morning (08h00-12h00) after feeding and evening (16h00-24h00) after feeding.

From the data presented in Figs. 2 to 5 and the regression of heat production on activity the data on activity-related heat production (H_{ac}) were calculated according to Eq. 2. In Table 4 these data on activity-related heat production at different temperatures and at different periods of the day are given. The mean increase in activity-related heat production when the two highest temperature levels (24 and 20 °C) are compared with the two lowest temperature levels (12 and 8 °C) for the

Table 3. Heat production (H) of pigs in W/kg$^{0.75}$ at three temperature levels in four periods of the day.

Experiment No	Temperature (°C)	Period 00h00-08h00	08h00-12h00	12h00-16h00	16h00-00h00
1	23.8+20.5	7.31	9.25	9.59	9.90
	11.7	8.40	10.89	9.40	11.74
	8.3	8.89	11.06	9.54	12.19
2	24.6+20.6	7.22	8.42	9.02	9.30
	12.6	7.99	10.28	9.02	10.60
	8.7	8.09	10.64	9.16	11.44

Table 4. Activity-related heat production (H_{ac} in W/kg$^{0.75}$) at three temperature levels in four periods of the day.

Experiment No	Temperature (°C)	Period			
		00h00-08h00	08h00-12h00	12h00-16h00	16h00-00h00
1	23.8+20.5	0.51	1.60	2.57	2.04
	11.7	0.68	2.40	1.53	2.91
	8.3	0.73	1.88	1.27	2.72
2	24.6+20.6	0.46	1.20	1.95	1.76
	12.6	0.51	1.65	0.77	2.11
	8.7	0.22	1.56	0.71	2.19

morning, afternoon, evening and night were 0.47, –1.19, 0.58 and 0.05 W/kg$^{0.75}$ respectively. Results in Table 4 show that activity during the night (00h00-08h00) is not affected by temperature. Especially during the cold periods before feeding in the afternoon (12h00-16h00) activity is reduced by about 50 %. After feeding both in the morning and evening there is an increase in activity-related heat production when temperature is below thermoneutral.

Taking into account the temperature related activity as such, the increase in metabolic rate during the night seems to be rather associated with feeding level. Combining results from Tables 3 and 4 it can be concluded that increase in metabolic rate associated with temperature is associated with feeding level and with activity.

Discussion

Heat production in growing pigs needs to be assessed in relation to the amount of feed eaten by the animals and to the ambient temperature (Mount, 1979; Close, 1982). Most experiments in the literature have been carried out to study the effect of ambient temperature on heat production during a 24-hour period at different feeding levels (Close, 1982). Metabolizable energy intake affects heat production at thermoneutrality (Mount, 1979). This explains the difference in daily heat production at thermoneutrality (24 °C) between Exp. 1 and 2. Below thermoneutrality heat production is mostly determined by the reaction of pigs to the temperature via thermal requirement. The difference in heat production between Exp. 1 and 2 below thermoneutrality therefore needs to be related to variation in reaction to ambient temperature such as differences in activity-related heat production (Table 2). This means that part of the variation in heat production between groups of pigs at low temperatures may be associated with differences in activity between the groups as related to feeding level.

Diurnal rhythm

In the present experiments heat associated with activity over 24 h was not clearly affected by ambient temperature. The diurnal rhythm in heat production and in activity at different temperatures (Figs. 2 to 5) show a pattern that is in agreement with the results of a previous study made by van der Hel et al. (1984). It should be pointed out here that these patterns of activity are obtained with pigs fed twice a day. Animals fed ad libitum may have a different activity pattern. Moreover, animals may show variation in activity pattern in reaction to the physical environment in a pen (Schouten, 1986). On the basis of activity pattern at thermoneutrality it was decided to differentiate between four periods: morning, afternoon, evening and night. These periods were chosen somewhat arbitrarily on the basis of changes in activity pattern with time of the day as presented in Figs. 3 and 5.

Metabolic rate and activity at various periods of the day were not similarly affected by ambient temperature (Tables 2 and 4). The variation in the effect of temperature on metabolic rate depending on the period of the day is related at least to a great part to activity (see Tables 3 and 4). The largest effect of temperature on heat production was measured after feeding during the morning and the evening hours. During the afternoon, however, no increase in heat production at lower temperatures was measured. Van der Hel et al. (1984) calculated that the increase in heat production at lower temperatures (mean of 8 and 12 °C) in comparison to thermoneutrality (20 °C) for the morning, afternoon, evening and night was 0.65, –0.37, 1.77 and 0.48 W/kg$^{0.75}$ respectively. Although there are some differences with the data presented in Table 4, these results show the same pattern as in our experiment.

Thermal demand may change therefore in relation to time of day in relation to activity and behaviour of the animals. Balsbaugh & Curtis (1979) reported that pigs preferred a higher temperature during day time than during night time. In their experiments pigs which were fed ad libitum could change the ambient temperature by operating a switch. According to Schrenk (1981) pigs have an innate diurnal rhythm in activity with a small peak in the morning and a great peak in the evening. In these activity periods pigs become more active at lower temperatures, this being associated with their greater heat loss. This suggests a relatively high thermal demand in these periods. In the present experiment pigs reduced their activity in the afternoon at lower temperatures by shifting it to another time of the day and reduced their heat loss by huddling. This suggests that pigs reduce their demand in this period.

During the night activity is relatively low at all temperatures. Huddling in combination with reduced metabolic rate during resting and a lower skin temperature (Mount, 1979) could explain a lower thermal demand during this period compared with the morning and the evening.

Thermoneutrality

One may speculate about the meaning of the changes in metabolic rate and activity in various parts of the day as affected by ambient temperature. At low temperatures groups of animals reduce heat loss by resting in a huddling position (Mount, 1979). Activity in such a position would increase thermal losses. In thermoneutral conditions the animals exhibit the same total activity as in the colder conditions. However they start being active some time before feeding. In the cold this part of activity is reduced and animals remain active for a longer time after feeding.

Apparently the heat in the cold associated with eating, digestion, absorption and retention give some compensation for the increased demand. Since the pigs started being active later they will continue a later time. Before feeding, on the other hand, the extra heat loss with activity will reduce the incentive to be active. The total effects will probably be such that the total thermal demand per 24 h is lowered somewhat by this shift in activity.

If lower critical temperatures are computed similarly to the procedure used by van der Hel et al. (1984), on the basis of data in Table 1 we arrive at 19.0 °C in Exp. 1 and 21.9 °C in Exp. 2 with an extra thermal demand of respectively 14.3 and 12.9 kJ $kg^{-0.75}$ K^{-1} d^{-1} respectively. These data are in accordance with the data for pigs as found in the literature and reviewed by Close (1982). Calculation of critical temperature at various parts of the day, as done by van der Hel et al. (1984), may not be completely justified since change in heat production at one part of the day in the present experiments was associated with that at another part of the day. Therefore changes in the thermal demand of pigs in various parts within a day are not independent from one another. Moreover the pattern needs to be discussed in relation to feed intake and way of feeding (ad libitum or restricted). Data in the present experiments show that the mean heat production during a day increases by about 120 kJ/$kg^{0.75}$ when temperature falls from about 20 to around 8 °C. The changes in heat production with temperatures at various times of the day increase in comparison with total heat production during the day. This means that the consequences of low temperature for total heat production depend on exposure to temperature and on time of day. Variation within the day increased from about 2.3 W/$kg^{0.75}$ at 20-24 °C to 3.5 W/$kg^{0.75}$ at 8-12 °C. This increase is clearly associated with the increase in activity related with heat production in these periods of the day and compensatorily with reduced activity in other periods.

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