Effects of environmental temperature on heat production, energy retention, protein and fat gain in early weaned piglets

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1. Six experiments, each involving two groups of six piglets, were designed to study the influence of environmental temperature on heat production, energy retention and protein and fat gain in early weaned piglets. Immediately after weaning, at a mean age of 25 d, the animals were raised in two open circuit respiratory chambers. Each chamber was equipped with a totally wired cage. The piglets were paired-fed and maintained at environmental temperatures of 20, 24 or 28°. Four replicates were used for each temperature. Metabolizable energy, heat production and nitrogen balance were measured during two consecutive periods (A and B), each of 6 d duration.

2. Heat production was higher at 20° than at 24 and 28° during periods A and B. Energy retention was negative during period A, it was positive during period B and increased with temperature.

3. Protein deposition was always positive and independent of environmental temperature. The net efficiency of protein utilization was 0·77.

4. Body fat was mobilized during period A at a higher rate at 20° than 28°. During period B, fat gain increased with increase in temperature.

5. The calculated ME requirement for maintenance amounted to 411 kJ/kg body-weight $^{0·75}$ per d at 28°.

6. The critical temperature of early weaned piglets raised in intensive modern housing and fed at about 90 % of the *ad lib.* intake is close to 28° during the first 12 d after weaning.

Considerable attention has been given during the last decade to the influence of environmental temperature on energy metabolism in the newborn pig and the growing pig (Holmes & Close, 1977). In contrast, there is little available information on the energy metabolism of piglets immediately after weaning in spite of the likely effects of thermal environment on performance (Le Dividich & Aumaitre, 1978). The thermal insulation of 3–4 weeks old piglets is poorly developed and modern intensive housing systems, particularly those of early weaning in totally wired cages, does not afford protection against adverse climatic conditions. Recently, Close & Stanier (1979) studied the effect of environmental temperature on energy and nitrogen metabolism in early weaned piglets. However, the authors did not take into account the immediate period following weaning. From a nutritional point of view, this period is associated with a temporary under-feeding (Leibbrandt *et al.* 1975*a*) so that the heat increment of feeding available for maintaining homoeothermy in the cold is limited. The question arises therefore as to the extent to which energy and protein intake contribute to the energy requirements for thermoregulation and growth in piglets exposed to cold environmental conditions immediately after early weaning.

The purpose of the present experiment was to investigate the effect of environmental temperature on energy and N metabolism of piglets immediately after early weaning, i.e. without any habituation to the experimental treatments. To make the conditions more closely comparable with those of the animals' normal mode of rearing, piglets were weaned between 3 and 4 weeks of age and raised in groups in totally-wired cages.

Table 1. *Design of the experiments including age at weaning (d),*
environmental temperature* (°) and initial mean body-weight (kg)

Experi-ment no.	Selected environmental temperature* (°)			Initial mean body-weight (kg)	Mean age at weaning (d)
1	—	24	28	7·85	28·5
2	20	24	—	5·90	27·5
3	20	—	28	5·82	27·0
4	20	24	—	5·24	20·0
5	20	—	28	7·33	22·0
6	—	24	28	6·43	23·0

* The actual dry bulb temperatures were 20·4, 24·4 and 28·4° ($\pm < 1°$).

Table 2. *Composition of diet (g/kg)*

Ingredient		
Barley meal		300
Cassava meal		175
Soybean-oil meal (500 g CP/kg)		150
Norway herring meal		90
Dry skimmed milk		150
Beef tallow		50
Sucrose		50
Mineral mixture		30
Vitamin mixture		5
Chemical composition	Mean	Range
Dry matter	927	924–935
Nitrogen	36	34–37
Ash	64	62–65
Gross energy (kJ/kg)	16 419	16 250–16 540

CP, crude protein ($N \times 6.25$).

MATERIALS AND METHODS

Animals

Seventy-two piglets were selected from the Large White herd of the Swine Breeding Research Station in Jouy-en-Josas. The sows and litters were penned in farrowing houses with straw bedding; the piglets had free access to a creep feed from 10 d of age. The males were castrated when 12–15 d old. The mean age at weaning was 24·8 d (range 21–28 d) corresponding to a mean live weight of 6.32 ± 1.24 kg.

Experimental design

Six experiments were carried out. Each experiment involved twelve piglets, six being chosen from each of two litters. In each experiment piglets were subjected to two environmental temperatures on the basis of initial live weight, litter of origin and sex. The experimental design is given in Table 1. This was an incomplete balanced block design of type no. 5 (Cochran & Cox, 1966). Each experiment lasted 12 d. Three environmental temperatures were selected, 20, 24 and 28°, assuming from the values of Kovacs & Rafai (1973) that 28° was close to the critical temperature.

Feeding

Piglets were group fed pellets; the ingredient composition and mean analysis are given in Table 2. The food was offered twice daily at 09.00 and 16.30 hours according to an increasing
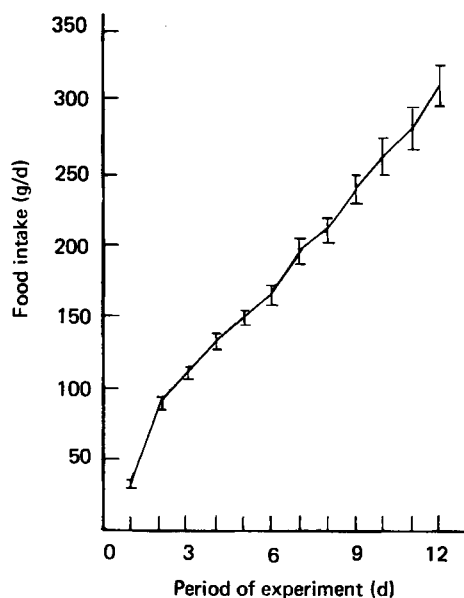
Fig. 1. Daily food intake (g) in piglets. The vertical bars represent
the standard error of the mean.

scale of feeding (Fig. 1) which was similar for all the treatments and replications. This was slightly lower than under *ad lib.* feeding conditions (Le Dividich *et al.* 1977) and helped to prevent the risk of scouring (Palmer & Hulland, 1965). The actual food intake represented approximately 90 % of the *ad lib.* intake found by Leibbrandt *et al.* (1975*a*) and Kornegay *et al.* (1979). The animals had free access to water from nipple type drinkers.

Experimental routine

The piglets were removed from the sows on the morning of day of weaning (day o), individually weighed and immediately transported in an insulated container to the Energy Metabolism Laboratory in Theix. Transport duration averaged 8 h. On arrival (approximately at 16.00 hours), piglets were reweighed and then introduced in groups of six into two respiration chambers where environmental temperature was already adjusted to that of the treatment. The animals were not fed until the morning of day 1. Measurements and records started on the morning of day 1 and ended on the morning of day 13. Consequently, the period of habituation of the piglets to their new environment averaged only 16 h.

Housing

Two open circuit respiration chambers designed for studies in nutrition and bioclimatology with animals up to 300 kg live weight were used (Vermorel *et al.* 1973). For experimental purposes, each chamber was equipped with a 1200 × 900 × 600 mm flat-deck cage constructed of 15 × 15 mm galvanized wire mesh. A groove type feeder, 900 mm long was placed on one side of the cage. The cage floor was raised 700 mm above that of the chamber to allow a tilted polyvinyl tray to be placed underneath for faeces and urine collections.

Measurements

Each experiment was divided into two main periods of 6 d duration; the first period (A) started on the morning of day 1 and ended on the morning of day 7 while the second

period (B) started on the morning of day 7 and ended on the morning of day 13. In addition each main period was divided into two sub-periods of 3 d duration (a_1 and a_2 and b_1 and b_2 respectively).

Piglets were individually weighed on day 0 as described previously and subsequently on the mornings of days 7 and 13. Their health state was estimated from the percentage of diarrhoeic animals. Food consumed was determined daily from supply and refusals (± 2 g). A food sample (50 g) was taken daily and pooled for each period for subsequent analysis.

Faeces and urine were collected together under 0·05 M-sulphuric acid; every morning the floor of the cage and the collection tray were washed with approximately 200 ml 0·05 M-H_2SO_4. Excreta and washings were subsequently weighed and mixed together and a representative sample was taken and stored at a temperature of $-18°$ for subsequent analysis.

The dry matter content of the food and food refusals was determined by drying in a ventilated oven at 80° until constant weight was obtained. Daily representative samples of excreta were pooled for each main period, mixed and analysed for N (six to eight determinations/period) by the macro-Kjeldahl method. The remainder was freeze-dried for determination of gross energy content determined by means of an adiabatic bomb calorimeter. The combustion gases were also analysed for carbon according to the method of Nijkamp (1961). Ammonia losses in the air from faeces and urine were measured to correct the N balances.

Metabolizable energy (ME) intake was calculated by subtracting the energy of excreta (faeces and urine) from the gross energy of the food eaten. Methane production was neglected as it has been found to account for less than 1 % of gross energy intake in growing pigs (Verstegen, 1971).

Gas exchanges were recorded at 2 min intervals over 22·5–23 h. The recording was stopped each morning for between 1 and 1·5 h in order to collect the excreta and food refusals, to calibrate the gas analysers and to analyse the representative samples of air leaving the chambers.

Heat production (HP) of piglets was calculated during each period from measurements of carbon dioxide production, oxygen consumption and urinary N losses using the formula proposed by Brouwer (1965). Urinary N losses were estimated assuming digestibility coefficients for N of 0·72 and 0·78 during periods A and B respectively (B. Sève, personal communication).

Energy balance (EB) was calculated by both the respiratory quotient (RQ) method (EB = ME−HP) and the carbon nitrogen (CN) method. CN balance exceeded RQ balance by on average 2 % of energy intake, in agreement with the results of H. Böhme (personal communication). EB obtained by the RQ method seemed more valid and only these observations are reported in the present paper.

Protein gain (N × 6·25) was computed from the N balance values and the energy stored as protein was calculated assuming the energy value of protein to be 23·8 kJ/g (Brouwer, 1965). Fat gain was estimated as the difference between EB and energy retained as protein, assuming the energy content of fat to be 39·8 kJ/g (Brouwer, 1965).

Statistical analysis

The data were analysed according to the method proposed by Cochran & Cox (1966) for a balanced incomplete block design of type no. 5. Values for EB were expressed as kJ/metabolic body-weight ($W^{0·75}$). All results presented in this paper are adjusted means.

Table 3. *Mean values for body-weight (kg), daily gain (g/d), food intake (g/d), metabolizability of food and percentage of diarrhoeic piglets*

		Environmental temperature (°)				
	Period	20	24	28	Mean	SEM
Metabolic body-wt	A	4·07	4·00	4·10	4·06[a]	
(kg body-wt$^{0·75}$)	B	4·38	4·30	4·43	4·37[b]	
	Mean	4·23[a]	4·15[a]	4·27[a]		0·6
Growth rate (g/d)	A	8	37	69	38[a]	
	B	210	198	198	202[b]	
	Mean	110[a]	117[a]	135[a]		17·4
Food intake (g/d)	A	115	112	116	114[a]	
	B	258	245	263	255[b]	
	Mean	186[a]	179[a]	193[a]		4·2
Metabolizable energy	A	78·8	80·2	83·7	80·9[a]	
(% gross energy)	B	82·1	81·2	79·7	81·0[a]	
	Mean	80·4[a]	80·7[a]	81·7[a]		2·1
No. of diarrhoeic piglets (%)	A	19·0	17·4	9·7	15·0	
	B	9·0	15·5	18·5	14·0	
	Mean	14·0	16·2	14·1		

a, b, Means with the same superscript did not differ significantly $P < 0.05$.

RESULTS

As a rule, piglets tolerated transportation very well and the weight loss averaged 1·7 % of live weight. During the first 3 d of the trial, the piglets were very active, and considerable fighting was observed, probably because of mixing of the litters. All animals survived the trials.

Food intake, energy metabolizability and growth rate

The results are presented in Table 3. Generally, piglets consumed their daily food allowance except in Expt no. 4 at 24° where the animals refused 12·9 % of the food offered. This was associated with a high incidence of diarrhoea in the animals.

No significant effect ($P < 0.05$) of environmental temperature on the metabolizability of the gross energy of the food was determined although this was inversely related to the percentage of scouring piglets. Maximum values ranged from 0·82 to 0·85 in healthy piglets (no diarrhoea), whereas a minimum value of 0·75 was obtained in a group of piglets raised at 24° (Expt 4) where 50 % were scouring.

During period A mean daily weight gain was low in piglets raised at 24 and 28°, i.e. 37 and 69 g respectively, and practically nil in those raised at 20°. During period B daily weight gain averaged 202 g/piglet. Over the 12 d period, there was no significant effect of environmental temperature on weight gain, but there was a significant difference between A and B.

Heat production and energy retention

The results presented in Table 4 show that HP increased linearly ($P < 0.05$) by 12·5 and 11·0 kJ/kg W$^{0·75}$ per d, i.e. 22 and 17 % as environmental temperature was lowered from 28 to 20° during periods A and B respectively. In addition, Fig. 2 shows differential changes in HP after weaning according to environmental temperature. Thus during sub-periods a_1 and a_2, HP remained practically constant in piglets raised at 20° or slightly

Table 4. *Effect of environmental temperature on energy balance*
(kJ/kg body-weight $^{0.75}$ *per d) in piglets*

	Period	Environmental temperature (°)			Mean	SEM
		20	24	28		
Gross energy intake	A	503	506	502	504[a]	
	B	1054	1013	1059	1041[b]	
	Mean	779[a]	760[a]	780[a]		24
ME intake	A	395	405	419	406[a]	
	B	887	843	854	861[b]	
	Mean	641[a]	624[a]	636[a]		33
HP	A	543	491	441	492[a]	
	B	606	573	520	566[b]	
	Mean	575[a]	532[ab]	481[b]		32 L**
Energy retained	A	−149	−86	−23	−86[a]	
	B	282	269	333	295[b]	
	Mean	67[a]	92[ab]	155[b]		38 L**

a, g, Means with the same superscript letter did not differ significantly.
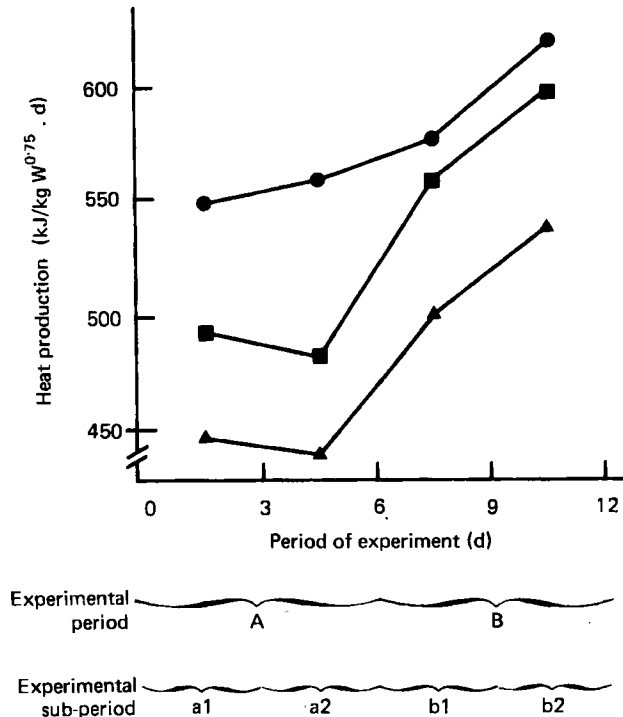**$P < 0.01$; L, linear effect; ME, metabolizable energy; HP, heat production.

Fig. 2. Heat production (kJ/kg $W^{0.75}$ per d) of piglets in relation to environmental temperature (°).
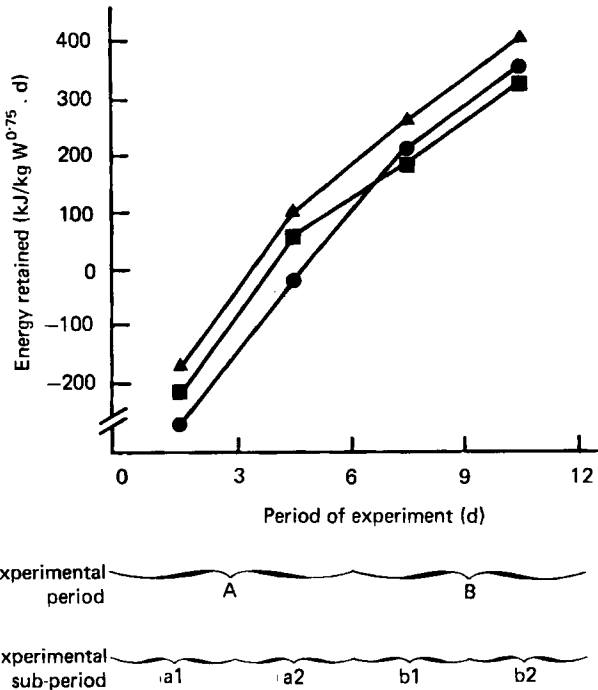(▲), 20°; (■), 24°; (●), 28°.

Fig. 3. Energy retention kJ/kg $W^{0.75}$ in relation to environmental temperature (°). (▲), 20°; (■), 24°; (●), 28°.

decreased by approximately 2 % in those raised at 24 and 28°. Taking a_2 as a reference period (from day 4, piglets were quiet, consumed more food and their EB was either positive or nil), it appeared that the percentage increase in HP (kJ/kg $W^{0.75}$ per d) between a_2 and b_2 was similar for piglets raised at 24 and 28° and averaged 23 %; it was 11 % for those kept at 20°.

During period A, HP exceeded ME intake and consequently EB was negative. The calculated body energy mobilized increased linearly ($P < 0.05$) with decreasing environmental temperature from 28 to 20° and amounted to 24, 86 and 149 kJ/kg $W^{0.75}$ per d at 28, 24 and 20° respectively. In addition, Fig. 3 shows that EB becomes positive from day 3, 4 and 5 in piglets raised at 28, 24 and 20° respectively. Thereafter, EB increased linearly ($P < 0.05$) with time and environmental temperature. However, because daily ME intake was slightly lower at 24° than at 20° (843 kJ/kg $W^{0.75}$ v. 887 kJ/kg $W^{0.75}$, Table 4) during period B, energy retention at 24° was slightly lower than at 20°.

From the values for sub-periods, a_2, b_1 and b_2, energy retention was related to ME intake at each temperature. The relevant equations are;

$$20° \quad Y = 0.91(\pm 0.07)\,X - 520(+49.1) \quad (r\ 0.97), \tag{1}$$

$$24° \quad Y = 0.76(\pm 0.07)\,X - 378(\pm 45.6) \quad (r\ 0.96), \tag{2}$$

$$28° \quad Y = 0.79(\pm 0.09)\,X - 325(\pm 52.5) \quad (r\ 0.94). \tag{3}$$

Where Y is the energy retained (kJ/kg $W^{0.75}$ per d), X is the ME intake (kJ/kg $W^{0.75}$ per d).

Table 5. *Effect of environmental temperature on nitrogen retention* $(g/kg\ body\text{-}weight^{0.75} per\ d)$ *and the partition of energy retention between fat and protein* $(kJ/kg\ body\text{-}weight^{0.75}\ per\ d)$

| | Period | Environmental temperature (°) | | | Mean | SEM |
		20	24	28		
N retained	A	0·43	0·47	0·46	0·45[a]	
	B	1·30	1·23	1·25	1·26[b]	
	Mean	0·86[a]	0·85[a]	0·85[a]		0·05
Energy retained as protein	A	64	70	68	67[a]	
	B	193	182	185	188[b]	
	Mean	128[a]	126[a]	127[a]		2·2
Energy retained as fat	A	−212	−155	−92	−153[a]	
	B	89	77	147	104[b]	
	Mean	−62[a]	−39[ab]	27[b]		64 L**

a, b, Means with the same superscript letter did not differ significantly.
** $P < 0.01$; L linear effect.

Nitrogen balance and the partition of energy retention between protein and fat gain

Table 5 shows that between 20 and 28°, N retention was not influenced by environmental temperature. N retention amounted to 0·45 and 1·26 g/kg $W^{0.75}$ per d on average, during periods A and B respectively, the difference between periods being significant ($P < 0.01$). Consequently, energy retained as protein was similar between 20 and 28°, but it increased linearly ($P < 0.05$) with food intake according to the following equation;

$$Y = 0.27\ (\pm0.02)\ X - 44.3 \quad (n\ 24;\ r\ 0.94). \tag{4}$$

Where Y is the protein gain (kJ/kg $W^{0.75}$ per d), X is the ME intake (kJ/kg $W^{0.75}$ per d).

When protein retention (Y, g/kg $W^{0.75}$) was related to protein intake (X, g/kg $W^{0.75}$) the following regression was obtained;

$$Y = 0.77\ (\pm0.15)\ X - 2.42 \quad (n\ 24;\ r\ 0.91). \tag{5}$$

This shows that the increment in protein retained is 77 % of the increment in protein intake. Extrapolation to protein retention equal to zero provides an estimate of protein requirement for maintenance of 3·14 g/kg $W^{0.75}$ per d. As the food contained 14·3 kJ ME and 0·245 g protein per g dry matter the energy cost of protein maintenance amounts to 183 kJ ME/kg $W^{0.75}$ per d.

During period A piglets gained protein although their EB was negative (Table 4). Consequently, energy requirement for maintenance, thermoregulation and production involved a partial mobilization of lipid reserves. The calculated energy derived from lipid mobilization increased linearly ($P < 0.05$) when environmental temperature decreased from 28 to 20° and amounted to 92, 155 and 212 kJ/kg$W^{0.75}$ per d at 28, 24 and 20° respectively. During period B piglets gained both fat and protein; fat gain increased with air temperature whereas protein gain was similar between treatments.

DISCUSSION

The effect of the environmental temperature on the energy metabolism in particular has been found to be closely related to the feeding level (Holmes & Close, 1977). In early

weaned piglets fed *ad lib*. food intake was found to decrease at high temperature (30–33°) (Fuller, 1965; Sugahara *et al*. 1970; Le Dividich *et al*. 1977), but an absolute increase in the cold (< 20°) was questionable (Fuller, 1965; Brown *et al*. 1976), particularly during the immediate post weaning period when the piglets are learning to consume solid food (Papp, 1976). As a result, it was decided to keep the level of food intake similar at the three environmental temperatures. Consequently the differences between the temperatures used apply only under our actual experimental conditions, i.e. one level of feeding averaging 90 % of the *ad lib*. level, and housing in wired cages.

Growth performance and energy metabolizability

No significant effect of environmental temperature on the daily weight gain was found, in spite of large differences in EB. However, it is in good agreement with the fact that N balance was not influenced by environmental temperature and the fact that the weight gain was mainly composed of lean tissue. Accordingly, the measurement of growth rate would not be a sensitive criterion for determining the effect of moderate temperature treatments on piglets in experiments of short duration.

Taking the value of 0·95 as the conversion coefficient of digestible energy into ME (Diggs *et al*. 1965; De Goey, 1973), the mean coefficient for the apparent digestibility of gross energy in the present experiments was 0·85, which is in agreement with results previously obtained with the same diet (Le Dividich *et al*. 1977). Entringer *et al*. (1975) reported detrimental effects of diarrhoea on the apparent digestibility of N in growing pigs. The present results similarly showed that scouring had an adverse effect on the metabolizability of gross energy intake.

Heat production and energy balance

The linear increase in HP when environmental temperature fell from 28 to 20° during periods A and B implied that the probable critical temperature (CT) lay at or above 28° for piglets fed slightly (10 %) below the *ad lib*. level. From the results of Cairnie & Pullar (1957), Studzinski (1972), Kovacs & Rafai (1973), it could also be reasonably assumed that a temperature of 28° was close to the CT for the actual feeding level. Thus the present results clearly showed that piglets raised in groups in totally wired cages require a high environmental temperature (approximately 28°) particularly during a period of 12 d after early weaning.

A decrease in environmental temperature below the CT resulted in an increase in HP. Between 30 and 20°, this increase amounted to 40 % in individually housed piglets of 2 kg live weight (Mount, 1968) as well as those 33–66 d old (Stombaugh & Roller, 1976). In the present groups of animals, an increase of only 20 % was obtained between 28 and 20° in good agreement with the fact that huddling of pigs considerably reduces their heat loss (Mount, 1960; Verstegen, 1971).

Immediately after weaning, the piglets were particularly active, which is in good agreement with the findings of Fraser (1978) but the transport after weaning also may have increased this activity. This explained, partly at least, why HP remained practically unchanged between a_1 and a_2 sub-periods although ME intake was increased by approximately 90 %. Thus the a_1 sub-period could be considered as an habituation period of the piglets to their new environment although the results (HP, EB) of this sub-period did not differ fundamentally from those of the subsequent sub-periods.

It is interesting to note that between a_2 and b_2 sub-periods the increase in HP was approximately 50 % higher in piglets kept at 28 and 24° than in those kept at 20° although the increase in ME intake was slightly lower in the former groups of piglets. This would indicate that the heat increment of feeding was, partly at least, used for thermoregulation

at 20°. A similar conclusion appeared from the results of Close *et al.* (1971), Verstegen (1971), Verstegen *et al.* (1973) and Fuller & Boyne (1972). These observations could be related to the variations in the efficiency of the ME utilization for growth. Calculations made from equations nos. 1, 2 and 3 give values decreasing from 0·91 at 20° to 0·76 and 0·79 at 24 and 28° respectively.

From equation no. 3, excluding the a_1 sub-period results (habituation period), the thermoneutral estimation of maintenance energy requirement (ME_m) is calculated to be 411 kJ/kg $W^{0.75}$ per d. This value agrees with that of 425 kJ/kg $W^{0.75}$ per d found by Jordan (1973) for piglets and those of Verstegen *et al.* (1973) and Close & Mount (1976) who obtained values of 418 and 440 kJ/kg $W^{0.75}$ per d for growing pigs, respectively. However, our estimate is lower than those found by De Goey (1973), Burlacu *et al.* (1973), Jordan (1974) and Close & Stanier (1979) for piglets.

Energy deposition as protein and fat

Between 20 and 28°, protein deposition was not influenced by air temperature in our piglets. Similar results were also found in piglets (Fuller, 1965; Close & Stanier, 1979) and in heavier pigs (Verstegen *et al.* 1973; Fuller & Boyne, 1971). N retention appears to be affected only under extreme environmental conditions, either in very cold (Close & Mount, 1976) or in very hot conditions (Holmes, 1973).

Whereas N retention was independent of air temperature, fat deposition closely depended on air temperature. Similar results were found in piglets (Fuller, 1965; Sugahara *et al.* 1970; Hacker *et al.* 1973) and in larger pigs (Verstegen, 1971; Verstegen *et al.* 1973; Close & Mount, 1976). In addition, fat reserves appeared to be easily mobilized during the weaning period, in good accordance with the previous results of Baur & Filler (1959), Leibbrandt *et al.* (1975*b*) and Whittemore *et al.* (1978).

Present results suggest that during the weaning period protein and fat deposition are independent, both being closely related to ME intake. Priority is given to protein deposition, independently of environmental temperature, whereas fat deposition depends on environmental temperature.

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