7.0 EFFECTS OF SPRINKLING DURATION ON TOTAL MOISTURE LOSSES FROM PIGS

7.1 Introduction

A short experiment (Laboratory Experiment 6) was designed to quantify the effects of length and pattern of sprinkling on the evaporative water loss from pigs as a preliminary to the accurate design of Laboratory Experiment 7 in which it was planned to investigate the influence of sprinkling on the biological performance of pigs raised at high temperatures.

7.2 Materials and Methods

7.2.1 Modifications of the Shinfield Crates

Two Shinfield metabolic cages (Frape *et al.*, 1968) were modified such that they were linked together by a walk-way at floor level. The aim was to sprinkle each pig in one crate and to then quickly move the pig into the second crate for the measurement of evaporative rate. The spray-crate was fitted with a manually operated sprinkler at a height of 140 cm above its floor. The sprinkler was adjusted to deliver water at the rate of 800 ml/min at 207 kPa (30 psi). The water temperature was approximately 10° C. The second crate was covered with heavyweight transparent polythere sheeting. Both its ends were sealed by doors; one fitted with an inlet and the other with an outlet air duct (see Figure 27). Air at 35±1° C was forced through the chamber thus formed in the second crate by an electric fan at the rate of 955 l/min. This rate corresponds to a mean air movement of 0.20 m/s over the 0.8 m² cross-section of the cage and is close to the

rate commonly encountered in the hotroom (Figure 19). A perforated masonite board was placed between the air inlet duct and the pig's head to act as a baffle and to ensure uniform air flow around the animal. The air velocity was continuously monitored by means of a hot-wire anemometer and was adjusted such that inside the chamber it remained at 0.20 m/s.

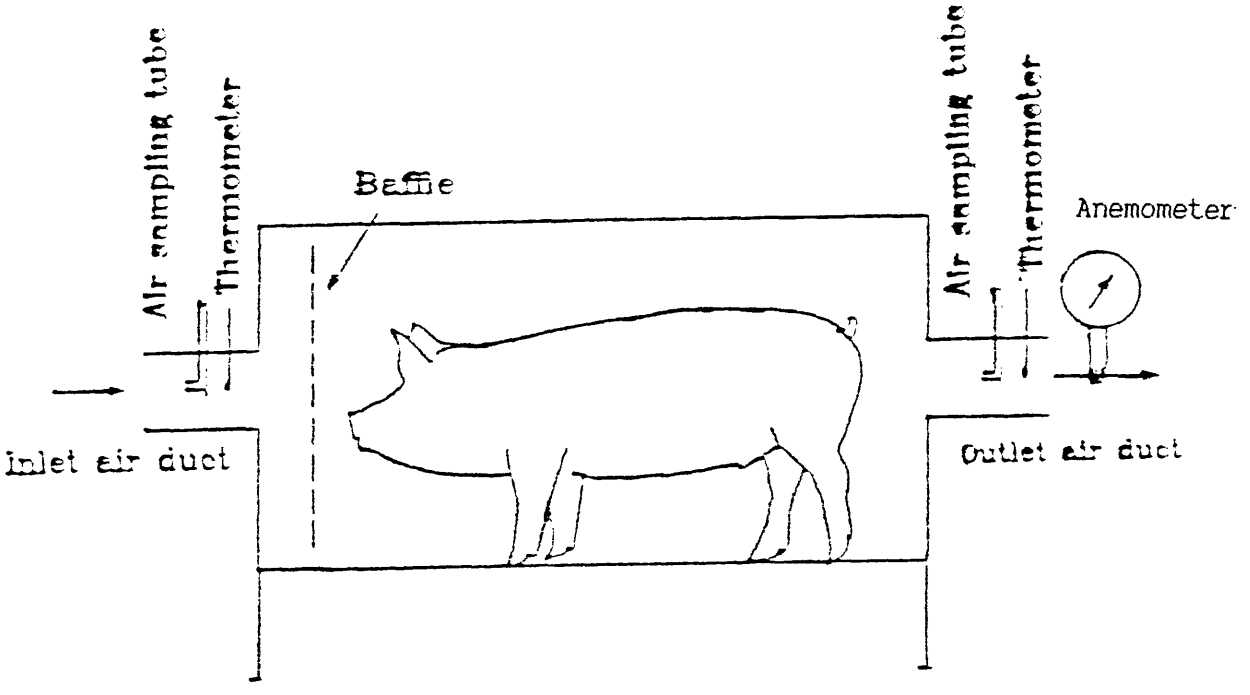

Figure 27. Diagramatic representation of the modified Shinfield crate used to measure total evaporative moisture losses from pigs.

7.2.2 Standard Routine

Test pigs were first confined in the spray-crate while the sprinkler was activated for the required interval. The pig was then immediately moved into the modified Shinfield crate and the end of sprinkling was noted as time zero. A 5-minute equilibrium period was allowed once the pig

entered the modified Shinfield crate and thereafter inlet and outlet air samples (0.3% of total flow) were collected over successive five minute intervals for measurement of moisture content by the acid trap and air-flow meter system illustrated in Plate 7. The routine of sampling and moisture determination was repeated until evaporation rate returned to pre-sprinkling levels as determined by the application of the above routine to non-sprinkled pigs. The basal (pre-sprinkled) evaporation rate so determined represented a combination of respiratory and transpiratory moisture losses.

7.2.3 Pigs, Husbandry and Treatments

Two entire male Large White X Landrace pigs weighing 80 and 90 kg were used. The animals were kept in the hotroom that was run according to the standard routine (see III-4.2.4) at all times. However, in order to minimize gut fill effects during the tests, the animals were fed only once a day in the evening.

Each of the pigs was sprinkled twice on separate occasions for each of 0, 30, 60, 90 and 120 seconds. Each treatment was allocated at random, with the first replicate being completed before the second one began.

The results of moisture evaporated after each sprinkling treatment were bulked (2 pigs, 2 replicates) and then regressed over time using polynomial regression analysis.

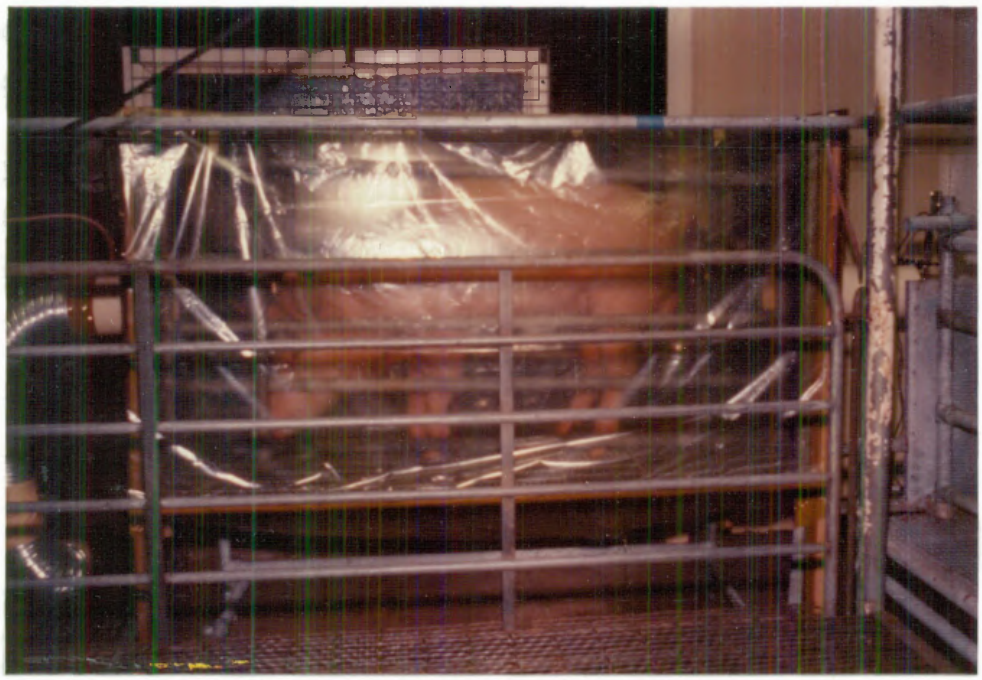

Plate 6. A pig in the modified Shinfield crate while evaporation rate was being measured.

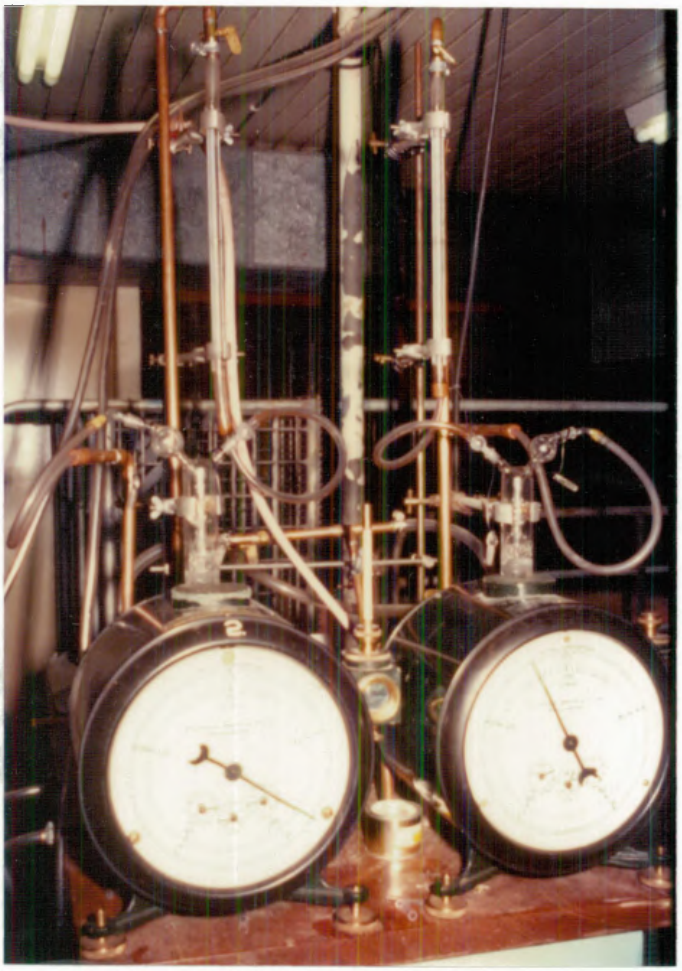

Plate 7. Acid trap and air-flow meter system used to sample air flow through the modified Shinfield crate and to measure evaporation rate.

7.3 Results

The influence of duration of sprinkling on the time course of the subsequent evaporation from the pig is shown in Figure 28, the regression equations for which are given in Appendix XXIV.

It can be seen from Appendix XXIV and the corresponding graphs (Figures 28 and 29) that the evaporation rate for each of the sprinkling durations declined linearly. The rates of decline in evaporation were 0.023, 0.033, 0.029 and 0.028 g/min for pigs that were sprinkled for 30, 60, 90 and 120 seconds respectively. In the case of the 90 seconds sprinkling, however, the quadratic regression relationship also proved to be significant and it is this one that is depicted separately in Figure 29.

7.4 Discussion

It should be pointed out that the chamber used in Laboratory Experiment 6 was designed to measure total evaporation, i.e. both respiratory and cutaneous evaporation; facilities were unfortunately not available to allow moisture losses from these two avenues to be accurately partitioned. While it is known that the respiration rate of pigs tends to increase with rising environmental temperature (Ingram, 1964a), this increase is not so great if heat-stressed pigs are sprinkled. Morrison, Bond and Heitman (1968b) thus found, for example, that sprinkling pigs relieved heat stress as indicated by a reduction in both respiration rate (threefold) and rectal temperature (aproximately 0.8° C). Furthermore, Morrison, Bond and Heitman (1967) found that moisture loss from respiration alone in 90 kg pigs at 29° C was only 0.80 ml/min/pig. The amount of moisture loss due to respiratory evaporation (Morrison, Bond and Heitman,

1967) was very small when compared to the amount of water available for cutaneous evaporation in the sprinked pigs in the present study. With the above considerations in mind, respiratory evaporation in the present study may be assumed to have been constant over each relatively short (30 to 110 min) testing period and the major changes observed can be assumed to have arisen from cutaneous evaporation of sprinkled water.

The total amount of water that can be evaporated from any surface to the surrounding air depends on the temperature of that water, the partial pressure of moisture in the ambient air and the surface area exposed, as well as the rate of surface air movement. The higher the temperature of the water and the bigger the surface area, the greater would be the rate of evaporation (Fong, 1976). In the present study the peak rate of cutaneous evaporation would presumably have occurred when the film of water on the pigs's skin was heated to skin temperature. The fact that pigs sprinkled for 60, 90 and 120 seconds all exhibited similar peaks of total evaporation (Figures 28 and 29) suggests that the pigs were fully wetted at sprinkling durations of 60 sec and above. Any increase in sprinkling duration such as to 90 and 120 sec presumably resulted in excess water run off. Conversely, the lower peak evaporation observed after sprinkling for 30 sec was possibly due to the fact that these pigs were not fully wetted and hence would have had a smaller wetted surface available for evaporation. On the other hand, a constant rate of evaporation representing the sum of the respiratory and transpiratory components only (Morrison, Bond and Heitman, 1967) would be expected when all the sprinkled water was completely evaporated.

It can be seen from Figures 28 and 29 that 30 min after sprinkling all

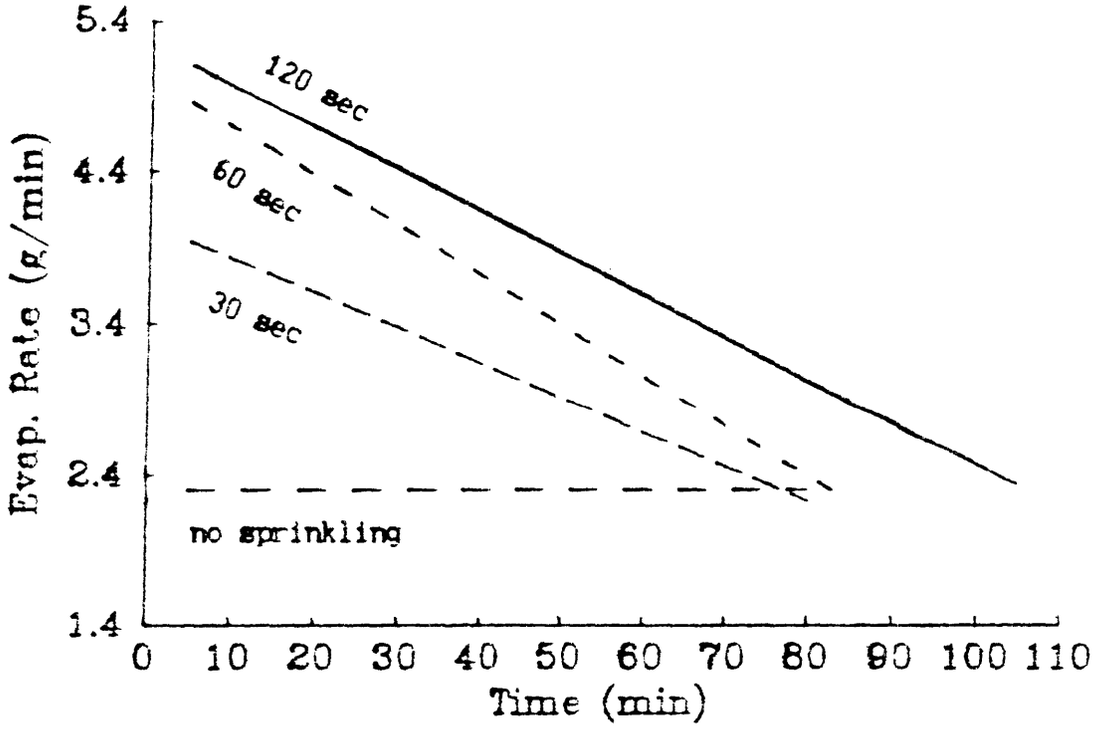

Figure 28. Evaporation following sprinkling of water on pigs for 0, 30, 60 and 120 seconds at the rate of 800 ml/min.

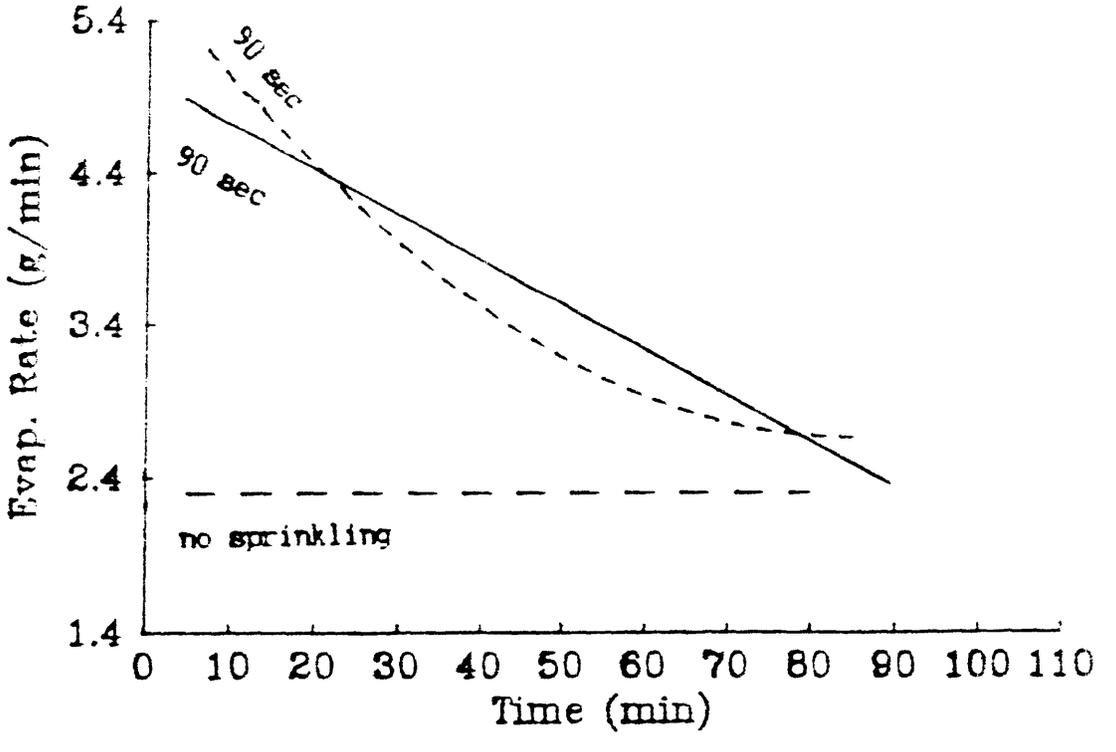

Figure 29. Evaporation following sprinkling of water on pigs for 0 and 90 seconds at the rate of 800 ml/min.

groups of pigs apparently still had an ample supply of water to evaporate; their evaporative rates were still considerably above the basal level of 2.3 ml/min.

On the above basis, and with economy of water usage and hygiene (Brennan, 1978) considerations in mind, the 30 and 120 sec sprinkling durations were selected as treatments in the subsequent major experiment designed to relate water utilization and performance in a diurnally variable hot environment.

8.0 SPRINKLING TO AMELIORATE THE EFFECTS OF HIGH TEMPERATURE ON GROWING PIGS

8.1 Introduction

It has been shown by several workers (Bond, Heitman and Kelly, 1964; Morrison *et al.*, 1972; Hsia, Fuller and Koh, 1974) that wetting pigs by sprinkling would increase the growth performance of pigs in a hot climate and there is some evidence that cold drinking water might lower rectal temperature and respiration rate (Bond, Heitman and Kelly, 1964). Therefore an experiment was designed to investigate the effects of sprinkling durations and drinking water temperature on growth performance of growing-finishing pigs.

8.2 Materials and Methods

8.2.1 The Climate Laboratory

The same climate laboratory used in previous experiments (see III-4.2) was modified to accommodate sprinklers and a temperature-controlled drinking water system (Figure 30). Provision was made for water sprinklers to be located above two pens. Each nozzle delivered 800 ml/min at 207 kPa (30 psi) and could be automatically activated for different lengths of time by a time-switch/solenoid control system. The sprinkling water temperature was thermostatically controlled at 30±1° C.

Two circuits for drinking water were established and in each of these water was continuously circulated by a small electric pump. The "warm" and "cold" drinking water circuits were thermostatically maintained at 30±1° C

and 11±1°C respectively (see Figure 30). The continuous water recirculation in each circuit was designed to avoid temperature variations due to water lying in the pipes between successive drinking episodes. The recirculatory systems developed had minimal "still-water" spaces immediately adjacent to the nipples (less than 50 ml).

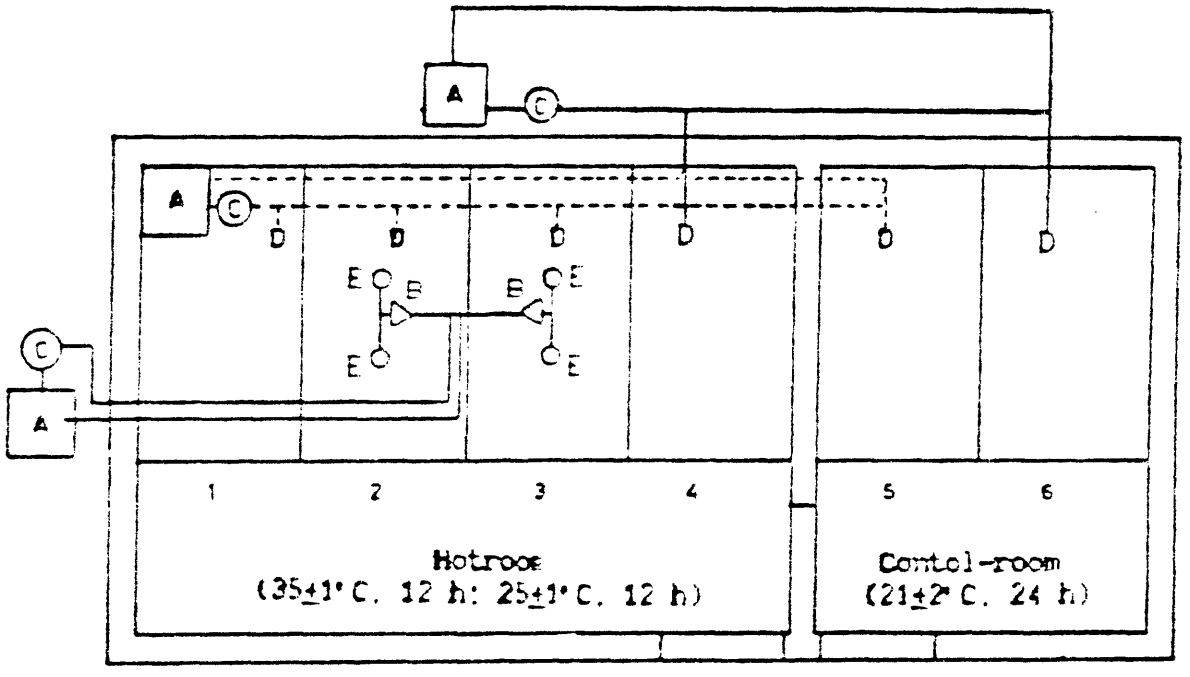

Figure 30. Watering systems used in Laboratory Experiment 7.
A - Thermostatically controlled water reservoir
B - Solenoid valve
C - Electric pump
D - Drinking nipple
E - Sprinkle nozzle

8.2.2 Animals and Husbandry

The same routine of obtaining, allocating and managing the pigs was employed as in the previous experiments (see III-4.2). However, in the

current experiment as no nutritional treatments were included all pigs were given the same commercial finisher diet (Fielders Gillespie Ltd., Australia). The diet composition is given in Table 36.

8.2.3 Treatments

The temperature regimes in both the hotroom and the control-room were set as those of the previous experiment (see III-4.2); the group treatments (5 pigs/group) were as follows:

Treatment 1: 30° C drink, no sprinkling, pair-fed*, hotroom.
Treatment 2: 30° C drink, 120 sec/30 min sprinkling, hotroom.
Treatment 3: 30° C drink, 30 sec/30 min sprinkling, hotroom.
Treatment 4: 11° C drink, no sprinkling, hotroom.
Treatment 5: 30° C drink, no sprinkling, pair-fed*, to group 1, control-room.
Treatment 6: 11° C drink, no sprinkling, control-room.

* - The pigs in Treatment 5 in the control-room received the exact amount of feed as their counterparts in Treatment 1 in the hotroom had eaten on the previous day.

When the pigs reached a group mean liveweight of approximately 85 kg, drinking water was metered to individual pens for five consecutive days to enable accurate measurements of water intake to be made. Figure 31 shows the recording system used for these water intake measurements, during which the temperature of the drinking water in each pen was kept as close as

possible to the predetermined values (i.e. 30° C and 11° C for warm and cold water, respectively).

Table 37. Diet composition (g/kg) of the diet used in Laboratory Experiment 7 (air dry basis).

Ingredient	g/kg
Fine wheat	664
Mill run (wheat)	200
Meat meal (M)	68
Sunflower M	15
Soyabean M	40
Lime	6
Vitamins	1
Grower premix	1
Payzone	0.5
Lysine-HCl	2
Salt	2

Vitamins A 5,000,000 iu; D3 500,000 iu; E 7,500; K3 0.5 g; B2 1.5 g; B12 7.5 mg; Nicotinic acid 7.5 g; Cal.-d-Pantothenate 5 g; Copper 3 g; Iron 40 g; Manganese 20 g; Iodine 400 mg; Zinc 75 g; and Ethoxyquin 250 mg per kg.

8.2.4 Measurement

Routine measurements of growth rate, daily dry matter and energy intake, anatomical changes and physiological activities were carried out as previously described in Laboratory Experiment 1 (see III-4.2.3). The digestibility measurements were carried out on two groups (Treatments 1 and 6) only, due to the fact that in the current study only one diet was used.

Plate 8. Pigs in the hotroom being sprinkled in Laboratory Experiment 7.

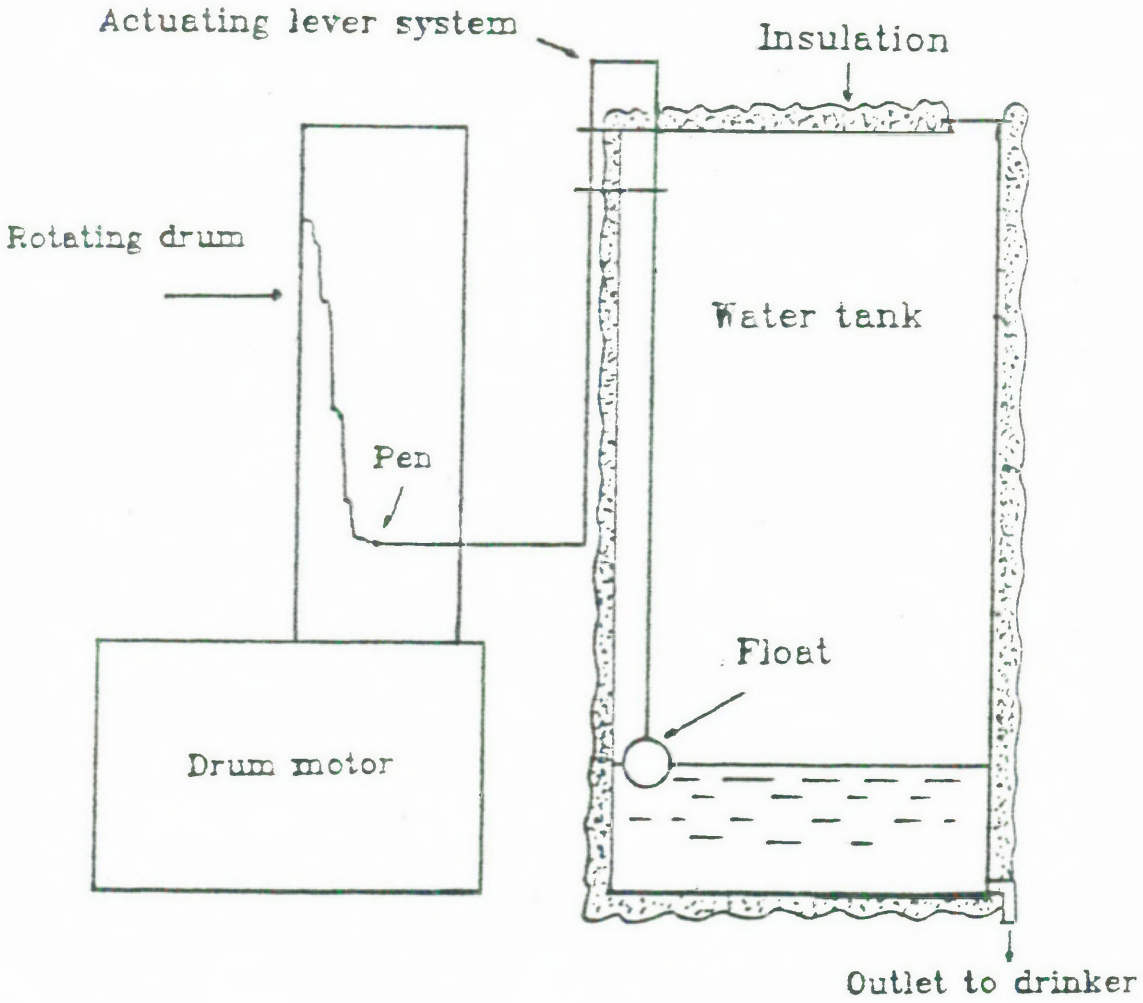

Figure 31. Equipment used for measuring the water intake of the pigs.

8.2.5 **Analyses of Results**

Analysis of variance and Duncan's Multiple Range Test were the standard statistical procedures applied to the raw data from individual pigs.

8.3 **Results**

Since the values obtained for water consumption were calculated from group averages, statistical analysis was not attempted. Nevertheless, the results (Figure 32) show that pigs that were not sprinkled (Treatments 1 and 4) drank (6.68 and 10.62 litres/pig/d respectively) more water than those that were sprinkled (Treatments 2 and 3; 3.97 and 5.25 litres/pig/d respectively). Pigs that were sprinkled for 120 sec every 30 min (Treatment 2) drank (3.97 litres/pig/d) less water than those which were sprinkled for only 30 sec every 30 min (Treatment 4; 5.25 litres/pig/d).

In the hotroom, water intakes were lower in the group provided with warm drinking water (Treatment 1) than the one given cold water (Treatment 4). It appeared that pigs in the control-room (Treatments 5 and 6) drank (3.89 and 3.36 litres/pig/d, respectively) less water than those in the hotroom (Treatments 1-4). The pigs in all treatments drank more during the day than during the night.

Results from the analysis of variance (Table 38-i) revealed that there were significant differences in DMI ($P<0.001$), DRG ($P<0.01$) and FCR ($P<0.05$) but not Dress% between groups of pigs which received the different water and environmental temperature treatments. The differences were such that pigs on Treatments 2 and 6 consumed more ($P<0.05$) dry matter (2120 and

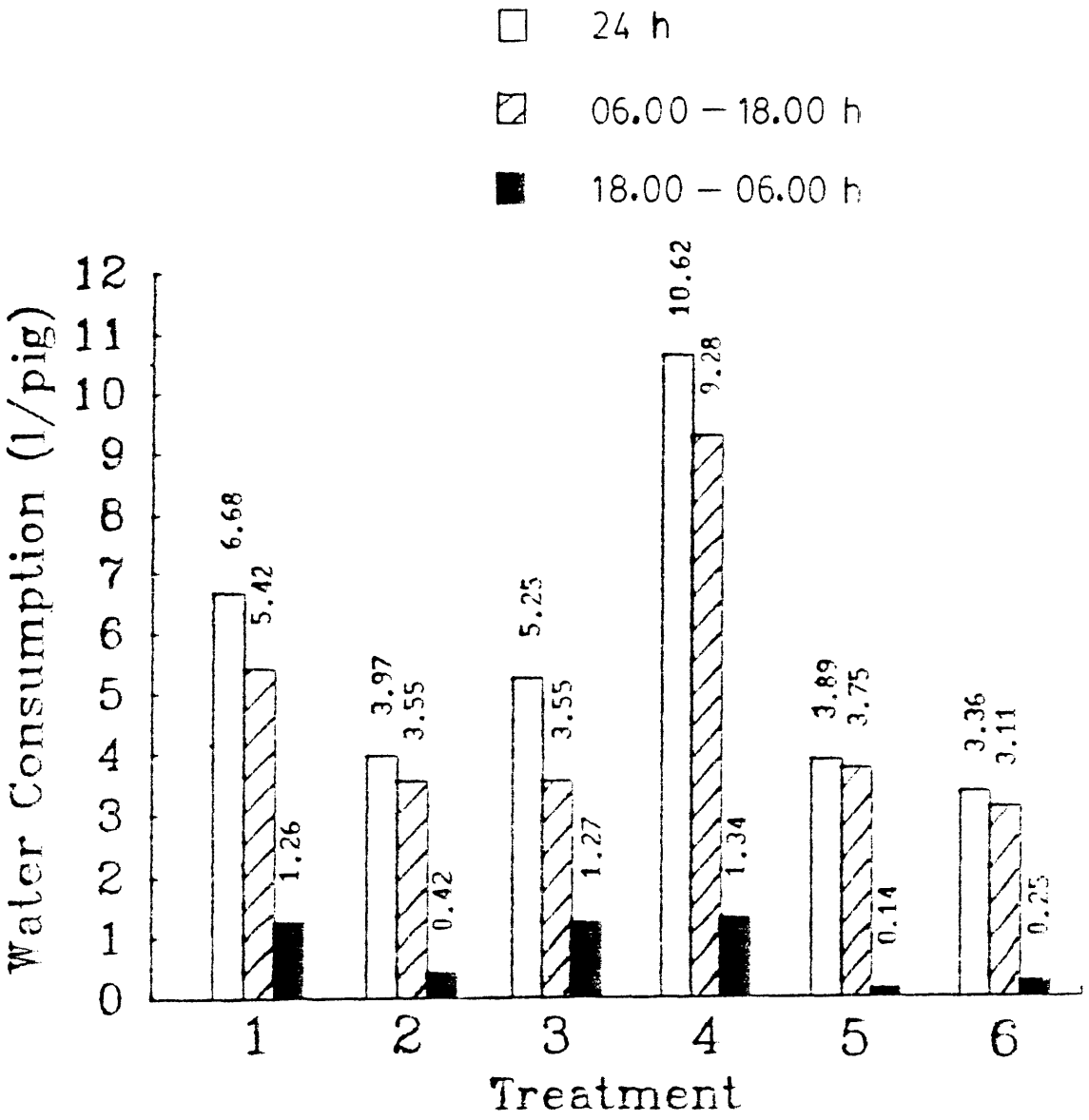

Figure 32. Average daily water consumption per pig in each treatment.
Treatment 1: 30° C drink, no sprinkling, pair-fed*, hotroom.
Treatment 2: 30° C drink, 120 sec/30 min sprinkling, hotroom.
Treatment 3: 30° C drink, 30 sec/30 min sprinkling, hotroom.
Treatment 4: 11° C drink, no sprinkling, hotroom.
Treatment 5: 30° C drink, no sprinkling, pair-fed*, to group 1, control-room.
Treatment 6: 11° C drink, no sprinkling, control-room.

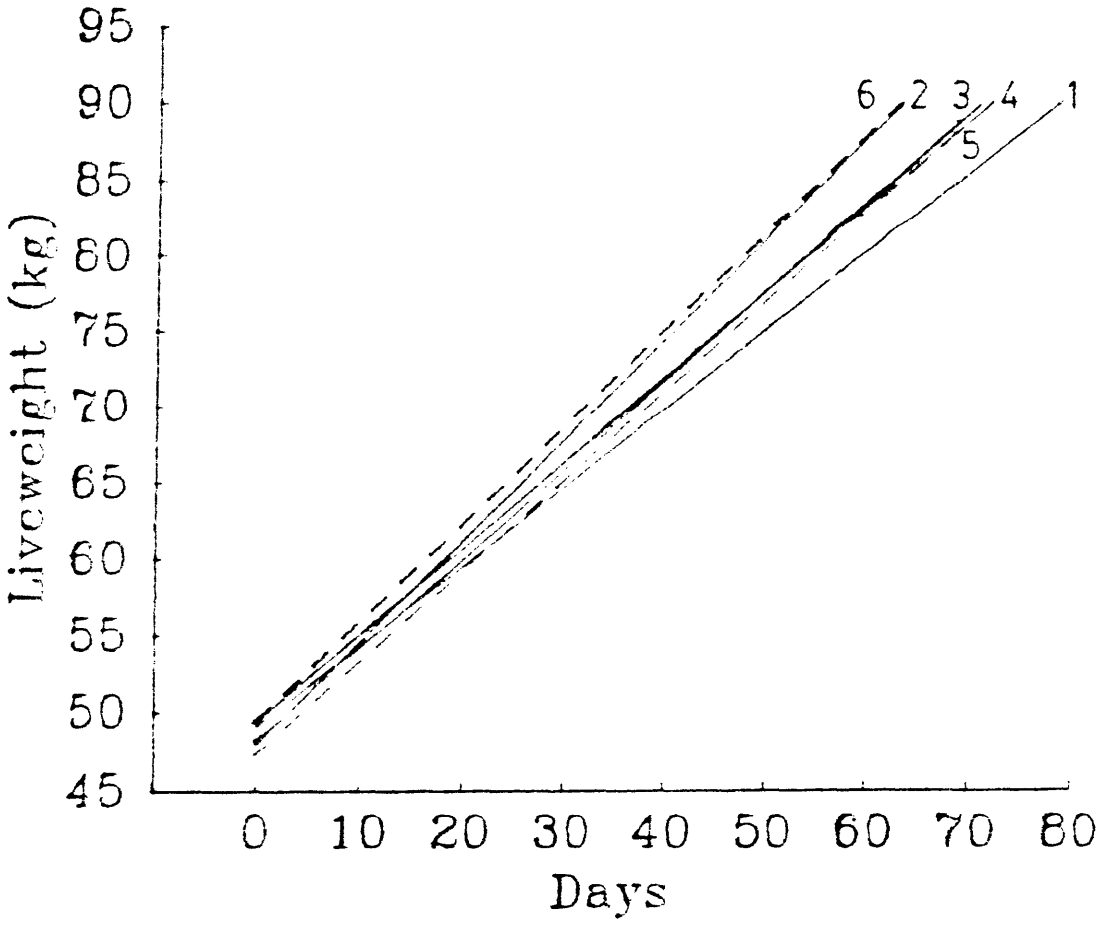

Figure 33. Plots of linear regressions of liveweights of pigs which received different water and environmental temperature treatments over days of experimental period in Laboratory Experiment 7.

1 - Treatment 1
2 - Treatment 2
3 - Treatment 3
4 - Treatment 4
5 - Treatment 5
6 - Treatment 6

Table 38. Mean values of Daily Dry Matter Intake (DMI), Daily Rate of Gain (DRG), Feed Conversion Ratio (FCR) and Dressing Percentage (Dress%) for pigs which received different water and environmental temperature treatments in Laboratory Experiment 7.

Treatment	Parameter			
	DMI (g/d)	DRG (g/d)	FCR (kg/kg)	Dress% (%)
(i) Analysed as 6 Treatments				
Treatment 1* (hotroom)	1724^{b}	521^{b}	3.35^{a}	73.3
Treatment 2 (hotroom)	2120^{a}	706^{a}	3.01$^{b\,c}$	74.3
Treatment 3 (hotroom)	1837^{b}	595^{b}	3.10$^{a\,b\,c}$	75.0
Treatment 4 (hotroom)	1747^{b}	588^{b}	2.98$^{b\,c}$	73.6
Treatment 5* (control-room)	1681^{b}	593^{b}	2.83^{c}	74.8
Treatment 6 (control-room)	2192^{a}	685^{a}	3.20$^{a\,b}$	75.7
LSD(5%)	225	29	0.31	2.2
Sig. Level	***	**	*	N.S.
(ii) Analysed for Pair-fed Groups only				
Treatment 1* (hotroom)	1724	512	3.35^{a}	73.3
Treatment 5* (control-room)	1681	593	2.83^{b}	74.8
LSD(5%)	234	95	0.39	2.1
Sig. Level	N.S.	N.S.	*	N.S.

Means with the same superscripts within a column are not significantly different (5% level).
* - pair-fed

Table 39. Means of Carcase Backfat Depth (P2) measured by ultrasonic (Scanoprobe) and optical (Introscope) methods, Carcase Length (CL), Chest Depth (CD) and Girth of pigs which received different water and environmental temperature treatments in Laboratory Experiment 7.

Treatment	Parameter				
	P2(mm)		Car.Length	Chest Depth	Girth
	Scanoprobe	Introscope	(cm)	(cm)	(cm)
(i) Analysed as 6 Treatments					
Treatment 1* (hotroom)	17.6	17.6	78.4	29.8	97[c]
Treatment 2 (hotroom)	18.0	22.0	79.3	31.8	105[a]
Treatment 3 (hotroom)	16.8	19.2	80.7	30.8	101[a b c]
Treatment 4 (hotroom)	16.8	18.2	81.0	31.2	98[c]
Treatment 5* (control-room)	18.0	19.8	80.1	30.4	99[a c]
Treatment 6 (control-room)	17.6	21.0	78.9	30.6	103[a b]
LSD(5%)	2.8	3.1	3.8	0.7	5
Sig. Level	N.S.	-	N.S.	N.S.	*
(ii) Analysed for Pair-fed Groups only					
Treatment 1* (hotroom)	17.6	17.6	78.4	29.8	97
Treatment 5* (control-room)	18.0	19.8	80.1	30.4	99
LSD(5%)	3.1	3.0	4.5	2.4	7
Sig. Level	N.S.	N.S.	N.S.	N.S.	N.S.

Means with the same superscripts within a column are not significantly different (5% level).

* - pair-fed

2192 g/d respectively) than those on the other four treatments. Associated with these differences in DMI were variations in DRG (Figure 33): the pigs on Treatments 2 and 6 grew ($P<0.05$) faster (706 and 685 g/d) than those on Treatments 1, 3, 4 and 5 (521, 595, 588 and 593 g/d respectively). Furthermore, pigs on Treatment 1 had a higher FCR (3.35 kg/kg, $P<0.05$) than those on Treatments 2, 4 and 5 (3.01, 2.98 and 2.83 kg/kg respectively). Other between-group differences were non-significant. Nevertheless, when analysed on a pair-fed basis, the results (Table 38-ii) indicated that the FCR of pigs in the hotroom (Treatment 1; 3.35 kg/kg) was higher ($P<0.05$) than in the control-room (Treatment 6; 2.83 kg/kg). There were no significant differences in DMI, DRG or Dress% between these pair-fed groups.

Table 39-i shows that there were no significant differences in carcase backfat depth measured by either the "Scanoprobe" or the "Introscope", nor in carcase length or chest depth. However, there were differences ($P<0.05$) in girth, with values for pigs in Treatments 2 and 6 (105 and 103 cm) being greater ($P<0.05$) than those in Treatments 1, 4 and 5 (97, 98, and 99 cm), repectively). Other differences were non-significant.

When the pair-fed groups only were analysed, the results (Table 39-ii) indicated that there were no significant differences in any of the above parameters.

From Table 40-i it can be seen that there were significant differences ($P<0.001$) in RR, RT and ST between groups when analysed on a 6 treatments basis. The differences were such that pigs in the control-room (Treatments 5 and 6) had lower RR, RT and ST values ($P<0.05$) than those in the hotroom. Pigs that received 120 sec/30 min sprinkling had lower RR values (72 b/min)

Table 40. Mean Respiration Rate (RR), Rectal (RT) and Skin (ST) Temperatures of pigs which received different water and environmental temperature treatments in Laboratory Experiment 7.

Treatment	Parameter		
	RR (b/min)	RT (°C)	ST (°C)
(i) Analysed as 6 Treatments			
Treatment 1* (hotroom)	151[a]	39.4[a]	37.6[a]
Treatment 2 (hotroom)	72[d]	38.8[b]	36.1[b]
Treatment 3 (hotroom)	89[c]	38.8[b]	36.1[b]
Treatment 4 (hotroom)	135[b]	39.4[a]	37.7[a]
Treatment 5* (control-room)	46[e]	38.5[c]	34.0[c]
Treatment 6 (control-room)	45[e]	38.5[c]	34.2[c]
LSD(5%)	15	0.1	0.3
Sig. Level	***	***	***
(ii) Analysed for Pair-fed Groups only			
Treatment 1* (hotroom)	151[a]	39.4[a]	37.6[a]
Treatment 5* (control-room)	46[c]	38.5[b]	34.0[b]
LSD(5%)	12	0.1	0.2
Sig. Level	***	***	***

Means with the same superscripts within a column are not significantly different (5% level).

* - pair-fed.

Table 41. Mean values for Average Daily Energy Intake (EI), Energy Conversion Ratio (ECR), Apparent Digestibilities of Dry Matter (ADM), Protein (ADP), Energy (ADE) and in the Digestible Energy (DE) and Crude Protein (DCP) contents of the diet given to pigs in Treatments 1 and 6 in Laboratory Experiment 7.

Treatment	Parameter						
	EI (MJ/d)	ECR (MJ/kg)	ADM (%)	ADP (%)	ADE (%)	DE (MJ/kg)	DCP (%)
Treatment 1	24.7^{b}	48.3	80.6	86.4^{a}	80.4	14.4	15.3
Treatment 6	30.7^{a}	44.9	79.2	83.7^{b}	78.5	14.0	14.9
LSD (5%)	4.1	7.1	2.2	1.6	2.4	0.5	0.5
Sig.level	**	N.S.	N.S.	**	N.S.	N.S.	N.S.

Means with the same superscripts within a column are not significantly different (P>0.05).

than those that received the 30 sec/30 min sprinkling treatment (89 b/min, P<0.05), which in turn were lower (P<0.05) than those on the cold drinking water treatment (135 b/min). Pigs provided with warm drinking water (Treatment 1) had higher RR values (151 b/min; P<0.05) than all other groups in the hotroom.

When analysed on a pair-fed groups basis only (Table 40-ii), the results indicated that pigs in the hotroom (Treatment 1) had higher RR, RT and ST values (P<0.001) than their counterparts in the control-room.

From Table 41 it can be seen that the average daily energy intake of pigs in Treatment 1 (24.7 MJ/d) was lower (P<0.01) than in Treatment 6 (30.7 MJ/d), and the apparent digestibility of protein in Treatment 1 (86.4%) was higher (P<0.01) than in Treatment 6 (83.7%). There were no significant differences in ECR, ADM, ADE, DE and DCP between Treatments 1 and 6.

8.4 Discussion

Observations in the current study indicated that pigs consumed more water during daytime than nightime. This difference is no doubt associated with the amount of time pigs spent on drinking activities, since in a behavioural study in a tropical environment Steinbach (1978) observed that pigs spent 10% of the time drinking in the middle of the day as compared to only 0.4% in the middle of the night. No doubt these behavioural differences are associated with diurnal variations in ambient temperature (Mount *et al.*, 1971) and thus the pigs' requirement for water for thermoregulatory purposes. At environmental temperatures above the

thermoneutral zone pigs in the current study increased their water consumption by 38% during the day and 64% during the night from the levels recorded in the control-room. Furthermore, the water consumption during the night in the hotroom where the environmental temperature was 25° C was 16.2% of the daily total. Mount *et al.* (1971) observed that pigs living in a constant 30° C environment consumed 30% of their total daily water intake during the night interval from 21.00 h to 09.00 h. Therefore, it appeared that the relatively low "night" temperature in the current study was giving the pigs some degree of respite from the high "day" temperature. Temperature of the drinking water had a marked effect on the amount consumed by pigs in the hotroom such that those with access to 11° C drinking water consumed 3.9 litres/pig/d more than animals offered water at 30° C. Sprinking the pigs appeared to reduce drinking water consumption, presumably due to its cooling effects via cutaneous evaporation (Morrison, Bond and Heitman, 1968b).

It should be noted, however, that the values presented in Figure 32 represent means of water "usage" by the pigs, not specifically the amount they drank. Not all of the water that passed through the drinking nipples was actually ingested by the pigs, and it was noted on many occassions that the animals allowed (or actively sought) part of this water to over-run their mouths while drinking. This spillage wetted the skin of the snout, neck and forelimbs and presumably had some cooling effects. It was not possible to measure the actual level of water ingestion in this study, but it may be assumed that such values would have been somewhat lower than those reported in Figure 32.

Furthermore, while drinking water temperature did not significantly influence either rectal or skin temperature in the pigs exposed to high

environmental temperatures (Table 40-i), the respiration rate of pigs given the cold (11°C) drink was 10.6% lower ($P<0.05$) than that of those given warm water to drink. This result is in general agreement with earlier work which showed that pigs that ingested either cold water (Bond, Heitman and Kelly, 1964) or cold whey (Holmes, 1970) experienced a reduction in respiration rates, rectal and skin temperatures.

Small amounts of cutaneous evaporation occur in all pigs as a result of diffusion of water through the skin (Ingram, 1965a), though not by sweating (Ingram, 1967). Therefore, water sprinkled onto the animal's skin presumably acts as artificial "sweat" and cools the animal by an enhanced rate of cutaneous evaporation. The current experiment clearly demonstrated that sprinkling pigs living in the hot environment led to significantly reduced respiration rates, rectal and skin temperatures. These results were in agreement with those of Bond (1963), Bond, Heitman and Kelly (1964) and, Morrison, Bond and Heitman (1968b).

Results obtained by Hsia, Fuller and Koh (1974) indicated that pigs that were sprinkled for 120 sec every 45 min had a better growth rate than animals sprinkled for the same duration but only every 90 min. The results from the present experiment (Laboratory Experiment 7) indicate that sprinkling for 120 sec every 30 min effectively lowered respiration rates by 19% compared to the 30 sec sprinkling duration. The amount of water available for cutaneous evaporative cooling depends on the duration of sprinkling and the delivery rate. It is apparent that at any given delivery rate optimum cooling might be achieved by varying not only the interval between sprinkling sessions but also the duration of each sprinkling.

The pair-fed treatment was included in Laboratory Experiment 7 to

eliminate the possible effects on growth performance that might occur due to different levels of feed intake when the pigs were exposed to the two ambient temperature regimes. Results from earlier sections of this thesis showed that heat stressed pigs performed badly (See III-4.0 and III-5.0) relative to those growing under temperate conditions. From this it follows that any alleviation of heat stress could be expected to lead to improvement in performance and the results from the current study support this hypothesis. As indicated in Table 38, cooling the drinking water led to a significant improvement in FCR and sprinkling for 30 sec at 30 min intervals offered some degree of relief from heat stress in terms of physiologicaal parameters, although not in terms of growth performance. By increasing the duration of sprinkling to 120 sec every 30 min, the pigs performed equally as well as those living in the control-room. This indicates that the 120 sec every 30 min sprinkling treatment totally eliminated the stressful conditions arising from the high environmental temperature. Improvements to "normal" levels as might be expected at thermoneutrality in DRG and FCR in sprinkled pigs living in tropical conditions were also reported by Ho and Khoo (1977) and Morrison *et al* (1972).

The results from the pair-fed groups in the current study indicate conclusively that environmental temperature played a very significant role in increasing the physiological activities of heat stressed pigs. This was also reflected in the growth performance of the animals, especially with respect to FCR. Because of higher physiological activities, part of the energy ingested might be channelled to satisfy those activities and less energy possibly became available for growth.

9.0 EFFECTS OF AMBIENT TEMPERATURE ON METABOLIC HEAT PRODUCTION IN PIGS

9.1 Introduction

Metabolic heat is the heat produced within the body as a result of the oxidation of food and a range of normal physiological activities. It contributes significantly to the maintenance of homeostasis within the pig's body (Mount, 1968). The rate of metabolic heat production is influenced by age, weight, feed intake of the pigs and by environmental temperature (see III-7.0); it is minimal within the thermoneutral zone and rises at both high and low temperatures. It is suggested from previous experiments (see III-4.0 to 7.0) that pigs kept particularly at high temperatures demonstrate variation in feed intake and growth rate. In order to allow a high intake at high temperature there may be differences in heat production among individual pigs. Animals with a characteristically low metabolic rate may be able to consume an unusually large amount of food at high temperature. The present study was designed to investigate the relationship between metabolic heat production and growth rate of pigs raised at both optimal temperature and at an elevated temperature of the type commonly experienced under commercial conditions in Australia during summer.

9.2 Materials and Methods

9.2.1 Animals and Husbandry

Twenty one Large White X Landrace entire male weaners were acquired from a commercial piggery (Fielder Gillespie Ltd., Australia). These pigs

were raised in individual pens until they reached approximately 45 kg liveweight, when they were transfered to the Climate Laboratory (see III-4.0).

Three pigs out of the 21 were selected at random for preliminary testing of the calorimeter system. The remaining 18 were then allocated to three groups each of six pigs using stratified randomization on a liveweight basis. One group (Group 3) was then selected randomly for the control-room (21±2° C) while the two remaining groups (Groups 1 and 2) were placed in the hotroom (35±1° C, day; 25±1° C, night).

Table 42. Composition of the diet used in Laboratory Experiment 8 (air dry basis).

Ingredient	g/kg
Fine sorghum	430
Fine wheat	244
Soyabean meal (M)	42
Meat M	95.2
Blood M	6.7
Millrun	170
Limestone	5
Vitamin Carrier	1
Supplement Pig Grower + Payzone	5
Analysed:-	
DE MJ/kg	13.67
DCP (%)	18.34
CF (%)	3.23
Ca (%)	1.25
P (%)	0.90
Total Lysine (%)	0.987

Both the hotroom and control-room were fitted with the pens and associated equipment described previously (see III-4.0). Since each pen

could accommodate only five pigs, it was necessary to use only three pens in the hotroom. The two groups of pigs in the hotroom were then placed in those three pens randomly; each pen accommodated four pigs. In the control-room, which had only two pens, the six pigs were assigned to each pen randomly, three in each pen.

Pigs were managed according to the same routines as in the previous laboratory experiments (see III-4.0). Pigs on both temperature treatments were fed the same commercial grower (Fielder Gillespie Ltd., Australia) diet, the composition of which is given in Table 42.

9.2.2 The Calorimeter

The unit consisted of three independent, open circuit, indirect respiration chambers, a ventilation system, and a gas flow and analysis system. The main features of the unit, which was housed in an air-conditioned room, are given in Figure 34. Lighting in the room was controlled by an automated time-clock (Venner Ltd., England) according to the same schedule as in the hotroom and control-room.

Each of the respiration chambers (1.60 m length X 1.30 m width X 1.60 m height) was constructed with a basic framework of PVC conduit (20 mm diameter) which was covered with polyethylene plastic sheeting (0.4 mm gauge, Halifax Trading, Australia). The plastic sheet was joined and sealed by heating. A galvanized sheet metal base, mounted on an iron framework 80 mm in height, had a water-filled channel (60 mm width X 90 mm height) around the perimeter to act as a gas seal. The plastic covered framework was lowered into this channel to provide a hermetic seal during periods of measurement of gaseous exchange.

A single animal cage unit was positioned within each chamber. Each cage unit (1.42 m length X 1.20 m width X 0.83 m height) was constructed on a angle iron framework covered with steel mesh. The floor was constructed from steel mesh (PYM PG13, A. R. C. Engineering Pty. Ltd., Australia). The cage was positioned 0.44 m above the base of each chamber. Beneath the steel mesh floor, a galvanized steel tray was mounted to collect faeces. This tray was sloped to one side and at one end had a tube attached in order to empty urine (under a paraffin layer) into a plastic container.

Two refrigerant air-conditioners (Muller Pty. Ltd., Australia) were positioned within each respiration chamber, each with a 0.75 kW cooling capacity and being thermostatically controlled (Honeywell, U.S.A.). In order to ensure uniform mixing of the air and to provide a more uniform environment within the chambers, the direction of the air-conditioners was reversed with respect to each other. Condensation was directed into the water-filled channel at the chamber base. The air velocity within the chambers was found to be 0.15 ± 0.04 m/s (measured with Kata thermometer). The chamber temperature and humidity were measured with a dry and wet bulb mercury in glass thermometers. The thermohygrograph was also used to continuously monitor temperature and humidity during gaseous exchange measurements.

9.2.3 **Mode of Operation**

Large single-phase diaphragm-type electric pumps (Thomas Industries, U.S.A.) withdrew air from each of the chambers. Fresh air entered each chamber at a point diagonally opposite the air outlet via 60 mm PVC pipes with inlets situated outside the room and 3.70 m above ground level.

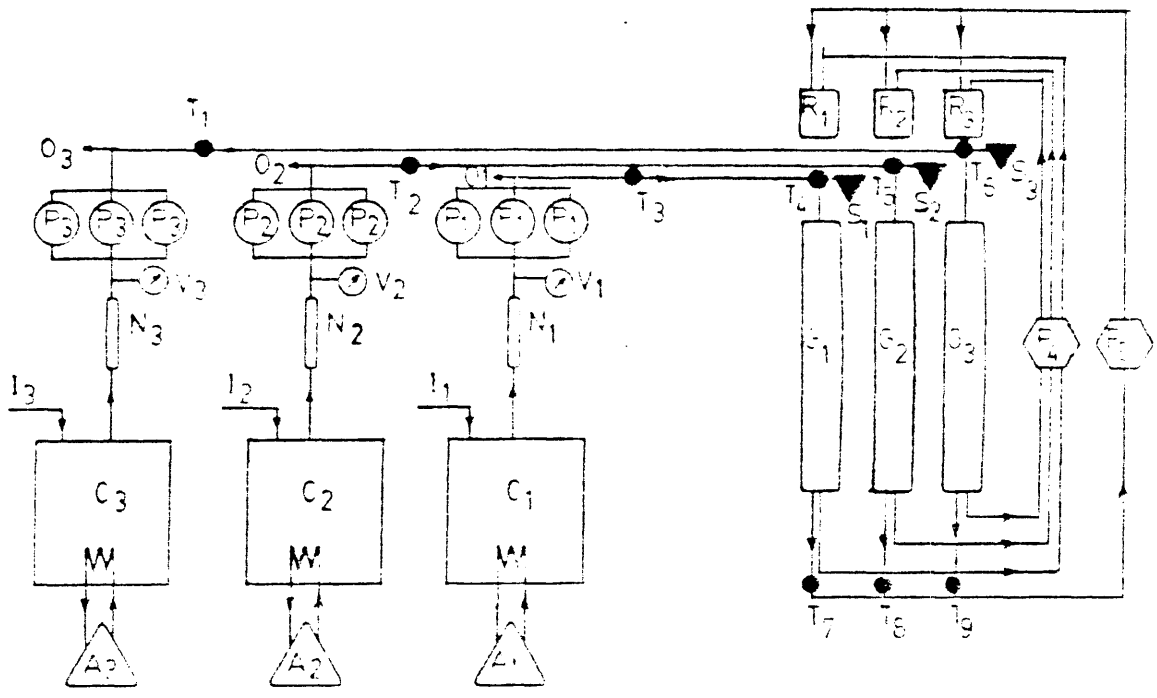

Figure 34. Calorimeter system used in Laboratory Experiment 8.
P1-P3 Air pumps; P4-Peristaltic pump; P5-Oil pump.
A1-A3 Refrigerant air conditioners.
C1-C3 Respiration chambers
R1-R3 Oil reservoirs
G1-G3 Glass cylinders
I1-I3 Fresh air inlets
N1-N3 Constant air flow nozzles
O1-O3 Effluent air outlets
S1-S3 Constant sampler air taps
T1-T9 Air taps
V1-V3 Vacuum gauges

Effluent air left the chamber via 32 mm diameter PVC pipes, with the ventilation rate being determined by calibrated brass nozzles (12 mm diameter, 60 mm length). These nozzles were situated adjacent to the pump inlets and operated on the principle of a choked supersonic flow (Shapiro,

1953; Emmons, 1958). Nozzles with different sizes were calibrated *in situ* against a dry gas meter (S. I. M. Brunt, U.S.A.) which had previously been calibrated against both a standard test meter and a precision wet gas meter (Alexander Wright & Co. Ltd., England).

Barometrically independent vacuum gauges (Edwards High Vacuum, England) continuously monitored pressure in the air lines between the nozzles and the pumps.

A peristaltic pump (C.S.I.R.O.) continuously withdrew samples of effluent air from each of the main pump outlets into glass cylinders (12 l). Small gas taps were also provided for sampling effluent chamber gas at the beginning and end of each measurement period. Excess effluent gas from each chamber was exhausted outside the building.

9.2.4 The Gas Analysis System

A paramagnetic oxygen analyser (Model 775, Beckman, U.S.A.) which operated in the 20-21% O_2 range, was used to measure the O_2 concentration of the sampled gas. Zero calibration gas was 20.434% O_2 in N_2 (C. I. G., Australia), while span gas calibration was fresh air of assumed O_2 concentration 20.946% (Machta and Hughes, 1970). Carbon dioxide was determined in gas samples by a physical absorption technique (Haldane and Priestley, 1935).

9.2.5 Standard Calorimeter Procedures

One pig from each of the original treatment groups was selected randomly in order to form one of six sub-groups (each of three pigs) for heat production estimates in the calorimeters. The sequence in which these

Plate 9. A pig panting in the hotroom at 35°C ambient temperature.

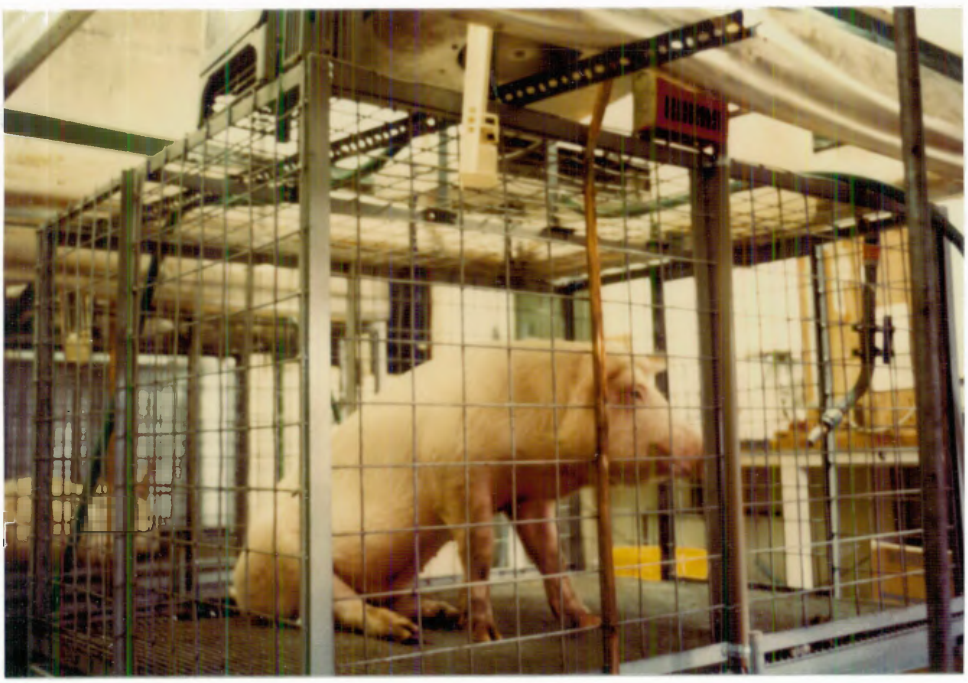

Plate 10. A pig in a cage under the hood of one of the respiration chambers.

sub-groups were allocated to the calorimeters was determined randomly. The chamber to which each pig was assigned was also determined randomly.

In order to eliminate possible abnormal results that might have occured as a result of handling and the new environment, each pig was put in the calorimeter for 22 hours as a training session, three weeks prior to the beginning of actual measurements.

There were two periods during the course of experiment when the metabolic heat production of the pigs was measured. The first period began in the 3rd and the second in the 7th week of the experiment. Hence, during the course of the experiment each pig had its heat production measured twice, at different liveweights. The sequence of measurement and the chamber to which a pig was assigned in the second measurement period were the same as during the first period.

On the day of each calorimeter run, the pre-determined sub-group of pigs was fed and weighed before being placed in the calorimeter chambers. The amount of feed consumed on that morning was determined and "empty" liveweight at the starting point were calculated. The hoods were lowered into the water-filled channel bases to seal the chambers and the large diaphragm pumps were turned on immediately. The system was then allowed to run for a 23-hour period in order to stabilize conditions (Depocas and Hart, 1957) within each chamber. A gas sample from each chamber was then taken through the air taps in the effluence air outlets using air syringes (45 mm diameter X 245 mm length). The peristaltic pumps were then turned on to start to collect gas samples continuously over the next 24 hours, at the end of which time more gas samples were taken from the air taps. The hoods of the chambers were then raised and the pigs were weighed and returned to their respective pens in the Climate Laboratory. During each calorimeter run, the pigs were not fed but water was made available at all

times. The faeces were trapped on a tray underneath the mesh floor and urine was collected under a paraffin oil film in a plastic container.

In order to eliminate any possible effects on heavy pigs of elevated carbon dioxide concentrations, the effluent gas flow rate was increased from 57 l/min in Period I to 99 l/min in Period II.

Rectal temperatures could not be measured during calorimeter runs due to the total enclosure of the animals by the chamber hoods. Two pigs from each room were thus randomly selected and put through the calorimeter routine again in order to follow body temperature changes during a typical calorimeter run. On this occasion and after the final calorimeter run was completed, the hoods were raised in order to give access to the animals and rectal temperatures were taken using thermister probes (Shibaura Denshi Seisakusho, Japan) at two hourly intervals for the first ten hours and at four hourly intervals thereafter. This routine was designed to detect any variation in rectal temperature associated with typical pattern of environmental change experienced during each calorimeter run as test pigs were transferred from either the hotroom ($35\pm1^{\circ}$ C) or control-room ($21\pm2^{\circ}$ C) to the calorimeters at $24\pm2^{\circ}$ C.

9.2.6 **Analysis of Data**

The data for each period were analysed using a factorial design with appropriate partitioning of the group sum of squares in order to assess the significance of the effect of high environmental temperature versus control treatments. Split-plot analyses over time were also carried out so that group (within similar partitioning) by time interactions could be examined. The relationships between metabolic heat production and growth performance

and physiological data were examined using polynomial regression.

9.3 Results

Pig 33 was sick during the Period II calorimeter run; its symptoms being lethargy and inappetance. Although the animal recovered after a broad spectrum antibiotic (Streptopen) was given intra-muscularly, it did not gain weight during Period II. Since metabolic heat production is influenced by feed intake (Holmes and Close, 1977) and a basic aim of this experiment was to relate metabolic heat production to growth rate (which for pig 33 was zero in Period II), data for this pig were excluded from all analysis. Furthermore, in analysis of variance, one pig was removed at random from the remaining two groups (pigs 29 and 118 from Groups 2 and 3 respectively) so that the balance of the design could be preserved.

The results of both the growth performance and the physiological responses of the animals over the experimental period are given in Table 43, from which it can be seen that there were significant differences between groups in average daily dry matter intake (DMI), average daily rate of gain (DRG) and feed conversion ratio (FCR). However, both respiration rate (RR: Group 1 = 101 b/min, Group 2 =109 b/min) and rectal temperature (RT: Group 1 = 39.4° C, Group 2 = 39.6° C) were higher ($P<0.05$) than in Group 3 (RR: 27 b/min; RT: 39.0° C).

When the effects of environment were investigated (Table 43), it was found that the DRG of pigs in the hotroom (591 g/d) was lower ($P<0.01$) than in the control-room. Both RR (105 b/min) and RT (39.5° C) in the hotroom were higher ($P<0.001$) than in the control-room (RR: 27 b/min; RT: 39.0° C). It was found that that although DMI in the hotroom (1573 g/d) was lower

than in control-room (1747 g/d) and FCR in the hotroom (2.66 kg/kg) was higher than in control-room (2.58 kg/kg), these differences were in both cases not statistically significant.

Table 43. Means of Daily Dry Matter Intake (DMI), Daily Rate of Gain (DRG), Feed Conversion Ratio (FCR), Respiration Rate (RR) and Rectal Temperature (RT) of the pigs in Laboratory Experiment 8, over the experimental period.

Treatment	Parameter				
	DMI (g/d)	DRG (g/d)	FCR (kg/kg)	RR (b/min)	RT (°C)
Group 1	1480	560	2.64	101[a]	39.4[a]
Group 2	1665	622	2.58	109[a]	39.6[b]
Group 3	1747	680	2.58	27[b]	39.0[c]
LSD(5%)	253	95	0.22	14	0.2
Sig. Level	N.S.	-	N.S.	***	***
Hotroom (Groups 1 & 2)	1573	591[b]	2.66	105[a]	39.5[a]
Control-room (Group 3)	1747	680[a]	2.58	27[b]	39.0[b]
LSD(5%)	219	82	0.19	12	0.2
Sig. Level	N.S.	**	N.S.	***	***

Means with the same superscript within each column are not significantly different (5% level).

Values of DMI, DRG, FCR, RR and RT presented in Table 44 are means calculated from data collected during the two weeks immediately prior to calorimeter runs. The Average Weight (WT) values recorded, on the other hand, are the means of data collected during the calorimeter runs.

From Table 44, it can be seen that during Period I, the DRG of pigs in Group 1 (462 g/d) was lower ($P<0.05$) than both in Groups 2 (675 g/d) and 3 (838 g/d). Both RR and RT of pigs in Groups 1 and 2 (RR: Group 1 = 100 b/min, Group 2 = 110 b/min; RT: Group 1 = 39.4° C, Group 2 = 39.5° C) were

higher ($P<0.05$) than in Group 3 (RR: 28 b/min; RT: 39.0° C). Other differences were non significant, however.

When these parameters were compared between pigs in the hotroom and control-room (Table 44) for two weeks prior to the chamber measurements, it was found that those in the hotroom had a lower DRG (569 g/d; $P<0.001$) than their counterparts in the control-room (838 g/d), but had both RR (105 b/min) and RT (39.5° C) values which were higher ($P<0.001$) than in control-room (RR: 28 b/min; RT: 39.0° C). Pigs in the hotroom consumed 393 g/d dry matter less than in the control-room; the difference only approaching significance ($0.10<P<0.05$). There were no significant differences in FCR or WT between pigs in the hotroom and control-room during Period I of the calorimeter runs.

During Period II (Table 44) of the calorimeter runs, it was found that both RR and RT of pigs in Groups 1 and 2 (RR: Group 1 = 100 b/min, Group 2 = 106 b/min; RT: Group 1 = 39.4° C, Group 2 = 39.6° C) were higher ($P<0.05$) than in Group 3 (RR: 26 b/min; RT: 39.1° C).

Furthermore, it was found that pigs in the hotroom had both RR (103 b/min) and RT (39.5° C) higher ($P<0.001$) than in control-room (RR: 26 b/min; RT: 39.1° C). Although pigs in the hotroom consumed 352 g/d less dry matter than those in the control-room, the difference only approached significance ($0.10<P<0.05$). Other differences in DRG, FCR and WT between pigs in the hotroom and control-room were not significant.

When the results of Periods I and II were analysed together (Table 45) it was found that the DRG of pigs in Group 1 (526 g/d) was lower ($P<0.05$) than in both Groups 2 (705 g/d) and 3 (783 g/d). Both RR (Group 1 = 100 b/min; Group 2 = 108 b/min) and RT (Group 1 = 39.4° C; Group 2 = 39.5° C) were higher ($P<0.05$) than in Group 3 (RR: 27 b/min; RT: 39.0° C). The

Table 44. Means of Daily Dry Matter Intake (DMI), Daily Rate of Gain (DRG), Feed Conversion Ratio (FCR), Respiration Rate (RR) and Rectal Temperature (RT) of the pigs in Laboratory Experiment 8, over two weeks prior to calorimeter runs; Average Weight (WT) is that of the pigs during the calorimeter runs (Periods I and II).

Treatment	Parameter					
	DMI (g/d)	DRG (g/d)	FCR (kg/kg)	RR (b/min)	RT (°C)	WT (kg)
Period 1						
Group 1	1461	462[b]	3.52	100[a]	39.4[a]	57.4
Group 2	1465	675[a]	2.24	110[a]	39.5[a]	59.0
Group 3	1856	838[a]	2.22	28[b]	39.0[b]	61.6
LSD(5%)	480	209	1.30	20	0.2	6.7
Sig. Level	N.S.	**	-	***	**	N.S.
Hotroom (Groups 1 & 2)	1463	569[a]	2.88	105[a]	39.5[a]	58.2
Control-room (Group 3)	1856	838[a]	2.22	28[b]	39.0[b]	61.6
LSD(5%)	416	181	1.13	17	0.2	5.8
Sig. Level	-	***	N.S.	***	***	N.S.
Period II						
Group 1	1831	589	3.15	100[a]	39.4[a]	74.0
Group 2	1803	735	2.47	106[a]	39.6[a]	76.6
Group 3	2175	729	3.13	26[b]	39.1[b]	79.9
LSD(5%)	504	180	0.94	19	0.2	9.7
Sig. Level	N.S.	N.S.	N.S.	***	***	N.S.
Hotroom (Groups 1 & 2)	1817	662	2.81	103[a]	39.5[a]	75.3
Control-room (Group 3)	2175	729	3.13	26[b]	39.1[b]	79.9
LSD(5%)	436	156	0.81	16	0.2	8.4
Sig. Level	-	N.S.	N.S.	***	***	N.S.

Means with the same superscript within each column are not significantly different (5% level).

differences between groups in FCR just failed to reach the 5% significance level ($0.10<P<0.05$), while the differences between groups in DMI and WT were not significant.

When these parameters were compared between the two periods it was found that the DMI during Period I (1594 g/d) was lower ($P<0.001$) than in Period II (1936 g/d). RR during Period I (39.3° C) was lower ($P<0.05$) than in Period II (39.4° C) but WT during Period I (59.3 kg) was lower ($P<0.001$) than in Period II (76.8 kg). Other differences between Periods were non significant and there was no significant interaction between Group and Period for the above parameters.

When the parameters were compared between the hotroom and control-room (Table 45), it was found that pigs in the hotroom had lower ($P<0.05$) DRG (616 g/d) but higher RR (104 b/min; $P<0.001$) and RT (39.5° C; $P<0.001$) values than those in the control-room (DRG: 783 g/d; RR: 27 b/min; RT: 39.0° C). The difference in DMI between pigs in the hotroom and control-room approached significance ($0.10<P<0.05$) while the differences in FCR and WT were clearly not significant ($P>0.05$).

Results of analysis of variance of metabolic heat production expressed in either kilojoules per unit metabolic weight ($kJ/kgW^{.75}$) or kilojoules per kilogram liveweight (kJ/kg), and of total heat production per pig per day (MJ/pig/d) and of respiratory quotient (R.Q.) when analysed separately for each period are given in Table 46. It can be seen that in both Periods there were no significant differences between groups nor beween the hotroom and control-room in metabolic heat production and respiratory quotient.

When the metabolic heat production parameters above were analysed for Periods I and II together, the results (Table 47) indicated that there were no significant differences between groups nor between pigs in the hotroom

Table 45. Means of Daily Dry Matter Intake (DMI), Daily Rate of Gain (DRG), Feed Conversion Ratio (FCR), Respiration Rate (RR) and Rectal Temperature (RT) of the pigs in Laboratory Experiment 8 over two weeks prior to calorimeter runs. Average Weight (WT) is that of the pigs during the calorimeter runs.

Treatment	Parameter					
	DMI (g/d)	DRG (g/d)	FCR (kg/kg)	RR (b/min)	RT (°C)	WT (kg)
Group 1	1646	526[b]	3.33	100[a]	39.4[a]	65.7
Group 2	1634	705[a]	2.36	108[a]	39.5[a]	67.8
Group 3	2015	783[a]	2.67	27[b]	39.0[b]	70.8
LSD(5%)	485	155	0.83	18	0.2	8.2
Sig. Level	N.S.	**	-	***	***	N.S.
Period I	1594[b]	658	2.66	80	39.3[b]	59.3[b]
Period II	1936[a]	684	2.92	77	39.4[a]	76.8[a]
LSD(5%)	68	97	0.63	5	0.05	1.4
Sig. Level	***	N.S.	N.S.	N.S.	*	***
Interaction: Group X Period						
LSD(5%)	117	168	1.10	8	0.09	2.3
Sig. Level	N.S.	-	N.S.	N.S.	N.S.	N.S.
Hotroom (Groups 1 & 2)	1640	616[b]	2.85	104[a]	39.5[a]	66.8
Control-room (Group 3)	2015	783[a]	2.67	27[b]	39.0[b]	70.8
LSD(5%)	420	134	0.72	16	0.2	7.1
Sig. Level	-	*	N.S.	***	***	N.S.

Means with the same superscript within each column are not significantly different (5% level).

Table 46. Means of Metabolic Heat Production in Kilojoules per unit Metabolic Weight per day ($kJ/kgw^{.75}/d$) or in Kilojoules per Kilogram Liveweight per day (kJ/kg/d) and of Total Heat Production (MJ/pig/d) and Respiratory Quotient (R.Q.) of pigs in Laboratory Experiment 8 when analysed separately for each calorimeter run.

Treatment	Metabolic Heat Production			R.Q.
	$kJ/kgw^{.75}/d$	kJ/kg/d	MJ/pig/d	
Period I				
Group 1	427	155	8.92	0.72
Group 2	416	150	8.84	0.70
Group 3	411	147	8.97	0.72
LSD(5%)	66	25	1.40	0.05
Sig. Level	N.S.	N.S.	N.S.	N.S.
Hotroom (Groups 1 & 2)	421	153	8.88	0.71
Control-room (Group 3)	411	147	8.97	0.72
LSD(5%)	57	22	1.21	0.04
Sig. Level	N.S.	N.S.	N.S.	N.S.
Period II				
Group 1	477	163	12.06	0.75
Group 2	421	142	10.89	0.78
Group 3	498	167	13.15	0.72
LSD(5%)	137	48	3.44	0.06
Sig. Level	N.S.	N.S.	N.S.	N.S.
Hotroom (Groups 1 & 2)	449	152	11.48	0.77
Control-room (Group 3)	498	167	13.15	0.72
LSD(5%)	119	41	2.98	0.05
Sig. Level	N.S.	N.S.	N.S.	-

Means with the same superscript within each column are not significantly different (5% level).

Table 47. Means of Metabolic Heat Production in Kilojoules per unit Metabolic Weight per day ($kJ/kgW^{.75}/d$) or in Kilojoules per Kilogram Liveweight per day (kJ/kg/d) and of Total Heat Production (MJ/pig/d) and Respiratory Quotient (R.Q.) of pigs in Laboratory Experiment 8 when analysed during both Periods I and II together.

Treatment	Metabolic Heat Production			R.Q.
	$kJ/kgW^{.75}/d$	kJ/kg/d	MJ/pig/d	
Group 1	452	159	10.49	0.73
Group 2	418	146	9.86	0.74
Group 3	454	157	11.06	0.72
LSD(5%)	91	33	2.17	0.04
Sig. Level	N.S.	N.S.	N.S.	N.S.
Period I	418[b]	151	8.91[b]	0.71[b]
Period II	456[a]	157	12.03[a]	0.75[a]
LSD(5%)	47	16	1.21	0.03
Sig. Level	*	N.S.	***	*
Interaction: Group X Period				
LSD(%)	82	28	2.09	0.05
Sig. Level	N.S.	N.S.	N.S.	N.S.
Hotroom (Groups 1 & 2)	435	153	10.12	0.74
Control-room (Group 3)	454	157	11.06	0.72
LSD(5%)	79	28	1.88	0.03
Sig. Level	N.S.	N.S.	N.S.	N.S.

Means with the same superscript within each column are not significantly different (5% level).

and control-room, nor any significant interactions between Groups and Periods. However, it was found that in Period I, the metabolic heat production when calculated per metabolic weight per day (418 $kJ/kgW^{.75}/d$) or per pig per day (8.91 MJ/pig/d) and respiratory quotient (0.71) were lower ($P<0.05$, $P<0.001$ and $P<0.05$, respectively) than in Period II (465 $kJ/kgW^{.75}/d$, 12.03 MJ/pig/d and 0.75, respectively). The difference in heat production when calculated per kilogram liveweight per day between Periods I and II was not significant, however.

Since results from analysis of variance (Tables 42-47) indicated that both the growth performance and the physiological responses of pigs in the hotroom were different to that in the control-room, the relationships between both growth and physiological parameters and the various metabolic heat production parameters were investigated for pigs in the hotroom and control-room separately. In the hotroom, the results indicated that there were significant relationships between both heat production per pig per day ($P<0.05$) and respiratory quotient ($P<0.05$) and DMI. It can be seen that the total heat production per pig per day increased by 3.08 kJ (Figure 35) and the respiratory quotient increased by 0.05 units (Figure 36) per kg increase in DMI.

Furthermore, although not significant statistically, there were general tendencies ($0.10<P<0.05$) for rectal temperature to increase with liveweight (Figure 37) and respiratory quotient to increase with DRG (Figure 38) and rectal temperature (Figure 39).

There were no significant relationships between other heat production parameter and either the growth or physiological parameters of pigs in the hotroom. There were also no significant relationships between any heat

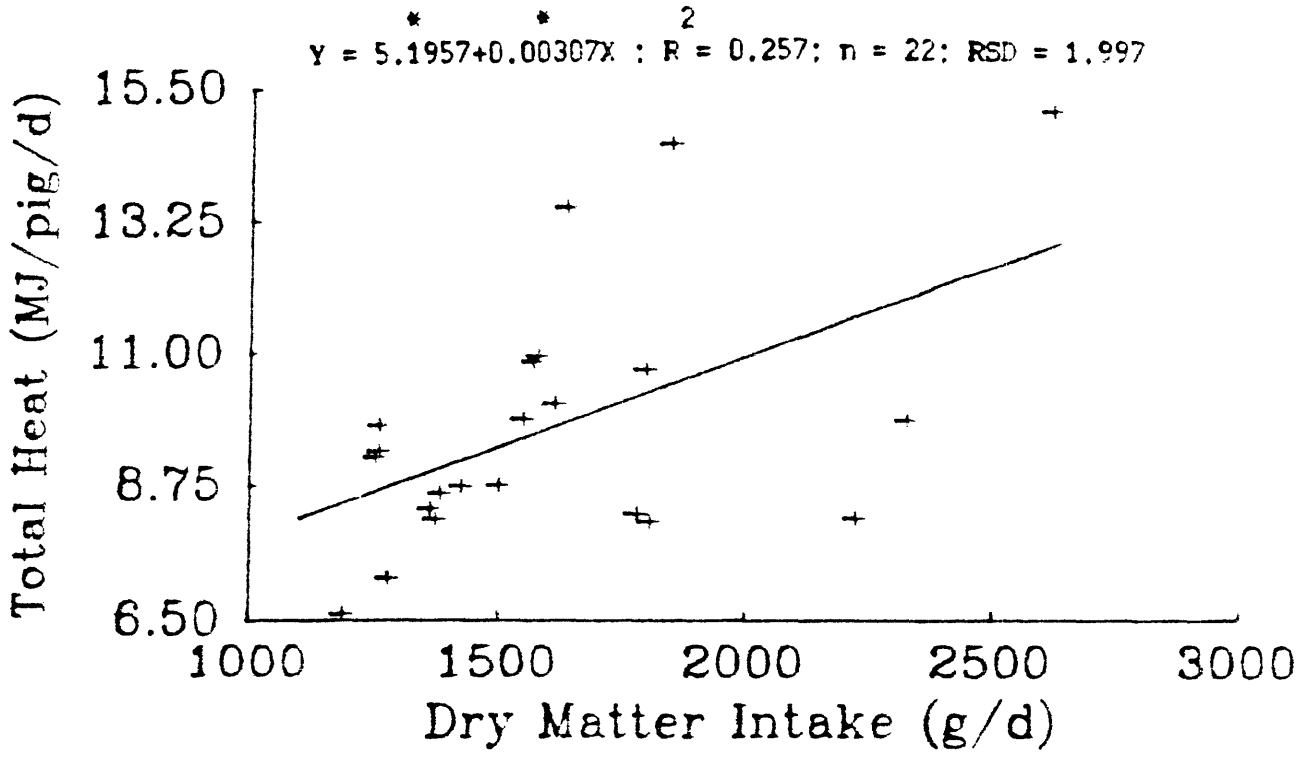

Figure 35. The relationship between Total Heat Production per pig per day and Daily Dry Matter Intake (DMI) measured during two weeks prior to calorimeter runs in both Periods I and II for pigs exposed to high environmental temperature only.

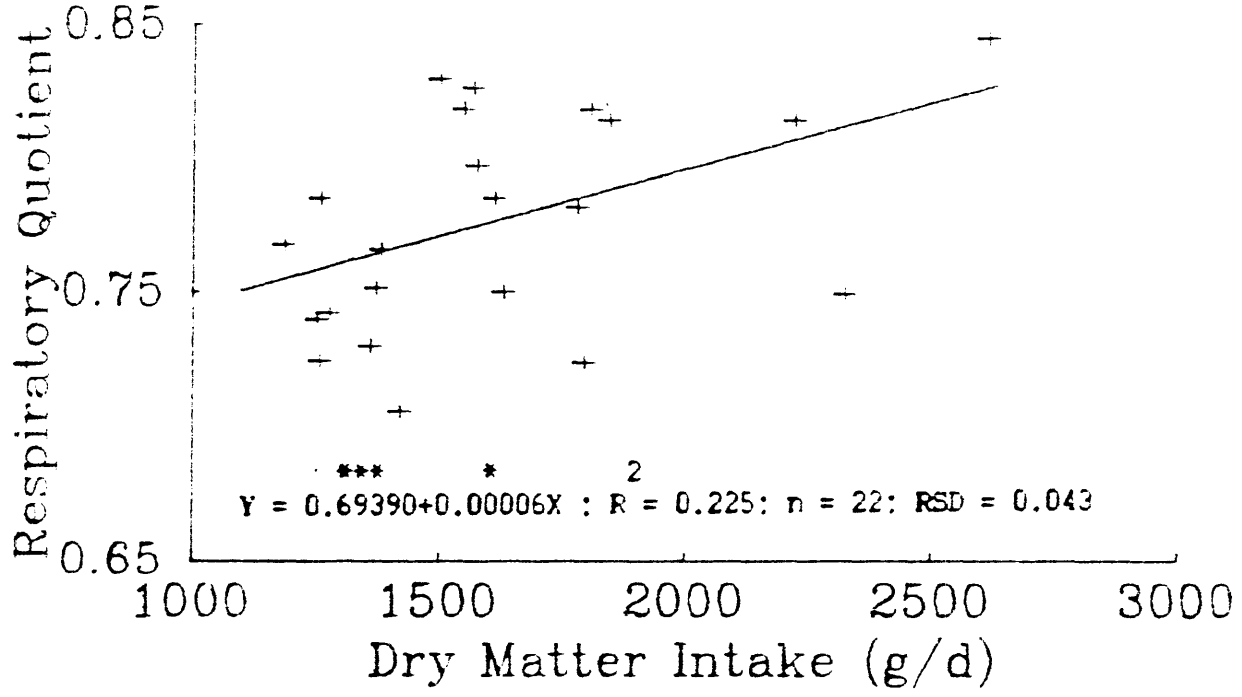

Figure 36. The relationship between Respiratory Quotient (R.Q.) and Daily Dry Matter Intake (DMI) measured during two weeks prior to calorimeter runs in both Periods I and II for pigs exposed to high environmental temperature only.

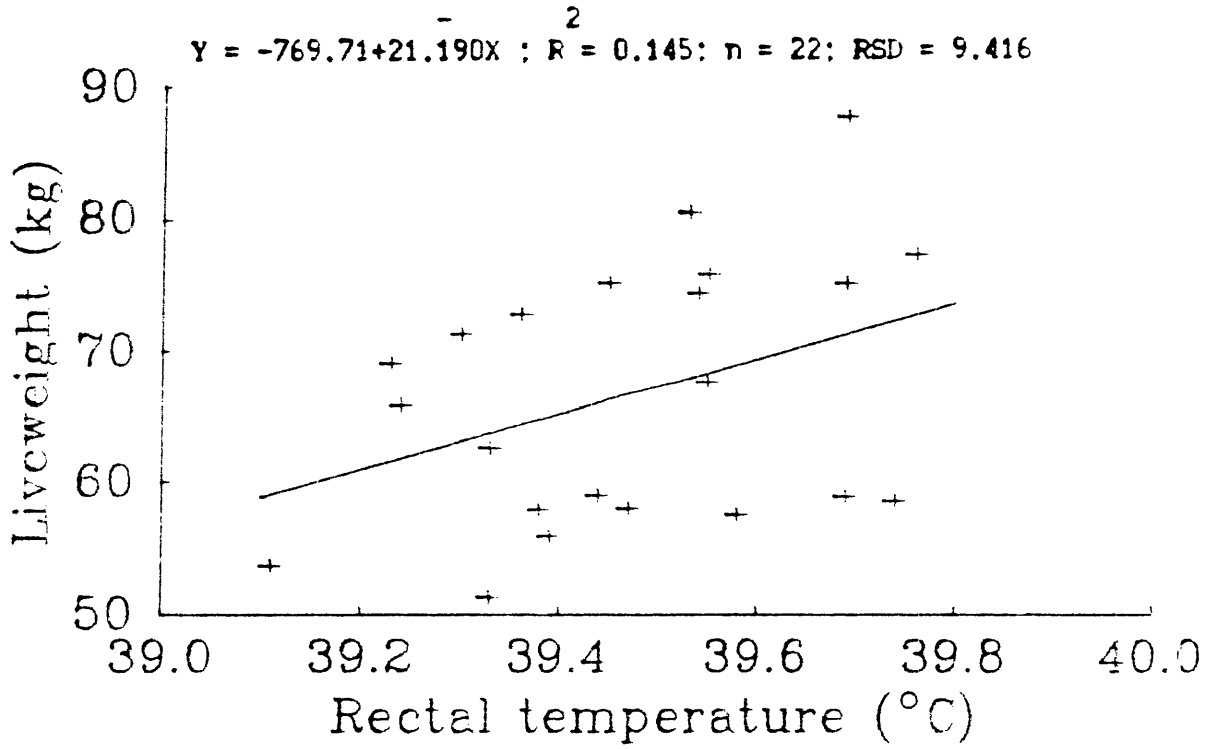

Figure 37. The relationship between Liveweight (WT) during calorimeter runs and Rectal Temperature (RT) of pigs in the hotroom measured during two weeks period prior to the calorimeter runs in Periods I and II.

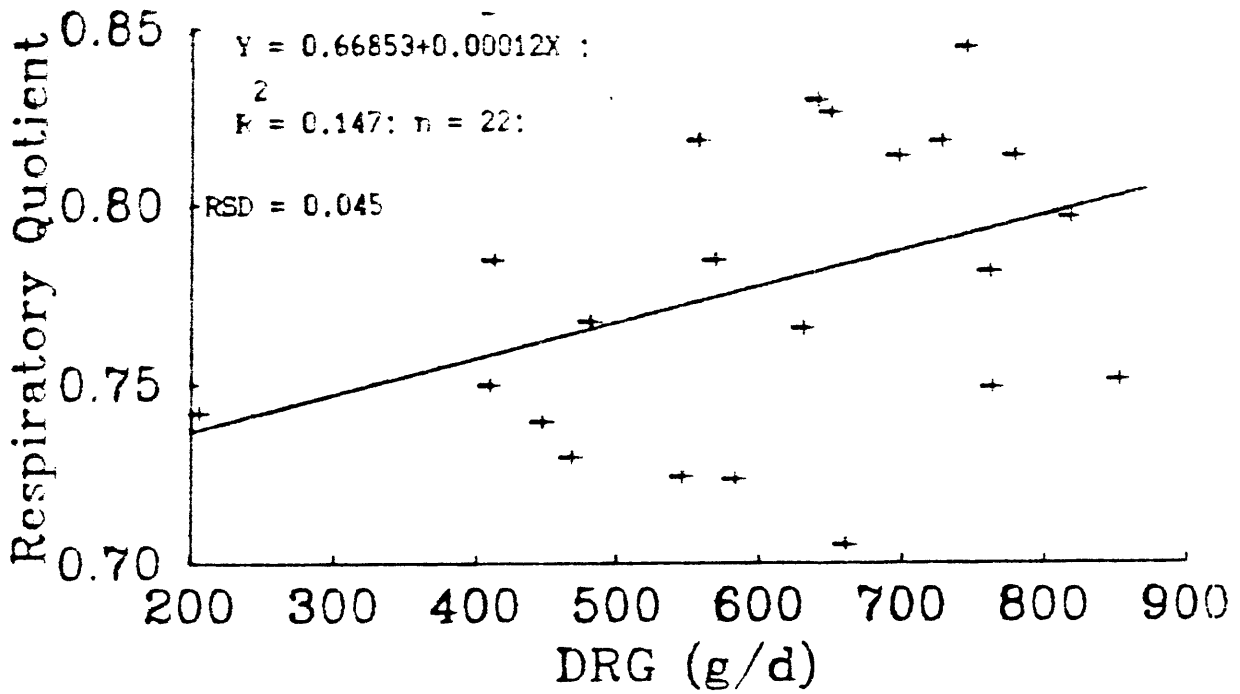

Figure 38. The relationship between Respiratory Quotient (R.Q.) and the Daily Rate of Gain (DRG) of pigs in the hotroom measured during two weeks period prior to the calorimeter runs in Periods I and II.

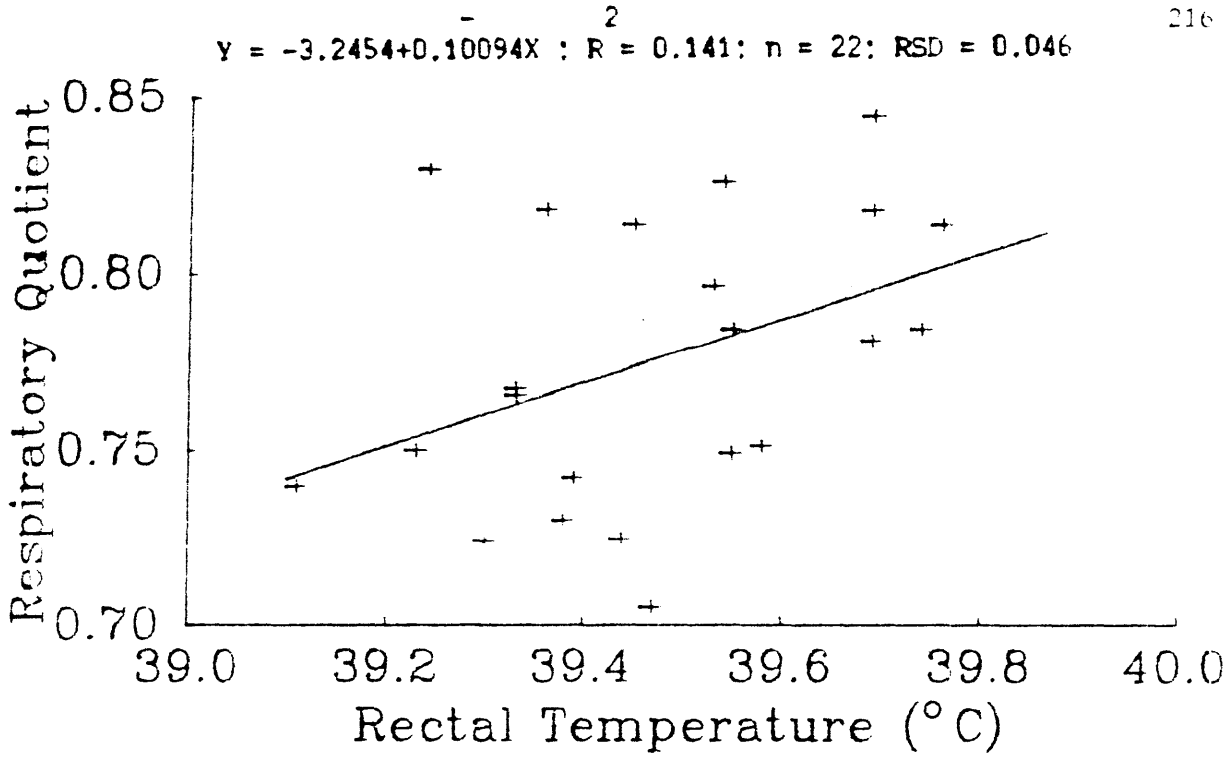

Figure 39. The relationship between Respiratory Quotient (R.Q.) and Rectal Temperature (RT) of pigs in the hotroom measured during two weeks period prior to the calorimeter runs in Periods I and II.

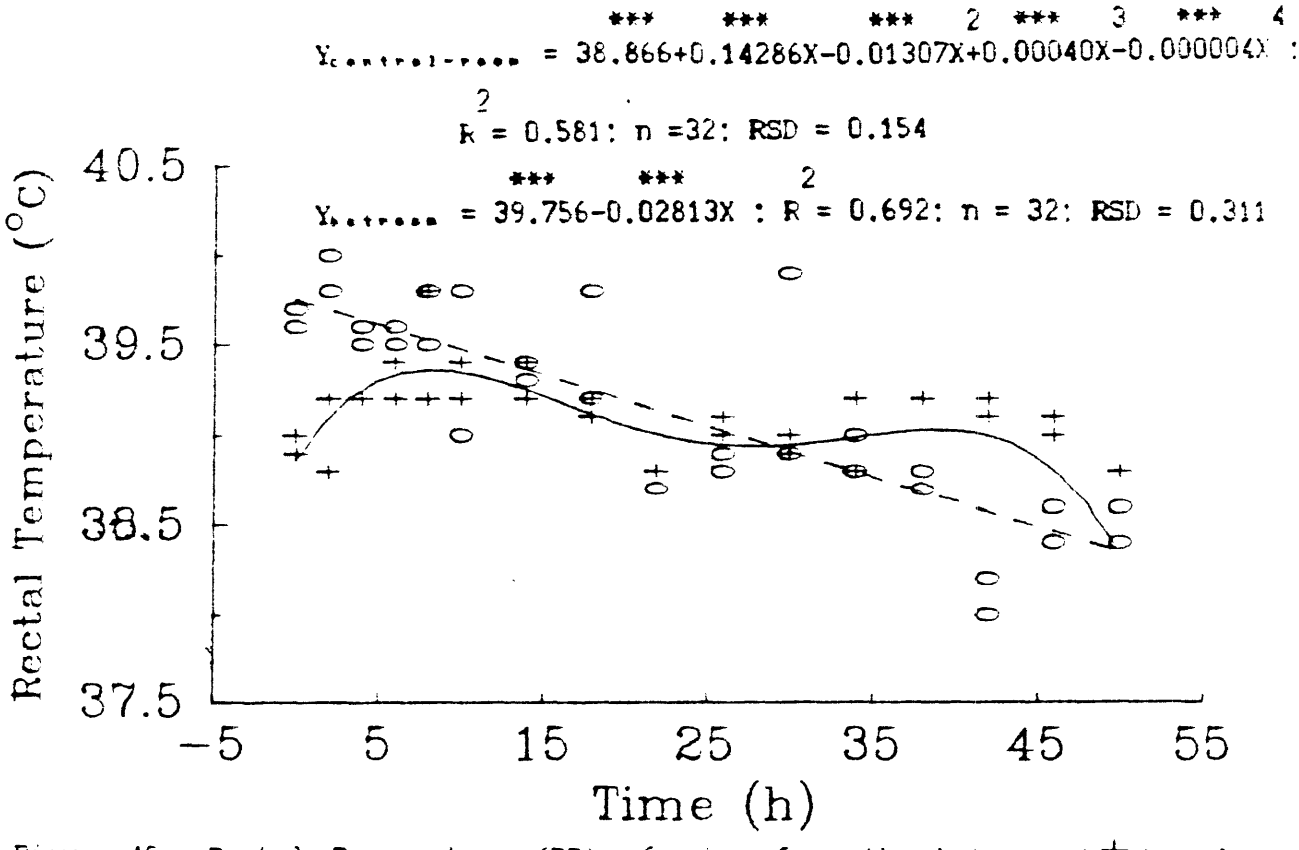

Figure 40. Rectal Temperature (RT) of pigs from the hotroom (±) and control-room (○) when put through the standard procedure of calorimeter runs with the respiratory hoods lifted.

production parameters and either the growth or physiological parameters for pigs in the control-room.

Results of RT changes during the simulated calorimeter runs are shown in Figure 40. It can be seen that the RT of pigs from the hotroom declined significantly ($P<0.001$) at the rate of 0.03°C/h, while in pigs from the control-room RT exhibited diurnal ($P<0.001$) fluctuations.

Figures 41 and 42 were the results of rectal temperatures and respiration rates, respectively, of pigs in the hotroom and control-room over a 24-hour period. From both Figures 41 and 42, it can be seen that during the night the rectal temperatures and respiration rates of both pigs in the hotroom and control-room are similar. During the day, when the temperature in the hotroom was increased from 25 to 35°C, both rectal temperature and respiration rate of pigs in the hotroom were higher than in pigs in control-room. Furthermore, when the hotroom temperature was increased, the respiration rate of pigs in the hotroom increased rapidly while rectal temperature increased at a more gradual rate.

9.4 Discussion

The present results confirmed those from the earlier laboratory experiments (III-4.0 to 8.0) in that high ambient temperatures (in this case 35°C by day, 25°C by night) may significantly depress DRG and increase respiration rate and rectal temperature over a long period of exposure. In this instance, growth rate was reduced by 21% and, rectal temperature and respiration rate increased by 0.5°C and 78 b/min respectively in the hotroom.The above effects of temperature on growth rate and rectal

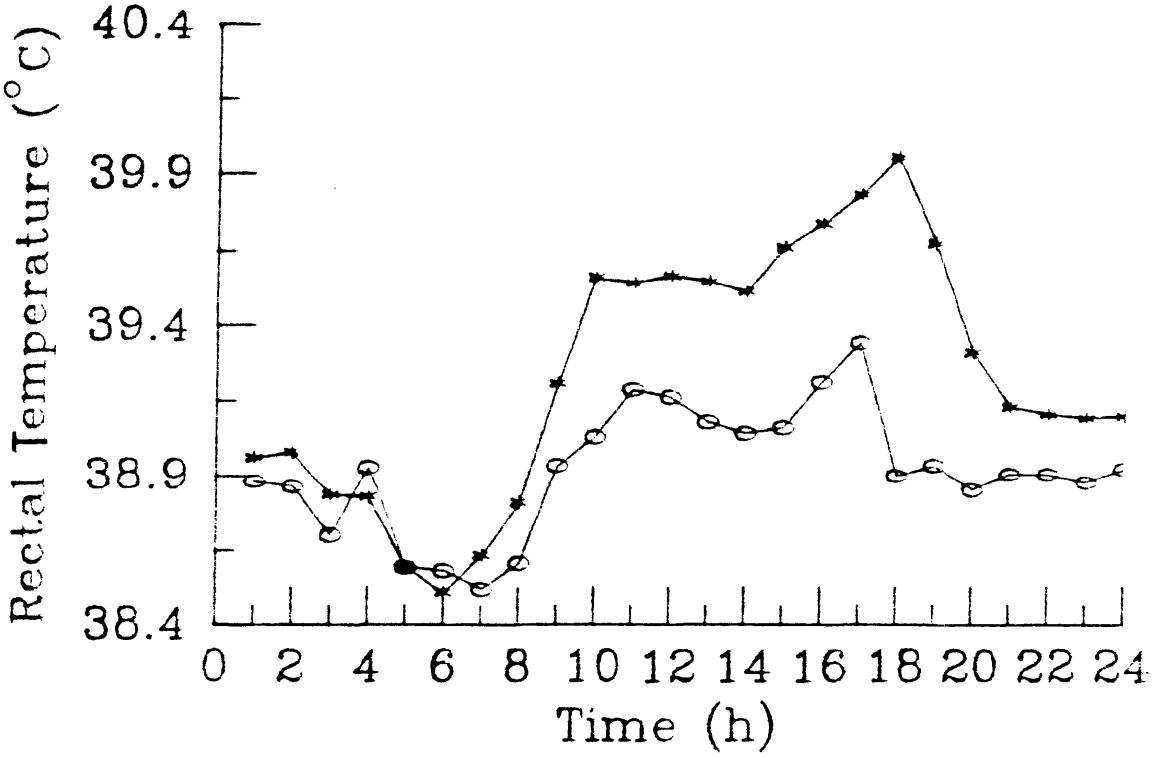

Figure 41. Rectal Temperature (RT) of pigs in the hotroom (-*-) and control-room (-o-) over a 24 hour period in Laboratory Experiment 8.

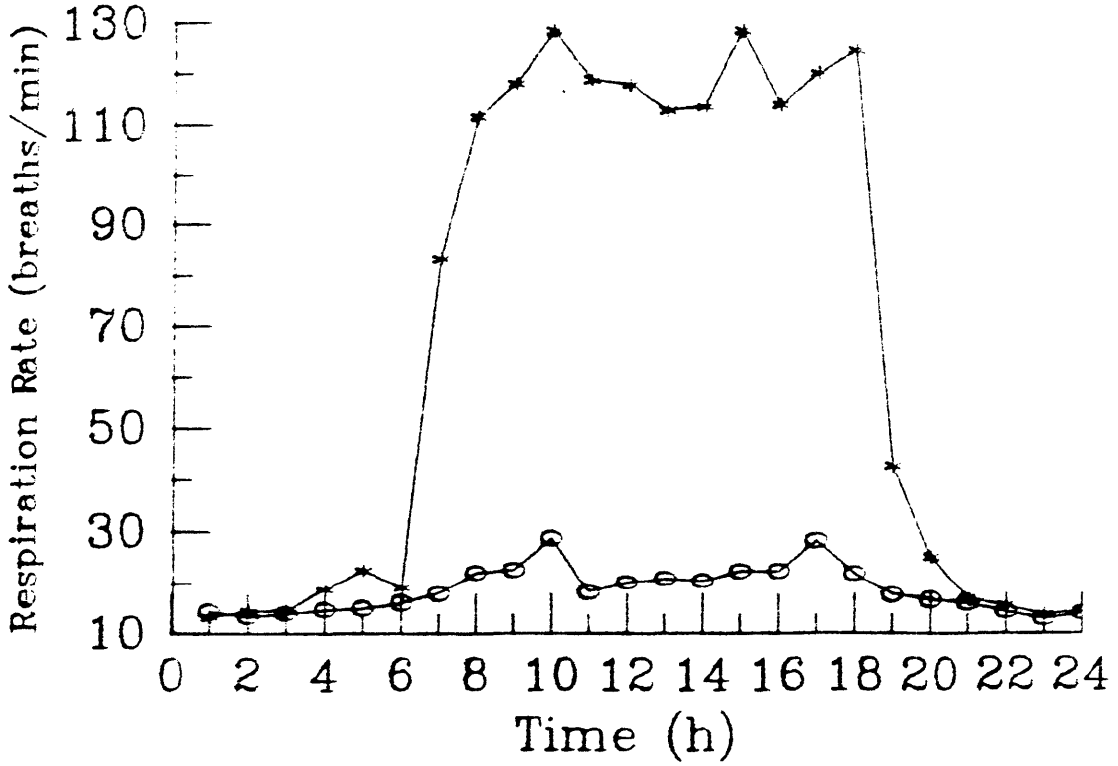

Figure 42. Respiration Rate (RR) of pigs in the hotroom (-*-) and control-room (-o-) over a 24 hour period in Laboratory Experiment 8.

temperature and respiration rate thus provided an ideal experimental situation in which to investigate both the effects of high temperature on heat production on the one hand and the relationships between growth rate and heat production under both cool and hot conditions on the other.

The present experiment did not reveal any significant differences in the metabolic heat production parameters studied between pigs in the hotroom and control-room within either of the two periods of measurement. The mean values of heat production were from 435 kJ/kgW$^{.75}$/d for pigs from the hotroom and 454 kJ/kgW$^{.75}$/d for pigs from the control-room. The trend, therefore, was for heat production to be reduced by high temperature, but this was not statistically significant. Nevertheless, there is other evidence (Holmes, 1974; Thorbek, 1975; Close and Mount, 1975) that the heat production of pigs at high temperatures is lower than that in a cooler environment. In the present study all measurements were made at 24° C, thus any effect would be a carry over effect.

The values of metabolic heat production found in the present study (average 425 kJ/kgW$^{.75}$/d; liveweight range 69-77 kg) was slightly higher than 397 kJ/kgW$^{.75}$/d reported by Holmes (1974) for pigs in the 25-75 kg liveweight range at 25° C, and Thorbek (1974) reported values of 442 and 299 kJ/kgW$^{.75}$/d for pigs in the liveweight range of 55-80 kg at 18 and 26° C, respectively.

In the present study, metabolic heat production was determined in calorimeters kept at 24° C. Thus calorimeter temperature was lower or similar to that experienced by the pigs in the hotroom and control-room. Interestingly when heat production was expressed per unit of metabolic size (W$^{.75}$) it was higher ($P<0.05$) during Period II than Period I. This is not so on a W$^{1.0}$ basis. It is generally thought that as an animal increases

in size heat production is reduced per unit of weight but constant per unit of metabolic size (Kleiber, 1961). This generalization has only been shown to be true for adult and not for growing animals. Furthermore differences in growth and intake during the two weeks prior to Period II (Table 44) were similar in all groups, and for groups 2 and 3 in Period I. Thus differences between groups in heat production may have been larger had the pigs in the hotroom and control-room shown significant differences in intake and growth during the critical periods two weeks before the two calorimeter runs. Morrison and Mount (1971), in a study of temperature adaptation in growing pigs, indicated that steady values for respiration rate and rectal temperature were reached in one and 12 days respectively after a change from 33 to 20° C. The most rapid decline in rectal temperature occured, however, in the first two days following a temperature change, the same time the current pigs spent in the respiration chambers at 24° C. Observation made on two pigs from both the hotroom and control-room groups during simulated calorimeter runs (Figure 40) immediately after the end of the experiment and with the chamber hoods raised to allow free access to the animals, revealed that the rectal temperatures of hotroom pigs declined rapidly from 39.8 to 39.1° C during the first 23 hours in the calorimeter (corresponding to the "acclimatization period" in the actual calorimeter runs). The rectal temperatures of hotroom pigs further declined from 39.1 and 38.4° C over the next 24 hours period (corresponding to the "measurement period" in the actual calorimeter runs). On the other hand, rectal temperatures of control pigs fluctuated between 38.9 to 39.4° C throughout the 48 hour period of simulated calorimetry, and exhibited similar diurnal variations to those observed earlier in a larger number of pigs in the control-room itself (Figure 41). A 'carry over' effect of high

ambient temperature on metabolic heat production of poultry was observed by Swain and Farrell (1975).

Respiration rates were not measured during this period of simulated calorimetry due to the fact that concealed observation facilities (e.g. one-way mirrors) were not available and the pigs tended to be both active and vocal as a result of disturbance by the observer at measuring times in the relatively strange environment of the calorimeter room. These behavioural tendencies were no doubt compounded by the fact that the pigs became increasingly hungry in the calorimeters. The net result was that reliable estimates of respiratory activity were not obtained. Nevertheless, from general observations by the author at these times it was apparent that the respiratory rates of the pigs from both the hotroom and control-room remained low while they were in the calorimeters. Furthermore, comparison of the current observations with the results of the respiration rate measurements in larger numbers of pigs while they were in the Climate Laboratory (Figure 42) indicated that the respiration rate of hotroom pigs entering the calorimeters declined rapidly and reached control values within 3 hours.

Mount (1967) reported that conductive heat losses from new born pigs increased with increasing differences between rectal and ambient temperatures. In the present study, where ambient temperature in the respiratory chambers was 24°C for all pigs, those with higher rectal temperatures would have had greater rectal-ambient temperature differentials and could thus have been expected on theoretical grounds to have had higher rates of heat production. However, the differences in rectal temperature actually observed during the simulated runs between pigs from the hotroom and control-room treatments were relatively small (Figure

40) during the calorimeter runs and thus the small and non-significant differences in metabolic heat production observed are not unexpected.

In a living animal, the so called "basal" heat production comes from those tissues that continue to function even when the body is at complete rest (McDowell, 1972). The intensity of energy metabolism in a resting, post-absorptive animal in a thermally neutral environment under the basal conditions is called the basal metabolic rate (Dale, 1970).

The daily maintenance energy component is that associated with productive and other processes associated with maintenance of the living cells of the tissues. These functions are sometimes referred to as "Specific Dynamic Action" (SDA) of the food. The contribution from these sources to the total body heat production depends on the general level of nutrition, as well as on the type and quality of feed ingested (McDowell, 1972). Furthermore, Neergaard and Thorbek (1967) found that heat production increased and reached a maximum about 50 minutes after feeding. The reduction in voluntary feed intake commonly observed in pigs at high temperatures, which was the order of 19% in the current experiment, may be an attempt by the animal to reduce its metabolic heat load (Stahly, 1982).

In order to reduce the SDA influence, animals are normally fasted prior to and during determination of basal heat production (Dale, 1970). Pigs in the present study were fasted for 23 hours prior to and during the calorimeter runs and since the basal state is seldom achieved in animals (Dale, 1970), the values observed in the present experiment would thus be expected to be higher than the "true" basal metabolic heat production rates of the pigs.

In calculating heat production, it is necessary to know how much of the oxygen is used by an animal. The ratio between the volume of carbon

dioxide produced and the volume of oxygen used is known as the respiratory quotient (McDonald, Edwards and Greenhalgh, 1973) and the ratio depends on the subtrate being oxidized.

The average respiratory quotient found in the present study was 0.73 which was the expected value during starvation. This was lower than the 0.88-0.89 values found by Holmes (1974) who fasted his pigs over the same period to those adopted in the present study. Such differences are possibly due to the different in experimental conditions imposed in the two experiments. The mean respiratory quotient found in the present study indicates that the starvation procedures adopted in the calorimeter had completely eliminated the effects of feed intake on heat production prior to calorimetry. However, there was a positive relationship between R.Q. and feed intake (Figure 36) suggesting that some nutrients were still being absorbed from the gut or that the tissues being catabolized differed according to the prior level of intake. It would also be expected that there would be a positive association between heat production and feed consumed prior to measurement (Figure 35). The larger the pig the higher the heat production and intake.

The suggested tendency (Figure 37) for rectal temperature to increase with liveweight and the significant increase in rectal temperature between Period I and II (Table 44) may be due to the fact that heavier pigs were more prone to heat stress than lighter ones (see II-2.2.1). Furthermore, the tendency for the respiratory quotient to increase with both average daily rate of gain and rectal temperature (Figures 38 and 39 respectively) may be related to the concurrent increase in average daily dry matter intake and liveweight.

Although there were no significant between-group differences in heat

production between pigs exposed to cool and hot conditions in either the current work or in that of Holmes (1974) who used different feeding regime. It is apparent that differences in dry matter intake may have influenced the results of the calorimetry measurements.

It was shown (Figure 35) that there is a significant ($P<0.05$) positive relationship between dry matter intake and total heat production. Similarly, Close, Mount and Start (1971) found that the metabolic heat production of growing pigs increased as the plane of nutrition increased and that pigs at 30° C ambient temperature on 34, 39 and 45 g of feed/kg liveweight, retained energy at 0.14, 0.21 and 0.24 MJ/kg liveweight, respectively. Therefore, it appeared that there might be a positive relationship between growth rate and total metabolic heat production. However, there was no clear indication of a relationship between fasting metabolic rate and daily gain that would help to explain differences in performance of individual pigs at high temperature or even at 24° C. In part the explanation may be that there were insufficient pigs in the present study, particularly as three pigs were excluded from the analysis. Furthermore, the growth rates of the three groups, particularly immediately prior to the calorimeter runs (Table 44, Period II), were unexpectedly close while pigs in group 3 performed below expectation. Any 'carry over' effect may not have been sufficiently large to allow differences to be identified between 24 and 48 hours at 24° C after exposure to 35/25° C. Measurement of pigs fasted for 24 hours in the Climate Laboratory and then placed in the respiration chamber, in hindsight, may have been more appropriate.