DISSIPATION OF BODY HEAT IN DOGS IN A CONTROLLED ENVIRONMENT

by 6791

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TABLE OF CONTENTS

INTRODUCTION

Pretreatment storage of laboratory animals is often required prior to laboratory or experimental treatment. When adaptation, acclimatization or quarantine is included in the pretreatment, storage within indoor facilities may be necessary. The Institute of Laboratory Animal Resources (40) has published guidelines for construction of such facilities. These recommendations together with those established elsewhere (1, 27, 35) are broad in scope, therefore non-specific, regarding optimum values of environmental parameters from which the facilities may be designed. If environmental parameters of indoor facilities are not properly controlled, physiological and psychophysiological stresses may occur (2, 6, 23). The maintenance of constancy of the bodily state by dynamic equilibrium (homeokinesis) may thus be affected, resulting in biased data of the experimental or laboratory treatment. To minimize this potential source of bias, the environmental parameters therefore should be controlled, to produce an optimum homeokinetic state requiring a minimum of energy expenditure by the animals.

Environmental control specifications for indoor storage facilities may be evaluated from the following criteria:

1. Health and comfort of animal handlers
2. Longevity of physical equipment
3. Maintenance of optimum animal homeokinetic state.

In most cases, the environmental conditions necessary to satisfy one of the above criteria also will satisfy the remaining criteria. However, under exceptional circumstances, specific attention to each of these criteria is necessary.

In such cases, the health and comfort of animal handlers may dictate the quality of the environment. For instance, it may be entirely possible

that ammonia concentration of 200 parts per million (ppm) may have no harmful effects upon a specific animal species, whereas, the threshold limit value for man is 50 ppm. It would then be necessary to design the ventilation system to provide sufficient dilution, or adequately treat the waste products chemically, to maintain this lower concentration.

It is also possible that the longevity of mechanical equipment or laboratory instrumentation contained within the facility, may be affected by environmental conditions which bother neither the animals nor the handlers. Gaseous contamination again may be used as an example. It is known that certain gases are vaporized from waste products of the animals, including H_2S, CO_2, NH_3, CH_4 and water vapor (26). These gases may combine to form substances which condense on wet cooling coils as H_2SO_4. This has been observed to occur within two years in environmental chambers at Kansas State University resulting in deterioration of copper cooling coil fins and reduction of cooling efficiency.

Generally, however, animal homeokinesis is of primary concern and the environmental parameters that must be controlled to maintain the optimum physiological state include:

1. Temperature and humidity
2. Ventilation rate
3. Air distribution
4. Photoperiodicity
5. Other (e.g., particulate and gaseous contamination, population density animal species, husbandry, sanitation, odor, etc.)

Temperature and humidity within the facility must be controlled within ranges necessary to maintain thermal neutrality. Brody (8, p. 284) defines thermal neutrality as "the environmental temperature at which heat loss from

the body is equal to the minimum heat production." He reports that thermal neutrality occurs when the environmental temperature is 7^{o} to 10^{o} C below the rectal temperature. Literature is sparce regarding the independent effect of environmental humidity on animal thermal neutrality. Recommendations of desired humidity conditions are based primarily on microbial supression, at approximately 50% RH, minimizing susceptability to disease (6, 18, 40). Rohles and Nevins (39) have shown that human "thermal comfort" may be expressed as a linear multiple regression relationship of temperature and humidity. A similiar relationship is expected to exist in non-sweating homeotherms (e.g., dog) but to a lesser extent.

Air exchange rates within indoor storage facilities may be considered from two aspects:

1. Air flow rate for heat exchange
2. Air flow rate for contamination control.

Ventilation has been defined by ASHRAE (5) as "the process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been air conditioned." Most indoor laboratory storage facilities are air conditioned to maintain animal thermal neutrality and to dissipate internal equipment heat loads. Therefore, for purposes of clarity, the air flow rate necessary for contamination control will be referred to herein as the ventilation rate. This air is usually supplied as "outside air" and the flow rate has been conventionally specified as 10 to 15 air changes per hour (1, 27, 40). Unless special conditions of extremely high internal heat loads exist, the air flow rate necessary to dissipate the heat within the facility will probably be less than these specified ventilation rates.

Accordingly, reduction of ventilation rates may require re-evaluation of air distribution patterns within the animal storage facilities. Even though

the Laboratory Animal Welfare Act of 1966 and its 1970 amendment (36, 41) specify the sizes of cages and number of animals that may be housed per cage, the premium on floor space in these facilities often forces high population density storage of animals. At high rates of air exchange (not necessarily ventilation air) a greater probability exists that all of the animals within the facility will be exposed to a nearly uniform air quality, even if they are contained within cages. This condition is known as an "isostate condition" (11, 32). However, if the air exchange rate is reduced, it is possible that a non-isostate condition may develop and the physiological state of the animals may be altered as a function of their location within the facility.

Consideration of biological rhythmicity is also required if homeokinesis is to be optimized in the animal storage facilities. Brody (8, p. 236) indicates that as early as 1897 polyphasic as well as diurnal rhythmicity patterns were detected in several species. More recently, Redding, et. al. (37) have reported polyphasic patterns in dogs, and Besch (7, 8) has demonstrated endogenous and exogenous rhythms in rats. Therefore, photoperiodic exposure, as well as diet and activity, should be controlled to maintain the natural biological rhythms of the animals in pretreatment.

Control of several other environmental parameters such as particulate and gaseous contamination, including odor, may be accomplished through mechanical and electronic afir filtration, chemical decontamination, improved techniques of animal husbandry and sanitation, and physical processing of the air within the facility. This allows potential reduction of air exchange rates necessary for contamination control while maintaining animal homeokinesis.

To be able to consider the control of these environmental parameters implies that heat loads within the facility are known. In the animal storage

facility, the major heat load is often the rate of heat dissipated by the stored animals. The heat produced by the animals is dissipated to the environment in the forms of sensible and latent heat. Sensible heat is the heat necessary to change the temperature of a substance without changing its phase whereas latent heat is the heat necessary to change the phase of a substance without changing its temperature (5). In the range of thermal neutrality sensible heat is dissipated from the animal body surface area and by respiration to the environment by convection, radiation and conduction. Latent heat is dissipated from the animal body surface area and by respiration (including panting) to the environment by evaporation (14, 15, 19, 21). The ratio of sensible to total heat dissipated by the animals (R) also must be known to maintain temperature and humidity conditions within the thermally neutral range of the animals. Fraser, et. al. (20) have recommended a value of 1.25 times the basal metabolic rate as a reasonable animal heat load upon which design conditions may be established for animal storage facilities. However, they have not recommended a value for the sensible to total heat ratio.

Data reported elsewhere and in preliminary testing at this laboratory, as shown in Table I, indicate that values of 2 to 3 times the "Standard Metabolic Rate" (SMR) (24, p. 175) with R values of 0.5 to 0.6 may be more reasonable design criteria. Several possible reasons exist which may account for these elevated heat dissipation values. First, the animals were not necessarily in the post-absorptive state. Second, activity levels were probably elevated above basal. Third, the animals were confined in cages or stanchions which may have resulted in psychophysiological stress. Yokoi (44) has demonstrated that either hyperthermia or hypothermia resulted when rabbits were subjected to various restraints and the most plausible explanation

Table I. Heat Dissipation in Various Species Under Varying Levels of Activity

Species	Activity Level	Body Weight (Kg)	Heat Dissipation (Kcal/hour)	Calculated Metabolic Body Size[1] (sq. meters)	Heat Dissipation per unit Metabolic Body Size (sq. meters)	Sensible To Total Heat Ratio (R)	Standard Heat Ratio (SHR)	Environment Temp [°F(°C)]	RH (%)	References
Human	Basal	64.5	66.8	22.8	2.93	-	1.0	- -	-	(32)
Dog	Basal	24.8	36.4	11.1	3.28	-	1.0	- -	-	(24, p. 205)
Dog	Basal	14.1	22.2	7.3	3.04	-	1.0	- -	-	(24, p. 205)
Dog	Basal	6.6	12.0	4.1	2.98	-	1.0	- -	-	(24, p. 205)
Rabbit	Basal	2.46	5.0	1.96	2.55	-	1.0	- -	-	(24, p. 205)
Rat	Basal	0.282	1.17	0.388	3.02	-	1.0	- -	-	(24, p. 205)
Human	Sedentary	65.9	90.0	23.0	3.91	0.58	1.34	78 (25.6)	50	(30)
Human	Low	65.9	141.7	23.0	6.16	0.58	2.11	72 (22.2)	45	(30)
Human	Medium	65.9	189.0	23.0	8.22	0.57	2.82	66 (18.9)	45	(30)
Cattle[2,3]	Stanchioned	455.0	820.0	98.5	8.33	0.63	2.87	60 (15.6)	55-70	(43)
Hogs[3,4]	Grouped in Hog House	68.2	167.0	23.8	7.02	0.56	2.41	65 (18.3)	-	(10)
Laying Hens[3,5]	Caged	1.82	8.75	1.66	5.27	0.65	1.92	70 (21.1)	70-75	(31)
Dogs[3,6]	Caged	22.7	89.4	10.4	8.59	0.52	2.94	75 (23.9)	45-55	(42)

Notes: 1. Derived from Ref. (24, p. 215): $M = (Kg)^{3/4}$

2. Mixture of Jersey, Brown Swiss and Holstein cattle. Data derived from values reported per 100 lb. weight. Thermal neutral range: 5-16°C.

3. SMR derived from Ref. (24, p. 215) - 70 $(Kg)^{3/4}$ Kcal/24 hour.

4. Data derived for 150 lb. hogs. Thermal neutral range: 0-20°C.

5. Data derived for 4 lb. White Leghorn hens. Heat production averaged for day and night. Thermal neutral range: 19-29°C.

6. Data derived from preliminary tests with Greyhounds in environmental chamber. Thermal neutral range: 18-25°C.

was that emotional stress impeded normal thermal regulatory mechanisms. Fourth, data were pooled for groups of animals. Kleiber and Winchester (25) have shown that social action such as crowding may effect heat production and dissipation rates. Odoriferous substances, known as pheromones, produced on the exterior surfaces of animals serve as "communication media" between animals (29) and also may have effected animal heat dissipation.

Since dogs are commonly used animals in laboratory and experimental designs and are large enough to produce sufficient heat to be measured by direct calorimetry, individually or in small groups, they were chosen as subjects for this heat dissipation study. Iampietro, et. al. (23) found that dogs began to hyperventilate at conditions of 37.8° C dry bulb temperature and 33.3° C wet bulb temperature or higher but that they knew of no systematic study describing conditions which would determine the threshold of hyperventilation.

This study, therefore, has been designed to evaluate heat dissipated by dogs confined in cages at recommended environmental conditions (40).

MATERIALS AND METHODS

General. Heat dissipation rates from four mature greyhound dogs, two male and two female, with average weights of 23.0 ± 0.3 Kg (mean ± standard error), were measured by the method of direct calorimetry. The heat produced by the dogs was dissipated to the environment by conduction, convection, radiation and evaporation, and no external work was done by the animals (14, 19, 21). Heat dissipation was determined by measuring the differences in the dry bulb and dew point temperatures of the air entering and leaving the chamber. Components of heat were partitioned as sensible and latent heat but the sensible heat was not further partitioned into convection, conduction or radiation components. Because of the size of the chamber (412 cu. ft.) no attempt was made to analyze O_2 or CO_2 partial pressures.

Environmental Conditions. The chamber was controlled to maintain 23.9 ± 0.1° C, 50% relative humidity (12.4 ± 0.2° C dew point) and 12 changes per hour (168 ± 1 Kg/hr) of ventilation air. These conditions were chosen to represent the midpoint conditions of the ranges recommended by the National Research Council for dogs in indoor facilities (40).

The photoperiod was maintained at 12L:12D for all tests. The period of light was maintained between 0600 and 1800 hours by four 160 watt fluorescent light bulbs located above the perforated ceiling in the chamber.

The only air filtration employed in these tests consisted of fiberglass throw-away filters in the ventilation air supply. No specific filtration was incorporated for contamination control of small particulate or gaseous components.

Equipment. The calibrated environmental chamber (Forma Scientific Co., Model C7-88) was arranged and calibrated (42) to measure heat dissipation under conditions similiar to those normally experienced in animal storage

facilities. The air flow schematic of this system is shown in Fig. 1. Two systems were operated simultaneously to achieve the desired results. The primary system supplied air into the ceiling plenum from where it was distributed through a plastic perforated ceiling into the chamber at a velocity of 25 feet per minute. This ceiling also provided diffusion of the chamber lighting. The air, some of which passed through the cages, then was discharged from the chamber through floor level wall grilles opposite the entrance door. The recirculated primary air was mixed with ventilation air from the secondary system and was cooled, reheated and humidified in a plenum within the shell of the chamber. Ventilation air was filtered, cooled, reheated, dehumidified and humidified in the secondary air system before it was mixed with the primary air system. Primary air was exhausted from the system at the same rate as the ventilation air was supplied to maintain a constant static pressure within the chamber.

The temperature of the primary air was regulated by an open loop control system to balance the fixed heat loads on the chamber such as transmission loads through the walls, loads imposed by blowers, lights, etc. The temperature and humidity of the secondary air were regulated by closed loop control systems to maintain constant conditions of the chamber air while dissipating the heat load from the dogs.

Dry bulb and dew point temperatures were sensed by thermistors (Yellow Springs, Series 700) and lithium chloride bifilar elements (Yellow Springs, Model 9102) respectively. All sensing elements were interfaced with a digital acquisition system ("Digitec", United Systems Corporation).

The volumetric air flow rate through the secondary system was determined by measuring the pressure drop across a short radius nozzle located in a special duct section. The nozzle and duct section were designed according to the procedures described in the ASME Power Test Code (4). The pressure

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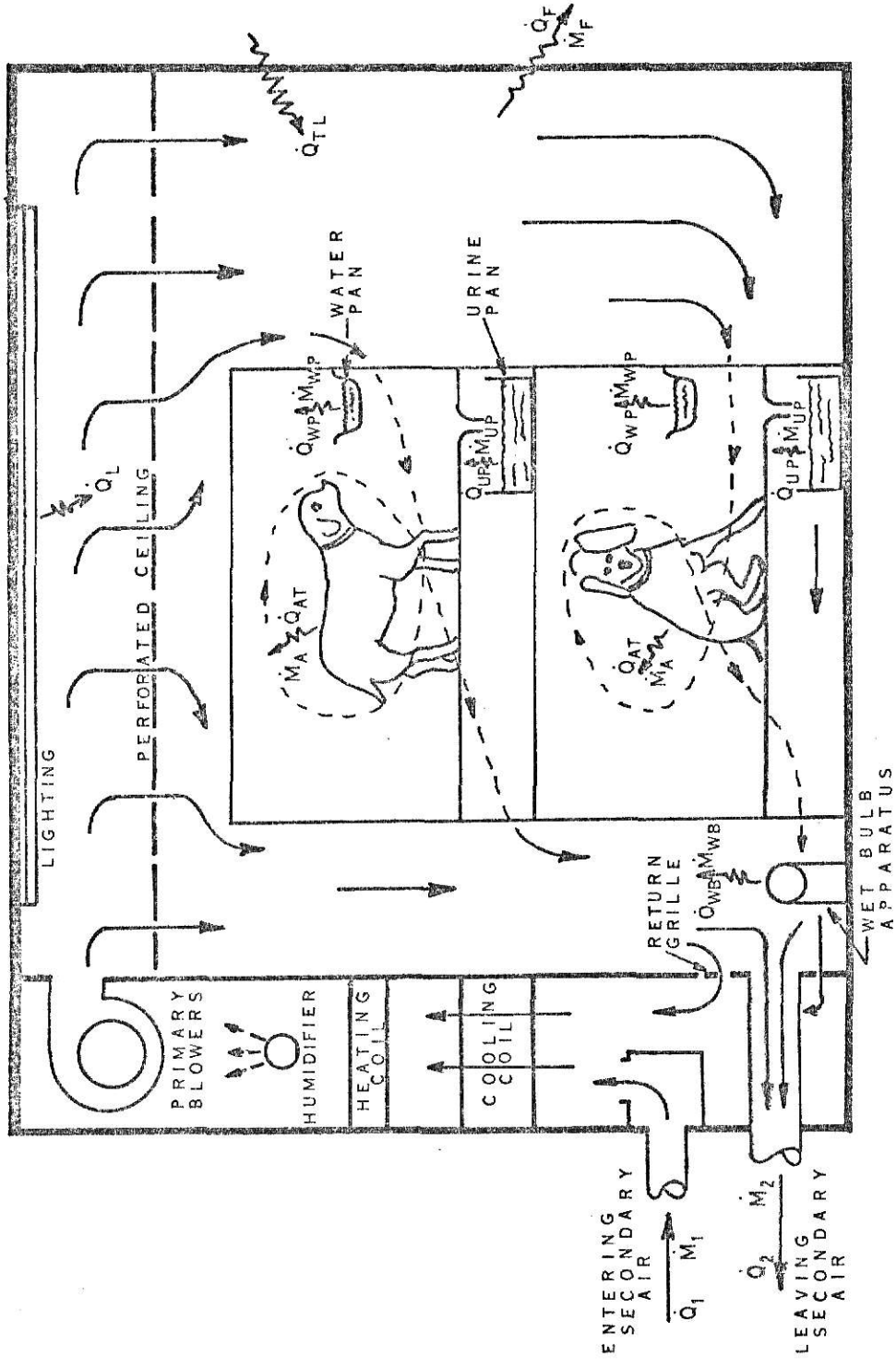

Fig. 1. Schematic of air flow pattern within chamber

drop was measured with a micromanometer (Meriam, Model 34FB2TM).

The dogs were individually confined in standard dog/primate metabolic cages (Hoeltge, Model HB108P-2). The floor space of these cages was approximately 56% of the size calculated by the method of Mackey, et. al. (28) and shown in Appendix I. However, these smaller cage sizes were considered necessary as confinement stress produces an increase in heat dissipation (44). The cages were centrally located within the chamber, as shown in Fig. 1, to provide as much air circulation through the cages as possible. However, due to the physical configuration of the cages, this air exchange rate may be less than the total air exchange rate through the chamber.

Collection of Data. Ten sets of heat dissipation data were recorded at two minute intervals, hourly, for a period of 23 hours, for each dog and for the group of four dogs. Approximately one hour was required between tests to clean the cages, weigh and exercise the dogs, and prepare the next condition to be tested.

In each test, food and water was available ad libitum for 24 hours followed by 24 hours without food or water. The tested dogs were then rested for a minimum of one day with food and water available ad lib. Each test was replicated after one complete set of data were collected. All dogs were given a minimum of ten days to acclimatize to ambient indoor cage conditions before being placed in the chamber. During the acclimatization period and periods between tests, the dogs were contained in holding cages similiar to those in the chamber and were weighed and exercised daily at the same time as the dogs being tested. All dogs were fed a dry, high protein (20%) maintenance diet (Riviana Foods Inc., Stock No. 6761) at approximately 1400 hours daily. The food intake (406 $\pm$ 39 grams/day during ad lib. testing) was measured by the net difference in the weight of the feed in the bowl

between days. Water intake was not measured.

Calculations from Data. Calibration of the chamber and calculation of animal heat dissipation rates were determined by evaluating energy and mass balances of the chamber. The method of direct calorimetry can be only as accurate as the determination of all of the variables effecting the thermal equilibrium of the chamber, but several large scale direct calorimeters have been designed to provide the accuracy necessary to determine animal heat loads (10, 17, 22, 31, 43). To obtain the accuracy necessary for the study reported herein, a mathematical model was developed to account for identifiable variables. The unidentifiable variables were considered by introducing an error function, E, into the model. The mode of chamber operation employed for this study allowed the fixed loads to be compensated by the primary system and only the animal heat loads to be dissipated by the secondary system. This allowed simplification of the energy and mass balance equations. The derivation of this model was reported previously (9, 42) and has been included as Appendix II. Calculation and statistical analysis of these data were obtained by use of a digital computer and the program is included as Appendix III.

RESULTS

Heat Dissipation Rates. Calculations from all tests were compiled on an hourly bases and analysis of these data indicated that transient conditions existed for a period of 4 to 5 hours after each test was initiated. Since these transients could not be identified as physical settling time of the chamber, acclimatization of the dogs or a combination of both, homeokinesis could not be assumed during this time. However, steady state was obtained in all tests by 1800 hours which coincided with the beginning of the dark cycle, and mean values of sensible and total heat dissipation rates (Q_{AS} and Q_{AT} respectively), as shown in Table II, were determined for a minimum period of 17 hours.

Based on these means, additional values were calculated for each test. The sensible heat ratio (R) was determined by dividing the mean sensible heat by the mean total heat. The standard metabolic rate (SMR) was determined from Kleiber's "three-quarter power law" (24, p. 215) using the weights of the dogs measured at the end of each test. The standard heat ratio (SHR) was determined by dividing the mean total heat by the corresponding SMR. Statistically significant differences between trials were detected in several cases, using the Fisher t-test.

Grouping and Activity Effects. For reasons explained later, data from these initial and replicate trials were combined to obtain average values of SHR and R for dogs tested individually and in groups as shown in Table III. The difference in mean SHR values between dogs tested individually and in groups with food and water available ad lib. was found to be statistically significant ($P < 0.01$), while the difference in mean SHR values between fasted dogs tested individually and in groups was not statistically significant. Differences in mean values of R between dogs tested individually and in groups,

Table II. Heat dissipation values for steady state, based on hourly data collection from 1800 daily. Sensible and total heat values indicated as means ± standard errors.

Sample	Diet	N (hours)	Sensible heat, Q_{AS} (Kcal/hr)	Total heat, Q_{AT} (Kcal/hr)	Sensible heat ratio R	Calculated Standard Metabolic rate, SMR (Kcal/hr)	Standard heat ratio, SHR	Significance Level $P_{Q_{AS}}$	Significance Level $P_{Q_{AT}}$
Male 1	Ad lib.	20	78.9 ± 7.1	135.4 ± 6.3	0.58	31.95	4.23	<0.01	<0.01
		19	49.1 ± 3.1	82.0 ± 5.8	0.60	30.94	2.65		
	Fasted	20	66.3 ± 7.6	93.2 ± 9.9	0.71	30.94	3.01	<0.05	NS
		20	90.4 ± 10.2	115.9 ± 10.4	0.78	30.14	3.85		
Male 2	Ad lib.	20	52.6 ± 9.0	74.4 ± 13.1	0.71	30.44	2.45	<0.01	<0.05
		20	150.0 ± 17.9	165.4 ± 22.4	0.91	29.93	5.52		
	Fasted	20	43.7 ± 5.9	58.7 ± 7.9	0.74	29.73	1.97	<0.01	<0.01
		18	153.9 ± 13.8	158.5 ± 19.2	0.97	29.12	5.44		
Female 1	Ad lib.	17	144.3 ± 9.5	166.6 ± 10.0	0.87	29.93	5.56	<0.01	NS
		17	90.4 ± 8.8	157.5 ± 10.5	0.57	29.63	5.31		
	Fasted	21	131.5 ± 9.1	145.9 ± 11.1	0.90	28.72	5.08	<0.05	NS
		20	106.7 ± 8.0	148.8 ± 12.3	0.72	29.02	5.13		
Female 2	Ad lib.	20	172.3 ± 14.4	193.1 ± 17.7	0.89	34.17	5.65	<0.01	<0.05
		20	108.6 ± 13.4	141.0 ± 10.9	0.77	32.52	4.34		
	Fasted	19	43.5 ± 7.6	60.7 ± 8.5	0.72	33.59	1.81	<0.01	<0.01
		17	101.2 ± 10.8	128.7 ± 10.3	0.79	32.02	4.02		
Grouped	Ad lib.	20	178.3 ± 6.9	249.5 ± 8.3	0.72	123.34	2.02	NS	<0.01
		20	191.5 ± 7.9	290.7 ± 13.1	0.66	123.34	2.36		
	Fasted	20	183.0 ± 3.5	245.8 ± 5.4	0.75	121.74	2.02	NS	<0.05
		20	159.9 ± 11.5	217.7 ± 9.5	0.74	120.54	1.81		

Table III. Means and standard errors for values of standard heat ratio, SHR, and corresponding values of sensible heat ratio, R from steady state data for dogs tested individually and in groups under ad lib. and fasted conditions.

Sample	Test	N	SHR	Significance Level P	R	Significance Level P
	Individuals	8	4.46 ± 0.49		0.74 ± 0.05	
ad lib.				< 0.01		NS
	Groups	2	2.19 ± 0.25		0.69 ± 0.04	
	Individuals	8	3.29 ± 0.75		0.79 ± 0.03	
fasted				NS		NS
	Groups	2	1.91 ± 0.17		0.74 ± 0.00	

either ad lib. or fasted, were not significant. No significant differences were found in mean values of SHR or R between ad lib. and fasted conditions for dogs tested individually or in groups.

Analysis of the hourly heat dissipation values indicated a possible time or activity dependent relationship of maximum and minimum standard heat ratios. To study the significance of the SHR range, the four largest and four smallest values which occurred during each test were selected, representing approximately one-half the total steady state hourly values per test. The means and standard errors of these values are shown in Table IV with their corresponding sensible heat ratios. The differences in mean values of maximum and minimum SHR between dogs tested individually and in groups for both ad lib. and fasted conditions were all highly significant ($P < 0.01$), while none of the corresponding values of R were found significant. Differences between mean values of maximum and minimum SHR for dogs tested individually and in groups during fasted and ad lib. conditions were all highly significant. However, in these cases, the corresponding differences in the mean values of R for dogs tested individually, ad lib. and for dogs tested in fasted groups were also significant ($P < 0.05$). The difference in mean values of minimum SHR between ad lib. and fasted dogs tested in groups was not significant, but the corresponding difference in mean values of R was highly significant. All other conditions were not significant.

Confinement Stress. Since stress due to confinement or restraint has been reported to effect thermal regulation in homeotherms (44), a comparison was made between the standard heat ratio determined for fasted dogs tested individually in the chamber and the SHR calculated for standard metabolic conditions. From the mean weight of dogs during individual fasted tests ($W = 22.7 \pm 0.6$ Kg), the standard metabolic rate was calculated as

Table IV. Means and standard errors for maximum and minimum values of standard heat ratio, SHR, and corresponding values of sensible heat ratio, R, from steady state data for dogs tested individually and in groups under ad lib. and fasted conditions.

Sample	Test	N	Max. SHR	Significance Level P	R	Significance Level P	Min. SHR	Significance Level P	R	Significance Level P
Ad lib.	Individuals	32	6.47 ± 0.31	<0.01	0.68 ± 0.04	NS	2.36 ± 0.21	<0.01	0.74 ± 0.05	NS
	Groups	8	2.71 ± 0.14		0.65 ± 0.02		1.65 ± 0.04		0.66 ± 0.01	
fasted	Individuals	32	5.86 ± 0.33	<0.01	0.74 ± 0.04	NS	2.20 ± 0.16	<0.01	0.82 ± 0.04	NS
	Groups	8	2.43 ± 0.07		0.69 ± 0.01		1.38 ± 0.15		0.74 ± 0.02	

30.35 ± 0.55 Kcal/hr for a sample size of 8. The corresponding standard heat ratio was 1.00 ± 0.04. The difference between this SHR value and the minimum SHR value, shown in Table IV, for fasted dogs individually tested was highly significant ($P < 0.01$) as determined by the Fisher t-test. Comparison of the SHR calculated for standard metabolism and the minimum SHR value for fasted dogs tested in groups (Table IV) also indicated a significant difference ($P < 0.05$).

DISCUSSION

General. One of the major advantages of measuring heat dissipation by the method of direct calorimetry was that restraints imposed on the animals from devices such as respirometers were minimized. Results were obtained, therefore, in environmental conditions more closely simulating those actually experienced by animals in storage facilities (40).

Another advantage to this method, compared to indirect calorimetry, was that data was compiled over a period of at least 17 hours, which provided information regarding the range of daily heat dissipation values as well as time averaged values of the means. Heat dissipation values, shown in Table I, for cattle, swine and hens were also obtained by this method (10, 31, 43).

Heat Dissipation Rates. Because significant differences were detected in the mean values of standard heat ratio between dogs tested individually and in groups, Table III, and because these sets of values appeared to be different from those previously reported (42), further comparisons of these data were made, as shown in Table V. The heat dissipation rates reported previously were from data collected daily at approximately 0800 hours from four greyhounds, two male and two female, tested as a group with food and water available ad lib. Therefore to compare data, the standard heat ratios and sensible heat ratios, from data reported herein, were calculated for dogs tested in groups, ad lib., from data recorded at 0800 hours. No statistically significant differences were found between the 0800 and mean values of SHR and R, reported herein, or between this 0800 SHR value and that reported previously for 0L:24D. However significant differences ($P < 0.05$) were detected between this 0800 value of SHR and that reported for 24L:0D, and between this 0800 value of R and those reported for both 0L:24D and 24L:0D.

Table V. Comparison of data compared to that previously reported (42) for group of 4 greyhounds, 2 male, 2 female. Data recorded at 0800 for conditions of ad lib. food and water, and for Mode 2 operations. Values shown are means ± standard errors.

Source	N	L:D (hr:hr)	Ave. wt. (Kg)	SHR	R	T_{out} (°C)	DP_{out} (°C)
From previous data	6	0:24	22.7	2.52 ± 0.10	0.54 ± 0.01	22.85 ± 0.12	9.71 ± 0.72
	11	24:0	22.7	2.92 ± 0.25	0.52 ± 0.04	23.58 ± 0.61	12.90 ± 1.35
				P < 0.05 NS	P < 0.05 P < 0.05		
	2	12:12	23.0	2.14 ± 0.14	0.76 ± 0.00	23.27 ± 0.14	12.42 ± 0.18

Since the data reported herein were for 12L:12D, with all other conditions similiar to those previously reported, it appears reasonable to assume the differences in results may have been due to two changes in biological rhythmicity:

1. photoperiodicity
2. seasonal rhythmicity

According to Pittendrigh (34), constant light or dark causes a "freerunning circadian rhythm " and Aschoff (3) states that this period is longer for day active animals in constant light than in constant dark. He also states that the activity of day active animals increases with increasing light intensity. This may explain why the SHR at 24L:0D was greater, though not significantly, than at 0L:24D. Evidence has been presented by Pittendrigh (33) that "aperiodic light regimes" were detrimental to several animals and plants. If 24L:0D and 0L:24D are considered aperiodic light regimes which were stressful to the dogs, thermoregulatory effects may have resulted in increased SHR values compared to 12L:12D.

Even though these arguments may explain the differences in the standard heat ratios, they do not appear to explain the differences detected in the sensible heat ratios between periodic and aperiodic light. Since the previous data were recorded during winter months while the data, reported herein, were recorded in early summer, seasonal periodicity may better explain these differences. Before both series of tests, the dogs were allowed to acclimatize to indoor thermal conditions for a period of at least 10 days. However, since they had been maintained outdoors previously, the additional resistance to heat transfer of their winter fur could have further impeded sensible heat transfer for the first series of tests compared to the more recent summer tests. Therefore to dissipate heat produced by metabolism, assuming the metabolic

rate remained constant for both series of tests, greater heat dissipation by evaporation was required resulting in a decrease in the sensible heat ratio. To produce this additional latent heat rejection rate required additional panting. Since panting is achieved by respiratory muscular activity (16), the O_2 consumption would have increased requiring additional heat rejection and causing an increase in the standard heat ratio.

The potential changes in biological rhythmicity as possible explanations for the differences in SHR and R detected between these series of tests indicate the need for further research in this area.

Grouping and Activity Effects. In 1964, Brewer (12) reported estimated standard heat ratios of 1.9 and sensible heat ratios of 0.75 for dogs under laboratory conditions but that standard heat ratios up to 10 could be expected. The values reported in Table II, were well within these estimates. Even though significant differences were detected between initial and replicate trials for many of the cases reported in Table II, these values were combined to obtain the results in Table III as these differences probably represented real differences that would also be experienced in laboratory facilities. In addition to changes in biological rhythmicity, as described above, these differences may have been caused by such variables as temperment (24, p. 232), estrus cycle (13, p. 228), fever (13, p. 299) and social interactions (25), all of which effect heat dissipation rates. Rohles and Osbaldiston (38) reported that social isolation caused the development of a freerunning circadian rhythm in rhesus monkeys, a phenonomon which may have existed in this study, as was vaguely apparent from analysis of the hourly heat dissipation values. In future studies using this chamber, this effect should be more closely analyzed.

The data presented in Tables III and IV have been plotted as standard

heat ratio and sensible heat ratio vs number of dogs tested, in Figures 2 and 3 respectively. Linear parametric functions have been shown in these figures since only two points were tested for each condition. Even though not all of these conditions were found to be statistically significant between dogs tested individually and in groups, the negative slopes of each set of curves indicate definite reductions in standard heat ratios and sensible heat ratios as functions of the number of dogs tested. As additional tests are performed on other numbers of dogs and sex combinations, exponential rather than linear functions should be expected since an interception with an abscissa would produce meaningless results. Fig. 2 also indicates the reduction of SHR during fasted conditions compared to ad lib. conditions at maximum, mean and minimum heat dissipation rates corresponding to activity levels. These reductions in SHR appear to become asymptotic as the number of dogs increases, indicating a trend suggesting that the effect of specific dynamic action (SDA) (8, p. 60) may become less significant, compared to other factors, as the colony size increases. Conversely, Fig. 3. indicates an increase in sensible heat ratio for fasted conditions compared to ad lib. conditions for each of the levels of heat dissipation (activity). A trend in the change of R as a function of colony size was not as apparent, but the observed increase in R, for fasted compared to ad lib. conditions, indicates that the dogs were apparently conserving body fluids as they had also been deprived of water during fasted conditions.

Dietary Effects. The values of SHR and R from Tables III and IV have been plotted against each other in Fig. 4. Although several of the differences between ad. lib. and fasted conditions were not statistically significant, Fig. 4 indicates the existance of another trend. Since all of the tests were run in the ad lib. condition followed by the fasted condition, it can be seen

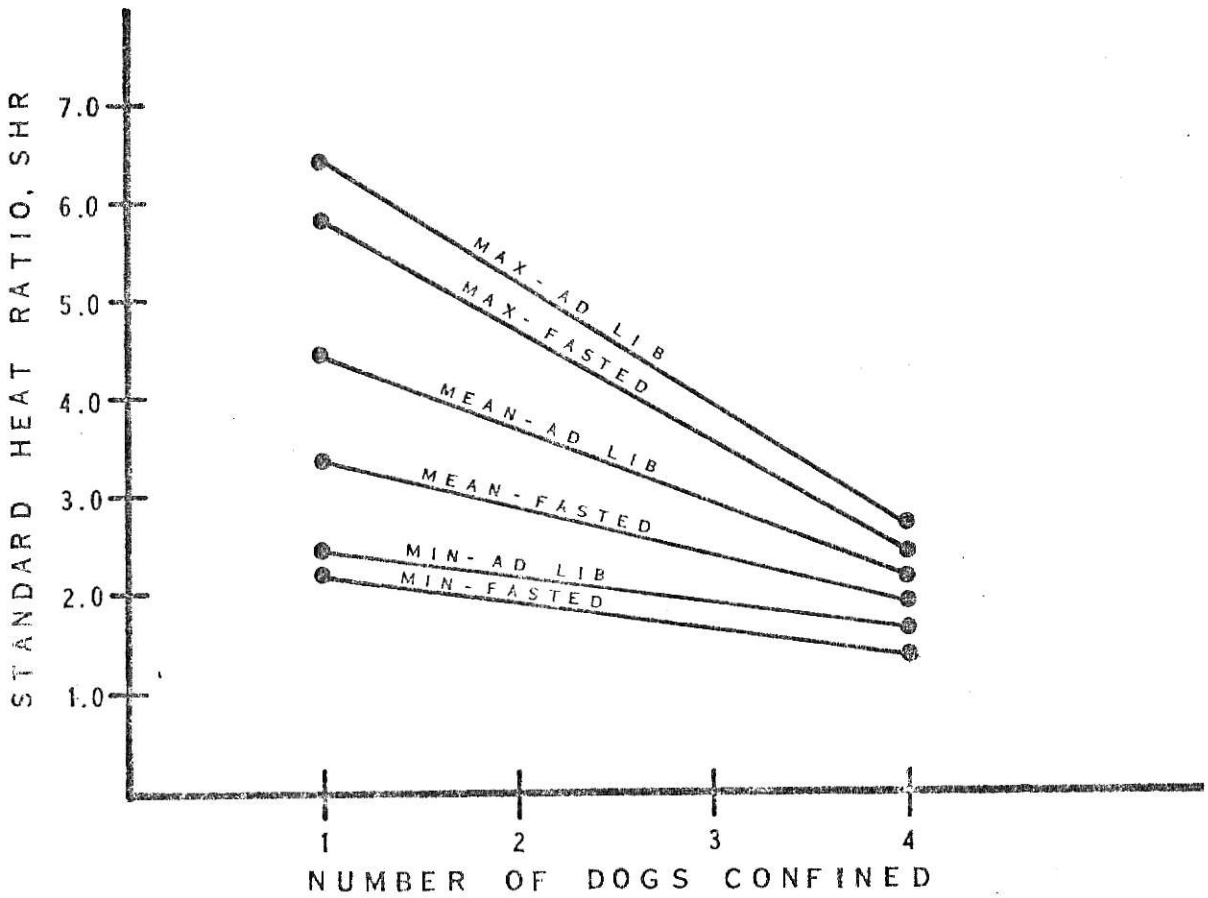

Fig. 2. Grouping effect on standard heat ratio, SHR, at maximum, mean and minimum heat dissipation rates during ad lib. and fasted conditions.

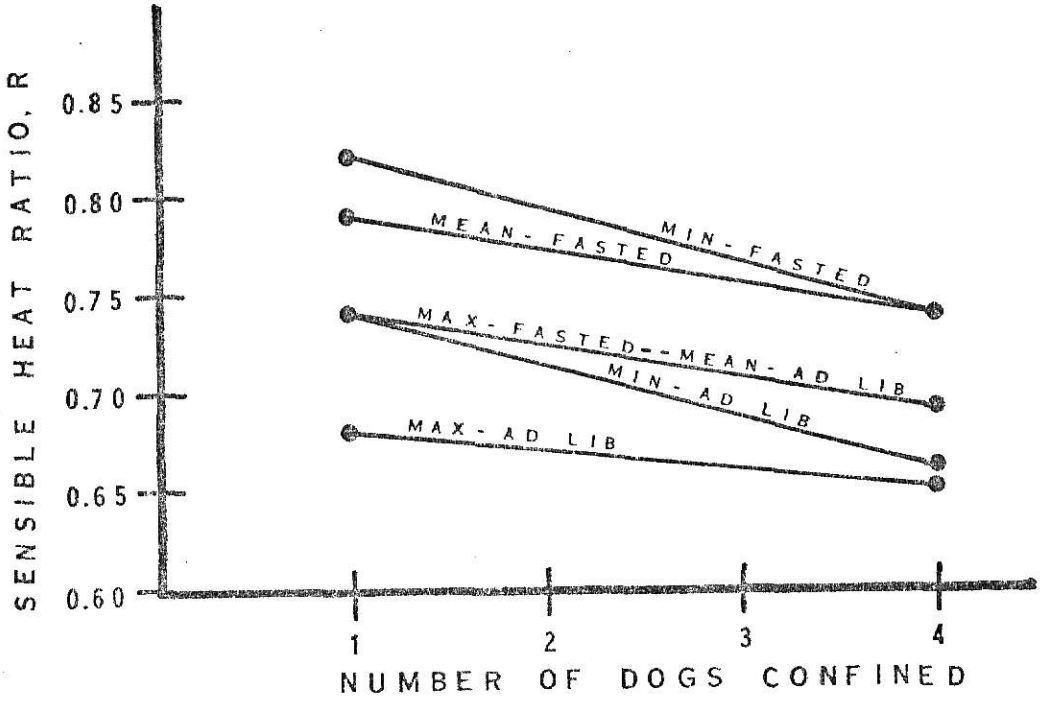

Fig. 3. Grouping effects on sensible heat ratio at maximum, mean and minimum heat dissipation rates during ad lib. and fasted conditions.

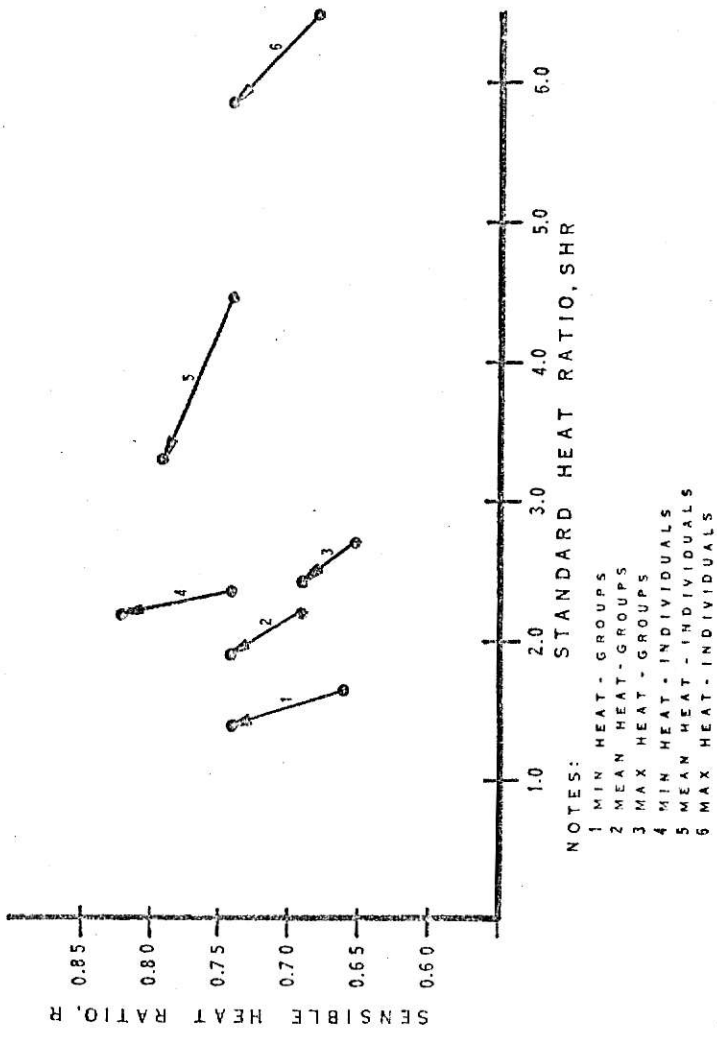

Fig. 4. Sensible heat ratio, R, vs standard heat ratio, SHR, at maximum, mean and minimum heat dissipation rates as dogs were tested individually and in groups during ad lib. then fasted conditions.

that this procedure uniformly resulted in a decrease in SHR with a corresponding increase in R. As mentioned previously these changes may be explained as a decrease in SDA with a corresponding increase of body fluid conservation, suggesting that these ratios may be practical indexes by which the physiological variables may be quantified while studying large numbers of animals.

Confinement Stress. The significance detected ($P < 0.01$) between the minimum SHR (Table IV) for individual dogs tested in the fasted condition and the corresponding SHR at standard metabolism (p. 18) provides an indication of the stress imposed on the dogs by the reduced size of the cages. This significance shows that it may be possible to use the SHR to quantify this confinement stress. Furthermore, this significance indicates that it may be possible to reduce the SHR and the corresponding confinement stress by increasing the size of the cages. Accordingly the mean and maximum SHR values also may be decreased with larger cages.

SUMMARY

Direct calorimetry has provided a method of measuring heat dissipation rates from individual and small groups of greyhound dogs under environmental conditions similar to those actually experienced in laboratory storage facilities. By normalizing the resultant values to dimensionless terms, comparison can be made easily with other homeotherms. The terms defined, herein, for these comparisons were the Standard Heat Ratio (SHR) and the sensible heat ratio (R). The SHR was determined by dividing the total heat dissipation rate by the standard metabolic rate ($SMR = 3(W)^{3/4}$ Kcal/hr), and the R was determined by dividing the sensible heat dissipation rate by the total heat dissipation rate.

The SHR and R values for small groups were found to be generally less than for individual dogs. When comparing dogs tested under ad lib. and fasted conditions, the SHR value was found to decrease under fasted conditions while the R value was found to increase.

Confinement stress was found to be significant during these tests by comparing the individual fasted SHR value with the SHR value at the calculated SMR.

Biological rhythmicity appeared to be detectable during these tests and areas of future research have been identified.

It is anticipated that the values of SHR and R determined herein will allow designers to more accurately predict heat loads within laboratory storage facilities.

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Appendix I

Determination of Canine Cage Size

According to the Animal Welfare Act of 1966 (2): "Each dog housed in any primary enclosure shall be provided a minimum square footage of floor space equal to the mathematical square of the sum of the length of the dog in inches as measured from the tip of its nose to the base of its tail, plus 6 inches, expressed in square feet." Additional requirements state that the cages should be large enough for the dog to stand up comfortably. These requirements presently pertain to those animals not being used in research. Mackey, et. al. (1) have developed linear regression equations for the length and height of a dog as function of weight:

$$L = 32.76 + 0.25\ (W - 40.47)$$

$$H = 19.27 + 0.18\ (W - 40.47)$$

where:

L = length from tip of nose to base of tail in inches.

H = height from top of withers to ground in inches.

W = weight of dog in pounds.

From data previously reported (3) the average weight of a mature greyhound dog was 22.7 Kg

Therefore:

$$W = 22.7 \text{ Kg} \times 2.2 \text{ pounds/Kg}$$

$$W \quad 50 \text{ pounds}$$

$$L = 32.76 + 0.25\ (50 - 40.47)$$

$$L \quad 35 \text{ inches}$$

$$H = 19.27 = 0.18\ (50 - 40.47)$$

$$H \quad 21 \text{ inches}$$

Minimum square footage required:

$$M.S.F. = \frac{(35 + 6)^2}{144}$$

$$M.S.F. = 11.67 \text{ sq. ft.}$$

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Appendix II

Calculation of animal heat and mass dissipation by direct calorimetry may be accomplished by heat and mass transfer analysis of the calorimeter during steady state conditions when certain assumptions are made.

First, it is assumed that the chamber will be brought to a steady state condition before any data is recorded. This assumption is made for heat and moisture calculations when the animals are not in the chamber as well as when there is an animal load.

Second, the energy balance is based on total heat produced in the system and may be considered as containing sensible and latent heat components.

A schematic representation of the heat and moisture sources in this model is shown in Figure 1 in the Material and Methods section. The heat and moisture sources include:

$\dot{Q}_1$: Energy in the preconditioned air entering the chamber, Btuh (Kcal/hr)

$\dot{M}_1$: Rate of water vapor entering chamber, $^{\#}W/hr$ ($^{Kg}W/hr$)

$\dot{Q}_2$: Energy in the air exhausted from the chamber, Btuh (Kcal/hr)

$\dot{M}_2$: Rate of water vapor exhausted from chamber, $^{\#}W/hr$ ($^{Kg}W/hr$)

$\dot{Q}_{TL}$: Heat transfer rate through the walls of the chamber, Btuh (Kcal/hr)

$\dot{Q}_L$: Heat dissipation rate from the fluorescent lamps within the chamber, Btuh (Kcal/hr)

$\dot{Q}_{AT}$: Heat production rate from animals, Btuh (Kcal/hr)

$\dot{M}_A$: Moisture production rate from animals, $^{\#}W/hr$ ($^{Kg}W/hr$)

$\dot{Q}_{WB}$: Heat dissipation rate from wet bulb apparatus within chamber, Btuh (Kcal/hr)

$\dot{M}_{WB}$: Rate of moisture evaporated from wet bulb apparatus within chamber $^{\#}W/hr$ ($^{Kg}W/hr$)

$\dot{Q}_{WP}$: Heat dissipation rate from water pans within chamber, Btuh (Kcal/hr)

$\dot{M}_{WP}$: Rate of moisture evaporated from water pans within chamber, $^{\#}W/hr$ ($^{Kg}W/hr$)

$\dot{Q}_{UP}$: Heat dissipation rate from urine pans within chamber, Btuh (Kcal/hr)

$\dot{M}_{UP}$: Rate of moisture evaporated from urine pans within chamber, $^{\#}W/hr$ ($^{Kg}W/hr$)

$\dot{Q}_{F}$: Heat transfer rate due to exfiltration, Btuh (Kcal/hr)

$\dot{M}_{F}$: Rate of moisture loss due to exfiltration

E : Heat production error function, Btuh (Kcal/hr)

The energy balance for this system may be written as follows:

$$\rho V \frac{dE_{ch}}{dt} = \dot{Q}_1 - \dot{Q}_2 + \dot{Q}_{TL} + \dot{Q}_L + \dot{Q}_{AT} + \dot{Q}_{WB} + \dot{Q}_{WP} + \dot{Q}_{UP} - \dot{Q}_F + E \qquad (1)$$

It has been assumed in this equation that energy entering the chamber is positive and energy leaving the chamber is negative. Terms in this equation not previously defined are:

ρ = Density of air, $\frac{^{\#}dry\ air}{ft^3}$ ($\frac{^{Kg}dry\ air}{M^3}$)

V = Volume of chamber, ft^3 (M^3)

$\rho V \frac{dE_{ch}}{dt}$ = Rate of change of energy within the chamber, $\frac{Btu}{hr}$ ($\frac{Kcal}{hr}$)

The energy contained in the preconditioned air entering the chamber is

defined as:

$$\dot{Q}_1 = \dot{M}_{a_1} h_1 \tag{2}$$

where:

$\dot{M}_{a_1}$ = Mass flow rate of air entering the chamber, $\frac{\#_{\text{dry air}}}{\text{hr}}\left(\frac{\text{Kg}_{\text{dry air}}}{\text{hr}}\right)$

h_1 = Enthalpy of air entering the chamber, $\frac{\text{Btu}}{\#_{\text{dry air}}}$ $\left(\frac{\text{Kcal}}{\text{Kg}_{\text{dry air}}}\right)$

Likewise, the energy in the air exhausted from the chamber is defined as:

$$\dot{Q}_2 = \dot{M}_{a_2} h_2 \tag{3}$$

where:

h_2 = enthalpy of air exhausted from the chamber, $\frac{\text{Btu}}{\#_{\text{dry air}}}$

$\left(\frac{\text{Kcal}}{\#_{\text{dry air}}}\right)$

The heat transfer rate through the chamber walls may be determined from the equation:

$$\dot{Q}_{TL} = UA\ (\bar{t}_a - \bar{t}_{ch}) \tag{4}$$

where:

U = Overall heat transfer coefficient, $\frac{\text{Btu}}{\text{hr ft}^2\ {}^{o}\text{F}}$ $\left(\frac{\text{Kcal}}{\text{hr M}^2\ {}^{o}\text{C}}\right)$

A = Overall surface area of chamber wall panels, ft^2 (M^2)

$\bar{t}_a$ = Average ambient air temperature surrounding the chamber ${}^{o}\text{F}$ (${}^{o}\text{C}$)

$\bar{t}_{ch}$ = Average air temperature within the chamber, ${}^{o}\text{F}$ (${}^{o}\text{C}$)

The heat produced by the chamber lighting may be expressed as a function of the power consumed:

$$\dot{Q}_L = C_1 NP \tag{5}$$

where:

C_1 = Aging coefficient for lamps

N = Number of lamps operating during test

P = Power output/lamp, Btu/hr (Kcal/hr)

The heat produced by the wet bulb apparatus may also be expressed as a function of the power consumed:

$$\dot{Q}_{WB} = \text{Measured operating power consumption} + \dot{Q}_{WB}' \tag{6}$$

where:

$\dot{Q}_{WB}'$ = Heat dissipation rate of water evaporated from the wet bulb apparatus, $\frac{\text{Btu}}{\text{hr}}$ $(\frac{\text{Kcal}}{\text{hr}})$

The energy transfer rate due to exfiltration may be evaluated from the equation:

$$\dot{Q}_F = (\dot{M}_{a_1} - \dot{M}_{a_2})\ (\bar{h}) \tag{7}$$

where:

$(\dot{M}_{a_1} - \dot{M}_{a_2})$ = Difference in entering and exhaust air mass flow rates, $\frac{\#_{\text{dry air}}}{\text{hr}}$ $(\frac{\text{Kg}_{\text{dry air}}}{\text{hr}})$

$\bar{h}$ = Average enthalpy of the air being transferred into or out of chamber, $\frac{\text{Btu}}{\#_{\text{dry air}}}$ $(\frac{\text{Kcal}}{\text{Kg}_{\text{dry air}}})$

Since steady state conditions have been assumed for this system, no change in chamber energy should occur. Therefore:

$$\rho V \frac{dE_{ch}}{dt} = 0 \tag{8}$$

By substituting equations (2) through (8) into equation (1) and rewriting in terms of $\dot{Q}_{AT}$, the energy balance is as follows:

$$\dot{Q}_{AT} = \dot{M}_{a_2} h_2 - \dot{M}_{a_1} h_1 - UA(\bar{t}_a - \bar{t}_{ch}) - C_1NP - \dot{Q}_{WB} - \dot{Q}_{WP} - \dot{Q}_{UP} + (\dot{M}_{a_1} - \dot{M}_{a_2})\ (\bar{h}) - E \tag{1a}$$

Threlkeld (1) states that when Dalton's rule and perfect-gas mixture relations are applied to moist air calculations, where ordinary atmospheric

pressure exists, only slight errors will result when compared to more rigorous calculations. Under these conditions the enthalpy of moist air may be expressed as:

$$h = (C_p\ t) + W\ (1061 + 0.45t) \tag{9}$$

where:

C_p = Specific heat of dry air, $\frac{\text{Btu}}{\#_{\text{dry air}}\ ^{\circ}\text{F}}$

h = Enthalpy of moist air, $\frac{\text{Btu}}{\#_{\text{dry air}}}$

t = Dry bulb temperature, $^{\circ}\text{F}$

W = Humidity ratio, $\frac{\#_{\text{water}}}{\#_{\text{dry air}}}$

For the purposes of this model, the heat produced by the animals is considered to consist of a <u>sensible heat</u> component and a <u>latent heat</u> component. In this model sensible heat is defined as the heat required to change the temperature of a substance without changing the phase of the substance. Latent heat is defined as the heat required to change the phase of a substance. Therefore, the enthalpy of moist air may be defined as:

$$h = h_S + h_L \tag{10}$$

where:

h_S = Component of enthalpy due to sensible load

h_L = Component of enthalpy due to latent load

By regrouping the terms in equation (9):

$$h = (C_p + 0.45W)t + 1061.0\ W \tag{9a}$$

and by combining like terms in equations (10) and (9a)

$$h_S = (C_p + 0.45W)t \tag{11}$$

$$h_L = 1061.0\ W$$

During steady state operation no net change of total heat will occur due to evaporation of water from the wet bulb apparatus, water pans or urine

pans as they are physically located within the boundary of this system. However, a conversion of heat within the chamber will occur from sensible to latent to produce the evaporation. The heat conversion rates for the wet bulb apparatus, the water and the urine pans may be determined from the equations:

$$\dot{Q}_{WP} = (\dot{M}_{WP}\, h_{fg_{WP}})_L - (\dot{Q}_{WPS})_S = 0 \tag{13}$$

$$\dot{Q}_{UP} = (\dot{M}_{UP}\, h_{fg_{UP}})_L - (\dot{Q}_{UPS})_S = 0 \tag{14}$$

$$\dot{Q}_{WB}' = (\dot{M}_{WB}\, h_{fg_{WB}})_L - (\dot{Q}_{WBS}')_S = 0 \tag{15}$$

where:

$\dot{M}_{WP}$ = Rate of evaporation from water pans, $\frac{\#_{water}}{hr}$ $(\frac{Kg_{water}}{hr})$

$h_{fg_{WP}}$ = Heat of vaporization of water from pans evaluated at the pan water temperature, $\frac{Btu}{\#_{water}}$ $(\frac{Kcal}{Kg_{water}})$

$\dot{M}_{UP}$ = Rate of evaporation of water from urine pans, $\frac{\#_{water}}{hr}$ $(\frac{Kg_{water}}{hr})$

$h_{fg_{UP}}$ = Heat of vaporization of water from urine pans evaluated at the urine pan water temperature, $\frac{Btu}{\#_{water}}$ $(\frac{Kcal}{Kg_{water}})$

$\dot{M}_{WB}$ = Rate of evaporation from wet bulb apparatus, $\frac{\#_{water}}{hr}$ $(\frac{Kg_{water}}{hr})$

$h_{fg_{WB}}$ = Heat of vaporization of water from wet bulb apparatus evaluated at the water temperature

$\dot{Q}_{WPS}$ = Sensible heat added to water pans from chamber to produce evaporation

$\dot{Q}_{WBS}'$ = Sensible heat added to wet bulb apparatus to produce evaporation

The heat production of the animals as expressed in equation (1a) may also

be considered to consist of sensible and latent terms. By substituting equations (10) through (15) into equation (1a) and then by regrouping and equating like terms the sensible and latent components of animal heat dissipation can be expressed as follows:

$$\dot{Q}_{AT} = \dot{Q}_{AS} + \dot{Q}_{AL} = \dot{M}_{a_2}(h_{2S} + h_{2L}) - \dot{M}_{a_1}(h_{1S} + h_{1L})$$
$$- UA(\bar{t}_a - \bar{t}_{ch}) - C_1NP - P_{WB} - (\dot{M}_{WB}h_{fg_{WB}})_L$$
$$+ (\dot{Q}_{WBS}{}')_S - (\dot{M}_{WP}h_{fg_{WP}})_L + (\dot{Q}_{WPS})_S - (\dot{M}_{UP}h_{fg_{UP}})_L$$
$$+ (\dot{Q}_{UPS}{}')_S + (\dot{M}_{a_1} - \dot{M}_{a_2})(\bar{h}_S + \bar{h}_L) - (E_S - E_L)$$

Therefore:

$$\dot{Q}_{AS} = \dot{M}_{a_2}(C_p + 0.45\ W_2)t_2 - \dot{M}_{a_1}(C_p + 0.45\ W_1)t_1$$
$$-UA(\bar{t}_a - \bar{t}_{ch}) - C_1NP - P_{WB} + (\dot{Q}_{WBS}{}')_S + (\dot{Q}_{WPS})_S$$
$$+ (\dot{Q}_{UPS}{}')_S + (\dot{M}_{a_1} - \dot{M}_{a_2})(C_p + 0.45\ \bar{W})\bar{t} - E_S \qquad (16)$$

$$\dot{Q}_{AL} = 1061.0\ (\dot{M}_{a_2}\ W_2 - \dot{M}_{a_1}\ W_1) - (\dot{M}_{WB}h_{fg_{WB}})_L$$
$$- (\dot{M}_{WP}h_{fg_{WP}})_L - (\dot{M}_{UP}h_{fg_{UP}})_L$$
$$+ (\dot{M}_{a_1} - \dot{M}_{a_2})\ 1061.0\ \bar{W} - E_L \qquad (17)$$

The terms in equations (16) and (17) which have not been previously defined are:

W_2 = Humidity ratio of exhaust air, $\frac{\#_{water}}{\#_{dry\ air}}$ $(\frac{Kg_{water}}{Kg_{dry\ air}})$

W_1 = Humidity ratio of entering air, $\frac{\#_{water}}{\#_{dry\ air}}$ $(\frac{Kg_{water}}{Kg_{dry\ air}})$

P_{WB} = Power consumption of wet bulb apparatus, $\frac{Btu}{hr}$ $(\frac{Kcal}{hr})$

$\overline{W}$ = Average humidity ratio of air being transferred into or out of the chamber, $\frac{\#_{water}}{\#_{dry\ air}}$ $(\frac{Kg_{water}}{Kg_{dry\ air}})$

$\overline{t}$ = Average temperature of air being transferred into or out of the chamber, ^{o}F (^{o}C)

E_S = Sensible heat error function, $\frac{Btu}{hr}$ $(\frac{Kcal}{hr})$

E_L = Latent heat error function, $\frac{Btu}{hr}$ $(\frac{Kcal}{hr})$

A mass balance for the system shown in Figure 1 may be written as follows:

$$\rho V \frac{d\overline{W}_{ch}}{dt} = \dot{M}_1 - \dot{M}_2 + \dot{M}_A + \dot{M}_{WB} + \dot{M}_{WP} + \dot{M}_{UP} - \dot{M}_F + E_M \qquad (18)$$

The same sign convention as for the energy balance has been assumed; that is mass flow into the chamber is positive while heat flow out of the chamber is negative. The terms in this equation not previously defined, are:

$\rho V \frac{d\overline{W}_{ch}}{dt}$ = Rate of change of moisture content within chamber, $\frac{\#_W}{hr}$ $(\frac{Kg_W}{hr})$

The mass flow rate of water vapor entering the chamber in the pre-conditioned air may be determined from the equation:

$$\dot{M}_1 = \dot{M}_{a_1} W_1 \qquad (19)$$

The mass flow rate of water vapor exhausted from the chamber is determined by a similar equation:

$$\dot{M}_2 = M_{a_2} W_2 \qquad (20)$$

The mass air flow rate of water vapor exfiltrated from the chamber may be determined from the equation:

$$\dot{M}_F = (\dot{M}_{a_1} - M_{a_2}) (\overline{W}) \qquad (21)$$

Since steady state conditions have been assumed, no change in chamber humidity ratio should occur. Therefore:

$$\rho V \frac{dW_{ch}}{dt} = 0 \tag{22}$$

By substituting equations (19) through (22) into equation (18) and rewriting in terms of $\dot{M}_A$ the mass balance becomes:

$$\dot{M}_A = \dot{M}_{a_2} W_2 - \dot{M}_{a_1} W_1 - \dot{M}_{WB} - \dot{M}_{WP} - \dot{M}_{UP} + (\dot{M}_{a_1} - \dot{M}_{a_2}) (\overline{W}) - E_M \tag{23}$$

Equations (16), (17) and (23) are the general equations used to determine the heat and moisture produced by the animals within the calorimetric chamber.

Before animal heat and moisture productions were measured, the calorimeter chamber was calibrated to determine the values to be used in the equations (16), (17) and (23). This calibration included:

1. Chamber dry bulb profile
2. Chamber dew point profile
3. Heat transfer analysis
4. Determination of heat and moisture error functions
5. Determination of fixed loads

Dry bulb temperatures were measured within the chamber at five locations in each of three horizontal planes. The dry bulb profiles were recorded at three dry bulb control temperatures: $60^{\circ}F$, $70^{\circ}F$ and $80^{\circ}F$. At each of these temperatures the primary air velocity control was set to maximum to provide a known velocity profile and the relative humidity was maintained at 50%. The analysis of variance tables for these profiles are shown in Table I.

Significances between planes for the 60° and $70^{\circ}F$ profiles were detected but since the maximum range of dry bulb gradient was $1.1^{\circ}F.$, (i.e. $\pm 0.55^{\circ}F$), this significance seems to primarily indicate the sensitivity of the instrumentation. This sensitivity will become important in analyzing microenviron-

Table I. Dry Bulb Temperature Profile Analysis

Dry Bulb Set Point

	60.0°F	70.0°F	80.0°F
Max Range	60.5 - 59.4 = 1.1°F	70.3 - 69.5 = 0.8°F	80.3 - 79.3 = 1.0°F
Mean Temp.	60.00°F	69.99°F	79.86°F
Std. Deviation	±0.904°F	±0.252°F	±0.226°F
Std. Error	±0.136°F	±0.037°F	±0.034°F

Analysis of Variance Tables

Set Point	Source	DF	SS	MS	F	P
	Plane	2	0.54	0.27	3.65*	<0.05
60.0°F	Error	42	3.13	0.074		
	Total	44	3.67			
	Plane	2	0.616	0.308	5.81**	<0.01
70.0°F	Error	42	2.243	0.053		
	Total	44	2.859			
	Plane	2	0.003	0.0015	0.028(NS)	>0.10
80.0°F	Error	42	2.260	0.054		
	Total	44	2.263			

ments, such as filter top cages. To indicate the significance of this minimized dry bulb gradient, this system has been compared to other chambers used by the Kansas State University Institute for Environmental Research where chamber dry bulb gradients have been found to be in the range of $10^{o}F$. Laminar Flow Cleanrooms, where average air velocities are nearly four times greater than in this chamber, normally do not have smaller dry bulb gradients unless special design considerations are incorporated (2).

Dew point temperatures were measured at the same locations reported for the dry bulb profile. These temperatures were sensed by a Yellow Springs Model 91 Dew Point Hygrometer and indicated through the digital acquisition system, providing a published accuracy of $\pm$ $0.75^{o}F$, and a repeatability of $0.10^{o}F$.

The first profile taken indicated a chamber dew point gradient of $9.5^{o}F$. By modifying the humidifier manifold, profiles were obtained with maximum chamber dew point gradient of $2.6^{o}F$.

Profiles were analyzed at dew points controlled at $45^{o}F$, $50.5^{o}F$ and $55.5^{o}F$, while maintaining the dry bulb temperature at $70^{o}F$ and the velocity at maximum rate. The analysis of variance tables, Table II, again indicated differences between planes for the two lower dew point settings. These differences again seem to primarily indicate the sensitivity of the instrumentation which will become important in analyzing microenvironments within the chamber.

The experimental determination of the overall heat transfer coefficient (UA) was accomplished by sealing the secondary air conditioning inlet and outlet ducts. The primary system was turned off and a known heat load was placed inside the chamber. The average chamber temperature and average ambient temperature were measured and Equation (4) was solved in terms of UA:

Table II. Dew Point Temperature Profile Analysis

Dew Point Set Points

	45.0°F	50.5°F	55.5°F
Max Range	46.5 - 43.9 = 2.6°F	51.8 - 50.0 = 1.8°F	55.7 - 54.0 = 1.7°F
Mean Temp.	44.75°F	50.71°F	54.75°F
Std. Deviation	±0.696°F	±0.490°F	± 0.381°F
Std. Error	±0.104°F	±0.073°F	±0.057°F

Analysis of Variance Tables

Set Point	Source	DF	SS	MS	F	P
	Plane	2	10.08	5.04	18.74***	<0.005
45.0°F	Error	42	11.289	0.269		
	Total	44	21.342			
	Plane	2	4.70	2.35	16.91***	<0.005
50.5°F	Error	42	5.84	0.139		
	Total	44	10.55			
	Plane	2	0.343	0.172	1.189 (NS)	>0.10
55.5°F	Error	42	6.389	0.152		
	Total	44	6.732			

$$UA = \frac{\dot{Q} \text{ known}}{(\bar{t}_{ch} - \bar{t}_{a})}$$

The mean and standard error were then determined.

The value of the heat source to maintain a $10^{o}F$ temperature differential was estimated to be 50 watts. A heating element, monitored by a wattmeter and regulated by a variac was placed inside the chamber. The chamber was sealed and all power except the heating element was disconnected. The resultant temperatures are shown in Fig. 1, as they varied with time.

The initial chamber temperature for this test was $117.4^{o}F$. The asymptotic final value of the differential temperature approached $9.2^{o}F$ in approximately 27 1/2 hours. The initial differential temperature was $(46.2 - 9.2)$ or $37.0^{o}F$.

The value of the differential temperature after one time constant was found to be:

$$T_1 = T_{max}e^{-1}$$

$$T_1 = (37.0)(0.368)$$

$$T_1 = 13.62^{o}F$$

This value is shown in Fig. 1 as:

$$T = 13.62 + 9.2 = 22.82^{o}F.$$

The corresponding time constant is:

$$T_1 = 6.0 \text{ hours}$$

To obtain 95% of the final value, the chamber requires operation for a time period of three time constants. Therefore, the settling time, T_S is 18.0 hours.

The steady state value of UA was determined using the differential temperatures of the last five data points before the test was terminated.

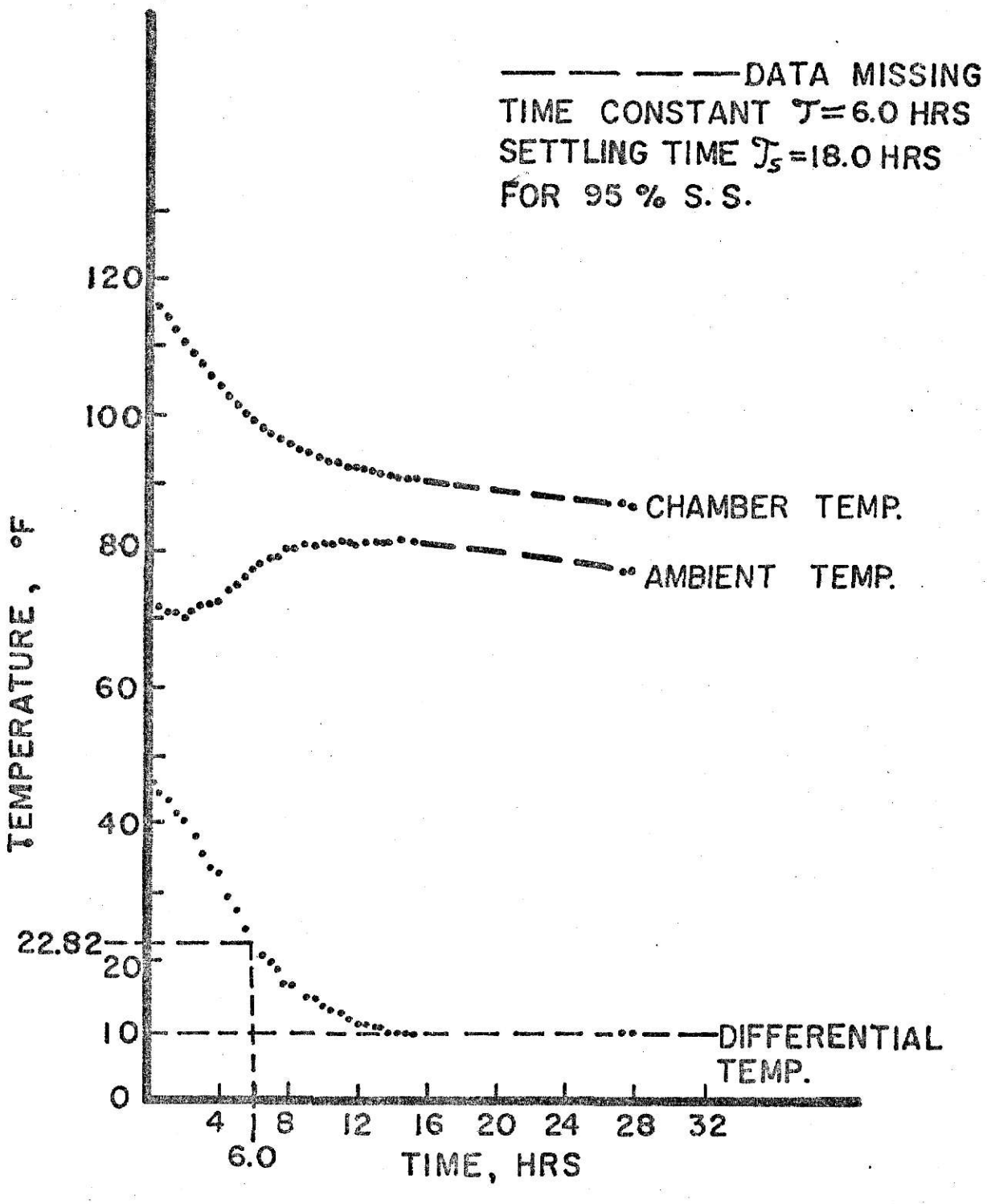

FIG. 1. TEMPERATURE DIFFERENCES THROUGH WALLS

Three of these points occurred before the settling time of 18 hours, but were used as they had the same value ($T = 9.2^{\circ}F$) as the subsequent points.

Statistical analysis of the resultant UA terms indicate, the mean value of UA was 19.08 $\frac{Btu}{hr^{\circ}F}$, with a standard error of 0.414 $\frac{Btu}{hr^{\circ}F}$. Therefore, 19.08 is used as the UA coefficient in equation (4):

$$Q_{TL} = 19.08\ (\bar{t}_a - \bar{t}_{ch})$$

Values of chamber and ambient dew point temperatures were also recorded with the heat transfer data. Only a small change in chamber dew point temperature, $2.6^{\circ}F$, was observed even though the ambient dew point varied considerably during the $27\frac{1}{2}$ hours. It has, therefore, been assumed, for preliminary investigations, that vapor transmission is small.

The use of error functions in equations (16), (17), and (23) allows certain simplifications to be made. As these equations are simplified, fewer fixed loads will be identified resulting in larger values of the error terms which represent the unidentified loads.

The remainder of the chamber calibration and the animal heat and moisture dissipation rates, therefore, have been based on the following assumptions:

1. Specific heat of air remained constant, $C_p = 0.240\ \frac{Btu}{\#_{dry\ air}\ ^{\circ}F}$.
2. Static pressure differential between the chamber and ambient air was less than 0.05 in. H_2O, therefore it has been assumed that $\dot{M}_{a_1} = \dot{M}_{a_2} = \dot{M}_a$.
3. Evaporation rates for the wet bulb apparatus, water pans and urine pans were assumed small when compared to the moisture produced by the animals and were incorporated into the error function.

4. Dry bulb and dew pint profiles indicated very small gradients throughout the chamber. The assumptions were made, therefore, that $\bar{t}_{ch} = t_2$ and $\bar{W}_{ch} = W_2$.

5. Power required for the wet bulb apparatus was assumed constant and was measured as 83.5 watts or 284.7 Btu/hr.

Equations (16), (17) and (23) therefore are simplified to the form:

Animal Sensible Heat:

$$\dot{Q}_{AS} = \dot{M}_a [0.240 (t_2 - t_1) + 0.45 (W_2 t_2 - W_1 t_1)] - C_1 NP - 19.08 (\bar{t}_a - t_2) - 284.7 - E_S \quad (24)$$

Animal Latent Heat:

$$\dot{Q}_{AL} = \dot{M}_a (W_2 - W_1) 1061.0 - E_L \quad (25)$$

Animal Moisture Production:

$$\dot{M}_W = \dot{M}_a (W_2 - W_1) - E_M \quad (26)$$

In Mode II operations, where the fixed loads are dissipated by the primary system and only the animal load is dissipated by the secondary system, equation (24) may be further simplified as fixed loads no longer appear in the secondary system.

Therefore:

$$Q_{AS} = \dot{M}_a 0.240 (t_2 - t_1) + 0.45 (W_2 t_2 - W_1 t_1) - E_S \quad (24a)$$

The total animal heat is found by adding equations (24a) and (25):

$$Q_{AT} = Q_{AS} + Q_{AL} \quad (27)$$

and the animal sensible to total heat ratio is found by dividing equation (24a) by (26):

$$R = \frac{Q_{AS}}{Q_{AT}}$$

The error functions in equations (24a), (25) and (26) were determined

by operating the chamber under the same conditions as when animal heat dissipation rates would be determined but without an animal load. The equations were then solved for E_S, E_L and E_M as Q_{AS}, Q_{AL} and $\dot{M}_W$ were zero. The equations, with the values of error functions included, were then solved for Q_{AS}, Q_{AL} and $\dot{M}_W$ after the dogs had been loaded into the chamber.

References

1. Threlkeld, J. L. Thermal Environment Engineering. New Jersey, Prentice Hall, Inc. 1962, p. 163.

2. Woods, J. E. Psychrometrics of laminar clean rooms. Building Systems Design, 67: 23-30, May 1970.

APPENDIX III

Computer Program and Typical Output

The following pages are reproductions of the digital computer program used to calculate the heat dissipation values reported in the thesis. A typical computer output has also been included to indicate the form in which the hourly values were analyzed.

```
$JOB          JEW,PAGES=200
C      HEAT DISSIPATION OF DOGS IN CONTROLLED ENVIRONMENT
C      DEFINITION OF TERMS:
C             NS      SAMPLE SIZE FOR SENSIBLE ERROR FUNCTION
C             NL      SAMPLE SIZE FOR LATENT AND MOISTURE ERROR FUNCTIONS
C             AVES    MEAN SENSIBLE ERROR (KCAL/HOUR)
C             AVEL    MEAN LATENT ERROR (KCAL/HOUR)
C             AVEM    MEAN MOISTURE ERROR (GRAMS/HOUR)
C             QAS     SENSIBLE HEAT DISSIPATION FROM DOGS (KCAL/HOUR)
C             QAL     LATENT HEAT DISSIPATION FROM DOGS (KCAL/HOUR)
C             QAT     TOTAL HEAT DISSIPATION FROM DOGS (KCAL/HOUR)
C             QDENS   TOTAL HEAT DISSIPATION FROM DOGS PER UNIT METABOLIC SIZE
C                     (KCAL/HR*SQ.M)
C             R       SENSIBLE TO TOTAL HEAT DISSIPATION RATIO
C             MW      MOISTURE DISSIPATION FROM DOGS (KG/HOUR)
C             TIN(C)  ENTERING AIR DRY BULB TEMPERATURE (DF-- DC)
C             TOUT(C) LEAVING AIR DRY BULB TEMPERATURE (DF-- DC)
C             DPIN(C) ENTERING AIR DEW POINT TEMPERATURE (DF-- DC)
C             DPOT(C) LEAVING AIR DEW POINT TEMPERATURE (DF-- DC)
C             MA(KG)  ENTERING AIR MASS AIR FLOW RATE (#/HOUR-- KG/HOUR)
C             TA(C)   AMBIENT AIR TEMPERATURE (DF-- DC)
C             PD      PRESSURE DROP ACROSS INLET AIR NOZZLE (IN.HG.)
C             VMIN    ENTERING AIR DEW POINT MILLIVOLT READING
C             VMOUT   LEAVING AIR DEW POINT MILLIVOLT READING
C             BAR     BAROMETRIC PRESSURE AT MANHATTAN (IN.HG.)
C             I       NUMBER SAMPLES PER HOUR
C             N       NUMBER HOURS PER TEST
C             DOGS    NUMBER OF DOGS IN GROUP
C             DIET    0=FASTED       1=AD.LIB.
C             W       AVERAGE WEIGHT OF DOGS IN CHAMBER (KG)
C             F       AVERAGE FOOD CONSUMPTION BY DOGS (GRAMS/DAY)
C             VF      VOLUMETRIC AIR FLOW (CFM)
C             QATT    OVERALL TOTAL HEAT DISSIPATED, KCAL/HR.
C             SMR     STANDARD METABOLIC RATE, KCAL/HR.
C             SIZE    BODY SURFACE AREA, SQ. METERS
C             MSIZE   METABOLIC SIZE, SQ. METERS
C             SHR     ACTUAL TO STANDARD HEAT RATIO
C             HFLUX   HEAT DISSIPATED PER UNIT SURFACE AREA, KCAL/(HR.)(SQ.METER)
      INTEGER TIME,DOGS,DIET
      REAL  MA,MW, MW1,KGMA1,KGMA2,KGMA,KGMA3,KGMA4,MW2,MSIZE
    1 FORMAT ('1',4X,'HEAT DISSIPATION OF DOGS IN CONTROLLED ENVIRONMENT
     1'/)
    2 FORMAT (I3,F9.0,F12.0,I3,F9.0,F12.0,2F7.0)
    3 FORMAT(1X,F8.0,6F9.0,I4)
    4 FORMAT(5X,'DOGS TESTED ',4(A3,5X)/5X,'DIET CONDITION:',I2/5X,'AVER
     1AGE DOG WEIGHT:',F6.2,' KG'/5X,'AVERAGE FOOD CONSUMPTION:',F6.2,'
     2GRAMS'/)
    5 FORMAT (5X,'SYSTEM ANALYSIS'/11X,'VARIABLE',5X,'TIME',6X,'MEAN',
     1  3X,'STD. DEV. ','STD. ERROR ','SAMPLE SIZE',10X)
    9 FORMAT(4A3,I2,2F10.0)
  119 FORMAT (13X,'QAS',6X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  120 FORMAT (13X,'QAL',6X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  100 FORMAT(13X,'QAT',6X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
 1001 FORMAT(13X,'QDENS',4X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  101 FORMAT(13X,'R',8X,I5,4X,F7.2,26X,I5)
  102 FORMAT(13X,'MW',7X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  103 FORMAT(13X,'TCIN',5X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  104 FORMAT(13X,'TCOUT',4X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  105 FORMAT(13X,'TAC',6X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  106 FORMAT(13X,'DPCI',5X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
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  107 FORMAT(13X,'DPCO',5X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  108 FORMAT(13X,'KGMA',5X,I5,4X,F7.2,3X,F7.2,3X,F7.2,6X,I5/)
  109 FORMAT('-',2X,'SUMMARY')
  121 FORMAT(5X,'SENSIBLE HEAT(QAS),  KCAL/HOUR',8X,F7.2,3X,F7.2,3X,F7.2
     1,6X,I5)
  122 FORMAT(5X,'LATENT HEAT(QAL),  KCAL/HOUR',10X,F7.2,3X,F7.2,3X,F7.2,
     16X,I5)
  110 FORMAT(5X,'TOTAL HEAT(QATT), KCAL/HOUR',11X,F7.2,3X,F7.2,3X,F7.2,6
     1X,I5)
  111 FORMAT(5X,'SENSIBLE HEAT RATIO(R)',16X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  112 FORMAT(5X,'TOTAL WATER RATE(AMWTT), KG/HOUR',6X,F7.2,3X,F7.2,3X,F
     17.2,6X,I5)
  113 FORMAT(5X,'AVE.INLET TEMP(TIN),C',17X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  114 FORMAT(5X,'AVE.OUTLET TEMP(TOUT),C',15X,F7.2,3X,F7.2,3X,F7.2,6X,I5
     1)
  115 FORMAT(5X,'AVE.AMBIENT TEMP(TA),C',16X,F7.2,3X,F7.2,3X,F7.2,6X,I5)
  116 FORMAT(5X,'AVE.INLET DP TEMP(DPIN),C',13X,F7.2,3X,F7.2,3X,F7.2,6X,
     1I5)
  117 FORMAT(5X,'AVE.OUTLET DP TEMP(DPOT),C',12X,F7.2,3X,F7.2,3X,F7.2,6X,
     1,I5)
  118 FORMAT(5X,'AVE. MASS FLOW RATE(KGMA), KG/HOUR',4X,F7.2,3X,F7.2,3X
     1,F7.2,6X,I5)
  131 FORMAT(5X,'STANDARD METABOLIC RATE, KCAL/HOUR',4X,F7.2)
  132 FORMAT(5X,'BODY SURFACE AREA, SQUARE METERS',6X,F7.2)
  133 FORMAT(5X,'STANDARD HEAT RATIO',19X,F7.2)
  134 FORMAT(5X,'HEAT FLUX, KCAL/(HOUR)(SQ.METER)',6X,F7.2,3X,F7.2,3X,F7
     1.2,6X,I5)
  135 FORMAT(45X,'MEAN',3X,'STD.DEV.',2X,'STD.ERROR',' SAMPLE SIZE')
  136 FORMAT(5X,'MET. SIZE, SQ.METERS',18X,F7.2)
C     INITIAL CONDITIONS
      J=0
      BAR=28.740
      WAVE1=0.0
      WAVE2=0.0
      FAVE1=0.0
      FAVE2=0.0
      QAS3=0.0
      QAS4=0.0
      QAL3=0.0
      QAL4=0.0
      QAT3=0.0
      QAT4=0.0
      R1=0.0
      R2=0.0
      AMW1=0.0
      AMW2=0.0
      TCI3=0.0
      TCI4=0.0
      TCO3=0.0
      TCO4=0.0
      TAC3=0.0
      TAC4=0.0
      DPCI3=0.0
      DPCI4=0.0
      DPCO3=0.0
      DPCO4=0.0
      KGMA3=0.0
      KGMA4=0.0
      QDENS1=0.0
      QDENS2=0.0
```

```
      WRITE(6,1)
      READ(5,9) DOG1,DOG2,DOG3,DOG4,DIET,W,F
      WRITE(6,4) DOG1,DOG2,DOG3,DOG4,DIET,W,F
      WRITE(6,5)
      READ (5,2) N
  500 DO 50 L=1,N
      READ (5,3) AVES,AVEL,AVEM
      TCO1=0.0
      TCO2=0.0
      TCI1=0.0
      TCI2=0.0
      DPCI1=0.0
      DPCI2=0.0
      DPCO1=0.0
      DPCO2=0.0
      KGMA1=0.0
      KGMA2=0.0
      TAC1=0.0
      TAC2=0.0
C
      SIZE=W**0.667
      MSIZE=W**0.750
      SIZE=SIZE*4.0
      MSIZE=MSIZE*4.0
C     DATA PROCESSING
      MW1=0.0
      MW2=0.0
      QAS1=0.0
      QAS2=0.0
      QAL1=0.0
      QAL2=0.0
      QAT1=0.0
      QAT2=0.0
      READ (5,2) I
      DO 40 M=1,I
   10 READ(5,3) PD,TA1,TA2,TIN,TOUT,VMIN,VMOUT,TIME
      TA=(TA1+TA2)/2.0
      DPIN=DP(VMIN)
      DPOT=DP(VMOUT)
      VPIN=VP(DPIN)
      VPOUT=VP(DPOT)
      CALL HR(BAR,VPOUT,WOUT)
      CALL HR(BAR,VPIN,WIN)
      CALL DENS(BAR,TIN,VPIN,RHOIN)
      VF=295.12*(PD**0.6186)
      MA=60.0*VF*RHOIN
   30 QAS=MA*(0.24)*(TOUT-TIN)+0.45*((WOUT*TOUT)-(WIN*TIN)))-AVES
      QAS=QAS/3.97
      QAS1=QAS1+QAS
      QAS2=QAS2+(QAS**2)
      AMW=MA*(WOUT-WIN)
      MW=(AMW-AVEM)/2.2
      QAL=1061.0*AMW-AVEL
      QAL=QAL/3.97
      QAL1=QAL1+QAL
      QAL2=QAL2+(QAL**2)
      QAT=(QAS+QAL)
      QAT1=QAT1+QAT
      QAT2=QAT2+(QAT**2)
      MW1=MW1+MW
```

```
      MW2=MW2+(MW**2)
      TCIN = TC(TIN)
      TCOUT= TC(TOUT)
      TAC = TC(TA)
      DPINC=TC(DPIN)
      DPOTC=TC(DPOT)
      KGMA=MA/2.2
      TCI1= TCI1+TCIN
      TCI2=TCI2+(TCIN**2)
      TCO1=TCO1+TCOUT
      TCO2=TCO2+(TCOUT**2)
      TAC1=TAC1+TAC
      TAC2=TAC2+(TAC**2)
      DPCI1=DPCI1+DPINC
      DPCI2=DPCI2+(DPINC**2)
      DPCO1=DPCO1+DPOTC
      DPCO2=DPCO2+(DPOTC**2)
      KGMA1=KGMA1+KGMA
      KGMA2=KGMA2+(KGMA**2)
      K=M
   40 CONTINUE
      CALL STAT(QAS1,QAS2,K,AVQAS,SDQAS,SEQAS)
      CALL STAT(QAL1,QAL2,K,AVQAL,SDQAL,SEQAL)
      CALL STAT(QAT1,QAT2,K,AVQAT,SDQAT,SEQAT)
      QDENS=AVQAT/MSIZE
      SDQD=SDQAT/MSIZE
      SEQD=SEQAT/MSIZE
      CALL STAT(MW1,MW2,K,AVMW,SDMW,SEMW)
      CALL STAT(TCI1,TCI2,K,AVTCI,SDTCI,SETCI)
      CALL STAT(TCO1,TCO2,K,AVTCO,SDTCO,SETCO)
      CALL STAT(TAC1,TAC2,K,AVTAC,SDTAC,SETAC)
      CALL STAT(DPCI1,DPCI2,K,AVDPCI,SDDPCI,SEDPCI)
      CALL STAT(DPCO1,DPCO2,K,AVDPCO,SDDPCO,SEDPCO)
      CALL STAT(KGMA1,KGMA2,K,AVKGMA,SDKGMA,SEKGMA)
      R=AVQAS/AVQAT
      WRITE (6,119) TIME,AVQAS,SDQAS,SEQAS,K
      WRITE(6,120) TIME,AVQAL,SDQAL,SEQAL,K
      WRITE(6,100) TIME,AVQAT,SDQAT,SEQAT,K
      WRITE(6,1001) TIME,QDENS,SDQD,SEQD,K
      WRITE(6,101) TIME,R
      WRITE(6,102) TIME,AVMW,SDMW,SEMW,K
      WRITE(6,103) TIME,AVTCI,SDTCI,SETCI,K
      WRITE(6,104) TIME,AVTCO,SDTCO,SETCO,K
      WRITE(6,105) TIME,AVTAC,SDTAC,SETAC,K
      WRITE(6,106) TIME,AVDPCI,SDDPCI,SEDPCI,K
      WRITE(6,107) TIME,AVDPCO,SDDPCO,SEDPCO,K
      WRITE(6,108) TIME,AVKGMA,SDKGMA,SEKGMA,K
      J=J+K
      QAS3=QAS3+QAS1
      QAS4=QAS4+QAS2
      QAL3=QAL3+QAL1
      QAL4=QAL4+QAL2
      QAT3=QAT3+QAT1
      QAT4=QAT4+QAT2
      QDENS1=QDENS1+QDENS
      QDENS2=QDENS2+(QDENS**2)
      R1=R1+R
      R2=R2+(R**2)
      AMW1=AMW1+MW1
      AMW2=AMW2+MW2
```

```
      TCI3=TCI3+TCI1
      TCI4=TCI4+TCI2
      TCO3=TCO3+TCO1
      TCO4=TCO4+TCO2
      TAC3=TAC3+TAC1
      TAC4=TAC4+TAC2
      DPCI3=DPCI3+DPCI1
      DPCI4=DPCI4+DPCI2
      DPCO3=DPCO3+DPCO1
      DPCO4=DPCO4+DPCO2
      KGMA3=KGMA3+KGMA1
      KGMA4=KGMA4+KGMA2
   50 CONTINUE
      CALL STAT (QAS3,QAS4,J,QAST,SDQAST,SEQAST)
      CALL STAT (QAL3,QAL4,J,QALT,SDQALT,SEQALT)
      CALL STAT(QAT3,QAT4,J,QATT,SDQATT,SEQATT)
      CALL STAT(QDENS1,QDENS2,J,HFLUX,SDHF,SEHF)
      CALL STAT(R1,RZ,N,RT,SDRT,SERT)
      CALL STAT(AMW1,AMW2,J,AMWT,SDAMWT,SEAMWT)
      CALL STAT(TCI3,TCI4,J,TCIT,SDTCIT,SETCIT)
      CALL STAT(TCO3,TCO4,J,TCOT,SDTCOT,SETCOT)
      CALL STAT(TAC3,TAC4,J,TACT,SDTACT,SETACT)
      CALL STAT(DPCI3,DPCI4,J,DPCIT,SDDIT,SEDIT)
      CALL STAT(DPCO3,DPCO4,J,DPCOT,SDDOT,SEDOT)
      CALL STAT(KGMA3,KGMA4,J,TKGMA,SDTMA,SETMA)
      WRITE(6,109)
      WRITE(6,135)
      WRITE(6,121) QAST,SDQAST,SEQAST,J
      WRITE (6,122) QALT,SDQALT,SEQALT,J
      WRITE(6,110) QATT,SDQATT,SEQATT,J
      WRITE(6,134) HFLUX,SDHF,SEHF,J
      L1=L-1
      WRITE(6,111) RT,SDRT,SERT,L1
      WRITE(6,112) AMWT,SDAMWT,SEAMWT,J
      WRITE(6,113) TCIT,SDTCIT,SETCIT,J
      WRITE(6,114) TCOT,SDTCOT,SETCOT,J
      WRITE(6,115) TACT,SDTACT,SETACT,J
      WRITE(6,116) DPCIT,SDDIT,SEDIT,J
      WRITE(6,117) DPCOT,SDDOT,SEDOT,J
      WRITE(6,118) TKGMA,SDTMA,SETMA,J
      SMR=2.917*MSIZE
      SHR=QATT/SMR
      WRITE(6,131) SMR
      WRITE(6,132) SIZE
      WRITE(6,136) MSIZE
      WRITE(6,133) SHR
      STOP
      END

      SUBROUTINE STAT(SUM,SUM2,N,AVE,SD,SE)
      A=N
      AVE=SUM/A
      SUM3=(SUM**2)/A
      B=A-1.0
      VAR=(SUM2-SUM3)/B
      SD=SQRT(VAR)
      C=SQRT(B)
      SE=SD/C
      RETURN
      END
```

```
      SUBROUTINE HR(BAR,VP,W)
      W=(0.622*VP)/(BAR-VP)
      RETURN
      END

      SUBROUTINE DENS(BAR,T,V,RHO)
      V=(0.75433*(459.67+T))/BAR
      RHO=1.0/V
      RETURN
      END

      FUNCTION VP(T)
      Y1=(16.386396+(0.00137804*T))-(5656.0/(459.67+T))
      Y2=ALOG((459.67+T)/100)
      Y3=Y1-(3.560573*Y2)
      VP=10**Y3
      RETURN
      END

      FUNCTION DP(VM)
      DP=105.648-(9.020*VM)
      RETURN
      END

      FUNCTION TC(T)
      TC=0.555*(T-32.0)
      RETURN
      END

$ENTRY
```

HEAT DISSIPATION OF DOGS IN CONTROLLED ENVIRONMENT

DOGS TESTED 90 79B 79E 91
DIET CONDITION: 1
AVERAGE DOG WEIGHT: 23.20 KG
AVERAGE FOOD CONSUMPTION:505.00 GRAMS

SYSTEM ANALYSIS

VARIABLE	TIME	MEAN	STD. DEV.	STD. ERROR	SAMPLE SIZE
QAS	1400	21.48	16.47	5.49	10
QAL	1400	93.88	29.13	9.71	10
QAT	1400	115.35	40.85	13.62	10
QDENS	1400	2.73	0.97	0.32	10
R	1400	0.19			
MW	1400	0.16	0.05	0.02	10
TCIN	1400	22.39	0.43	0.14	10
TCOUT	1400	23.22	0.11	0.04	10
TAC	1400	21.63	1.00	0.33	10
DPCI	1400	12.02	0.38	0.13	10
DPCO	1400	14.30	0.27	0.09	10
KGMA	1400	167.25	0.45	0.15	10
QAS	1500	55.06	7.92	2.64	10
QAL	1500	54.55	28.56	9.52	10
QAT	1500	109.61	26.34	8.78	10
QDENS	1500	2.59	0.62	0.21	10
R	1500	0.50			
MW	1500	0.09	0.05	0.02	10
TCIN	1500	22.56	0.26	0.09	10
TCOUT	1500	24.25	0.13	0.04	10
TAC	1500	21.29	0.96	0.32	10
DPCI	1500	11.67	0.45	0.15	10
DPCO	1500	13.41	0.22	0.07	10
KGMA	1500	166.31	0.91	0.30	10
QAS	1600	64.09	18.82	6.27	10
QAL	1600	90.53	43.58	14.53	10
QAT	1600	154.61	57.45	19.15	10
QDENS	1600	3.66	1.36	0.45	10
R	1600	0.41			
MW	1600	0.16	0.07	0.02	10
TCIN	1600	22.65	0.40	0.13	10
TCOUT	1600	25.00	0.08	0.03	10
TAC	1600	21.50	1.09	0.36	10
DPCI	1600	11.68	0.58	0.19	10
DPCO	1600	13.65	0.46	0.15	10
KGMA	1600	166.33	0.49	0.16	10
QAS	1700	271.09	16.04	5.35	10
QAL	1700	178.67	42.13	14.04	10
QAT	1700	449.75	56.58	18.86	10
QDENS	1700	10.64	1.34	0.45	10
R	1700	0.60			
MW	1700	0.31	0.07	0.02	10
TCIN	1700	17.31	0.38	0.13	10
TCOUT	1700	25.14	0.09	0.03	10
TAC	1700	20.87	1.14	0.38	10
DPCI	1700	10.73	0.74	0.25	10
DPCO	1700	13.52	0.46	0.15	10
KGMA	1700	172.73	0.74	0.25	10

QAS	1800	168.15	16.77	5.59	10
QAL	1800	87.49	31.40	10.47	10
QAT	1800	255.65	46.55	15.52	10
QDENS	1800	6.05	1.10	0.37	10
R	1800	0.66			
MW	1800	0.18	0.05	0.02	10
TCIN	1800	17.22	0.36	0.12	10
TCOUT	1800	24.78	0.06	0.02	10
TAC	1800	21.29	1.10	0.37	10
DPCI	1800	11.21	0.63	0.21	10
DPCO	1800	13.44	0.20	0.07	10
KGMA	1800	173.09	0.55	0.18	10
QAS	1900	121.04	20.21	6.74	10
QAL	1900	76.07	31.38	10.46	10
QAT	1900	197.11	49.83	16.61	10
QDENS	1900	4.66	1.18	0.39	10
R	1900	0.61			
MW	1900	0.13	0.05	0.02	10
TCIN	1900	17.79	0.44	0.15	10
TCOUT	1900	24.90	0.04	0.01	10
TAC	1900	20.80	1.13	0.38	10
DPCI	1900	11.09	0.55	0.18	10
DPCO	1900	13.07	0.12	0.04	10
KGMA	1900	172.68	0.86	0.29	10
QAS	2000	118.38	24.15	8.05	10
QAL	2000	76.95	33.20	11.07	10
QAT	2000	195.34	54.71	18.24	10
QDENS	2000	4.62	1.29	0.43	10
R	2000	0.61			
MW	2000	0.13	0.06	0.02	10
TCIN	2000	17.93	0.55	0.18	10
TCOUT	2000	25.01	0.04	0.01	10
TAC	2000	21.16	1.07	0.36	10
DPCI	2000	11.63	0.62	0.21	10
DPCO	2000	13.41	0.22	0.07	10
KGMA	2000	172.82	1.05	0.35	10
QAS	2100	136.91	19.13	6.38	10
QAL	2100	75.77	35.86	11.95	10
QAT	2100	212.68	53.43	17.81	10
QDENS	2100	5.03	1.26	0.42	10
R	2100	0.64			
MW	2100	0.13	0.06	0.02	10
TCIN	2100	17.80	0.45	0.15	10
TCOUT	2100	25.07	0.04	0.01	10
TAC	2100	21.03	1.12	0.37	10
DPCI	2100	11.51	0.67	0.22	10
DPCO	2100	13.31	0.22	0.07	10
KGMA	2100	173.05	0.37	0.12	10
QAS	2200	164.49	21.13	7.04	10
QAL	2200	93.97	31.78	10.59	10
QAT	2200	258.46	50.33	16.78	10
QDENS	2200	6.11	1.19	0.40	10
R	2200	0.64			
MW	2200	0.16	0.05	0.02	10
TCIN	2200	17.58	0.47	0.16	10

TCOUT	2200	24.73	0.00	0.00	10
TAC	2200	20.51	1.19	0.40	10
DPCI	2200	11.11	0.55	0.18	10
DPCO	2200	12.99	0.10	0.03	10
KGMA	2200	173.11	0.82	0.27	10
QAS	2300	164.11	21.87	7.29	10
QAL	2300	63.58	47.63	15.88	10
QAT	2300	227.69	63.41	21.14	10
QDENS	2300	5.38	1.50	0.50	10
R	2300	0.72			
MW	2300	0.11	0.08	0.03	10
TCIN	2300	17.79	0.53	0.18	10
TCOUT	2300	24.73	0.04	0.01	10
TAC	2300	20.94	1.17	0.39	10
DPCI	2300	11.80	0.83	0.28	10
DPCO	2300	13.32	0.17	0.06	10
KGMA	2300	172.75	0.96	0.32	10
QAS	2400	190.65	21.06	7.02	10
QAL	2400	82.57	32.45	10.82	10
QAT	2400	273.21	52.51	17.50	10
QDENS	2400	6.46	1.24	0.41	10
R	2400	0.70			
MW	2400	0.14	0.06	0.02	10
TCIN	2400	17.59	0.49	0.16	10
TCOUT	2400	24.81	0.04	0.01	10
TAC	2400	20.55	1.14	0.38	10
DPCI	2400	11.83	0.57	0.19	10
DPCO	2400	13.51	0.15	0.05	10
KGMA	2400	173.33	0.62	0.21	10
QAS	100	222.48	21.86	7.29	10
QAL	100	125.12	38.96	12.99	10
QAT	100	347.60	58.20	19.40	10
QDENS	100	8.22	1.38	0.46	10
R	100	0.64			
MW	100	0.22	0.07	0.02	10
TCIN	100	17.63	0.46	0.15	10
TCOUT	100	24.50	0.02	0.01	10
TAC	100	20.23	1.11	0.37	10
DPCI	100	11.38	0.57	0.19	10
DPCO	100	13.56	0.15	0.05	10
KGMA	100	172.92	0.98	0.33	10
QAS	200	219.02	16.65	5.55	10
QAL	200	78.65	34.70	11.57	10
QAT	200	297.67	47.44	15.81	10
QDENS	200	7.04	1.12	0.37	10
R	200	0.74			
MW	200	0.14	0.06	0.02	10
TCIN	200	17.68	0.41	0.14	10
TCOUT	200	24.32	0.07	0.02	10
TAC	200	20.58	1.15	0.38	10
DPCI	200	11.65	0.61	0.20	10
DPCO	200	13.21	0.26	0.09	10
KGMA	200	172.28	0.71	0.24	10
QAS	300	218.54	13.68	4.56	10
QAL	300	144.12	46.86	15.62	10

QAT	300	362.67	58.54	19.51	10
QDENS	300	8.58	1.38	0.46	10
R	300	0.60			
MW	300	0.25	0.08	0.03	10
TCIN	300	17.64	0.29	0.10	10
TCOUT	300	24.25	0.05	0.02	10
TAC	300	20.15	1.25	0.42	10
DPCI	300	11.18	0.75	0.25	10
DPCO	300	13.76	0.22	0.07	10
KGMA	300	171.76	0.51	0.17	10
QAS	400	205.19	26.27	8.76	10
QAL	400	75.66	24.70	8.23	10
QAT	400	280.86	50.12	16.71	10
QDENS	400	6.64	1.19	0.40	10
R	400	0.73			
MW	400	0.13	0.04	0.01	10
TCIN	400	17.55	0.61	0.20	10
TCOUT	400	23.88	0.04	0.01	10
TAC	400	20.58	1.07	0.36	10
DPCI	400	11.26	0.48	0.16	10
DPCO	400	12.81	0.12	0.04	10
KGMA	400	172.36	0.72	0.24	10
QAS	500	206.63	37.84	12.61	10
QAL	500	82.49	30.87	10.29	10
QAT	500	289.12	55.47	18.49	10
QDENS	500	6.84	1.31	0.44	10
R	500	0.71			
MW	500	0.14	0.05	0.02	10
TCIN	500	17.71	0.44	0.15	10
TCOUT	500	24.06	0.89	0.30	10
TAC	500	20.29	1.11	0.37	10
DPCI	500	11.54	0.64	0.21	10
DPCO	500	13.13	0.34	0.11	10
KGMA	500	171.80	0.87	0.29	10
QAS	600	190.28	17.91	5.97	10
QAL	600	97.10	27.57	9.19	10
QAT	600	287.39	37.16	12.39	10
QDENS	600	6.80	0.88	0.29	10
R	600	0.66			
MW	600	0.16	0.05	0.02	10
TCIN	600	17.78	0.40	0.13	10
TCOUT	600	23.80	0.17	0.06	10
TAC	600	20.64	1.00	0.33	10
DPCI	600	11.98	0.42	0.14	10
DPCO	600	13.75	0.27	0.09	10
KGMA	600	172.06	0.69	0.23	10
QAS	700	207.74	23.63	7.88	10
QAL	700	82.60	33.14	11.05	10
QAT	700	290.34	55.20	18.40	10
QDENS	700	6.87	1.31	0.44	10
R	700	0.72			
MW	700	0.14	0.06	0.02	10
TCIN	700	17.54	0.50	0.17	10
TCOUT	700	23.57	0.06	0.02	10
TAC	700	20.34	1.17	0.39	10
DPCI	700	11.59	0.54	0.18	10

DPCO	700	13.21	0.13	0.04	10
KGMA	700	172.44	0.70	0.23	10
QAS	800	212.84	21.85	7.28	10
QAL	800	83.88	19.70	6.57	10
QAT	800	296.71	37.36	12.45	10
QDENS	800	7.02	0.88	0.29	10
R	800	0.72			
MW	800	0.14	0.03	0.01	10
TCIN	800	17.69	0.50	0.17	10
TCOUT	800	23.34	0.03	0.01	10
TAC	800	20.58	1.11	0.37	10
DPCI	800	11.52	0.40	0.13	10
DPCO	800	13.21	0.16	0.05	10
KGMA	800	172.50	0.90	0.30	10
QAS	900	217.14	24.87	8.29	10
QAL	900	92.35	34.71	11.57	10
QAT	900	309.49	56.56	18.85	10
QDENS	900	7.32	1.34	0.45	10
R	900	0.70			
MW	900	0.16	0.06	0.02	10
TCIN	900	17.66	0.58	0.19	10
TCOUT	900	23.06	0.04	0.01	10
TAC	900	20.54	1.21	0.40	10
DPCI	900	11.42	0.65	0.22	10
DPCO	900	13.21	0.28	0.09	10
KGMA	900	172.13	0.51	0.17	10
QAS	1000	220.75	17.44	5.81	10
QAL	1000	89.89	30.77	10.26	10
QAT	1000	310.64	45.60	15.20	10
QDENS	1000	7.35	1.08	0.36	10
R	1000	0.71			
MW	1000	0.15	0.05	0.02	10
TCIN	1000	17.76	0.41	0.14	10
TCOUT	1000	23.05	0.06	0.02	10
TAC	1000	20.84	1.02	0.34	10
DPCI	1000	11.59	0.52	0.17	10
DPCO	1000	13.25	0.14	0.05	10
KGMA	1000	172.15	0.44	0.15	10
QAS	1100	226.73	20.89	6.96	10
QAL	1100	166.18	21.09	7.03	10
QAT	1100	392.91	40.75	13.58	10
QDENS	1100	9.29	0.96	0.32	10
R	1100	0.58			
MW	1100	0.29	0.04	0.01	10
TCIN	1100	17.71	0.50	0.17	10
TCOUT	1100	23.10	0.06	0.02	10
TAC	1100	20.96	1.08	0.36	10
DPCI	1100	11.62	0.53	0.18	10
DPCO	1100	14.45	0.21	0.07	10
KGMA	1100	172.34	0.85	0.28	10
QAS	1200	217.11	17.00	5.67	10
QAL	1200	166.31	25.82	8.61	10
QAT	1200	385.41	39.74	13.25	10
QDENS	1200	9.11	0.94	0.31	10
R	1200	0.56			

MW	1200	0.29	0.04	0.01	10
TCIN	1200	17.84	0.38	0.13	10
TCOUT	1200	23.00	0.06	0.02	10
TAC	1200	20.74	1.16	0.39	10
DPCI	1200	11.62	0.47	0.16	10
DPCO	1200	14.39	0.21	0.07	10
KGMA	1200	171.95	0.26	0.09	10
QAS	1300	208.69	23.71	7.90	10
QAL	1300	133.95	25.23	8.41	10
QAT	1300	342.64	47.29	15.76	10
QDENS	1300	8.10	1.12	0.37	10
R	1300	0.61			
MW	1300	0.22	0.04	0.01	10
TCIN	1300	17.83	0.55	0.18	10
TCOUT	1300	23.02	0.06	0.02	10
TAC	1300	20.94	1.29	0.43	10
DPCI	1300	11.87	0.53	0.18	10
DPCO	1300	14.08	0.28	0.09	10
KGMA	1300	171.73	0.65	0.22	10

SUMMARY

	MEAN	STD.DEV.	STD.ERROR	SAMPLE SIZE
SENSIBLE HEAT(QAS), KCAL/HOUR	177.02	63.77	4.13	240
LATENT HEAT(QAL), KCAL/HOUR	99.76	46.08	2.98	240
TOTAL HEAT(QATT), KCAL/HOUR	276.79	95.63	6.19	240
HEAT FLUX, KCAL/(HOUR)(SQ.METER)	0.65	2.06	0.13	240
SENSIBLE HEAT RATIO(R)	0.62	0.12	0.03	24
TOTAL WATER RATE(AMWTT), KG/HOUR	0.17	0.08	0.01	240
AVE.INLET TEMP(TIN),C	18.28	1.68	0.11	240
AVE.OUTLET TEMP(TOUT),C	24.11	0.78	0.05	240
AVE.AMBIENT TEMP(TA),C	20.79	1.13	0.07	240
AVE.INLET DP TEMP(DPIN),C	11.52	0.63	0.04	240
AVE.OUTLET DP TEMP(DPOT),C	13.50	0.49	0.03	240
AVE. MASS FLOW RATE(KGMA), KG/HOUR	171.74	2.11	0.14	240
STANDARD METABOLIC RATE, KCAL/HOUR	123.34			
BODY SURFACE AREA, SQUARE METERS	32.57			
MET. SIZE, SQ.METERS	42.28			
STANDARD HEAT RATIO	2.24			

CORE USAGE OBJECT CODE= 12848 BYTES,ARRAY AREA= 20 BYTES,TOTAL AREA AVAILABLE= 29584 BYTES

COMPILE TIME= 8.47 SEC,EXECUTION TIME= 20.92 SEC, WATFIV - VERSION 1 LEVEL 2 AUGUST 1970 DATE= 71/195

DISSIPATION OF BODY HEAT IN DOGS IN A CONTROLLED ENVIRONMENT

by

JAMES EDWARD WOODS

B. S., University of New Mexico, 1962

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Physiological Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

ABSTRACT

Four mature greyhound dogs, two male and two female, each with an average body weight of 23.0 ± 0.3 Kg (mean ± standard error) were confined, individually in standard dog cages. These cages and dogs were placed in a calibrated walk-in chamber and maintained under environmental conditions of 23.9 ± 0.1 °C, 50% relative humidity (12.4 ± 0.2°C dew point) and 12 changes of ventilation air per hour (168 ± 1 Kg/hr). Heat dissipation rates were determined by the method of direct calorimetry for individual dogs and for the group of four dogs. Tests were conducted for a day with food and water available ad libitum followed by a day without food or water. The photoperiod was held constant during all tests at 12L:12D. Significant differences in heat dissipation were found between dogs tested individually and in groups and between maximum and minimum activity levels. Differences in heat dissipation between ad lib. and fasted conditions were not statistically significant but definite trends were shown to exist. Significant differences in heat dissipation between replications occurred in several cases, thought to be caused primarily by changes in biological rhythmicity. Heat dissipation was reported as the ratio of total heat dissipation to the calculated standard (basal) metabolic rate (standard heat ratio) and as the ratio of sensible heat dissipation to total heat dissipation (sensible heat ratio). The standard heat ratios were found to vary from 4.46 for individual dogs tested ad lib. to 1.91 for grouped dogs tested in fasted condition while the sensible heat ratios were found to vary from 0.79 for individual dogs tested in the fasted condition to 0.69 for grouped dogs tested ad lib. Variations in values for grouped dogs tested ad lib. compared to values previously measured were thought to be caused by seasonal rhythmicity. However these ratios were found to be

similar to previously reported data for dogs and other animals. The ratios used in those comparisons suggest the possibility of characterization of animal heat equivalents and their use as indexes in measuring related physiological responses.