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CONTROL OF SWEATING IN AYRSHIRE CATTLE AND WATER BUFFALO

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ABBREVIATIONS

Area of Surface of a body/object - A

Heat Transfer by Convection - C

Evaporative Heat Loss - E

Sweat Rates - E_h, E_o

Evaporimeter Flow Rate - F

Calibration factor of Evaporimeter - f

The Convection Coefficient - h

Other Sources of Heat Gain and Heat Loss - I

Specific Insulation - i

Heat Transfer by Conduction - K

Conductance of the Surface - k

Metabolic Heat Production - M

Evaporimeter Readings - M_o, M_o^1, M_1, M_1^1, M_2, M_2^1

Radiative Heat Transfer - R

Thickness of Surface - t

Temperature of Coat - T_c

Temperature of Environment - T_e

Temperature inside Evaporimeter - T_o, T_o^1, T_1, T_1^1, T_2, T_2^1

Air Velocity - V

Weight - W_1, W_2

Emissivity - ε

Stefan-Boltzmann constant - σ

Saturation Water Vapour Pressure - $X_{sat}\ T$

Change in Evaporimeter Reading - σM

Change in Relative Humidity inside Evaporimeter - $\sigma\phi$

ABSTRACT

Three Ayrshire Cattle and 3 water buffaloes were exposed to temperatures of between 25.0 and 28.5°C in hot rooms. An area on one side of the back of each animal was heated by radiation from an electric bulb. Sweat rates and skin temperatures were measured on both the heated and unheated sides of the animals. Rectal temperatures and respiratory rates were also measured.

Skin temperatures, rectal temperatures and respiratory rates were higher for the Ayrshires than for the buffaloes. The maximum sweating rates were 60 mg $m^{-2}s^{-1}$ and 45 mg $m^{-2}s^{-1}$ for Ayrshire cattle and the buffaloes respectively. High sweat rates were associated with high skin temperatures and all the animals sweated more (on the average) on the heated than the unheated areas. In response to radiant heating the difference in skin temperature between the heated and unheated sides of the Ayrshires was considerably less than for the buffaloes. This difference may result partly from a better local control of sweat rate in the Ayrshire than the buffalo.

The relationships between sweat rate and rectal temperature and between sweat rate and respiratory rate were less predictable than that between sweat rate and skin temperature but they did suggest that high sweat rates are associated with both high rectal temperatures and rapid respiratory rates. However, the respiratory rates of the buffaloes remained very low throughout the experiment.

INTRODUCTION

INTRODUCTION

One of the major purposes for the keeping of livestock is food production. The nomad in the dry hot tropical areas of the world is particularly concerned with subsistence from his herd of cattle. The modern livestock farmer is concerned about the level of output in relation to input on his farm which determines profitability. It has been pointed out that even in some pastoralist societies the level of off-take may increase if productivity could be increased. Livestock productivity however, is known to be under the influence of several factors:- These factors include, the genetic merit of the animals, the presence and effects of diseases, management levels and educational standards of the livestock owner, availability of feeds, availability of capital and marketing facilities and the direct and indirect effects of climate.

In all parts of the tropical world livestock of all breeds and species come into direct contact daily with solar radiation. In parts of Northern Nigeria, in West Africa, for example, where over 70% of the cattle of the country are owned, there is an annual dry period (season) that may last over six months. Daily air temperatures may reach over 35°C and persist for several hours. Similar conditions exist in other tropical areas in Asia where large numbers of cattle and water buffaloes are kept for draught and dairy purposes. Animals in such hostile environments have to rely upon behavioural and physiological responses to cope with the effects of heat. Animals of different breeds and species differ in the extent and effectiveness to which they employ these responses.

Knowledge about the specific responses of different livestock to heat stress may prove to be a vital tool in the hand of the modern livestock farmer in the hot areas of the world in evolving management practices aimed at minimizing their delecterous effects. It is likely also to be useful to the animal scientist who selects animals for use in the tropical areas.

Sweating control in livestock is important because sweating involves the loss of certain vital body nutrients; water and some minerals. Although sweating is beneficial in terms of heat loss, excessive generalized sweating of an animal to a localized source of heat stress, such as direct sunlight, is wasteful in terms of minerals and water which are often scarce commodities in the dry tropical areas. A high degree of local control over sweating in response to a local source of heat must help the animal to conserve water. The main objective of this study therefore is to see the extent of regional ("local") sweat control.

LITERATURE REVIEW

Heat Stress

There is a range of environmental temperature called the zone of thermal neutrality within which the metabolic rate of an animal is minimum. Maximum productivity also occurs within the zone of thermal neutrality. However animals in their natural and man-made habitats are often subjected to temperatures outside this zone.

In hot environments animal productivity is reduced by heat stress. For instance the milk yield of *Bos taurus* dairy cattle is reduced by 20% when ambient temperature is increased from the zone of thermal neutrality to 30°C (Miescke, Johnson, Weniger and Steinhauf, 1978). Much of this reduction in productivity can be attributed to a reduced food intake (Seif, Johnson and Lippincot, 1977; Terui, Ishino, Matsuda, Shoji, Ambo and Tsuda, 1979).

Animals minimise heat stress by behavioural and physiological mechanisms. This literature review examines the reactions of cattle and buffalo in a hot environment, with particular reference to sweating.

Energy Budget

The energy budget of an animal may be represented by an equation. It may be summarised simply as heat gain equals heat loss. The terms in the energy budget may be equated as in equation (1) below:-

$$M = C + K + R + E + I \quad \text{(Richards, 1973)} \qquad \ldots\ldots (1)$$

where M = Metabolic heat production, C = Convective heat transfer, K = Conductive heat transfer, R = Radiative heat transfer, E = Evaporative heat loss and I = Other sources of heat gain and heat loss but it is usually considered to be negligible compared to the other terms in the energy budget.

The general representation of the energy budget becomes:-

$$M = C + K + R + E \qquad \ldots\ldots (2)$$

Metabolic Heat Production

The internal heat production of an animal comprises heat that results from the fermentation of food in the rumen, the digestive process and tissue metabolism. The heat that may become available from the various metabolic processes is popularly called heat increment. Evidence suggests that heat stress affects the release of certain hormones vital in metabolism. Mitra, Christison and Johnson (1972) reported that heat stress appears to depress the synthesis and release of the somatotrophic hormone and that it also tends to depress thyroxine output. This could be attributed to secondary effects such as underfeeding rather than direct effects of heat stress since reduction in feed intake would mean a reduction in blood level of glucose resulting in a negative feedback causing a reduction in the release of thyroid stimulating hormone. However, even when the feed intake deficit was compensated for by directly introducing feed via a fistula into the rumen there appeared to be a continued depression of thyroid activity (Yousef and Johnson, 1966). There are also reports of reductions in the levels of insulin (Kamal, Ibrahim, Seif and Johnson, 1970) and of glucocorticoids concentration (Yousef and Johnson, 1967) due to heat stress. These reductions in the release of the hormones that are generally considered to be vital in metabolism are aimed at reducing the rate of metabolism and therefore reduce metabolic heat production of the animal.

Heat Transfer

In general heat transfer may occur in both directions except in the case of heat loss by evaporation. In other words, the animal may gain and/or lose heat by conduction, convection and radiation and lose heat by evaporation. Physical laws of heat transfer have been applied to animals. Newton's and Fourier's laws may be used to express the relationship between the rate of heat loss from an animal and the difference in temperature between the surface of the animal and the environment ($T_c - T_e$), the surface area of the body exposed to the environment (A) and the thickness of the surface of the animal (t). Fourier's law was also applied to the relationship between the rate of heat loss (H_L) of a body and the resistance to heat flow per unit area (i) called specific insulation of the animal.

Thus $$H_L = \frac{A(T_{core} - T_{surface})°C}{i}$$

The specific insulation of an animal is the ratio of the thickness of the surface (t) and the conductance of the surface (k)

$$i = \frac{t}{k}$$

Insulation

In animals and birds provided with thick covering, the coat covering the skin is considered to be the chief means of insulation. In pigs the main means of insulation is the thick layer of subcutaneous fat. In animals provided with a good fur covering thermal insulation is proportional to the thickness of the layer of still air that it can retain.

Conductive Heat Transfer

In conductive heat transfer, collisions take place between molecules of the material and as the frequency of these molecular collisions increases conduction rates increase but the translocation of these molecules does not take place. For animals, conductive heat loss becomes significant only if the animal establishes contact between a large area of its body and a solid object such as the ground.

Convective Heat Transfer

In contrast to heat transfer by conduction that by convection results from the movement of the molecules of the fluid in contact with the surface. Natural convection, sometimes referred to as free convection occurs when the fluid in direct contact with the body surface is warmed up, expands and its density falls. It rises and is replaced by cooler, denser air. Forced convection occurs not because there is a difference in temperature but because an external pressure is exerted on the fluid as it flows past the body. This external pressure usually results in winds. For a stationary animal body, convective heat loss is proportional to the surface area (A) exposed and the square root of the product of the air velocity (V) and the temperature difference between body surface and the environment $(T_c - T_e)$.

$$C = hA\sqrt{V(T_c - T_e)}$$

h = the convection coefficient.

Radiative Heat Loss

The energy of radiative heat exchange travels by electromagnetic waves and at a temperature above absolute zero, the electromagnetic waves radiate energy in accordance with the Stefan-Boltzmann law:-

$$R = \varepsilon\sigma AT^4$$

ε = emissivity which may be defined as the measure of the blackness of the body. A perfect black body has emissivity of 1. The body with the least emissivity is a well polished, perfect reflector such as highly polished silver and has an emissivity of about 0.02, T = surface temperature in kelvin, σ = Stefan-Boltzmann constant and A = effective radiating area. The live animal emits long-wavelength energy and also absorbs radiant energy of the short-wavelength from the sun and absorbs energy of the long-wavelength from other objects in the environment. The net transfer of long-wave radiation is described by the Hardy's equation:-

$$R = \varepsilon_c \varepsilon_e \sigma A(T_c - T_e) \quad \text{or} \quad R\ \alpha(T_c - T_e).$$

ε_c and ε_e are the emissivity of the surface of the body and of the environment respectively, T_c and T_e are the temperatures of the body surface and environment. For short-wave radiation the darker the colour of the animal the more radiant energy it absorbs and the lighter the colour, the higher the capacity of the animal to reflect some of the short-wave radiant energy incident on its coat surface (Robertshaw and Finch, 1974).

Evaporative Heat Loss

When mammals are subjected to heat stress, the rate of sensible heat loss from the animal to the environment decreases because of a reduction in the thermal gradient between the animal and the surroundings. Excess heat produced by the animal is stored in the body unless it can be lost as the latent heat of evaporation of water (Bligh, 1973). Animals differ in the way they achieve this evaporative water loss. The same author identified four physiological processes employed by different animal species to achieve evaporative heat loss:- wallowing, saliva spreading, panting and sweating. Wallowing does not involve the loss of body fluid and body minerals, panting involves the loss of body fluid, saliva spreading and sweating involve the loss of body fluid and body minerals.

Wallowing

Wallowing is quite effective in bare-skinned or sparsely coated species. The domesticated pig does not sweat (Ingram, 1964), the water buffalo secrets some sweat (Joshi, McDowell and Sadhu, 1968) but both species of animals wallow considerably. Wetting the skin of the pig will increase the evaporation from the skin but only transiently, therefore the animal requires to remain close by a water source for frequent wallows if it is to effect the proper cooling of its body in severe heat stress.

Panting

Bligh defines panting as the use of forced movements of air over the moist surface of the upper respiratory tract to facilitate evaporative heat loss from these surfaces. The same author claimed that respiratory frequency can be effected by local heating and cooling of the anterior hypothalamic region of the brain as well as the skin suggesting a neural connection between anterior hypothalamic thermoregulator centre and the respiratory control complex.

Cutaneous Water Loss

Water is lost passively through the skin and is evaporated. This type of cutaneous water loss is termed insensible perspiration. It is achieved by simple diffusion. Taylor and Buettner (1953) stated that water diffuses through the skin at a rate proportional to the difference between water vapour pressure at skin temperature and is independent of sweat gland activity.

It has also been established that cattle (Taneja, 1958,1959; Pan, Donegan and Hayman, 1969 and Schleger and Bean, 1971) and the buffalo (Joshi, McDowell and Sadhu, 1968) do actively sweat. According to Hardy (1979) each gram of water evaporated from the surface of the skin at room temperature is associated with a heat loss of about 2.45 kJ.

The Morphology of Sweat Glands

Findlay and Yang (1950) described the structures associated with cattle sweat glands. Nay (1958) noted that in the same animal there exist sweat glands with varying morphology. He also described the following types of sweat glands in cattle: (a) the tubular, more or less coiled type that have varying lengths with a fairly constant but low diameter (b) the baggy type with varying lengths but shaped like a cucumber or a sausage often with an indentation at the upper end indicating a rudimentary coil with a wide diameter and (c) the club shaped intermediate type which has a wider baggy lower end and a narrower more or less coiled upper end. Findlay and Yang (1950) described sweat glands as having two layers of epithetum, an outer myoepithelium consisting of cells with spindle shaped nuclei and an inner glandular epithelium composed mainly of cells with round or ovoid nuclei.

The Mode of Sweat Secretion and Terminology

Allen and Bligh (1969) citing Schiefferdecter (1917) stated that apocrine implied the breakdown of cell membranes and the extrusion of cellular contents to form the glandular secretion. Findlay and Yang (1950) observed a protuberance from the epithelium linning the gland's lumen. The protuberance appeared to form a clear chain of granules which eventually broke off and accummulated in the lumen of the gland. They described this process as the necrobiotic (apocrine) phase of sweat discharge. They also observed a homogenous fluid like product in the lumen of sweat glands which they concluded indicated existence of a phase of simple sweat secretion. However, Findlay and Jenkinson, (1964) found that the colloidal solutions observed in sweat glands persisted over 36 hours and concluded that necrebiotic sweat secretion did not occur.

Allen and Bligh (1969) postulated that sweat secretion may involve myoepithelial contractions and by a simple overflow of filled gland lumen. They concluded that in cattle the main way the sweat glands empty is by simple overflow reinforced by periodic myoepithelial contractions. In sheep and goats, Bligh (1961) and Robertshaw (1968) concluded that sweat secretion is achieved by myoepithelial contactions only; consequently these ruminants cannot sustain a continuous outflow of fluid from their sweat glands.

The relationship between sweat gland function and histological changes in the gland epithelium has been investigated. Findlay and Jenkinson (1964) and Amakiri and Adepoju (1979) found that at low environmental temperatures and prior to the commencement of outbreak of sweating in cattle, the epithelial cells of the sweat glands were mainly of the flattened low cuboidal epithelium with relatively fewer numbers of the high cuboidal and the high columnar bleb-forming epithelium. They reported that as sweating progressed at higher ambient temperatures the morphology of the secretory cell surfaces was found to vary such that the percentage of the high cuboidal and high columnar cell types increased. They also observed changes in the morphology of the myoepithelial cells which varied from the elongated form to the contracted form. These changes indicated myoepithelial contraction (Elder, Jenkinson and Montgomery, 1977).

Allen and Bligh (1969) suggested the use of the term epitrichal to replace the term apocrine since the necrobiotic process of sweat secretion was still being disputed; epitrichal describes cattle sweat glands adequately since it has been established (Findlay and Yang (1950), Dowling (1955), and Nay (1958)) and other workers that there is a close association between cattle sweat glands and follicles.

Control of Sweating

Bligh (1973) identified three structures concerned with sweat regulation. (a) There are central intergrator organs which receive input impulses from (b) both central and peripheral sensors and send out efferent impulses to (c) effector organs aimed at activating the appropriate responses. The hypothalamus is not only the main intergrator organ but it also contains central sensors similar to these reported in the spinal cord. Sensors perceive heat and cold stimuli and initiate the appropriate impulses. The same author stated that despite doubts about the existence of distinct peripheral cold and warm sensors or discrete neural pathways from these sensors to the central nervous system that their existence seems to be firmly based on experimental observations. Taneja (1956) and Findlay and Robertshaw (1965) showed that adrenaline injections caused increased sweating in cattle. Taneja (1956) blocked adrenaline induced sweating with dibenazine injection and Findlay and Robertshaw (1965) showed that sympathetic denervation reduced thermal sweating in the ox but the denervation of the adrenal medulla did not reduce the rate of moisture loss from normal skin when the ox was subjected to heat stress. It was therefore concluded that sweating in cattle is controlled by an adrenergic mechanism requiring intact sympathetic nerves to the sweat glands. Robertshaw and Taylor (1968) concluded that sweat secretion in the wild bovids was also under adrenergic neural control.

The flow of fluid into the vicinity of the sweat glands is by blood arterioles (Findlay and Jenkinson, 1964) and the blood arterioles and venous drainage to the skin are closely associated with cholinergic nerves (Schleger and Bean, 1971). Bligh (1973) stated that evidence suggests that the sympathetic nerve supply to at least some areas of the skin contains vasoconstrictor fibres and under normal conditions the activity of these fibres keeps the cutaneous blood flow in the state of partial constriction. Current evidence suggests that vasodilation occurs during heat stress resulting in the formation of increased amounts of interstitial fluid which is absorbed and secreted as sweat by sweat glands (Hardy, 1979).

Air, Skin and Rectal Temperatures, Respiratory Rate and Cutaneous Evaporation Interactions

Taneja (1958) reported that in the zebu cross cattle when air temperature was increased cutaneous evaporation also increased, and McLean (1963) and Allen and Bligh (1969) reported that evaporation rates in cattle rose during the first two hours of exposure to high air temperatures in a series of steps. These steps occurred at irregular intervals but between steps, vapourization rates tended to remain steady though fluctuations may occur. However, sweating in domestic and wild bovids does not occur until the threshold air temperature for the animal is exceeded (McDowall, McDaniel, Barrada and Lee, 1961).

Taneja (1958) reported that there was linear relationship between skin temperature and cutaneous evaporation rate in the Shorthorn while in the Zebu cross cutaneous water loss increased but skin temperature remained relatively constant. Murray (1966) reported a poor relationship between cutaneous evaporation rate and skin temperature. Isabirye and Robertshaw (1972) and Gatenby (1979) found that an exponential relationship existed between sweating rate and skin temperature in cattle. The exponential relationship proposed by these authors were supported by different explanations. Gatenby (1979) has reported that the relationship between cutaneous evaporation rate and rectal temperature in cattle was less predictable than that between evaporation rate and skin temperature. She however noted that both cutaneous evaporation rate and rectal temperature of cattle increased under high ambient temperatures similar to the observations of McLean, (1963).

Respiratory rates of cattle generally increase in response to high ambient temperatures. Amakiri and Funsho (1979) found an increasing trend in respiratory rates of both *Bos taurus* (BT) and *Bos indicus* (BI) in response to high ambient temperatures but Allen (1962) reported that the respiratory rates of the BI remained relatively low at high ambient temperatures and explained that this characteristic of the BI was aimed at water conservation. One of the few indications of the relationship between cutaneous water loss and respiratory rate was by McLean (1963) who reported increases in both Ayrshire calves at high ambient temperatures. Bianca (1963) has suggested that under moderate heat conditions respiration rate was not a good measure of heat tolerance in cattle because the relationship between respiration rate and respiratory minute volume varied with degree of heat stress and panting represented only one among many factors involved in an animal's thermal balance.

Sweating Rates

Taneja (1958) reported sweating rates of about 39 mg s^{-1} and 60 mg s^{-1} in the Shorthorn and the Zebu respectively at the ambient temperature of 40°C, and Aner and Weniger (1982) reported sweating rates of about 39 mg $m^{-2}s^{-1}$ at 35°C for Friesian Cattle. The sweating rates reported are as varied as the conditions (temperature and humidity) under which they were measured, the equipment used in the measurements and the individual animal and breed of cattle on which the measurements were made. Attempts have been made in the literature to compare sweating rates of the BT and the BI. Hayman and Nay (1958), Amakiri and Onwuka (1980) and Taneja,(1960) concluded that the BI sweated more than the BT at similar environmental conditions. The differences between breeds of cattle in sweating rates were attributed to differences in sweat gland volume (Nay and Dowling, 1957; and Nay, 1958) and sweat gland density (Pan *et al* 1969). However, Findlay and Jenkinson (1964), Shafie and El-Tannikchy (1970) and Schleger and Bean (1971) have established that sweat gland activity is associated with vascular supply to the sweat glands and since arterial supply and venous drainage to sweat glands are closely associated with neuronal supply (Schleger and Bean, 1971) sweat gland activity may be more a function of these than of sweat gland density. Gatenby (1979) has disputed reports that conclude that the BI sweated more than the BT if such reports failed to take the respective local skin temperatures at the areas of sweat rate measurement into consideration. This is because it has been established that local skin temperature has an influence on sweat rate (Isabirye and Robertshaw, 1972).

Regional Variations in Sweating Rates

Pan *et al* (1969), McLean (1963) and Amokiri and Onwuka (1980) have reported regional variations in sweating rates of cattle and pointed out that cutaneous evaporation rates were higher on dorsal than on ventral parts of cattle. However, Schleger and Bean (1971) found that sweating rates in cattle varied even between subareas within a given body region. It has already been argued (Gatenby, 1979) that these variations in sweating rates of different parts of the body may be due to differences in local skin temperatures.

The Buffalo

The buffalo has skin thickness of about 6.5 mm as compared to 4.3 mm in cattle (Hafez, Badreldin and Shafei, 1955) but there were no differences between the buffalo and cattle in the composition of the hair follicle unit but these authors noted that arteriol branching was more frequent and more superficial in buffalo than in cattle. They reported that the skin of the buffalo was more darkly pigmented than the skin of cattle.

Reports on the sweating response of the buffalo are very few in the literature. Joshi, McDowell and Sadhu (1968) found a negative correlation between evaporation rates and skin and rectal temperatures in Murrah buffaloes.

MATERIALS AND METHODS

Plate 1. Buffalo Cow

Plate 2. Ayrshire Steer

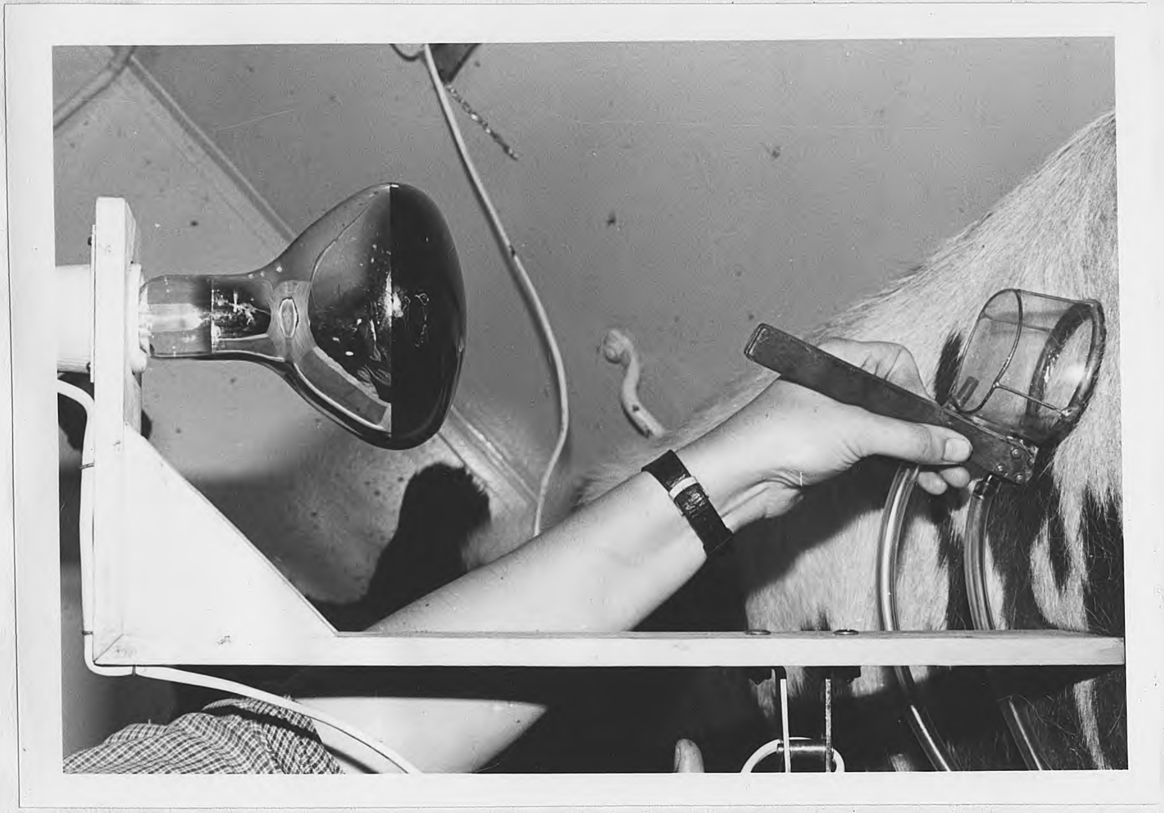

Plate 3. The Heating of an Area on a Cow with an Electric Bulb and Measurement of Skin Water Evaporation Rate.

Plate 4. Thermocouple - Measurement of Skin Temperature.

MATERIALS AND METHODS

The study was conducted at the Centre for Tropical Veterinary Medicine, Edinburgh. The experimental animals were housed in hot rooms of the size 9 m^2. Air temperature during the day were about 27^0C but the night temperatures were allowed to drop to about 23^0C. The work was conducted between July 13th and August 13th 1982.

The Experimental Animals

The study started with four buffaloes (*Bubalis bubalis*) and four Ayrshire cattle (*Bos taurus*); however one male buffalo and one Ayrshire cow were excluded at the end of the 10 days acclimatisation and trial period because they were highly irritable and dangerous. The composition of the three pairs of animals used in the study is as summarised in appendix 1a and the photographs of one buffalo cow and Ayrshire are presented in plates 1 and 2 - respectively. One buffalo and one Ayrshire were paired and the animals were tethered in each hot room. Feeding was provided at the rate of about 8 kJ of metabolisable energy per kg of animal liveweight and drinking water was *ad libitum*. A trial period of ten days was used to acclimate the animals to the hot rooms and get them accept the use of the various instruments on their body surfaces. All three pairs of animals were also used at the same time for a study on the rate of passage of food.

The Instruments

A ventilated cup evaporimeter (Gatenby, 1980) was used for the measuring of the cutaneous evaporation rates. The evaporimeter consists of a cup which is made of polythene film stretched over a light copper frame. The cup is connected to the evaporimeter by a pair of plastic tubings. Manually-operated valves direct the incoming ambient air-stream either through the cup or directly over the temperature and humidity sensors. A diaphragm pump is powered by a 12V battery. Relative humidity is measured with an electrical capacitance sensor and the temperature of the air-streams is measured with a 1.5 mm diameter bead thermistor situated about 3 mm downstream of the humidity sensor.

Skin temperatures of the animals were measured with a copper-constantan thermocouple plugged into a microvoltmeter. One junction of the thermocouple was attached to a 100^{0}C mercury-in-glass thermometer and kept in a thermos flask containing engine oil. A 240 volts, 250 watts electric bulb was mounted on a wooden frame (plate 3) which was used to heat an area on the back of the animal.

The rectal temperature of the animals was measured with a mercury-in-glass clinical thermometer attached to a long piece of string. This was to avoid violent kicks from some of the animals which resisted the manipulation of their ani. The respiratory rates of the animals were estimated at the flank and timed with a watch.

The Calibration of the Instruments

The Evaporimeter

An evaporimeter flow rate (F) of 2 litres per minute was chosen followed by the flow rate of 5 litres per minute. A plastic dish filled half way with cold tap water plus a cover were weighed (W_1 gram). The airstream was directed at the sensors of the evaporimeter and the corresponding meter reading (M_o) and Temperature (T_o) were taken. Then the airstream was directed at the cup and the dish and water without the cover was placed under the evaporimeter ventilated cup and the stop watch started. After one minute, the evaporimeter reading (M_1) and temperature (T_1) were taken and after 9 minutes another meter reading ($M^1{}_1$) and temperature ($T^1{}_1$) were taken. The dish containing water was then weighed (W_2 gram). The airstream was redirected at the sensors and the corresponding meter reading ($M_o{}^1$) and temperature ($T_c{}^1$) were taken. The same procedure was repeated but instead of evaporating water from an open mouthed dish, the dish was covered with discs of different hole sizes in turns. The meter readings M_o, M_o^1 constituted the dry readings and the values of M_1 and $M^1{}_1$ constituted the wet readings. The values of the M_o and M_1 were arranged for each disc size seperately and the saturation water vapour pressure was obtained from the standard table corresponding to the value of the average of all the temperatures (T_o, T_o^1, T_1, T_1^1) and designated χ_{sat} (T). The difference between the mean values of M_1 and M_o was the actual change in meter reading (σM).

The change in relative humidity inside the evaporimeter ($\sigma\phi$) was calculated from the equation:-

$$\sigma\phi = \frac{W_1 - W_2}{\text{Time}} \times \frac{1}{F\chi_{sat}(T)} \qquad \text{Gatenby (1980)}$$

A graph of $\sigma\phi$ against σM was plotted (figure 1) and a regression line fitted. The slope of the regression was the calibration factor (f=0.00236).

The evaporimeter reading as taken on the skin surface of the animals, the corresponding flow rate (F) and the saturation water vapour χ_{sat} (T) and the calibration factor obtained from figure 1 above were used to calculate the evaporation rates using the equation given by Gatenby (1980):-

$$E = \frac{\sigma Mf \times F \times \chi_{sat}\ (T)}{A}\ \text{g m}^{-2}\ \text{s}^{-1}$$

where E = evaporation rate, σM = change in meter reading, and A = cross sectional area of the evaporimeter cup.

The Thermocouple

Two pieces of copper wire of lengths between 0.5 and 1.0 m and a piece of constantan wire of length about 1.0 m were used. The piece of constantan wire was soldered to the two pieces of copper wires and the soldered ends became electrical junctions. One junction of the thermocouple was attached to a 100^{0}C mercury-in-glass thermometer and kept at a constant temperature in a beaker filled with ice. The free junction of the thermocouple was mounted on a small piece of wood and placed into a beaker containing water at different temperatures. The thermocouple measurements were recorded by a microvoltmeter. A graph of thermocouple readings in microvolts was plotted against the mercury-in-glass thermometer readings. A regression line was fitted (figure 2). The slope of the regression was used as the conversion factor (0.04) between the microvoltmeter readings and the corresponding mercury-in-glass thermometer readings.

Measurements

The order in which the measurements were done by room and animals was randomized for the first day followed by rotation during the remaining days of the experiment. An example of a typical ordering of the rooms and animals is illustrated:-

date	rooms			animals		
5/8/82	2	3	4	AB	BA	BA
6/8/82	3	4	2	AB	AB	BA
9/8/82	4	2	3	BA	AB	BA

The respiratory rate of the animals was first estimated at the flank in one minute prior to the start of the measurement of other parameters to avoid the introduction of other influences on the respiratory rates.

The electric bulb was then directed at the mid-trunk of the animal (plate 3) and allowed to heat the area for about one minute, then the evaporimeter cup was placed on the skin of the heated area (plate 3) and the corresponding evaporimeter readings ($M_2{}^1$ and $T_2{}^1$) taken after it had stabilized. The flow rate used was 2 litres per minute. The airstream was then directed at the sensors and the dry meter readings taken (M_2 and $T_2{}^1$ ^{0}C). This was followed by the measurement of the skin temperature (plate 4) which was taken after allowing the junction of the thermocouple to rest on the skin surface of the animal for about 30 seconds. The cutaneous evaporation of the opposite side of the animal (unheated) was then taken followed by the measurement of the skin temperature. The temperature of the fixed junction of the thermocouple was taken (reference temperature) and the measurements described above repeated on the other animal of the pair of animals in the room. The dry and wet bulb temperatures of the room were taken. The microvoltmeter readings which were in microvolts were converted to degrees celsius by dividing each value by the conversion factor of 0.04. The resultant value in degrees celsius was added to the reference temperature of the thermocouple to give the skin temperature.

The rectal temperatures of the animals were then measured with a mercury-in-glass clinical thermometer per rectum allowing an equilibrium period of about 2 minutes.

RESULTS AND DISCUSSION

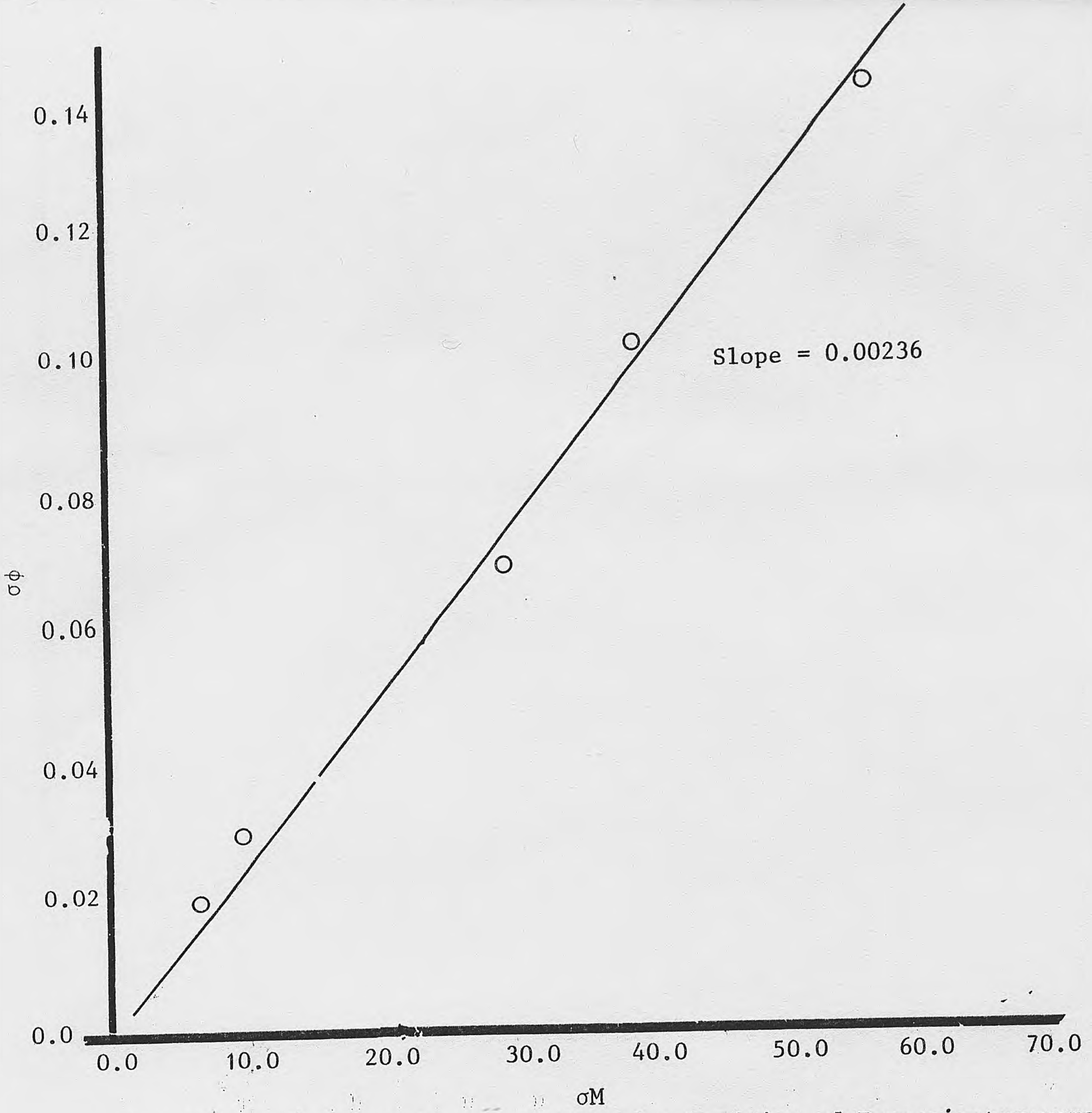

Fig. 1. The Graph of Change in Relative Humidity of Evaporimeter versus Change in Evaporimeter Reading.

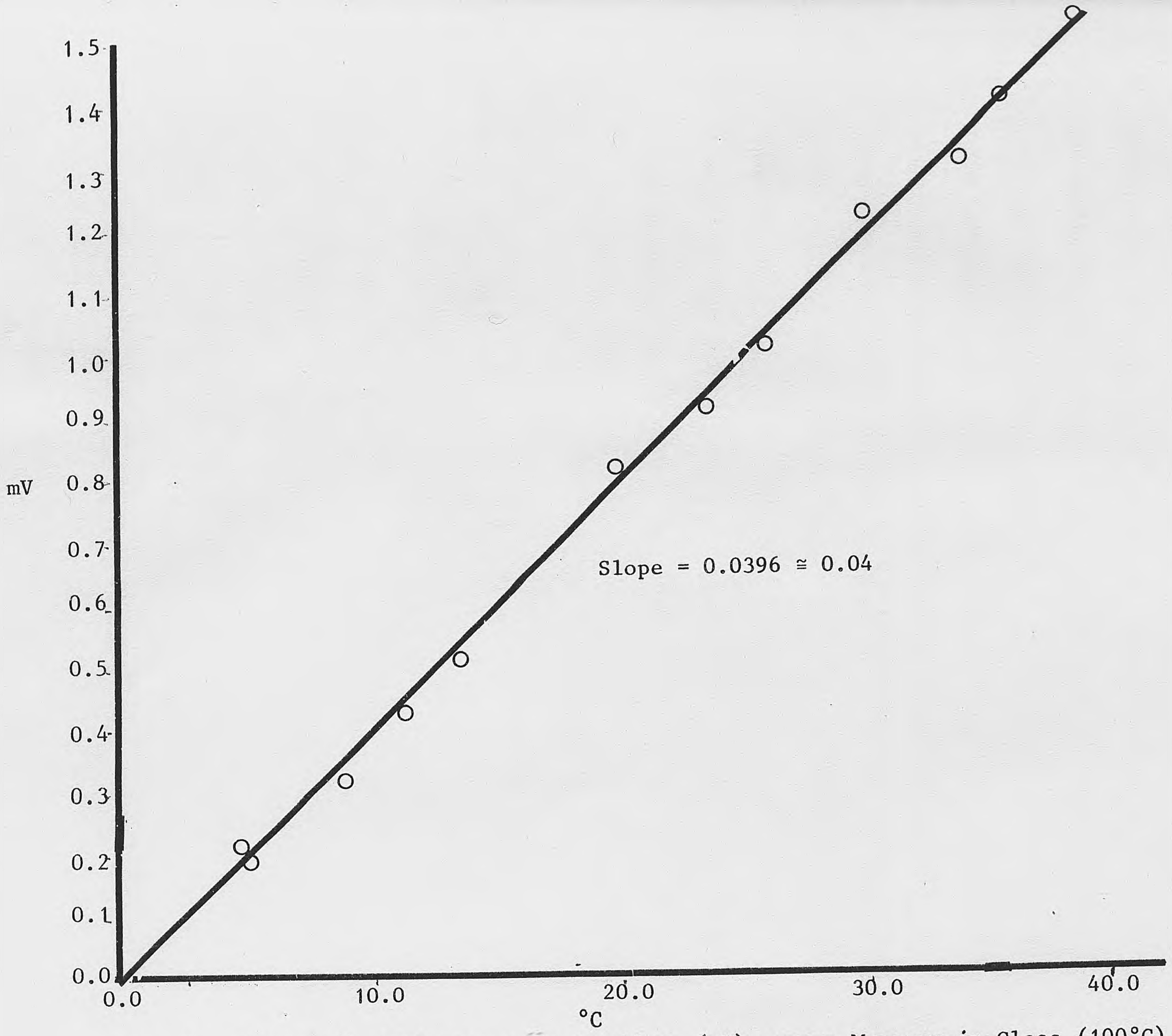

Fig. 2. The Graph of Thermocouple Readings (mV) versus Mercury-in-Glass (100°C) Thermometer Readings.

RESULTS AND DISCUSSION

Skin Temperatures

The skin temperatures recorded on the unheated sides of the animals were analysed using an analysis of variance which is summarised in table 1. The skin temperatures recorded on the 10 days were significantly different and the species effect was highly significant ($p<0.01$). The mean skin temperature for the Ayrshire cattle was 35.8 and that for the buffaloes was 34.8°C. There are two possible reasons for this finding. There is marked difference between Ayrshire cattle and the water buffalo in coat cover. The former is provided with a considerable amount of hair but the buffalo is almost bare skinned. The thick coat cover tends to limit the effectiveness of air flow over the skin (Mount, 1979). Consequently it may be inferred that the buffalo benefited more from the relatively small airstream flow that was allowed in the hot rooms. It may also be argued that the Ayrshire cattle retained high skin temperatures in order to increase sweating (Allen, 1962).

TABLE 1. The analysis of variance of the mean skin temperatures of the animal.

Source	df	MS	F
Days	9	0.13	2.80*
Animals	5	0.28	5.92***
species	1	0.34	7.31**
rooms	2	0.13	2.79^{ns}
Between animals	2	0.39	8.28***
Error	45	0.05	

where ns: not statistically significant

*: statistically significant ($p<0.05$)

**: statistically highly significant ($p<0.01$)

***: statistically very highly significant ($p<0.001$)

The skin temperatures recorded on day 8 were lower than on the other 9 days (appendix II). The only apparent but significant variable between day 8 and the other days was in the relative humidity of room 3. The relative humidity of room 3 had been consistently high at about 85% until day 8 when it dropped to about 70%. This change in relative humidity was not accompanied by a similar decrease in dry air temperature. The skin temperatures of the animals in room 3 on that day were the lowest values for the period of the experiment (30.0 and 28.6°C, unheated areas, Buffalo and Ayrshire respectively). Within each of the two species, differences between animals in skin temperatures were not statistically significant.

Rectal Temperatures

The analysis of variance of the rectal temperatures is shown in table 2.

TABLE 2. The analysis of variance of the rectal temperatures of the animals.

Source	df	MS	F
Days	9	0.13	2.80*
Animals	5	0.28	5.92***
species	1	0.34	7.31**
rooms	2	0.13	2.79^{ns}
Between animals	2	0.39	8.28***
Error	45	0.05	

where ***: statistically very highly significant ($p<0.001$)

The analysis shows that the day had a significant effect on rectal temperature. However, there was no apparent significant pattern in the daily changes in rectal temperatures. That is, changes in rectal temperatures of the animals were not associated with higher air temperatures and/or relative humidity. They may have been affected by a diurnal influence noted by Amakiri and Funsho, (1979). As the measurements were done within one hour daily this effect was not detected.

The rectal temperatures of the animals were higher in days 8, 6 and 9 than on the other days. The differences in mean daily rectal temperatures were between 0.1 and 0.5°C and differences of 0.3°C and higher were statistically significant. The comparatively higher daily rectal temperatures on days 6 and 9 may be explained in relation to the skin temperatures of the animals (Allen, 1962) but on day 8 the skin temperatures of the animals were low and the relative humidities of the rooms were also low. Mullick, (1960) reported a similar finding in Hariana cattle and water buffaloes exposed to the sun and then taken to the shade. He found that at high relative humidity, the rectal temperature of the cattle tended to decrease which suggests that at lower relative humidity, rectal temperatures of the cattle were higher. This finding may be of no apparent significance unless the daily metabolic status of these animals at the same time of the experiment were monitored because at moderate heat conditions internal heat production may be a major source of body temperature changes.

The differences in rectal temperatures between the six animals were very highly significantly different ($p<0.001$) and much of this difference may be attributed to within species variation. For example, the rectal temperature of the buffalo of room 4 (B_4) showed less fluctuations than the other animals. Its mean rectal temperature (38.0°C) was statistically significantly lower than the mean rectal temperatures of all the other animals and the differences between the other 5 animals in mean rectal temperatures were not statistically significant. It was observed during the experiment that B_4 was highly cooperative when its rectal temperature was being taken, while the other two buffaloes vigorously resisted the taking of rectal temperatures. It may therefore be inferred from this that the rectal temperatures of B_4 were more typical of buffalo response and the greater fluctuations in rectal temperature noted on the other two buffalo cows were mainly due to exercise or physical stress other than heat stress noted by Anderson, (1977). Moreover, the response of B_4 in terms of rectal temperatures over the experimental period is similar to the findings of Mullick (1960) on water buffaloes at air temperatures of 29.4 to 34.0°C and relative humidity of 33 to 88%. He reported that buffaloes failed to show appreciable changes in rectal temperatures at these conditions of temperature and humidity.

Despite the great variations within species (buffaloes), the interspecies differences in rectal temperatures was highly significant ($p<0.01$). The mean rectal temperature for the Ayrshire cattle was 38.4°C and that for the buffaloes was 38.2°C. Because the Ayrshire cattle were less disturbed by the measurement procedure this difference is unlikely to be a result of temperament, and probably indicates a real difference in rectal temperature under this type of temperature regime.

Respiratory Rates

The mean respiratory rates of the animals did not vary much between days (table 3) but the differences between animals and the species in mean respiratory rates were highly significant.

TABLE 3. The analysis of variance of the mean respiratory rates of the animals.

Source	df	MS	F
Days	9	63.01	1.14^{ns}
Animals	5	3730.09	67.28***
species	1	17578.82	317.05***
rooms	2	210.62	3.80*
Between animals	2	325.22	5.87**
Error	45	55.44	

The highest mean respiratory rate for the Ayrshires was 55 min^{-1} and the highest recorded mean respiratory rate of the buffaloes was only 14 min^{-1}. All 3 buffaloes however, had similar respiratory rates whereas the mean respiratory rate of A_3 (55 min^{-1}) was statistically significantly greater than the mean respiratory rates of the other two Ayrshire cattle. Mullick (1960) reported a consistently lower respiratory rates in buffaloes than in *Bos taurus* cattle. The differences between animals and especially between the two species of animals in mean respiratory rates may be related to the role respiratory activity plays in evaporative heat loss in the species and will be considered later.

Sweating Rates

Sweat rates were not analysed using the analysis of variance because there was evidence to show that they were not normally distributed (on several occasions the rate of evaporation was negligible). The sweating responses of the animals were variable, consistent with other reports (Schleger and Turner, 1963; Allen, 1962) that there is a high degree of individuality in cattle sweating responses to high air temperatures. The highest sweating rate among the Ayrshire cattle was 60 mg $m^{-2}s^{-1}$ and for the buffaloes, it was 45 mg $m^{-2}s^{-1}$. Overall, all Ayrshire cattle sweated more consistently than the buffaloes, this may be a result of their higher skin and rectal temperatures. It was also noted that the buffaloes lost liveweights of between 3 to 9% by the end of the experiment. This suggests that the buffaloes were more disturbed by the conditions in the hot rooms and reduced voluntary feed intake. This may explain the marked differences between the Ayrshire cattle and the buffaloes in sweating rates. Allen, (1962) had found that when feed was witheld from some *Bos indicus* cattle, their sweat rates decreased considerably.

The animals of room 3 had the lowest sweat rates. The reason for this may be because relative humidity was consistently higher in room 3 (more than 80%) compared to the other rooms (approximately 75%) until on day 8 when it dropped to about 70% in that room - and both animals sweated. It rose again on day 9 to 84% and sweat rates decreased to 0.0 for the buffalo and 4.5 mg $m^{-2}s^{-1}$ for the Ayrshire (average heated and unheated sides). The relative humidity of room 3 decreased to 58.5% on day 10 and sweat rates of both the animals of the room increased. This finding is consistent with the findings of Taneja (1959) and Joshi *et al* (1968) that cutaneous evaporation rates are proportional to the difference in vapour pressure between the skin surface and the surrounding air.

The Relationship between Sweating Rates and Skin Temperatures

The relationship between sweating rates and skin temperatures of the animals are presented in figures 3 and 4. The sweating rates of the animals tended to increase with increase in skin temperatures. The trend in the relationship between the evaporation rates and skin temperatures was similar to those reported by Allen (1962) and Gatenby (1979) for the Ayrshire cattle but less so for the buffalo.

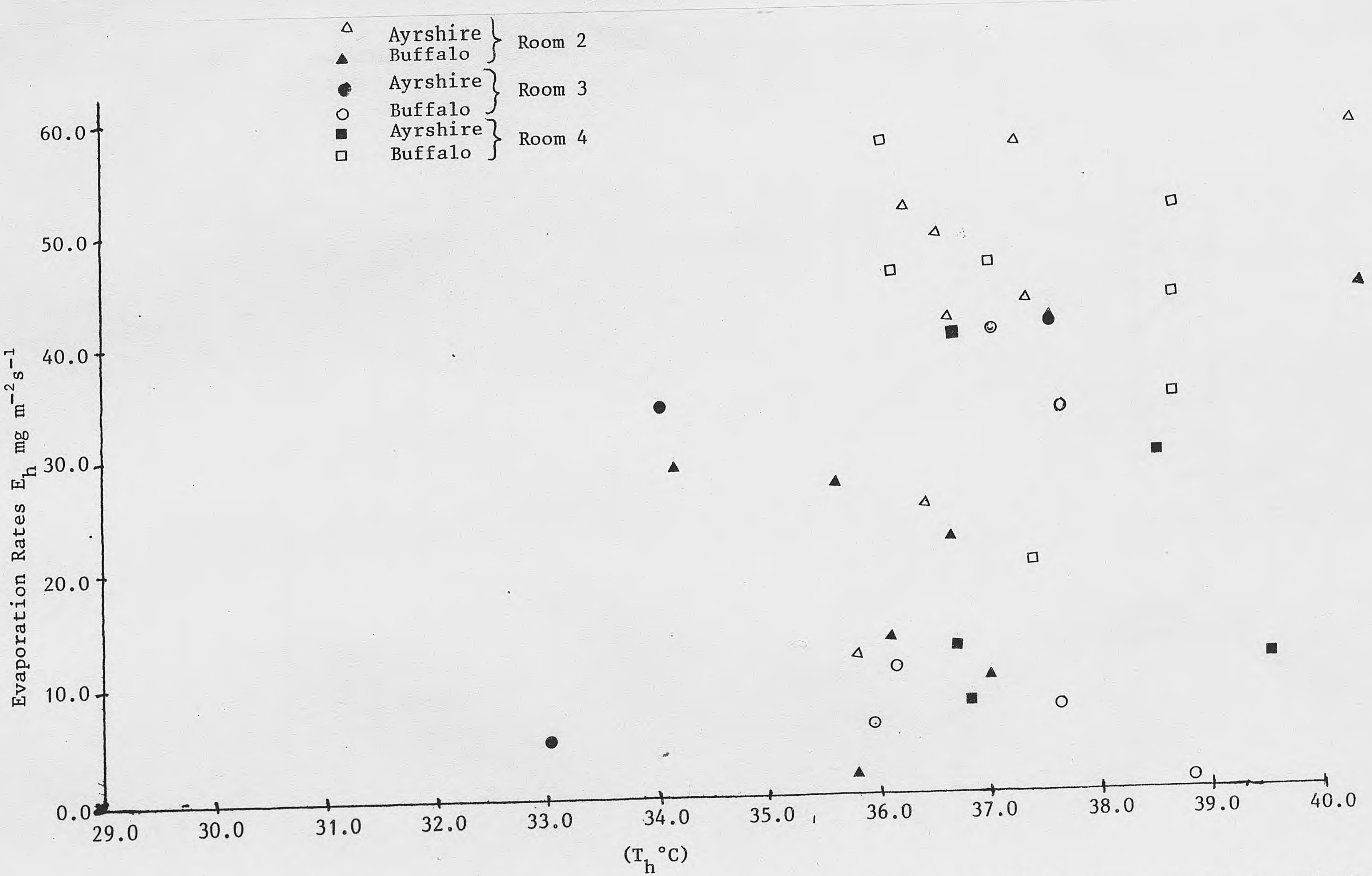

Fig. 3. The Graph of the Evaporation Rates of the Heated Sides Against the Skin Temperatures of the Animals.

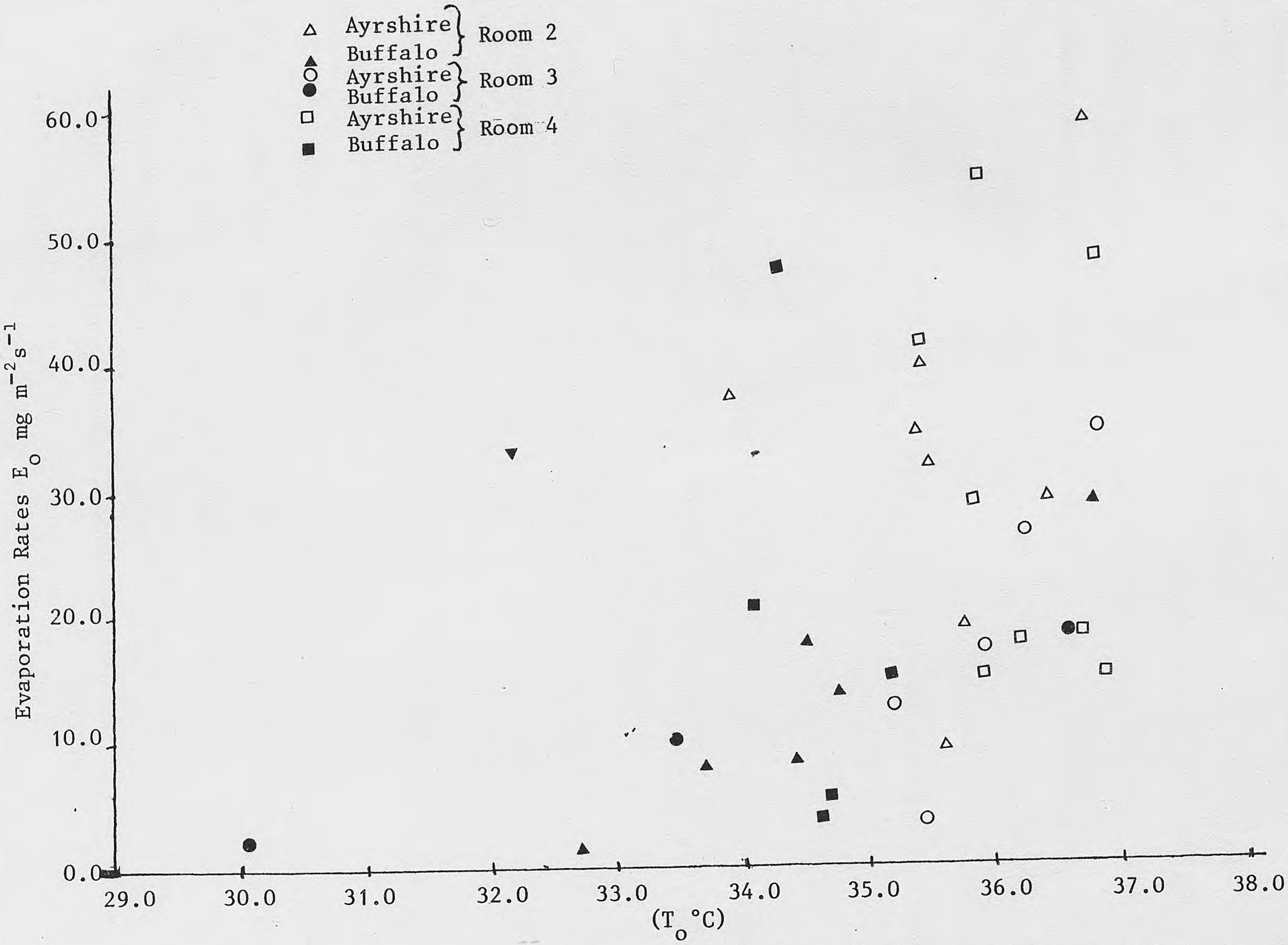

Fig. 4. The Graph of Evaporation Rates Versus the Skin Temperatures of the Unheated Sides of the Animals.

Regional Control of Sweating

For all the animals the sweat rate of the heated area (E_h) was generally greater than that of the unheated area (E_o). This in itself demonstrates that there is a local control of sweat rate, ie the animals sweat more on the parts of the body which are receiving the most severe external heat load. The ratio of $E_h:E_o$ was similar for the Ayrshire cattle and the buffaloes even though the difference in skin temperature between the two sides ($T_h - T_o$) was greater for the buffalo than the Ayrshires. Figure 5 shows the relationship between $E_h:E_o$ and ($T_h - T_o$) for all the animals. For the Ayrshires there is a positive correlation (r = 0.59) between $\frac{E_h}{E_o}$ and ($T_h - T_o$) and this can be expressed as:-

$$E_h:E_o = 1.3\ (T_h - T_o)$$

Therefore if one side of an Ayrshire is heated to a temperature of 1°C above the other side, the sweat rate will be an average of about 30% greater on the heated side than on the unheated side. This difference is similar to that reported by Isabirye and Robertshaw (1972) and Gatenby (1979). In contrast for the buffaloes, figure 5 shows that there is not a clear relationship between $E_h:E_o$ and ($T_h - T_o$). This confirms that the sweat rate of the buffaloes appears to be under less precise control than that of the Ayrshires.

Isabirye and Robertshaw (1972) and Gatenby (1979) postulated that there is likely to be an exponential relationship between local sweat rate and local skin temperature. If this is so, one would expect a graph of $\log_e E_h:E_o$ versus ($T_h - T_o$) would give a straight line relationship with a slope equal to the response constant, C, in the exponential equation:-

$$E_h = E_o \exp C\ (T_h - T_o)$$

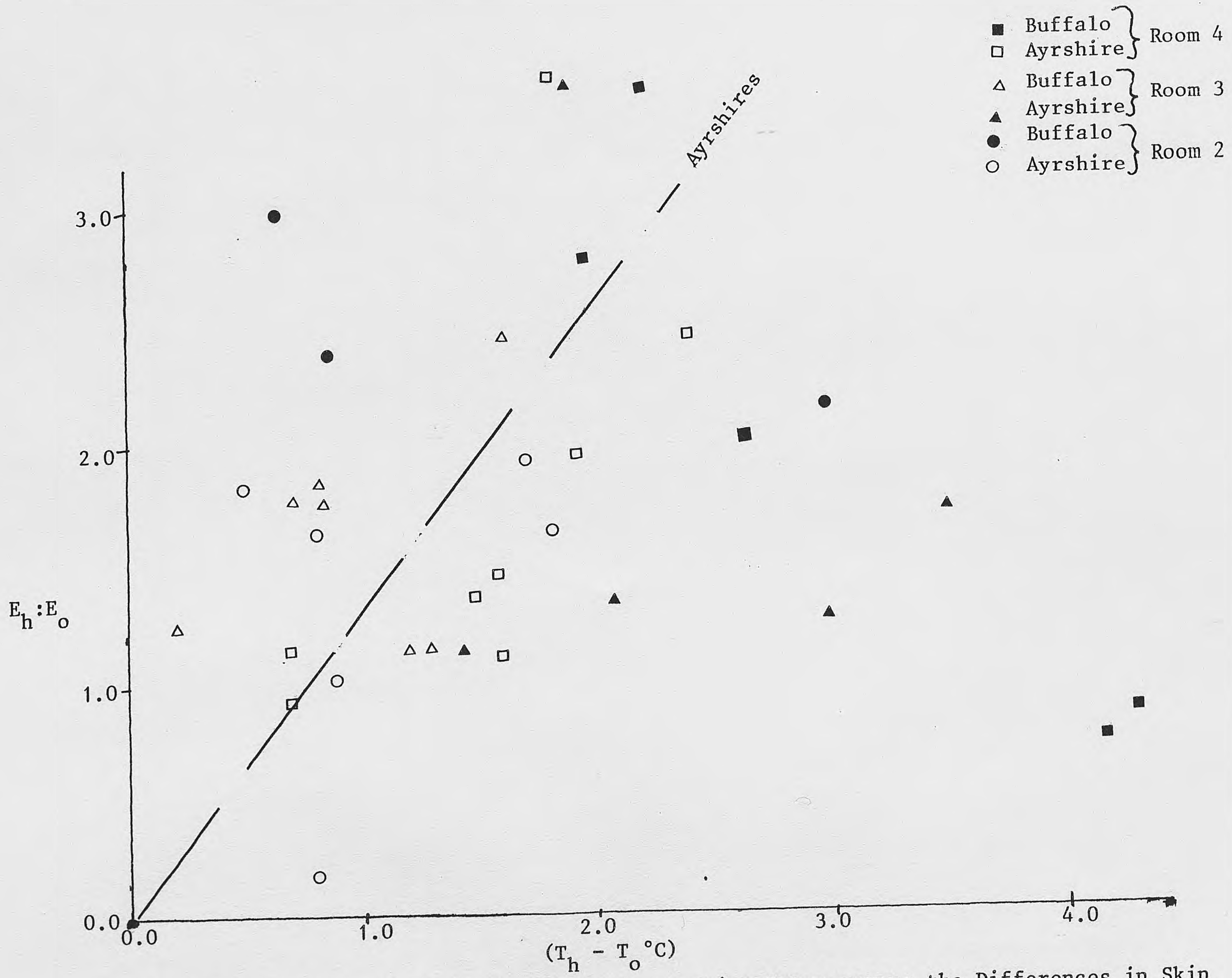

Fig. 5. The Graph of the Ratio of the Evaporation Rates versus the Differences in Skin Temperature of the Heated and Unheated Sides of the Animals.

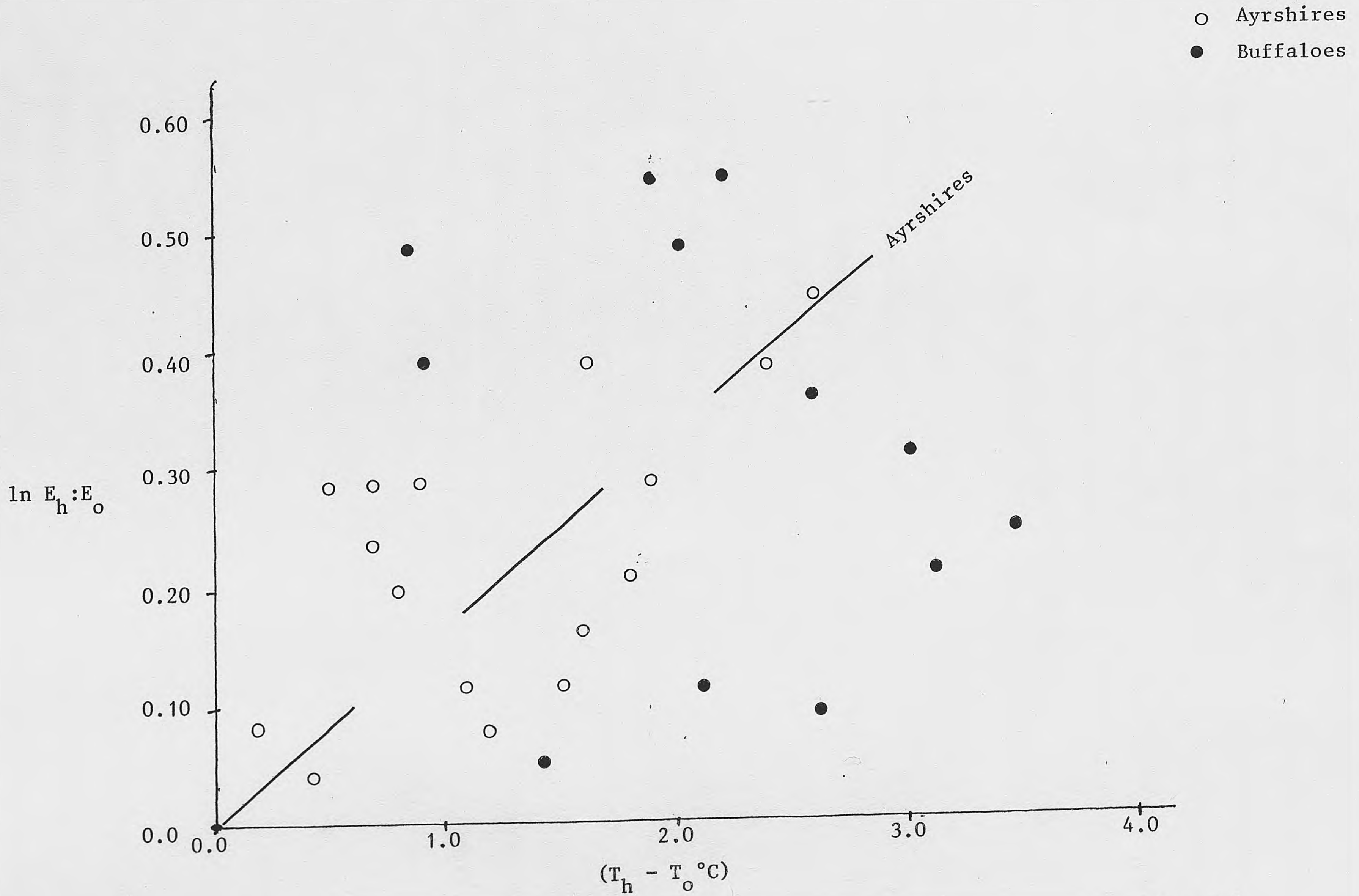

Fig. 6. The Graph of the ln $(E_h:E_o)$ versus the Differences in Temperature $(T_h - T_o)$ Between the Sides.

Figure 6 shows this relationship. The best estimate for C for the Ayrshire cattle is 0.18. Every 1°C increase in local skin temperature increases local sweat rate by a factor of 1.2 for the Ayrshire. The relationship for the buffalo is not well-defined. These figures suggest that for the degree of heat stress given, the Ayrshire has a better local control of sweat than the buffalo. This may result because sweating is only secondary to wallowing for buffaloes.

The Relationship between Sweating Rates and Rectal Temperatures

In both species of animals the sweat rates responses did not demonstrate any specific pattern of relationship with rectal temperatures (figure 7). The correlation coefficient ($r = 0.24$) for all animals between sweating rates and rectal temperatures was positive but not statistically significant. Taneja (1958) found that in the *Bos indicus* cross and *Bos taurus* when air temperature increased, skin water loss increased and rectal temperatures increased while Allen (1962) reported that rectal temperatures of cattle did not increase until mean skin temperatures increased to 36.7°C. There appears to be a low degree of predictability of the relationship between sweat rates and rectal temperature. This may be because animals tend to differ in their heat storage abilities especially at moderate air temperatures.

The Relationship between Sweating Rates and Respiratory Rates

Figure 8 shows the relationship between sweat rate and respiration rate for both species. The correlation coefficient between E_o and respiration rate for the Ayrshire cattle was 0.10. This value is not statistically significant. For the buffaloes, the respiration rates remained lower than 20 min^{-1} even when the sweat rate rose above 25 $\text{mg m}^{-2}\text{s}^{-1}$ and this is consistent with the results of Mullick (1960).

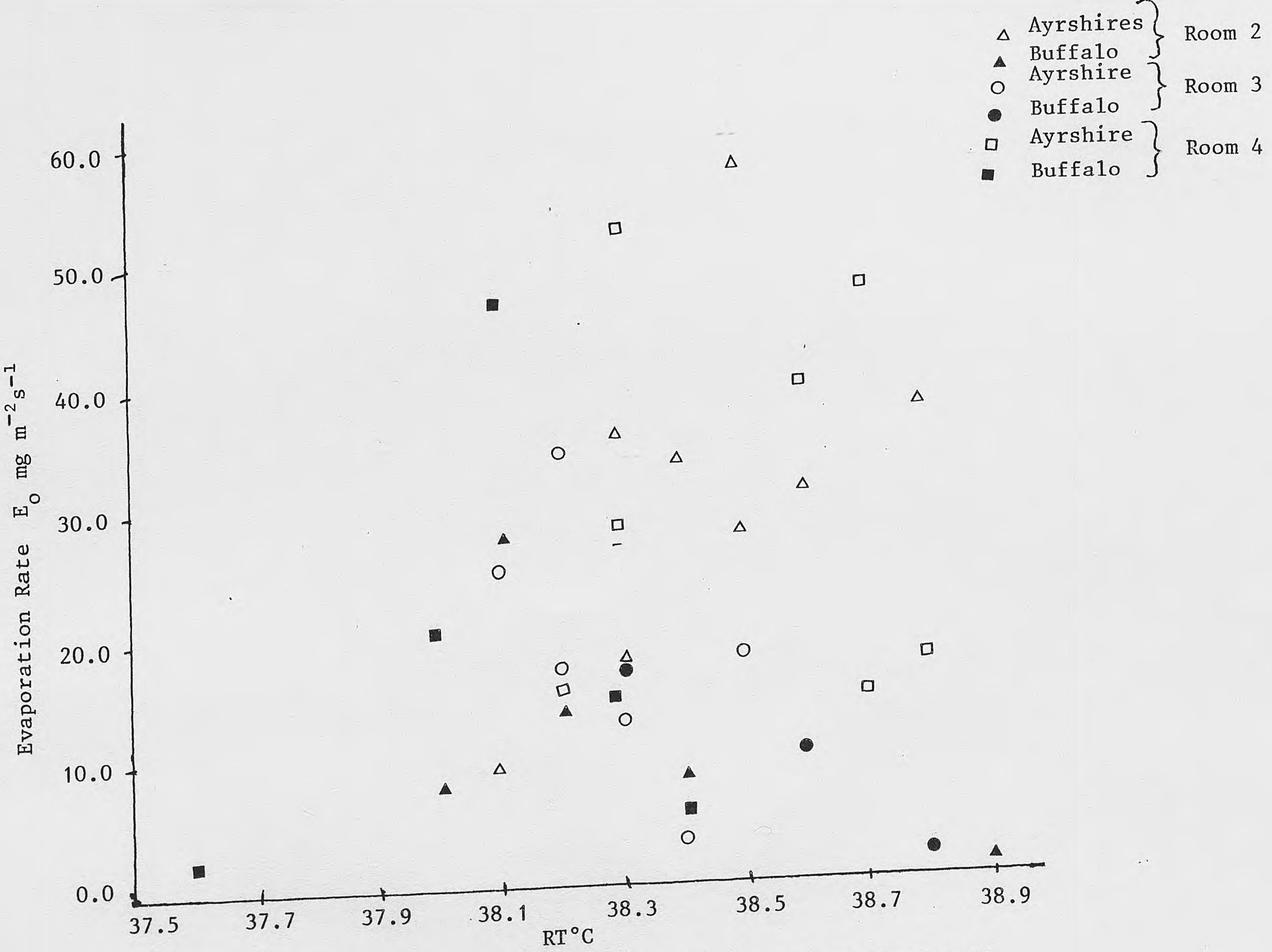

Fig. 7. The Graph of the Evaporation Rates (E_o) against the Rectal Temperatures of the Animals (RT).

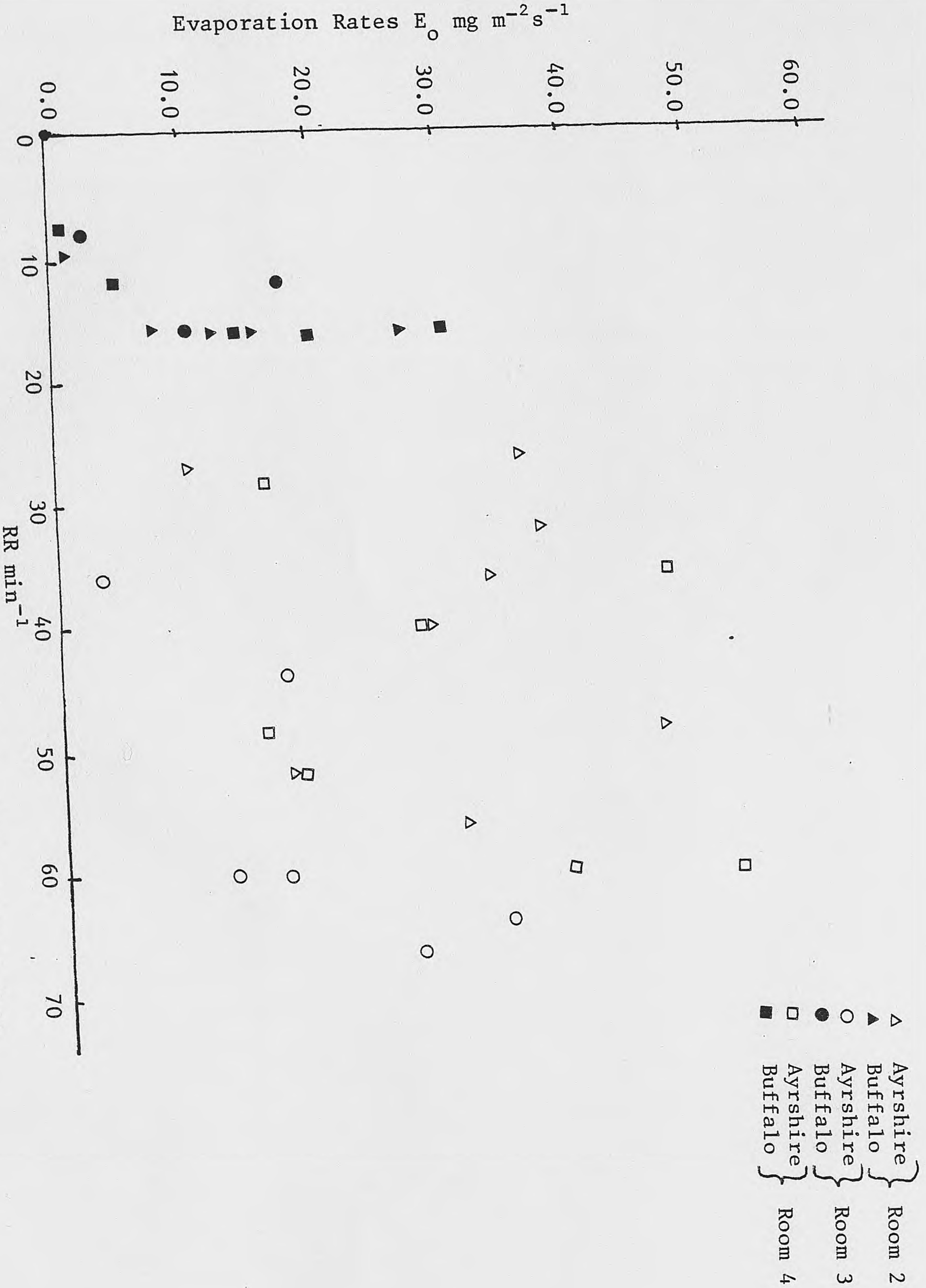

Fig. 8. The Graph of Evaporation Rates versus Respiratory Rates (RR)

The response of the Ayrshire cattle may be interpreted to suggest that they use respiratory water loss to complement skin evaporative water losses. Nevertheless the rate of heat loss by evaporation from the respiratory tract is likely to be considerably less than heat loss by evaporation of sweat (McLean, 1963b).

CONCLUSIÓNS

CONCLUSIONS

The sweat rates of Ayrshire cattle were greater than the sweat rates of the buffaloes and were also more consistent. This may be attributed to the higher skin temperatures of the Ayrshires and their higher rectal temperatures than those of the buffaloes. The buffalo relies considerably on wallowing and thus may sweat less than cattle. The respiratory rates of the Ayrshires were much higher than the respiratory rates of the buffaloes which suggests that Ayrshire cattle complement their skin water loss with respiratory water loss.

In response to a local radiant heat load both Ayrshire cattle and buffaloes increased skin evaporation rates on the heated area of the body. There was a better correlation between the proportional increase in sweat rate and the increase in skin temperature for the Ayrshires than for the buffaloes. Differences in temperature between the heated and unheated sides were much greater for the buffalo than for the Ayrshire indicating that the Ayrshire are better able to maintain uniform skin temperature in response to localised heating.

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APPENDIX

APPENDIX 1a

The animals, sex, age, room allocation, liveweights (LWT) and liveweight changes by the end of the experiment.

The Buffaloes

Animal	Sex and age (yrs)	Room	Initial LWT (kg)	Final LWT (kg)	Liveweight Changes (kg)	Liveweight Changes %
Ferdi	Steer, 6	4	735	715	-20	2.7^{loss}
Dewi	Cow, 5	3	615	559	-56	9.1^{loss}
Suri	Cow, 5	2	640	590	-50	7.8^{loss}

The Ayrshire Cattle

Animal	Sex and age (yrs)	Room	Initial LWT (kg)	Final LWT (kg)	Liveweight Changes (kg)	Liveweight Changes %
M 34	Cow, 3	4	435	430	- 5	1.2^{loss}
K 219	Steer, 4	3	590	595	5	0.1^{gain}
H 220	Cow, 4	2	540	605	65	12.0^{gain}

APPENDIX 1b

(i) The Calibration of the Evaporimeter

Change in meter reading (σM)	Change in the relative humidity inside evaporimeter ($\sigma\phi$)
6.5	0.02
10.0	0.03
30.0	0.07
40.0	0.10
57.0	0.14

(ii) The Calibration of the Thermocouple

Mercury-in-glass thermometer readings (°C)	Thermocouple readings in microvolts (mV)
39.9	1.563
38.5	1.501
36.4	1.423
35.1	1.363
33.9	1.316
29.9	1.157
25.9	0.993
23.5	0.893
20.0	0.750
13.9	0.522
11.5	0.432
9.0	0.332
5.2	0.187
4.9	0.180

APPENDIX II

The daily evaporation rates (E_h and E_o), skin temperatures (T_h and T_o), the respiratory rates (RR) and the rectal temperatures (RT).

Room 2

Day	1	2	3	4	5	6	7	8	9	10
T air (°C)	27.0	26.5	27.5	27.5	27.0	27.5	27.0	25.5	26.5	25.2
T wet (°C)	23.5	21.8	25.0	24.5	23.0	23.5	23.0	19.5	21.5	18.5
RH %	73.0	69.5	80.5	77.0	70.0	70.0	70.0	55.5	62.5	50.0
Time (hrs)	1420	1450	1425	1450	1445	1425	1500	1445	1420	1445

Buffalo

Day	1	2	3	4	5	6	7	8	9	10
E_h mg $m^{-2}s^{-1}$	1.4	13.7	10.0	0.0	44.9	0.0	0.0	22.4	27.2	-
E_o mg $m^{-2}s^{-1}$	0.9	12.8	8.5	0.0	27.0	0.0	0.0	17.0	7.8	-
T_h °C	35.8	36.1	37.0	36.9	40.3	40.5	34.7	36.6	35.6	37.6
T_o °C	32.7	34.7	34.4	35.9	36.8	35.5	33.9	34.5	33.7	34.5
RR min^{-1}	10	16	16	12	16	12	16	16	16	12
RT °C	38.9	38.2	38.0	38.0	38.1	38.3	38.5	38.3	38.4	38.5

Ayrshire

Day	1	2	3	4	5	6	7	8	9	10
E_h mg $m^{-2}s^{-1}$	11.9	53.7	44.0	52.5	60.1	5.7	25.9	50.0	42.3	-
E_o mg $m^{-2}s^{-1}$	9.8	28.7	18.6	31.2	58.7	0.0	36.4	38.8	34.5	-
T_h °C	35.8	37.2	37.3	36.2	40.3	40.5	36.4	36.5	36.6	36.1
T_o °C	35.6	36.4	35.7	35.5	36.7	37.1	33.9	35.4	35.4	35.8
RR min^{-1}	27	40	52	56	48	40	26	32	36	44
RT °C	38.1	38.5	38.3	38.6	38.5	38.5	38.3	38.8	38.4	38.5

Room 3

Day	1	2	3	4	5	6	7	8	9	10
T air (°C)	28.5	27.5	28.5	25.5	28.5	28.0	27.5	26.5	27.0	25.0
T wet (°C)	24.8	25.1	26.0	25.5	26.5	25.8	25.5	22.5	25.0	20.0
RH %	81.0	80.5	81.0	-	85.0	84.0	84.5	69.5	84.0	58.5
Time (hrs)	1442	1415	1450	1415	1415	1445	1430	1500	1430	1410

Buffalo

Day	1	2	3	4	5	6	7	8	9	10
E_h mg $m^{-2}s^{-1}$	0.0	0.0	0.0	0.0	42.3	0.0	0.0	4.6	0.0	29.0
E_o mg $m^{-2}s^{-1}$	0.0	0.0	0.0	0.0	17.9	0.0	0.0	2.2	0.0	9.8
T_h °C	37.4	37.6	36.3	36.7	37.5	37.7	36.4	33.0	38.7	34.1
T_o °C	35.8	35.8	35.6	34.4	36.6	35.4	34.9	30.0	35.3	33.4
RR min^{-1}	10	20	12	12	12	12	8	8	16	16
RT °C	38.3	38.4	38.3	38.1	38.3	38.6	38.4	38.8	38.5	38.6

Ayrshire

Day	1	2	3	4	5	6	7	8	9	10
E_h mg $m^{-2}s^{-1}$	41.1	0.0	0.0	0.9	7.3	0.0	12.6	28.9	6.1	33.9
E_o mg $m^{-2}s^{-1}$	25.9	0.0	0.0	0.0	34.9	0.0	12.5	18.2	3.3	18.1
T_h °C	37.0	36.7	38.3	38.8	37.6	40.3	36.1	30.4	35.9	37.6
T_o °C	36.2	35.9	37.6	36.3	36.8	37.4	35.2	28.6	35.4	35.9
RR min^{-1}	66	60	52	48	64	56	60	60	36	44
RT °C	38.1	38.6	38.0	38.1	38.2	38.8	38.3	38.5	38.4	38.2

Room 4

Day	1	2	3	4	5	6	7	8	9	10
T air (°C)	27.5	28.5	27.5	27.0	28.0	27.5	27.0	26.4	27.4	26.5
T wet (°C)	24.0	24.5	25.0	24.0	24.3	24.4	23.0	20.6	23.5	21.5
RH %	73.0	70.5	80.5	77.0	73.0	76.0	70.0	58.0	70.0	62.5
Time (hrs)	1455	1440	1410	1430	1425	1500	1445	1415	1450	1430

Buffalo

Day	1	2	3	4	5	6	7	8	9	10
E_h mg m^{-2}s^{-1}	8.0	0.0	0.0	0.0	30.3	11.2	0.0	13.6	40.6	0.0
E_o mg m^{-2}s^{-1}	2.3	0.0	0.0	0.0	46.5	14.4	0.0	4.8	20.2	-
T_h °C	36.8	37.0	36.5	39.5	38.5	39.5	38.1	36.7	36.7	37.6
T_o °C	34.6	36.2	35.3	36.6	34.3	35.2	35.1	34.7	34.1	34.5
RR min^{-1}	8	12	16	16	16	16	12	12	16	12
RT °C	37.6	37.5	38.0	38.3	38.1	38.3	38.1	38.4	38.0	37.9

Ayrshire

Day	1	2	3	4	5	6	7	8	9	10
E_h mg m^{-2}s^{-1}	45.8	59.2	44.0	0.0	39.9	52.5	20.1	35.6	47.4	-
E_o mg m^{-2}s^{-1}	40.4	53.2	18.6	0.0	29.5	15.0	15.0	18.5	48.2	-
T_h °C	36.1	37.4	38.6	38.0	37.4	38.7	37.4	38.6	37.5	38.3
T_o °C	35.4	35.8	36.2	36.4	35.8	36.1	35.9	36.7	36.8	34.5
RR min^{-1}	60	60	52	60	40	48	28	52	36	48
RT °C	38.6	38.3	38.2	38.2	38.3	38.7	38.2	38.8	38.7	38.6

APPENDIX III

The Analyses of Variance

The sums of squares were calculated from:-

$$\text{Days Sums of Squares } (D_{ss}) = \frac{\varepsilon D^2}{6} - \frac{(\varepsilon X)^2}{60}$$

$$\text{Animals Sums of Squares } (An_{ss}) = \frac{\varepsilon An^2}{10} - \frac{(\varepsilon X)^2}{60}$$

$$\text{Specie Sums of Squares } (Sp_{ss}) = \frac{\varepsilon sp^2}{30} - \frac{(\varepsilon X)^2}{60}$$

$$\text{Rooms Sums of Squares } (R_{ss}) = \frac{\varepsilon R^2}{20} - \frac{(\varepsilon X)^2}{60}$$

$$\text{Between Animals} = An_{ss} - (Sp_{ss} + R_{ss})$$

$$\text{Error} = \text{Total ss} - (D_{ss} + An_{ss})$$

$$\text{Total ss} = \varepsilon x^2 - \frac{(\varepsilon X)^2}{60}$$

1. Skin Temperatures

Source	df	SS	MS	F
Days	9	42.020	4.669	2.68 *
Animals	5	16.062	3.212	1.84 ns
Specie	1	13.820	13.820	7.94 **
Rooms	2	2.037	1.019	0.58 ns
Between Animals	2	0.195	0.098	0.006 ns
Error	45	78.355	1.741	

2. Rectal Temperatures

Source	df	SS	MS	F
Days	9	1.143	0.130	2.8 *
Animals	5	1.376	0.275	5.9 ***
Specie	1	0.343	0.343	7.3 ***
Rooms	2	0.259	0.129	2.8 ns
Between Animals	2	0.770	0.046	8.3 ***
Error	45	2.091	0.046	

3. Respiratory Rates

Source	df	SS	MS	F
Days	9	567.084	63.0093	1.136ns
Animals	5	18650.484	3730.0968	67.276***
Specie	1	17578.817	17578.8170	317.051***
Rooms	2	421.234	210.6170	3.800*
Between Animals	2	650.433	325.2165	5.866**
Error	45	2495.016	55.4448	

Where ns: not statistically significant

*: statistically significant ($p<0.05$)

**: highly statistically significant ($p<0.01$)

***: very highly statistically significant ($p<0.001$)