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"AN INVESTIGATION INTO THE BODY TEMPERATURE, RESPIRATION
RATE, PULSE RATE AND SKIN TEMPERATURE OF DAIRY COWS
UNDER NEW ZEALAND CONDITIONS, AND A REVIEW OF
EXISTING KNOWLEDGE ON ANIMAL CLIMATOLOGY
WITH PARTICULAR REFERENCE TO CATTLE."

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A. DISSERTATION.

I. INTRODUCTION.

Domestication of animals had only to begin before it became evident to man that some shelter from heat, cold and other environmental extremes was desirable for the animals as well as himself.

Down through the ages and particularly in the present century refinement of methods, materials and degree of shelter have been added. There has not been a refinement corresponding in knowledge of the environmental influence in the range between obviously harmful extremes. Narrow margins for farm profit, increasing attention to production efficiency, increasing cost of shelter, war and post-war demands for high production, have exerted increasing pressure to correct this situation. The delay in attempting to get more accurate information on objectives in environmental control has been due to the immensity of the undertaking. Consider the range of environmental variables involved. The environment to be considered includes an almost infinite variety of combinations of temperature, radiation, humidity, air control, air movement, light, sound space, surfaces, forms, pressure, presence of other animals and time phases.

The range of possible temperatures is vast. Man and animals occupy a relatively narrow zone. True, they are exposed to the heat of the tropics and the cold of the arctic regions but animals really live, not in the air, but inside their own skins. The active cells of the body are all beneath the skin, the most important of them a long way below the surface. In the process of evolution mammals have arrived at a certain optimal temperature for the body cells and the organism strives to preserve this temperature as closely as possible. The problem is to define the limits of this zone, to describe the mechanism by which the optimal temperature is maintained, and to give an idea of the results when temperature control fails.

The factors which tend to displace temperature equilibrium in normal healthy mammals are concerned chiefly with the everyday topic of climate and weather. Climate plays an extremely

important role in the life of man and animals. Much of the relationship between climate and man has been emphasised on the side of climate affecting vegetation and therefore food supplies. However climate affects successively, soils, crops, animals and man, in an elaborate chain reaction mechanism. The soil types of the world are classified largely on the influence which climate plays as a major soil forming factor. Such soil types may be fertile or infertile with graduations in between depending to a large extent on the degree of leaching and weathering as a result of climate. The fertility determines the type, and to a certain extent, the nutritive value of crops and forage plants. Man may use these directly or more often indirectly per medium of his domestic animals. This chain link—up with climate is one which is well known to everybody and to many it is the main force attributed to climate.

However, there is another chain reaction linking climate and man; a more direct one which links up the affect of climate first on the nervous system, then the endocrine system and then the enzyme systems. These three systems control, regulate and co-ordinate body activities including heat regulation. For instance, the activity of enzyme levels determines the level of metabolism, and metabolism determines the level of productive processes such as work, meat and milk production, etc. It is this aspect of climate with which the present volume is concerned.

Physioclimatology, bioclimatology or environmental physiology has been, up till quite recently, a neglected subject particularly as regards to cattle. But animal research men, are taking an increasing interest in the environment of the animal, not from the feed angle but from the aspect of the direct affect of climatic elements on animal performance.

Workers in tropical and subtropical regions have observed the degeneration and low milk production of important British breeds of cattle. Improved methods of transport has placed the

selection of breeding stock on a global basis but breeders have considered only pedigree and gallons of milk in their breeding policies rather than a consideration of the direct effects of climate, particularly in hot areas.

It is now becoming clear that animal reactions to heat and cold needs investigating but on looking into the matter it has been found that the physiology of heat regulation covers a wide and involved field. Further it is found that the evidence and information on the physiology of heat regulation as it applies to cattle is conflicting and most of the evidences and hypotheses are based on assumptions derived from work in human heat regulation in which a large volume of work has been carried out. To counteract this lack of knowledge in the animal field, there has been set up in several countries, centres for fundamental research on the heat regulatory mechanisms of cattle. Because the natural climate cannot be controlled there has been built large laboratories or psychroenergetic rooms in which air temperature, humidity and air movement can be controlled at will as described by Kelly et al (1), McCalimont (2), Thompson (3) and Rhoad (4).

Work has also begun on the morphological and physiological differences between *Bos taurus* (European) and *Bos indicus* (Indian) types of cattle with a view to observing any differences in relation to heat regulation. Regional adaptation of cattle and the significance of the morphological transition of cattle types between regions is also being considered.

Some workers have given estimates of the role which solar radiation plays in the heat loss of an animal. The evidence suggests that the effects of solar radiation are very great in tropical regions. It probably does not apply to the same extent in temperature regions but could quite possibly be a contributing factor to low milk production during the summer months. A fall in solids-not-fat has been shown to occur during high temperature conditions. Others again state that high summer temperatures cause 15-20% of the fall in fat percentage irrespective of

lactation effects. So that if production of dairy cattle is significantly influenced by direct climatic effects, then research is surely warranted, firstly to work out the fundamental mechanisms, secondly to formulate the best methods of assessing animal reactions to climate stress, and thirdly, methods such as showers, sprinklers, shade, barns, etc., on the one hand, and breeding on the other, to help reduce the direct effects of climate.

Over many parts of the world stock have to be housed for varying lengths of the year. Costs of erection of such houses is considerable and the farmer wishes to know the most economical hot and cold weather shelters to build. Such information requires first a knowledge of the reactions of animals to various environmental factors.

There is a growing appreciation therefore of the importance of the relation of the animal's heat regulatory mechanism to its performance. The direct effect of climate affecting metabolism by way of the neuro-endocrine-enzyme system will determine to a certain degree the level of productivity of animals within a region. Just whether in various regions, the local climate is sufficient to reduce metabolism, needs a great wealth of research, both fundamental and applied to supplement the controversial and inadequate information available at the present time.

Object of Section A.

The direct relation between climate and animals has in the past received very little attention and animal husbandmen have concentrated on breeding and feeding within the levels set by climate, i.e., the influence of climate has been considered only in an indirect way. A dissertation on what available information there exists in the literature on the direct effect of climate on animal welfare is therefore presented. Because this field covers various aspects of physiology, chemistry and physics, a preparatory explanatory chapter on the physiological background is given.

II. PHYSIOLOGICAL BASIS AND DEFINITIONS.

The "heat" or thermal elements of climate, composed of air temperature, relative humidity, air movement and radiant heat, operate universally in time and place, and since much more is known about them they are used as the central pivot for discussions of the relation between climate and animals. The non-thermal interactions between climate and animals are limited, and of secondary importance. All the systems of the body moreover are involved in reactions to heat, so that heat reactions are the primary concern of the environmental physiologist. The 'heat environment' of an animal is indicated by its body temperature and it is the regulation of body temperature under various conditions with its associated complex chain of body reactions set up by the organism in response to environmental changes - changes involving mainly the heat elements of climate - with which this chapter is chiefly concerned.

1. BODY TEMPERATURE.

In all normal warm blooded animals the body temperature remains constant, despite widely varying climatic conditions. Homeothermy, as it is called, is achieved by maintaining an equilibrium between the heat produced by the animal and the heat lost. Most body reactions involve chemical anabolism and catabolism setting free large quantities of heat. The superiority of higher forms of animal life is due in no small way to their ability to maintain a constant body temperature. To keep this constant the heat being produced within the body from various sources must be eliminated. Thus the heat loss, or thermolysis, of an animal must equal its heat production, or thermogenesis, to maintain a homeothermic state. Many of the lower forms of life are cold-blooded, i.e., poikilothermic, e.g., fish, amphibians, reptiles, and in these animals body temperature varies directly with the environment, whereas warm blooded animals or homeotherms have a body temperature, normally independent of climatic condition

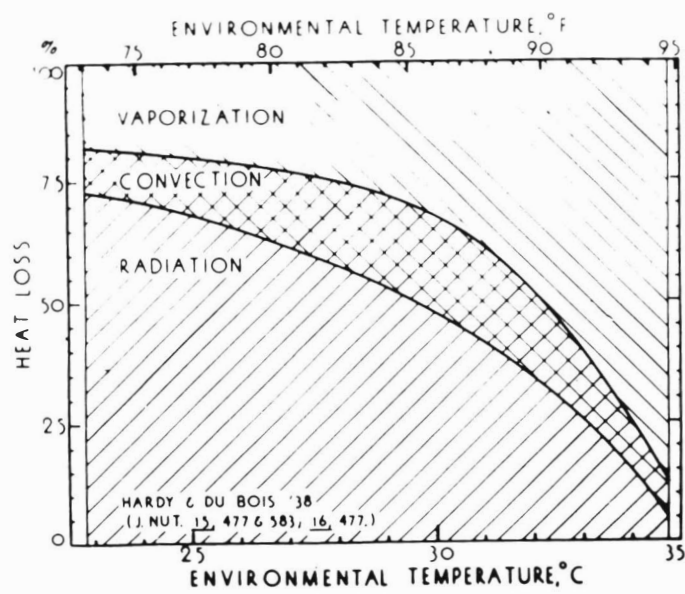


Fig. 1. Pathways of heat loss at various air temperatures - Brody.

In practise this constant body temperature can be achieved in a variable environment only by having an inherently high rate of heat production balanced by a controllable rate of heat loss.

The temperature of the living body like that of an inanimate object tends to come into equilibrium with its environment by such processes as conduction, convection, and radiation. In a typical animal living a free life, the rate of heat production is largely determined by the biological needs of the animal, and the function of preserving a heat balance is left to the heat regulatory mechanism controlling the various methods of heat loss. The pathways of heat loss are radiation, conduction, convection and evaporation, and the importance of these varies with the temperature of the environment. At low temperatures there is little evaporation of water and heat loss is affected by way of radiation and convection with a small amount by conduction. Now radiation, conduction and convection are reversible processes, each depends on a temperature difference at an interface and the flow of heat is from the hotter to the cooler regions. As the two sides of the interface approach each other in temperature, then the pathway of heat loss by means of radiation, convection or conduction becomes increasingly difficult. In other words, when the air temperature is the same as the animal's skin temperature, then the body cannot lose heat by the above three pathways - indeed they are tending rather to gain heat from their surroundings by those processes. At this stage and at higher temperatures heat cannot be eliminated except except by way of evaporation. See Figure I.

Thus as environmental temperature approaches body temperature heat dissipation is shifted from radiation, conduction and convection, to evaporation. In sweating species there is a sharp change to the evaporation method at 84°F. but in non-sweating, or rather poorly sweating species, there is no sharp

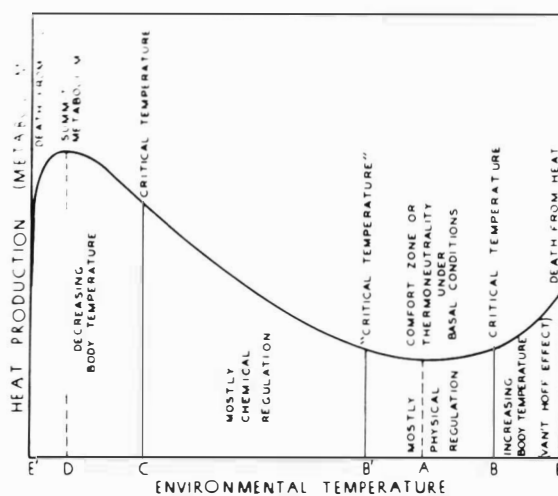


Fig. 15.—Generalized diagram of the influence of environmental temperature on heat production in warm-blooded animals. Note the broad accommodation range to low temperatures and restricted range to high temperatures. The increased heat production with increasing cold (from B' to D) is a biological adaptation, protective to the animal; the increasing heat production with increasing heat (from B to E) is a consequence of a physico-chemical necessity expressed by the van't Hoff-Arrhenius generalization, and is destructive to the animal, ending in death (E). One purpose of our project is to obtain data for part of this diagram as related to dairy cattle of different size and productivity.

Fig. 2. Regulation of Heat Production to Air
Temperature - Brody.

change to evaporation but the respiration rate increases rapidly to compensate for the inability to sweat. The main regulator of thermal balance then is by way of controlling the heat loss.

2. HEAT PRODUCTION.

Under extreme conditions some modification may be made in heat production. Thus heat production too, varies with environmental temperature, but at more extreme temperature changes. A diagram showing the type of variation which occurs has been shown by Brody (6), Figure 2.

When the environmental temperature is very low heat production reaches its highest value, which is known as the "summit" metabolism but as environmental temperature decreases still further, body temperature also decreases, and the animal eventually dies. The zone of minimal heat production - often called the zone of thermalneutrality - is where the animal is in harmony with its environment. The heat balance is regulated in this region principally by physical means such as changes in peripheral blood flow, evaporation from skin and lungs, seeking shade or sunshine, as the case may be. It is within this zone that the heat production of a resting animal, in the post absorptive state, is at a minimum, and it is therefore in this zone, that basal metabolism is measured. As the environmental temperature increases beyond this neutral zone, the animal begins to have difficulty in eliminating excess heat, and its body temperature rises. Finally, at the upper limit, with very high environmental temperatures death occurs.

One may note in the diagram, the terms upper, and lower critical temperatures. These are important as they indicate the regions in which the following methods of heat loss take place, by means of:

- (a) Physical regulation.
- (b) Chemical regulation.

These are not absolute divisions but refer to method of regulation from the heat concept point of view.

(a) Physical Regulatory Mechanisms are:-

1. Evaporation of moisture from skin, sweat glands, respiratory passages and saliva.
 2. Movement of blood to and from the skin peripheries and changing calibre of superficial blood vessels.
 3. Huddling or relaxed posture.
 4. Wallowing, use of shade or sun.
- and 5. More long range changes (i) Layers of fat for insulation against cold.
(ii) Different types of hair and hair colour.

These operate most effectively between the upper and lower critical temperature zones. Below the lower critical temperature chemical methods to increase heat production come into play. In the region of upper critical temperature the physical regulation has about reached its limit and sweat runs off without evaporating and in man metabolism rises.

(b) Chemical Regulatory Mechanisms are:-

1. Change of metabolic rates by increased activity and feed intakes.
2. Increasing internal heat production by increasing tonus of muscles or, as in more extreme cold, by shivering.
3. Increased adrenaline and thyroxine secretions.

These operate at colder temperature ranges than that indicated by the lower critical temperature.

The position of the comfort zone, or thermalneutrality zone, and the qualitative manner of response of the animal to a change in environmental temperature varies with the following:-

1. Age of the animal.
2. Nature of the sweating apparatus.
3. Qualitative and quantitative effects of insolation.
4. Body size.
5. Body temperature.
6. Nature of the protective coverings.
7. Acclimitization.

and 8. Mainly on the activity level of the body. For instance a resting man in a post absorptive state would be comfortable at a higher temperature than a man who had just eaten a heavy meal or

run a race.

The critical temperatures B^1-B in Figure 2 are thus variably conditioned by various circumstances and since their published values were obtained on fasting and resting animals they are not applicable to normally fed, active and productive animals. However, they do serve as a rough guide.

Brody (6) lists the results of various workers indicating limits of thermal neutrality for various animals.

<u>Species</u>	<u>Lower Critical Temperature</u>	<u>Upper Critical Temperature</u>
Rat	81	84°F
Mice	82	87
Guinea pig	84	88
Rabbit	59	68
Sheep	69	77
Goat	55	70

The major factors influencing level of metabolism and therefore heat production in animals are:-

1. Basal metabolic rate.
2. Resting metabolic rate.
3. Work rate.
4. Food, - nature and amount eaten.
5. Milk production.

High increments of each of these will tend to set the limits of B^1B in Figure 2 at a corresponding lower level.

Exercise and Regulation of Thermal Balance - Work Rate.

Exercise not only modifies heat production but also heat loss. Due to active movements, convection and evaporation are aided. The limits for normal increases in rectal temperatures during work cannot be stated precisely. The change is greater, the heavier the work, but is independent of environmental conditions except at extremes. The rise in body temperature during work presumably assists the work. Part of this may be explained by the rise in surface temperatures increasing the temperature

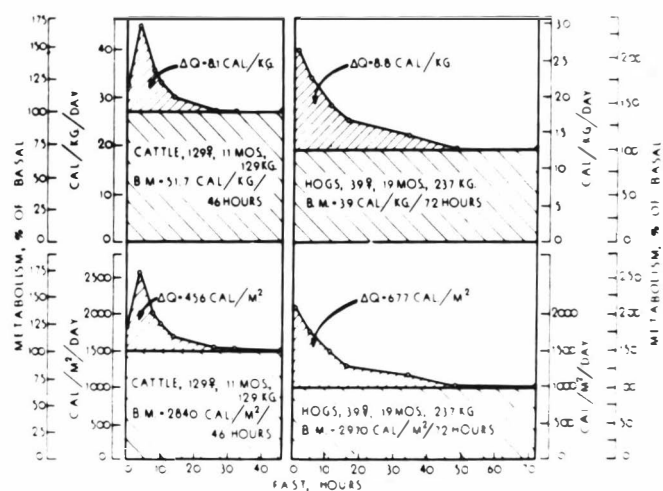


Fig. 10.—The heat increment of feeding in farm livestock (useful for warmth in cold weather but unpleasantly heating in hot weather); hence the reduction of feed consumption (and therefore reduction in productivity) in hot weather.

Fig. 10. Heat increment of feeding in farm livestock
— Brody.

difference at the interface, of air and skin temperature, facilitating heat loss. Also a large proportion of the heat released would come from the muscles and should facilitate chemical reactions there.

Bazett (7) reports that moderate increases in rectal temperature in subjects at rest in a hot environment is associated with considerable discomfort and with inefficiency in mental tasks. Similar rises during exercise is associated with less discomfort and no sign of mental disability. The cause of this anomaly is unknown.

Cattle with their ruminant microflora have a large heat increment or specific dynamic effect of feeding, and this can be useful for warmth in cold weather but unpleasantly heating in hot weather.

Figure 3 from Brody shows for cattle that metabolism due to feeding may be increased up to 50% of basal metabolism within 3-10 hours after feeding. Milk production will cause an additional heat increment.

3. HEAT TRANSPORT.

Warm-blooded animals may be regarded for basic discussion as having a central core of tissue at a uniform 'body temperature.' Surrounding this is a shell of tissue through which the temperature progressively falls as the surface is approached, and through which heat flows to the surface by conduction and convection, mainly via the blood stream.

Though the blood stream is the main organ in heat transport all parts of the body transport heat. According to Bazett the body temperature as measured is not the temperature of the body as a whole or even the central areas, e.g., heart, lungs, abdominal organs and brain. From these deep centred organs heat flows to the lesser active organs and tissues with a lower temperature and so the process goes on until the exterior is reached.

The thermal conductance of the superficial tissues is important for facilitating or restricting heat transport. In the cold, fat deposits in the subcutaneous tissue hinders conductance of heat and the thermal gradient across the superficial tissues would be greater in an animal with natural fat deposits, e.g., pig, than in an animal free of such deposits. By thermal gradient is meant the drop in temperature across the tissue or region.

However, the main regulation of thermal conductance of the peripheral tissues is exhibited in two ways.

(a) Vasodilation of capillary blood vessels.

(b) Vasoconstriction of capillary blood vessels.

These two actions increase the volume and rapidity of blood flow on the one hand, and decreases and slows down the speed of blood flow on the other, in the peripheral tissues.

These vasomotor reactions are exhibited universally by all mammals.

Effects of Vasodilation.

In response to heat, superficial blood vessels dilate, and increased blood is passed through them. This blood carries heat from the interior, and during its passage through the superficial tissues it gives up its heat load to the exterior. At the same time the superficial tissues being well supplied with blood, have a lower thermal conductance and heat passes through them more readily. Now the volume of blood ejected by each systole of the left ventricle of the heart is inversely proportional to the pulse rate. Vasodilation requires a large volume of blood to be supplied to more distant regions, usually at the expense of blood supplying the visceral areas, and in most mammals a rise in pulse rate but a fall in heart output takes place at high air temperatures.

Because of the heat which the blood carried and the increased conductance of the tissues the thermal gradient between the deep body organs and the surface is reduced, i.e., surface

temperature is increased. This in itself, helps in a small way to facilitate heat loss by increasing the temperature difference between the surface temperature and the ambient air, thus facilitating more rapid loss of heat by conduction, convection and radiation.

The richer blood supply also yields a plentiful supply of raw products for active sweat secretion.

(b) Effects of Vasoconstriction.

In response to cold, part of the mechanism to conserve excessive loss of body heat involves vasoconstriction and the reverse of what occurs in vasodilation takes place, viz. lessened blood flow, decreased blood volume, decreased thermal conductance, decreased surface temperature, etc., - heat loss restricted and pulse rate tends to fall.

4. HEAT EMISSION.

It has been stated previously that the four pathways of loss of body heat is by way of:-

- (a) Convection.
- (b) Conduction.
- (c) Radiation.
- (d) Evaporation.

From the surface of the animal heat is exchanged with the environment by the physical processes of radiation and convection in whatever direction the difference in temperature lies according to simple physical laws.

(a) Convection.

Hardy (8) defines this term as that which refers to the exchange of heat between hot and cold objects, by the physical transfer of the liquid or gas with which the objects are in contact. In other words this type of heat transfer depends upon the existence of a fluid medium between the warm and cold objects, and upon the actual streaming movement of warm molecules, from the warmer object to the cooler one.

The rate of heat dissipation by convection at the surface of the animal skin, i.e., rate at which hot air near the skin is replaced by cooler air which is in turn heated, and moved away, is indicated by Brody's (5) equation:-

$$C = kA \sqrt{V} (t_1 - t_2).$$

where C = convection rate

A = surface area

V = velocity of the air

k = unit convection conductance constant.

t_1 and t_2 are respectfully the temperature of the body surface and the environment.

The rate of convection will depend largely on this difference of temperature.

The convection rate is influenced to a certain extent by wind movement but is increased by only the square root of the velocity as shown by the equation.

This formulae indicates how the larger the surface area of a given body the greater the rate of heat transfer. The same holds for heat transfer by vapourization, conduction, and radiation. Since from geometrical considerations the larger the body the smaller the surface area per unit volume or per unit weight, heat dissipation becomes more difficult as the body size of the animal increases.

Convection losses also takes place from the lungs. According to Lee (9) the amount of heat exchanged with the environment by warming or cooling the inspired air is directly proportional to the difference between air and body temperatures and to the volume of air respired. Under cold conditions this may represent an important avenue of heat loss but under warm conditions it is not nearly so important.

Figure 1 shows that convection along with radiation and evaporation plays a major part as a pathway of heat loss.

(b) Conduction.

The flow of heat through a medium without the physical

transfer of material is called thermal conduction - Hardy (8). This is a loss by actual physical contact of surfaces, as for example, when an animal lies on a cold floor. It is also proportional to the area, through which the heat flows at right angles, and to the temperature gradient. Cattle which are standing, lose little heat by way of conduction because only the hooves are in actual contact with another surface.

The physiological significance of heat transfer from the body by conduction is that still air has an extremely low conductivity. According to Lusk (10) hair, feathers or clothes contain much air and so are good insulators or non-conductors. The larger and denser the hairy coat the greater the thermal gradient between the skin surface and the hair surface.

Conduction is not so important as an avenue of heat loss once the hair surface is reached but within the body it is an important method of heat transfer.

(c) Radiation.

The transfer of energy by electromagnetic waves of various lengths between solid objects is called radiation - Brody (5).

The rate of loss or gain of heat by radiation is also proportional to the surface area of the animal. A feature of radiation is that it is concerned with solid objects. Suppose we have two solid objects A and B a few yards apart. If A is at higher temperature than B, then A will lose heat to B which will gain in heat content. This can take place even when the objects are in a vacuum. The electromagnetic waves travel in straight lines and with the speed of light. Thus, if object A is screened from B it will not lose heat to B by radiation because the energy travels in straight lines. A, may however if the air temperature is well below its temperature lose heat to the air by convection to the point where B 'feels' the impact of warmer air and if the air becomes still warmer may receive heat from the air by virtue of its temperature, i.e., it has acquired heat indirectly from A.

(d) Evaporation.

Inanimate bodies may lose heat by radiation, conduction

and convection, but warm-blooded animals have a unique method of heat dissipation and that is, moisture evaporation from the skin and respiratory tract.

When the body cannot lose any more heat to the environment by radiation, conduction and convection, all the heat must be dissipated by way of evaporation.

Figure 1 shows how moisture vapourization from the body increasing with increasing air temperatures. The rate also tends to increase with increasing metabolic rate and therefore with increasing rates of productive processes. A high producing cow therefore, needs extra water above that of a low producing cow, and above the extra water included in her milk.

The chief property of water of concern in the study of heat regulation is its remarkable thermostatic properties. Brody (5) lists the following:-

1. Water has the highest specific heat of any substance. It takes one Calorie to heat one klg. of water 1°C . as contrasted with 0.241 Calories for air. Experiment shows that if different bodies of the same mass and at the same temperature are dropped into equal quantities of water, in general, the rise in temperature is different in each case. The bodies are said to have different specific heats and have different thermal capacities. Thermal capacity of a body is the amount of heat necessary to raise the temperature of the body one degree in temperature.

2. It has a very high heat of fusion. It takes 80 Calories to melt or freeze one klg. of water. This tends to make water a fairly stable medium to changes in external heat and cold.

3. It has an especially high latent heat of vapourization. It takes 580 Calories to vapourize one klg. (about 2.2 lb.) of water from the skin.

(One Calorie is the heat required to raise the temperature of one klg. of water 1°C . at 15°C . The British system is the

B.T.U. which is about $\frac{1}{4}$ as large as the Calorie.)

Altogether these thermostatic properties indicate the vital role water plays in heat regulation. Thus, the vasometer reactions to heat and cold conditions but serve to fill or empty the peripheral tissues with a medium which allows ready conductivity of heat.

The remarkable thermal properties of water make it a basic stabilizing factor within the animal body. Because of its thermal capacity the body can absorb considerable amounts of heat before a rise in body temperature takes place. Also the large amount of heat lost from the body by evaporation of sweat enables the animal to maintain a fairly stable body temperature. In those species which do not sweat or whose sweating apparatus functions poorly, this remarkable avenue of heat loss is largely closed and more reliance has to be placed on loss by radiation and convection, at the higher temperatures.

Water is thus a prime physiological factor in regulating the internal environment, especially temperature, of the body.

Factors influencing loss of Heat by Convection, Conduction, Radiation and Evaporation.

(a) Convection and Conduction.

Losses by conduction and convection depend very much on the nature of the body surface. It has been indicated how an air layer trapped in hair or feathers acts as an effective insulator and restricts conduction of heat to the surface, there to be lost to the air mainly by convection. The amount of air trapped will depend on the nature of the coat and the air movement. In perfectly still atmosphere the layer of air next to the skin becomes warmed and loaded with water vapour and constitutes a protective envelope removed slowly by gaseous diffusion. Strong air movement removes this envelope with its heat load and replaces it with another layer of air which can readily accept heat and so the process goes on.

One sometimes hears the statement, a moist cold is worse to bear than a dry cold. The reason lies in the good conductivity of water. A layer of air next to the skin saturated with water vapour allows heat by conduction to pass through to the surface, and there to be readily lost by convection at cold temperatures. A dry cold with little moisture in the atmosphere would not cause such a rapid heat loss because the layer of air next to the skin would not be so saturated with water vapour - in this case only that derived by diffusion through the animal's skin. Conversely at high temperatures a high moisture content in the atmosphere restricts evaporation of water and this overbalances any slight increase there may be due to conduction. The importance of surface area has been noted previously.

(b) Radiation.

The main factors which affect loss by radiation are the temperature of the surroundings in relation to the temperature of the radiating surface, the area of radiation surface and its emissivity. Findlay (11).

Now radiation depends on heat exchange between solid bodies.

(i) Area. Suppose we have a solid object in a room and it is at a higher temperature than the room. This means a temperature higher than that of the wall and ceilings and other objects not at the air temperature. The amount of heat which the body can radiate to the lower surface temperatures of the walls, etc., depend on the area of its radiating surface. This will not be the total area but rather the area which is seen by the walls and ceiling. Thus, for a cattle beast when dealing with radiation there is a configurational factor involved, as the area is not the total surface area of the animal but the area seen by the surroundings. Areas between the legs, ears, etc., where surfaces are opposing, will be radiating to surfaces at the same temperature, and the net transfer of heat will be zero. This must be deducted from the total area of the animal to arrive at the radiating area.

In man this radiating area is 80-85% of the total anatomic-

al area (Hardy (8)). Kelly and Ittner (12) in their calculations of radiation exchange for cattle deducted 2 square feet from the total surface area. If the animal is receiving radiation from surrounding objects then the area of these objects becomes a factor. This is impossible to determine and instead an instrument is used to measure the radiation being received.

(ii) Temperature. The greater the difference between the temperature of the radiating surface and the receiving surfaces, the greater will be the loss of heat by this pathway. Thus, under cold conditions the animal body surface temperature is much higher than surrounding object surface temperatures, and loses of heat to them fairly rapidly.

The mean temperature of surroundings will influence the amount of heat which the animal can lose to the surroundings, or on the other hand influence the amount of heat which the animal will receive, from objects with a higher surface temperature than itself. This would be impracticable to determine in an outside or even an indoor environment and instead the mean radiation from the surroundings is determined either fairly accurately with a radiation thermopile or with a globe thermometer. (Findlay (11)). This is a hollow 6" diameter sphere with a blackened surface and a thermometer with its bulb in the centre. If the surroundings to which the animal is exposed are hotter than the animal, the globe will receive heat by radiation from the surroundings and will show a higher surface temperature than the air temperature. If the surrounding objects are at a lower temperature than the air then the globe thermometer will record a lower temperature than the air temperature because it is losing heat by radiation. Thus, if the air temperature, the air velocity, (since this will influence heat loss from the copper sphere), and the globe thermometer readings are known, a value known as mean radiant temperature of surroundings may be computed. Radiation thermopiles will be mentioned later.

(iii) Emissivity. Brody (5) defines emissivity (or absorptivity) as the ratio of the rate of emission (or absorption)

of radiant energy per unit area by the given body, to the rate of emission (or absorption) from a black body at the same temperature.

A simpler definition given by Findlay (11) is that emissivity of a body is the ratio of the brightness of the substance to the brightness of a black body at the same temperature.

In other words it is concerned with the reflectivity of objects. Radiation is composed of various wavelengths, and bodies vary with the amount of various wavelengths which they absorb or reflect. Thus, suppose an animal is in the centre of a large sphere, which had highly reflecting walls, nearly all the radiation emitted by the animal would be reflected back to it and there be absorbed by the skin; even though the wall of the sphere may be quite cold, the animal cannot lose heat to it because of the high emissivity of the walls.

Determination of emissivity is important in determining radiation exchange between the radiating surface and surrounding objects.

More details will be given concerning radiation under the section dealing with climatic elements affecting animals.

(c) Factors affecting Rate of Evaporation.

(i) Surface area of the animal is very important because the larger the area of the wetted surface exposed for evaporation the greater the loss of heat. This surface area also includes the area composing the lungs and respiratory passages, for heat is lost in respiration by evaporation as well as by convection - in fact in cattle it is the main region where evaporation takes place.

(ii) Temperature of the water being evaporated.

(iii) Air temperature.

(iv) Relative humidity.

(v) Air movement.

Evaporation is governed by the temperature of the water being evaporated and the relative humidity of the air at that temperature - not the relative humidity of the ambient air which may

have a different temperature to the skin temperature. Air movement will, of course, facilitate loss by evaporation.

Physiological Control of Heat Emission.

The physical factors concerned in heat loss have been considered, now we look at the heat loss from the physiological aspect.

The animal organism varies its heat loss as follows:

- (i) By alteration in the mean temperature of the surface.
- (ii) By changes in the pattern of heat distribution on the surface.
- (iii) Alterations in the conditions of the body surface affecting losses by radiation, convection, and especially by evaporation.

(i) If the mean skin temperature is raised there is an increase in temperature difference between the surface and the environment and so improves conditions for heat loss. Conversely, a lowering of skin temperature by withdrawing blood at cold temperatures, decreases the temperature difference and decreases heat loss. At any given rate of heat transfer, however, no such increase in surface temperature is possible without either an increase of deep body temperature or a reduction of thermal conductance of tissues. Normally it is the latter action which takes place in extreme heat.

(ii) Changing the pattern of heat distribution on the surface in effect alters the insulating value of the air. According to Bazett (7) this insulative effect of air is less for cylinders of small diameter than those of large diameter. This is because of convection effects around small cylinders. A rise of skin temperature of the fingers and toes, hands or feet is therefore more effective in promoting heat loss than a similar rise in skin temperature in the trunk region.

At high air temperature, heat is lost from hands and feet by sweating. At intermediate temperatures heat is lost mainly by convection though partly by evaporation. At low temperature again local heat loss from hands and feet depends to a considerable extent on evaporation as a result not of increased.

evaporation but of lowered convective loss - this evaporation says Bazett, is of osmotic or diffusion water, not water derived from sweat glands.

The prevention of direct heat loss in the cold in spite of the great thermal difference between the internal tissues and the environment depends on utilizing insulation along the length of the limb as well as across the thin layer of subcutaneous tissue.

Blood supplying the hand or foot can be subjected as needed to the cooling effect of the blood returning from the periphery via the venous comites which in the limbs usually lie on both sides of the artery and have anastomosing branches which cross it. The heat which arterial blood has lost is used to warm returning venous blood. Thus there is an internal economy of body heat in the cold.

(iii) Under hot conditions, the animal may cut down on its heat production by restricted activity and may assume a relaxed or extended posture thus exposing the maximum surface for evaporation. In the cold huddling will reduce the surface area and help minimise radiation losses. Erection of hairs and roughening of skin - goose flesh - will cut down on convection loss by providing a barrier to air movement. Humans respond to heat by regulating the amount of clothing they wear.

Summarizing, the following bodily factors may influence heat loss:-

- (a) Physical nature of the more superficial tissues, especially their water and fat content - concerned with thermal conduction.
- (b) Blood flow through more superficial tissues.
- (c) Area of body surface.
- (d) Colour of body surface - reflective power.
- (e) Transudation of water to the body surface - osmotic water loss.
- (f) Sweat production and nature of its distribution on the body surface.
- (g) Nature of the body surface as it affects air flow over it, especially thickness and density of hair or wool covering and its contours.

- (h) Movements of body surface.
- (i) Coverings applied to body surface.
- (j) Volume of respiratory ventilation per minute.

Heat Balance.

At the present stage the complete picture of factors influencing heat production and heat loss may be drawn together. An animal's body temperature at any moment is the net result of two sets of events, heat gains and heat losses.

The following table adapted from Kibler and Brody (13) depicts the various factors:

HEAT BALANCE SHEET.

<u>Heat Gains.</u>	<u>Heat Losses.</u>
Basal Heat Production	Radiation
Heat Effects of	To other objects of the environment
Endocrine Stimulation	Convection
Muscular activity by	To air passing over the body
Tensing of muscles	To air passing through the lungs
Exercise	Conduction
Shivering	To floor or ground or anything else with which the animal is in direct contact.
Feed (S.D.A.)	Vaporisation
Productive processes	From Respiratory Tract
Gestation	From skin
Lactation	Osmotic or diffusion moisture.
	Sweat.

Du Bois (14) likens these factors to the counterpans of a balance, when the load on either side is increased, e.g., by more activity or by a cooler environment then the proper adjustment to correct the balance to zero point is made on the other side. The great emergency mechanism in heat production is exercise or shivering, and on the heat loss side, sweating or panting is the emergency pathway.

5. REGULATION OF BODY TEMPERATURE.

(a) Short term adjustments.

Lee and Phillips (15) report that it has been fairly well established that there are a group of nerve cells in the

hypothalamic portion of the forebrain which collectively form the heat regulating centre since they exert a marked effect in the control of the processes regulating heat loss from the body. These centres are very sensitive to changes in the temperature of the blood passing through them. This prevents overheating or overcooling.

Also the regulation is attained in part by the thermal receptors on the skin surface. In response to external stimulus the amount of heat loss is regulated in a reflex reaction to sensory impressions derived from the receptors in the skin.

The hypothalamus acts as a guardian to internal stress while the receptors guard against external stress. Hardy (8). Internal rise of heat load brought about by work, exercise, chemical agents, under conditions of a constant environmental temperature, heats the blood which stimulates the hypothalamus to send nerve impulses so as to set in motion pathways for increased heat loss.

Much other evidence shows that with a constant or basal metabolism, the first protection against environmental temperature changes is by way of the thermoreceptors in the skin. Of course with external stress it would not be long before the hypothalamus became stimulated as well. Though not clear or finally proven the evidence indicates that a particular level of thermoregulatory adjustment is a balance, established between the effects of the stimulation of heat and cold receptors, and the the excitation of the hypothalamic centres by the level of blood temperature. Depending on the intensity of stimulus to one or another of these, the thermal adjustment is made.

Mechanism of Nerve Receptors.

It is often popularly assumed that the sensation of heat or cold is dependent on the skin temperature change set up.

However, Bazett states that it is generally agreed amongst

workers in this field that the sensations of temperature do not depend so much on the actual level of skin temperature but on the setting up of a thermal gradient between the surface and the blood in the superficial tissues. If this temperature gradient is maintained at sufficient intensity, sensations of temperature continue.

Suppose an arm is immersed in a water bath at, say, 40°C . then the surface temperature of the arm soon becomes this temperature. Vasodilation takes place and blood flows rapidly through the tissues and is warmed to a temperature a little below 40°C . - say, 37°C . With its rapid motion blood is not exposed long enough to heat to 40°C . Temperature sensation of warmth therefore, continue. If the surface temperature is then dropped to 38°C . by immersion in another bath, the temperature difference between the skin and blood is reduced so that the gradient becomes inadequate for stimulation and sensations of warmth decrease. After a while the tissues cool and the blood flowing through them is warmed to a less extent so that a gradient is re-established and sensations of warmth return. When the arm is put into cool water the gradient between the surface and blood is in reverse and sensations of cold are generated. The cold causes reflex vasoconstriction and the reduction of blood flow allows the blood which supplies the skin to be cooled to a greater extent. Ultimately the cooling of the slowly flowing blood is sufficient to reduce the gradient to a value below the threshold for such sensation, and sensation stops.

Nervous response to cold.

Sympathetic nerves supplying the involuntary muscles of the blood vessels cause vasoconstriction. Pilomotor muscles associated with the hair follicles are also caused to contract, giving rise to goose flesh which diminishes air movement over the skin and so improves air insulation. The adrenaline from the adrenal medulla is probably also associated in these reactions. With shivering the ordinary skeletal nerve supply is in-

involved. Shivering consists of the synchronous contractions of small groups of motor units which react out of phase with other groups and alternate with antagonistic muscles. Unfortunately a small part of the heat gained from shivering is lost as there is no way to prevent the carrying of a portion of the heat so produced directly to the neighbouring skin. The arteries supplying the skin over the big muscles of the limbs pierce the muscles and though this arrangement is valuable in active work to get heat quickly to the surface, in moderate or severe cold this can be a handicap.

(b) Long Range Adjustments:-

There is little doubt that endocrines play an important role in long term adjustments to temperature but definite information is limited. Thermal homeostasis involves control of water balance, and to maintain a normal body temperature control of water balance is absolutely necessary. Water is a product of metabolism and its evaporation is a valuable pathway of heat loss. Thermal control also demands regulation of heat production and possibly also of food storage since fat deposits can influence thermal insulation.

The pituitary gland is the master endocrine and there is probably a significance in its close anatomical relationship to the hypothalamus. The pituitary appears to be stimulated by the composition of blood which supplies it. An increase in osmotic pressure of the blood by ingested salt solutions as shown by Robinson (16) can cause an increase in antidiuretic hormone output and a reduction of urine volume - a common reaction to heat. It is an adjustment to conserve body water and to allow water to play its more important role under hot conditions, of dissipating heat by evaporation.

Endocrines play a role in regulating metabolism at various temperatures. The adrenals play a predominant role in thermoregulation through their effects on the general adaptation syndrome (Selye (17)). Adrenaline liberated by nervous means

through impulses which reach the gland via the splanchnic nerves control heat loss by causing vasoconstriction which forces blood supply to the active muscles. It liberates glucose from the liver glycogen, and increases the capacity of the tissues to assimilate glucose. Evidence that adrenal cortex is involved in the calorigenic action of thyroxine has been presented by Chambers (18). Adrenalectomy reduced the rise in O_2 consumption produced by thyroxine but this response was restored to normal by cortical extract. While the posterior pituitary exercises hormonal regulation of water excretion by the kidney, the excretion of Na and K is at least in part regulated by the adrenal cortex (Selye (17)) so that the latter also appears to play a part in water metabolism.

Dempsey and Astwood (19) have shown how rats produce much more thyroxine at a low temperature than at a higher one. This is to be expected in line with the theory of thermoregulation that increasing cold causes increased metabolism mediated by way of anterior pituitary and the thyroid. This has also been shown in the rat by Schwabe et al (20) and in the rabbit by Lee (21) and by Ring (22).

Evidence has been presented by Boder et al (23) that the diurectic effect of cold exposure in man is due to stimulation of the posterior lobe, inhibition of cold diuresis being brought about by intramuscular doses of pitressin.

Endocrine factors in general are probably very important in the co-ordination of reactions to heat and cold and also acclimatization effects. However, the evidence of their exact and specific role is yet limited. We have but unidentified pieces in a complicated puzzle formed by the total reactions.

6. EFFECTS OF EXTERNAL HEAT AND COLD.

The immediate reactions to thermal stress is the transmission of impulses from the hypothalamus and thermoreceptors in the skin which set in train the regulatory adjustments to either increase heat production or increase heat loss.

Thermal stress causes changes in many of the major physiological systems.

(a) Cardiovascular system.

The adequacy of the circulatory system depends on whether there is sufficient liquid to fill the system and whether the heart is maintaining its output. Under cold conditions vasoconstriction will ensure an adequate volume of blood and the heart will have no difficulty in maintaining its output. Bazett states that long exposure to cold causes a decreased blood volume. The change in volume is mainly through the plasma and a proportional amount of plasma protein is also removed from circulation. Ultimately a reduction in circulatory haemoglobin presumably develops. Blood pressure is raised during cutaneous vasoconstriction to acute exposure to cold. However, on continuous exposure to cold a fall in blood pressure is common in the early stages of adaptation. It disappears gradually as subject becomes more acclimatized to the conditions.

However, with vasodilation in response to heat a large volume of blood is required for the superficial tissues. This may be carried out initially by constriction of splanchnic vessels and reduction of urine volume to give some compensation but the extent of this is limited. The deficiency of O₂ causes the heart to increase its beat to compensate for O₂ lack of the tissues and pulse rate rises.

In any long term adjustment to heat a greater blood volume is required and the body may adjust it by increasing the blood plasma protein content causing more water to enter the blood-stream; but the concentration of haemoglobin would be lowered. Whether it increases too, is not known. The increase in blood volume overcomes vasoconstriction in the splanchnic area. Blood pressure may be lowered by exposure to mild heat but with more intense heat there is greater efforts to supply the surface with blood and blood pressure rises. However, with acclimatization there may be a gradual fall in blood pressure.

(b) Alimentary System.

The diversion of blood from the viscera to the periphery must constitute a threat to the appetite of the animal.

According to Lee and Phillips (15) with the O_2 lack in the visceral region it would be the motor functions which would be affected more than the secretory and it is largely with motor functions that appetite is associated. Brobeck (24) has shown with rats how appetite is reduced at high temperatures and suggests that food intake is a regulator of body temperature since it is depressed in the heat and increased in the cold. Depression of appetite would lessen the animal's internal heat load so that not so much heat would have to be lost. Thus, animals unable to get rid of surplus heat, cut down on their nutritive levels and reduce metabolic rates in an effort to restrict the amount of heat to be dissipated. Energy for activity, growth and fat deposition can only be derived from metabolism of foodstuffs. If the metabolic rate is cut down then the animal's ability to thrive is restricted and animals which are adapted to a high level of feeding, as Bonsma (25) has shown, are affected most. Thus, the rate of heat expulsion determines the metabolic level which again influence the rate of growth, fertility and other important body functions. Mills and Ogle (26) contend that it is the ease or difficulty of body heat loss which determines the metabolic level. This will be cut down with difficult heat elimination.

Increased appetite under cold conditions to increase heat production does not necessarily cause an increase in production. On the contrary, production may decrease as more nutrients are needed to provide fuel for increased metabolism and the increased heat loss. This will be elaborated more later.

(c) Urinary System.

Typically in the cold there is increased urine volume because of the increased water supply to the kidneys through vasoconstriction and the necessity to reduce blood volume. Under hot conditions urine volume is reduced as Robinson (16) has shown, because of the need to conserve water for increased blood volume and evaporation. However, there is never complete suppression of the kidneys due to hot weather as a small amount of water is used for excretion of waste products. Lee (15) suggests that

these low volumes of urine may predispose some species to urinary calculi.

(d) Acid base balance.

Large increases in respiratory activity can lead to large losses of CO_2 from the blood. This will tend to make the blood alkaline and cause alkalosis effects. This has been noted by many workers - Bazett (7), Robinson (16) and Lee (15). For determining the CO_2/O_2 exchange the effective ventilation is the tidal air minus the dead space whereas for evaporation of water, which is why respiration rate is increased in hot weather, the whole tidal air is effective, since the entire respiratory tract is lined with a moist membrane. Increasing the dead space per breath, therefore, increases the rate of ventilation, and hence evaporation without increasing the alveolar ventilation. Shallow breathing as observed by Kleiber and Regan (27) increases the dead space per breath.

(The rate of pulmonary ventilation is the volume of air breathed per minute. Depth of respiration is the volume of air per breath = respiratory rate divided by the rate of pulmonary ventilation).

With most animals tidal air decreases with rise in respiration rate while pulmonary ventilation rate rises. Thus, the tendency is for shallower breathing at high air temperatures for those animals which typically pant at high temperatures, e.g., dogs and cattle.

Bazett (7) and Robinson (16) report that in man a rise in respiration rate is not nearly so marked as with many other animals and there is probably little increased benefit from evaporation. The breathing with humans is slow and deep and this lowers the alveolar CO_2 tension so that increased CO_2 is driven out of the lungs and alkalosis develops.

(e) Endocrine System.

This has been elaborated somewhat already but it can be briefly said that increased heat causes:-

(a) Decreased thyrotrophic hormone production by

Anterior pituitary.

- (b) Decreased thyroxine production.
- (c) Under more extreme heat adrenalin may be secreted.
- (d) Extreme heat as reported by Selye (17) causes histological changes in the adrenal cortex indicating increased secretions of corticoids.

Increased cold causes:

- (a) increased thyrotrophic hormone production.
- (b) increased thyroxine production.
- (c) decreased anti-diuretic hormone production.
- (d) increased adrenaline secretion and possibly also corticoids.

The evidence for any one of these is limited and one can only speculate on their possible role at the moment.

(f) Energy Metabolism.

The zone of thermalneutrality is where the metabolism is at a minimum; on either side of the critical temperatures, metabolism rises. On the cold side it rises because of the necessity to increase heat production to compensate for the increased heat loss. On the heat side the metabolism goes up and obeys Van't Hoff's rule that increasing the temperature of a physical chemical system increases its reaction rate. Brody (6). This has been shown to take place in man by McConnel (28) and Du Bois (29), whether it occurs in cows is not so certain and some evidence suggests that a decrease in metabolism occurs. More will be said about this later. Work and productive processes such as milk production will automatically set the critical temperature points at a lower level and will accentuate heat stress reactions and will decrease cold stress reactions.

(g) Reproductive System.

Animals which are constantly exposed to excessively high temperatures to which they are not normally accustomed, show stunted growth and poor fertility and what young are born are stunted and do not do well. Bonsma (30) says this is because of the reduced metabolism which takes place at high temperatures in an endeavour to reduce the heat load. Under such conditions animals develop poorly even if offered an adequate diet.

Indeed, Bonsma cites cases where reproductive organs may remain infantile in exotic breeds reared in tropical regions of South Africa.

Under subarctic conditions the breeding seasons of animals is usually very restricted. It has been well known for a long time that fertility is reduced in summer months in regions with high summer temperatures. Little seems to be known of the influence of the direct effect of season on the female reproductive organs. More attention has been focused on the male. The tendency for a period was to regard the fall in fertility of the male to be due to the direct effect of hot temperatures on the scrotum and the consequent harmful effect on spermatogenesis. Attention has recently been focused on the thyroid gland by the demonstration in some animals that seasonal variations in thyroid activity corresponds with variations in fertility and semen characters and that the seasonal effect can be converted by thyroprotein in summer and thiouracil in winter, as shown by Bogart and Mayer (31). Also, since the high air temperatures at which will reduce fertility in the ram are below the temperature at which the testes normally function and since thyroprotein restores reproductive activity during periods of high temperature they concluded that temperature does not influence reproductive physiology by its direct effect on the testes.

Thyroid activity is under the control of the Anterior Pituitary and the latter controls other endocrines as well as the gonads. The pituitary activity must be influenced therefore by meteorological factors and so must all other glands that are under the influence of the pituitary. Climate, especially temperature and light, thus appears to control to a certain degree most endocrine activities. It has long been recognised that light exercises important effects on physiological activities of many birds and mammals. The effects are particularly noticeable upon reproductive functions and upon the plumage of birds and coat of mammals. The exact mechanism by which light invokes these reactions is still being investigated but Lee (9) reports

that certain areas of the facial region and perhaps the eyes give rise to nervous responses which influence the anterior pituitary and thus the general endocrine balance controlling metabolism, reproduction and coat characters. It is difficult to disentangle the effects of light as such from the heat elements in climate, but Yeates (32) has made some progress in this direction.

(h) Water Balance.

Man and some panting animals can become dehydrated. - Adolph (33). Deprivation of body water causes dehydration exhaustion which is believed to represent a deficient circulation from a decreased circulating blood volume. The blood loses 2-3 times as much of its volume as does the body, as a whole. Under conditions of active sweat secretion salivary flow diminished, but urine formation and sweat activity persist even during greater degrees of dehydration. The dehydrated individual becomes intolerant to heat since the circulatory system no longer carries heat to the surface for dissipation.

Muscular work increases heat production and therefore, increases sweating rate in man. Adolph and Dill (34), 1938, have indicated that under desert conditions a working man vapourises about 4 lbs of moisture per hour. Under more normal conditions 2 lbs. per hour is quite common. In an atmosphere of high moisture content this rate of sweat production can be considerably increased, but not all of it will be vapourized, however, because of the unfavourable atmosphere. Thus, man has great powers to dissipate heat by means of sweating, but such sweating rates do tend to cause dehydration, and Adolph (35) states that a reduction of 3% body weight by sweating has serious effects.

1. Firstly, there is a reduction in blood plasma volume, and this decreases the blood volume.

2. The effective blood volume for the heart is further decreased by the vasodilation which takes place in response to heat.

3. There is then not enough blood to fill the heart and blood vessels and an increase in pulse rate takes place,

which increases the work load of the heart leading to increased heat production.

4. The increased solids and viscosity of the blood caused by the fall in plasma content further adds to the work of the heart and therefore to heat production.

5. The rise in heat production causes body temperature to rise which still further increases heat production according to Van't Hoff's law so that a vicious cycle is set up. Death usually follows when the rectal temperature exceeds the normal level by about 80°F .

Thirst. Water intake in man is regulated by thirst, but thirst does not always cause a man to keep up his water intake to the rate of output. Man tends to be dehydrated whereas it has been shown by experiments with cows (described later) that they tend to become hydrated at hot temperatures. According to Robinson (16) unacclimitized men particularly tend to become dehydrated. They secrete large volumes of sweat with nearly as high a concentration of salt as the body fluid from which it is produced. In this case, sweat formation involves little modification of the osmotic pressure of the extracellular phase and therefore does not greatly reduce the water content of the cells and does not cause a degree of thirst proportional to the water lost. On the other hand, in acclimitized man, sweat is very dilute and thirst will be more intense because of the raising of the osmotic pressure of the extracellular phase which causes abstraction of water from the body cells.

(i) Acclimitization.

When an animal is continually exposed to a hot environment two time processes are involved:- (a) Acclimitization.

(b) Deterioration.

Which gains the ascendancy depends upon the species and the individuality of the animal. There is not so much evidence that these two reactions occur universally in response to cold.

The resistance of an animal to heat stress could be altered by varying heat loss or by increasing tolerance of the tissues to thermal stress.

Adolph (33) likens the process of deterioration to a question of rates of destruction and repair within the body cells. Suppose for example, an enzyme oxidase which furnishes energy to a cell, is slowly inactivated at 35°C. The cell can produce new oxidase and can repair the damage. As temperatures become greater the rate of repair falls behind the rate of destruction and we have accumulative deterioration.

In man, the evidence for reduced thyro-adrenal activity and thus reduced basal energy production in heat is not so well established but it is so in some of the lower mammals and this would be one way to adjust against excessive heat production. In the cold, on the other hand, increased thyroxine causing increased metabolism helps considerably. An adjustment to heat loss is the dilution of sweat with repeated exposure thus helping to ensure an adequate intake of vital water per medium of thirst. There is some evidence for increased surface area as, for example, in exotic breeds imported into South Africa, as reported by Bonsma (25). However, as shown by Lee (15) the greatest change on repeated exposure to heat appears to be in the efficiency of the animals. By improvement in blood volume and perhaps a finer balance in circulation so that there is less danger of O₂ lack in some regions, the animal is able to perform the same tasks as before with less total energy production.

(j) Results of Displaced Thermal Equilibrium.

Thermal equilibrium will depend: 1. On the external environment.

2. On the status of the animal.

The external environment will vary from day to day, season to season, and the changes are often quite considerable from extreme heat to extreme cold. Animals possess wide powers to maintain normal body temperature under a given range of climatic conditions. Its zone of thermal neutrality will depend on its status - as to whether it has a high heat production because it is milking, or poor fat deposits to provide against protection in the cold. However, death depends not only on body temperature but also on

the time interval the animal is under stress.

According to Lee (15) the results of displaced body temperatures are as follows:-

<u>Results in Cold</u>	<u>Results in Heat.</u>
Increased shivering	Agitation
Huddling	Complete loss of appetite
Decreased activity	Diarrhoea
Slow cerebration	Failure of heat regulation with gasping and sweating.
Depressed metabolism	Weakness and stupor.
Depressed respiration and heart rate.	Staggers.
Failure of heat regulation with cessation, shivering & death by respiratory failure or cardiac failure.	Convulsions.

7. CLIMATIC FACTORS AFFECTING HEAT LOSS:

The meteorological components of weather include air temperature, air humidity, air movement, radiation from the sun, earth and other objects. These factors are very changeable from day to day - this is weather. In addition we have weather rhythms, spring, summer, autumn and winter. This long range weather pattern is climate. Brody (5) states that the polar axis of the earth tilts some $23\frac{1}{2}^{\circ}$ from the perpendicular. The climate within a given region depends therefore, on its latitude, its inclination to the vertical sun rays and to the rotating movement of the earth around the sun.

Large bodies of water play a predominant role in regulating climate because of its thermostatic properties. Water is a prime physical factor regulating climate as well as prime physiological factor regulating body temperature.

(a) Radiation.

The sun is the source of all our energy including,, through the process of photosynthesis, the energy derived from food. The sun transfers its energy by radiation, and radiation is an important avenue of heat loss in an animal and an equally important avenue of heat gain - beneficial in cold, harmful in the heat.

Radiant energy being composed of electromagnetic waves,

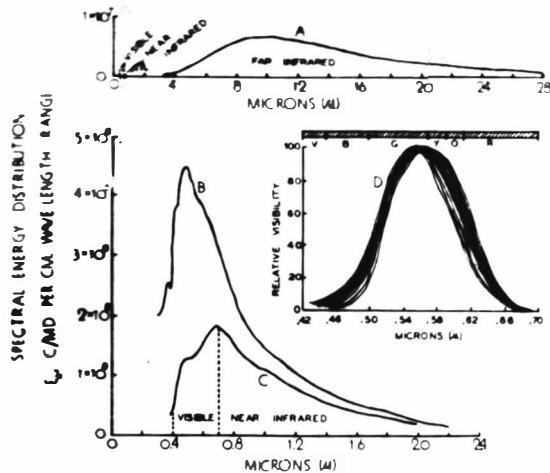


Fig. 13.—The insert (Curve D) shows the light wave lengths in the *visible* spectrum (from Coblentz and Emerson, Bull. Bureau Standards, 14, 167, 1918). Curves A, B, and C are presented by courtesy of A. D. Moore in a book manuscript on "Comparative Animal Energy". Curve A represents Far infrared radiation at 27° C and includes the energy interchange between animal and ground, grass, trees, water, snow, etc. But if the solar radiation strikes the animal, it is mostly in the visible and in the Near infrared spectrum, 0.4 to 2μ; Curve B, solar radiation before entering atmosphere; Curve C, transmitted solar radiation (normal incidence) for a clear sky with the sun at 70.7° from zenith when the atmosphere path length is 3 atmospheres. C/MD represents kg.-cal. per square meter per day.



Fig. 4. Solar Radiation Spectrum - Brody.

does not heat the air directly, but rather indirectly by radiating to solid objects, where radiant energy is transformed to thermal energy which heats the air by conduction and convection.

If a body does not reflect or transmit any of the incident radiation, it is called a black body. Hardy (35). No body is perfectly black but many are nearly so. Reflectivity is the ratio of the rate of reflection to the rate of incident radiation. Most surfaces are black to some radiations and not for others. Hardy and Du Bois (36), have shown that human skin acts as a black body to some radiation and as a reflector to others. Surfaces which are good radiators are poor reflectors and vice versa. Skin is a poor reflector except in the visible and near infra red and in the far infra red, skin acts as a black body radiator, regardless of its colour. A peculiarity of black body radiation is that it either absorbs all radiation which strikes it, if the body is at a lower temperature than the radiating source, or emits all its radiant energy if it becomes the radiating body. Hence, the term emissivity.

The Solar spectrum (Fig. 4) ranges from short ultraviolet waves $0.1 - 0.4\mu$ in length, through the visible spectrum $0.4 - 0.7\mu$, to the near infra red $0.7 - 2\mu$. Very little of the solar radiations that reach the earth are in the infra red due to the fact that all wavelengths are not absorbed equally. Ozone present in the atmosphere absorbs ultraviolet and water vapour absorbs infra red. Also dust and gas molecules scatter the radiation with the result that only the near infra red from the sun manages to reach the earth.

Bodies having a temperature below 900°F . radiate in the far infra red from $2-100\mu$. According to Hardy and Du Bois (36) the human body radiates its heat in the $5-20\mu$ region. This means that human skin, whether white or black absorbs and emits within this range. With regards the visible spectrum, the human skin acts as a reflector and this will depend on its colour.

Edwards and Duntly (37) reported that the reflection of visible radiant energy is about 15% for Negro skin, 30% for mulatto skin, 60% for brunette skin and 65% for blonde skin. What is not reflected is absorbed so that for dark races the absorption of visible radiation is considerable.

However, it is in tropical countries with high solar radiation that we find the dark coloured people and in the temperature zones that we find the light skinned people. From the point of view of heat regulation a dark skin in the temperate zone and a light skin the tropics would be the ideal yet the opposite, is found.

Edward and Duntly state that skin pigments include melanin, melanoid, carotene, oxyhaemoglobin and haemoglobin. White skinned people develop temporary pigmentation on exposure to the sun but the coloured people's pigmentation is a hereditary characteristic.

Ultraviolet light is known to be bacteriocidal and toxic to skin and nerve, and perhaps the purpose of the black mans skin pigment is to protect against the injurious effects of ultraviolet light. Also the overall effect of greater heat absorption with dark skin would be to accelerate sweating and may more than offset the greater heat absorption.

To determine the radiation exchange between a man and his environment Hardy (8) gives 6 measurements which have to be made.

<u>Physiological</u>	<u>Environmental</u>
1. Skin or surface temperature	1. Average radiant temperature
2. Effective surface area.	2. Emissivity of the environment
3. Reflectivity power of skin and clothing, e.g., the emissivity.	3. Intensity of radiant sources.

The emissivity of the environment is the most difficult to measure and workers usually assume a value of 0.95.

The radiant temperature of the environment is defined by Yaglou (38) as the temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the non-uniform environment. It is thus an

average black body temperature of all the surrounding surfaces and is usually measured with a globe thermometer.

Brody (5) gives the following formulae used in calculating the heat loss by radiation from the animals body.

$$A \left(e_1 T_1^4 - e_2 T_2^4 \right).$$

A = effective surface area.

T_1, T_2 are the 4th powers of temperatures of surfaces of animal and environment.

σ is a proportionality factor - constant derived from the Stefan Boltzman law which states that the exchange of radiation between two surfaces treated as black body radiators is proportional to fourth power of the difference between their absolute temperatures.

e = emissivity.

These methods of approach to radiation loss deal mainly with radiation exchange between the body and its immediate environment. However, many workers have shown the importance of the solar heat load.

The amount of solar radiation at any one time will depend on several factors (Riemerschmid (39), (40)).

1. The altitude of the sun.
2. Midday intensity of direct solar radiation.
3. The length of days.
4. The number of hours with bright sunshine.
5. The total amount of sun and sky radiation during various months.

Solar Radiation may be partitioned into three sections:

1. Direct Solar Radiation.

The rate at which heat is gained from the animal from direct solar radiation involves several measurements.

- (i) The intensity of sunshine.
- (ii) The altitude of the sun.
- (iii) The area of the animal presented to direct solar radiation.
- (iv) Measure of the reflectivity of its coat (see definition).

The amount of direct radiation may be deduced by multiplying the area exposed by the intensity of direct solar radiation.

2. Solar radiation received from the sky.

With high sun altitudes additional radiation reflected from

the sky and falling on a horizontal surface may be estimated according to Riemerschmid (40), at about 15% of the direct solar radiation. The absorption of sky radiation can be measured by noting the amount of radiation reflected by the hide, when it is shadowed from the direct rays of the sun at various sun altitudes, Riemerschmid found that the amount reflected was about 75% regardless of altitude.

5. Solar radiation reflected from the ground.

Bare ground reflects about 25% (Lee) of the total solar radiation falling upon it and from grass Riemerschmid calculated a figure nearer 30%. Reflection from the hide was of the same order as from direct solar radiation. Since ground reflected radiation is similar in composition to direct solar radiation in that it is composed of all wavelengths, and Riemerschmid used 30% for reflection.

Thus summarizing, the following measures are needed to obtain the full picture of the effect of solar radiation.

1. Intensity of direct Solar radiation.
2. Intensity of reflected sky radiation.
3. Intensity of reflected ground radiation.
4. The body surface area influenced by direct sky radiation (Shadow of animal measured at various altitudes).
5. The body surface area influenced by reflected sky radiation - ($\frac{1}{2}$ area of animals skin)
6. The body surface area influenced by reflected ground radiation - ($\frac{1}{2}$ area of animal skin)
7. Absorption coefficient of direct sky radiation at various altitudes.
8. Absorption coefficient of reflected sky radiation at various altitudes.
9. Absorption coefficient of reflected ground radiation.

A further factor to be considered which some workers have failed to make due allowance, is the amount of heat radiated from the animal to outer space. Blum (41) reports that the transparency of water vapour permits some of the radiation to pass to higher layers of the atmosphere which are cooler than the ambient air layers. Black bodies at temperatures of the human body and

the terrain, emit radiation over a broad range, with a maximum at about 10 μ . Water vapour is transparent to a wide spectral band at about this wavelength but strongly absorbs wavelengths on either side of this band. The other gases of the atmosphere do not absorb in the spectral region to which water vapour is transparent. Thus, bodies can radiate to the outer space per medium of water vapour.

Accurate estimation of this radiant energy loss is difficult but Simpson (42), in considering heat loss from the earth, estimates values for atmospheric transmission, taking differences in the amounts of water vapour into account, and arrives at values for long wavelength radiant energy lost to the heavens by a horizontal surface. This is sometimes called "nocturnal radiation" because it is usually measured at night and is comparable to that occurring during the day and is dependent chiefly on humidity and temperature. Heat radiated to outer space on a clear day may be estimated at 150 Cal. per square m. per hour from a horizontal surface.

Lee (9) calculated radiation exchanges by all channels for a hypothetical sheep.

Heat Exchange of Sheep by Radiation (Cal/hr)

Hour of day	6	7	8	9	10	11	12
Net Direct Solar receipt	119	211	266	290	309	308	279
Net Reflected Sky receipt	8	26	46	61	79	87	93
Net Reflected ground receipt	11	38	67	94	115	130	136
Total receipt	138	275	379	445	503	525	508
Lost to Heavens	<u>173</u>	<u>173</u>	<u>173</u>	<u>173</u>	<u>173</u>	<u>173</u>	<u>173</u>
Net Radiation gain	35	102	286	272	330	352	335

For comparison the basal heat production of this sheep is 35-50 Cals. per hour. Riemerschmid (40) also calculates that the heat absorbed by a 1000 lbs. bull on mixed rations during a 15 hour mid-summer day in South Africa would be about 17,000 Cals. whereas heat produced by the animal would be about 6000 Cals. Blum (43) worked out a heat balance sheet for man and

found a somewhat similar situation in that the heat absorbed was greater than the heat production.

Thus, the additional heat load imposed by solar radiation may be 2-3 times the animal's normal heat production and the animal has to eliminate not only the heat which it normally produces but also the heat from solar radiation if body temperature is to remain normal. This indicates the great importance of shade in hot weather, to cut off solar radiation.

The factors which determine the amount of radiation absorbed on the body surface of cattle change from hour to hour and day to day. The amount absorbed depends on the intensity of incident radiation which in turn depends largely on the cloud formation. It varies with the altitude of the sun, thickness of the air layers, and composition of the air. With any given intensity of solar beam the amount actually absorbed depends on the colour and nature of the surface of the animal as well as on its size. Then there is the animal itself which constantly changes its position presenting various aspects of its body to various sources of solar radiation.

(b) Air Temperature.

Even without the effects of Solar Radiation air temperature in itself causes wide changes in an animal's method of heat loss. With low air temperatures, the temperature difference between the animal and the ambient air is considerable and losses by convection, conduction and radiation will be increased. As air temperature increases so does the surface temperature of the animal but at a lower rate so that eventually a stage is reached when air temperature and surface temperature are the same - at about 94° for man and 102°F. for cattle, as shown by Thompson et al (44).

Further increases in air temperature cause the processes of convection, conduction and radiation to be reversed and the animal absorbs heat by these processes. The only method of heat loss left to the animal is by evaporation of moisture, i.e., by

sweating. This method is quite effective in maintaining body temperature constant in some species such as man with an efficient sweating mechanism, but for cattle which have a poor sweating mechanism their ability to dissipate heat by evaporation is limited and body temperature rises markedly. Actually, in cattle it begins to rise well before 102°F . This is probably due to the hairy coat of the animal which make losses by convection difficult. Also the cow's main method of evaporation is through the respiratory tract and the amount evaporated through this channel is limited. Man begins to sweat at about 84°F . (Kuno (45)) i.e., well before air and skin temperature are equal. This is because although heat can still be lost by radiation, conduction and convection, the amount so lost is not enough to allow all heat produced within the body to be dissipated and recourse has to be made for the balance of it to be lost by evaporation. The same applies for cattle. Man's body temperature is about 98°F ., whereas for cattle it is about $101-102$ so that it would be at a higher temperature in cattle before skin temperature equals air temperature. At such a point the thermal gradient between deep body organs and the surface is very small. Indeed, the deep internal body temperature extends right to the surface.

The amount of heat exchanged between the skin surface and the ambient air is, of course, proportional to the difference between skin and air temperature, but is also influenced by the thermal resistance or insulating effect of transitional layers between the skin surface and the free ambient air.

Also heat is exchanged by warming or cooling the inspired air in the respiratory tract. This is proportional to the difference between air and body temperatures and to the volume of air respired.

(c) Air Humidity.

Relative humidity is defined by Haynes (46) as the ratio of the mass of water vapour actually present in unit volume to that contained in unit volume when the atmosphere is saturated.

Humidity has an important effect on the ease of evaporation of water from the animal surface. If humidity is high more sweat may be produced than can be evaporated and this leads to inefficiency of the sweating mechanism and danger of dehydration effects. In the cold high humidity can cause a greater loss of heat by conduction and convection from the body due to the conduction of a layer of moisture laden air trapped in the hairy coat of an animal.

The amount of heat lost by evaporation from the skin surface depends on the difference between the vapour pressure of the ambient air and the saturation vapour pressure of the skin.

Evaporation is governed by the temperature of the water being evaporated and the humidity of the air at the temperature, but the temperature is that of the body surface and not that of the ambient air. Lee (15) advocates the use of absolute rather than relative humidity when considering the effects upon heat loss by evaporation from a homeotherm.

Another avenue of heat loss to the environment is by evaporation per medium of the respiratory tract. The amount of heat lost is directly proportional to the difference between the vapour pressure of the inspired air and the saturation vapour pressure at body temperature and the volume of air respired. Under cold conditions Lee believes that this avenue of heat loss may be serious and under hot conditions provided they are dry it can become a major avenue of heat loss - as it is with cattle.

(d) Air movement.

The resistance of air layers to the outward passage of heat from the skin surface in animals will obviously be reduced by wind movement. The rate of air movement is thus important in determining the rate of heat exchange by conduction and of heat loss by evaporation from the surface of the animal. Strong winds will assist at high air temperatures but will be a disadvantage at low air temperatures due to excessive heat loss.

Thus various combinations of the thermal climatic elements can impose a severe test on the animal in its ability to maintain thermal equilibrium. Solar radiation especially in tropical countries can cause an increased heat load to be borne and even in temperate climates on hot summer days a similar load would be imposed. Usually with high solar radiation, air temperatures tend to be high thus further hindering the animal by hindering losses by radiation, conduction and convection. Evaporation has to be resorted to at an early stage but this too can lose its efficiency if the absolute humidity is high and air movement is low. The important feature to be stressed is that the animal not only has to eliminate its own body heat from normal body metabolism but has to cope with large amounts of heat absorbed from solar radiation and at very high air temperatures to heat absorbed by the animal by radiation, conduction and convection. All this heat must be eliminated by evaporation and if efficient evaporation is hindered by adverse humidity and air velocity the animal is in a sorry plight.

Solar radiation can, of course, be beneficial with low air temperatures and the body is pleasantly warmed by radiant energy from sun and terrain provided air movement is not excessive.

8. MISCELLANEOUS FACTORS.

Homeotherms living in their chosen environment are subject to seasonal variations in climate from cold in the winter to heat in the summer.

With the approach of cold weather animals grow a woolly coat and develop subcutaneous fat deposits. An increase in thyroid activity, an increase in food consumption, the seeking of shelter from wind and rain, and an increase in activity, are exhibited by most animals on approach of winter conditions.

In hot weather the coat becomes less dense, shorter and smoother, there is a depression of thyroid activity, appetite and activity, and the seeking of shade from solar radiation and wallowing in water in some species, e.g., the pig, to facilitate cooling by evaporation.

Sweating:

Profusely sweating species can withstand very high environmental temperatures. The 3-4 lbs. of moisture which man can sweat per hour ensures a heat loss of about 1000 Calories,- remembering that the latent heat of vapourization of water is 580 Calories per kilogram. Kuno (45) states that sweating in man begins at about 84°F. , air temperature. Numerous investigators have revealed a clear cut relation between the rate of sweating and skin temperature. Winslow (47) found that sweating is initiated in the average nude man, at rest in an environment, when the skin temperature = 34.5°C. Above this threshold sweating increases markedly with small increments in skin temperature, evaporation tending to minimize the rise in skin temperature with rising air temperature. The internal body temperature does, however, play an important part in the regulation of sweating. But Burton (48) has shown that a resting man with a low body temperature due to exposure to cold does not begin to sweat due to rapid elevation of skin temperature with improved environmental conditions, until sufficient heat has accumulated in the body to restore temperature to normal.

In working man it is possible to vary the skin and body temperatures independently of each other. Winslow and Gagge (49) had men working at a constant rate. Skin temperature increased with environmental temperature, body temperature remained much the same and sweating increased with increases in skin temperature. By keeping the environmental temperature constant and varying the intensity of work Robinson (16) showed that the skin temperature remains the same and the body temperature and rate of sweating increase together. In these experiments at a given environmental temperature there were no increases of skin temperature to increase cutaneous reflexes and cause the rise in sweating. The rise in sweat production was apparently a direct effect of internal temperature on the heat regulating centres in the hypothalamus region. Thus, it appears that skin temperature and internal body temperature both participate in the regulation

of sweating.

Even under cold conditions loss of heat by evaporation takes place but this is evaporation of osmotic or diffusion water not water from the sweat glands. Bazett states that heat loss in man by evaporation of water at low temperatures is some 24% of the total heat loss in the absence of sweating. (14% from the skin and 10% from the respiratory tract). At very low temperatures most of the heat loss from the hands and feet may be evaporated as a result not of increased evaporative loss but of lowered convective loss due to the extreme vasoconstriction which takes place in these regions.

Osmotic water loss is often termed insensible perspiration and is water that passes through the skin solely by the physical process of diffusion. Sensible perspiration or sweat is that which appears on the skin solely as a result of the activity of the sweat glands.

Up to the point 84°F. which according to Kuno is the critical temperature threshold for sweating in man, insensible moisture losses increases with temperature until near the threshold level it may account for 35% of the total heat dissipated.

Skin temperature.

The importance of skin temperature is clear from the above effects on sweating regulation. Changes in the pattern of heat distribution on the surface which in effect alter the insulating value of the air, is one of the physiological methods on controlling heat loss. Insulation is smaller for cylinders of small diameter than for those of large diameter and the fingers and toes, hands and feet, arms and legs, are important avenues of heat loss and also important regions where heat loss can be reduced to very low levels when the occasion demands. Thus, the skin temperature of these regions changes very rapidly. Under hot conditions the skin temperature of the extremities may exceed those of the trunk and the reverse is true in the cold. Also skin temperatures fluctuate from minute to minute with strong air currents and with psychological or emotional stimulus.

In an attempt to obtain some measure of average body temperature Du Bois (50) divided the human body into 6 segments and chose 15 different points over these 6 segments where skin temperature measurements were made. The mean temperature of the whole body is calculated by adding the products of mean segmental temperatures and surface area of the segments and dividing the sum by the total area.

The average skin temperature is related to the rectal temperature according to the heat production and the average thermal insulation of the tissues. The greater the values of either of these factors the greater must be the thermal gradient of the tissues.

The average temperature of the skin surface is in its turn determined by:-

1. the heat which must be transmitted by radiation and convection.
2. by the temperature of the environment.
3. the amount of air movement aiding convection.
4. conditions for evaporation of water.
5. the type of hairy coat.

Any failure to attain a thermal balance stimulates the thermal control mechanisms. One of the adjustments may be changes in circulation - vasodilation or vasoconstriction, which in effect alter the tissue thermal conductance. An increase in conductance makes the surface temperature approximate more closely that of the deep body organs and so facilitates heat loss. Skin temperature, therefore, depends on two physiological variables, the thermal conductivity of the underlying tissues and the volume of blood flowing through it.

Time sequence of adjustments to cold. Bazett (7)

The initial effect of cold temperatures is a cooling of the superficial layers of the skin with a resulting increase of the thermal gradient and the stimulation of cold receptors. To this stimulus would occur vasoconstriction, splanchnic dilation, pilomotor contractions and goose flesh, and possibly shivering. Surface temperatures begin to fall at once but changes proceed slowly owing to heat capacity effects. The body temper-

ature rises as a result of the shifting of blood distribution and the slowing up of the return of cooled venous blood. Later, blood flowing from the periphery still fairly slowly would have a low enough temperature to reduce body temperature and rectal temperature would fall to its original level or even lower. The superficial veins of the skin constrict and no longer serve to cool blood as it returns to the heart. Now the venous blood returns mainly through the vena comits near the arteries. The entering blood is consequently cooled by the exchange of heat with the venous blood, while the latter is warmed at its expense so that the blood entering the hand or foot does so at a temperature very little above that of the surface. Thus, these parts receive O_2 from the cooled blood yet lose little heat to the environment. With continued cold there may be a reduced blood volume.

Time sequence of adjustments to heat.

The first effect of a hot environment is the warming of the skin surface and a consequent reduction in the thermal gradient. Vasodilation takes place and this at first causes a return of cooled peripheral blood along the path of entering arteries so that the blood is cool. The return of this venous blood is too rapid to allow its temperature to be raised to that of the deep tissues. Consequently, venous blood returns to the heart in quantity while still inadequately warmed and rectal temperatures fall and there is a feeling of cold.

The effects of warmth spreads rapidly throughout the tissues and soon blood sufficiently warmed flows to the interior and body temperature returns to normal. Respiration rate may rise and sweating develop. With mild warmth there may be a fall in blood pressure but severe heat may raise the blood pressure. Most of the returning venous blood returns in the superficial veins and helps to maintain high skin temperatures in the limbs. Venous blood does not now return via the venae comits and is not prewarmed but is rather further cooled as it passes along the superficial veins.

III. REVIEW OF LITERATURE.

1. HEAT PRODUCTION.

We have seen how to maintain a normal body temperature heat production must equal heat loss and that heat production varies with the environmental temperature. Under normal conditions, however, the main regulation is by way of heat loss, the heat production of an animal being more or less incidental to its normal biological functioning. However, it will be seen how heat production also has been found in cattle to vary with environmental temperature.

The heat production of an animal may be derived from the following sources:-

- a. Heat of maintenance of vital body processes - respiration, circulatory activity, tonus of muscles, etc.
- b. In cattle there is the heat of fermentation from the rumen.
- c. The heat of activity - foraging for food.
- d. The heat of production, e.g., milk production.
- e. And in tropical countries there is an additional heat load from solar radiation and the surroundings.

All these functions result in heat production at some stage or other and such heat must be eliminated by the four pathways of radiation, conduction, convection and evaporation. All except No. 5 result from energy derived from food or body reserves.

(a) The heat of maintenance.

Brody (6) gives for adult Jerseys and Holstein cattle the following values for resting energy maintenance cost:

<u>Jersey</u>		<u>Holstein</u>	
Body wgt. lbs.	Cals/day	Body wgt. lbs.	Cals/day
880	8492	1100	10570
990	9071	1200	11190
1100	9630	1320	11790

These measurements on resting metabolism were computed from O₂ consumption data measured with the animals at rest

under ordinary barn conditions. As the animals were not fasted the heat production included some of the heat increment of feeding as they were taken just before the morning feed.

(b) Heat of Fermentation.

Brody again gives data estimating that the well fed average dairy cow produces about 600 litres of rumen gases - mainly CH_4 and CO_2 per day, giving a fermentation energy of about 4000 Calories per day which is roughly $\frac{1}{2}$ - $\frac{1}{3}$ the resting maintenance heat production.

(c) Heat of Activity.

Bonsma (30), in South Africa, compared the reactions of different exotic and indigenous breeds when forced into walking tests. Exotic breeds could not proceed very far but Africander were able to walk all day under the same conditions. The British breeds with their poor adaptability to heat stress soon became hyperthermic as a result of the increased heat production involved in walking.

According to Brody (6) the energy required by a cow to walk one mile in addition to that of maintenance and energy cost of standing is 330 Calories per 1000 lbs. L.W.

Posture of the animal can affect its energy output. Most animals except perhaps horses - which have powerful suspensory and check ligaments and can rest standing as well as they can lying - have a greater energy expenditure on standing. The energy cost of standing above lying is about 9% in cattle and sheep. Ritzman and Benedict (51) found a fasting steer expended 9% more energy on standing - full fed, 12%. Hall and Brody (52) estimated the energy cost in getting up and down to be about 11 Calories per 1000 lbs. L.W.

(d) The Heat of Production.

(1) Gestation.

Brody (53) on work with Jersey and Holstein cattle has shown that the increased heat production with advancing gestation does not represent a heat increment of feeding, because

gestation according to his paper in itself does not increase food consumption and the increase in heat production is due to the increase in living tissue of the foetus. However, cows may put on weight over this period if given a liberal food supply. A Jersey cow had prior to breeding for its first gestation a heat production of 2000 Calories per square metre per day. There was a slight decline during the following 3 months and rose gradually till prior to calving it was 2200 Calories per square metre per day.

(2) Lactation.

In the same paper Brody shows that there is roughly a 60% increase in heat production 3 months after lactation begins, compared with that at the breeding level.

Heat Production of Jersey and
Holstein Cattle.

	<u>Age</u> <u>6 mths.</u>	<u>Breeding</u> <u>level</u>	<u>9th Mth.</u> <u>of gest-</u> <u>ation</u>	<u>1st Mth.</u> <u>of lact-</u> <u>ation</u>	<u>Lactation-</u> <u>al peak</u>
Cals/day J.	4097	7216	9762	10060	12024
H.	4980	8685	12954	12618	15004
Cals/sq. m./day J.	2087	2068	2211	2390	3003
H.	2113	2033	2455	2672	3118

This illustrates very clearly the great increase in heat production caused by lactation, due to the increased food intake, increased activity, and increased metabolism involved in the processes of milk manufacture, etc.

Ritzman and Benedict (5) worked out the heat balance of milking cows, taking into account the calorific value of all food ingested as well as that of all excreta, secretions and heat loss.

From the following table it can be seen that cows producing as these were, 2 gallons of milk per day, ingested food equivalent to 50,000 Calories and emitted 20,000 Calories in the form of heat.

Energy Exchange of Lactating Cows.

Av. Wgt. Kgm.	612	587	603
Gross Energy - food. Calories	53,211	44,306	52,173
Faeces	"	}	
Urine	"		
Methane	"		
	22,512	23,228	22,125
Brushings	-	-	-
Milk	7,163	7,836	6,832
Body Deposit	3,813	6,074	1,040
Heat	18,710	20,015	22,817

With all these functions there is the heat increment of feeding or specific dynamic action of food. In farm animals this energy increase due to feeding is quite large. Brody (6) states that it is 20% of the gross energy of a balanced mixed ration or about 50% above the fasting level - see Fig. 3.

The following table adapted from Brody (6) shows that the heat increment is considerable, though not as large as Brody's previous statement of a 50% increase. This would probably be due to the fact that these figures were worked out from results

Heat Production. Cals./day.

<u>Body Weight</u>	<u>Resting Metabolism</u>	<u>Basal Metabolism</u>	<u>S.D.A.</u>
<u>Jerseys</u>			
880	7680	5706	1974
990	8235	6119	2116
1100	8850	6576	2274
<u>Holsteins</u>			
880	8360	6379	1981
990	8910	6801	2109
1100	9450	7210	2240

on animals subjected to experimental conditions. Also the S.D.A. is very variable depending on many factors, many of which are not clear or agreed upon today. The plane of nutrition has an effect obviously as well as the balance between nutrients and on the productive process being observed. In cattle and sheep a large part of this heat increment would include the heat of fermentation, a heat not able to be

separated from true S.D.A. Under good feed conditions and with a lactating animal this heat increment is an important factor in heat regulation. It assists in maintaining the balance in cold weather but in hot weather it becomes a burden as the extra heat of feeding cannot be eliminated so readily as at lower temperatures.

Robinson and Lee (54) report an experiment in which hens, sows and ewes, were exposed one a week to 7 hours of hot temperature conditions. One group of each species was well fed and another group were given just maintenance. They found that the higher rate of feeding resulted in a very definite increase in rectal temperature, respiratory rate and rate of water loss in all the animals studied and pulse rate only moderately affected in sows, though markedly increased in hens, and to a less extent in ewes. Thus, these animals with poor thermal regulatory devices suffered from the high feed intakes at the higher temperatures. Cattle also react adversely to high temperatures and the same would probably apply to them. Robinson and Lee fed different proportions of protein in iso-caloric diets and found that the various measures of stress were not consistently affected by the percent of protein in the diet. This is surprising when it is usually believed that a protein diet gives rise to an increased heat production of 30-40% of its net calorific value. High protein and high temperatures did not cause the same adverse effects as did a normal ration given at high temperatures.

Bonsma (55) on the basis of observations rather than specific experimental data on metabolism maintains that animals in hot weather will cut down on their intake in order to reduce the load of heat to be dissipated. A cattle breed, developed in a cool temperate region will not thrive in the sub-tropics no matter how well it is fed. This is because such breeds readily become overheated and automatically eat less and the whole process of normal metabolism is disturbed.

Brody et al (56) (57), in a series of papers give a more scientific approach to the changes in heat production and food consumption with temperature. In this series of experiments 12 animals were housed for several months in a heat controlled room. Depressing the temperature from 50°F. to 40°F. increased the heat production 30-35% in lactating Jerseys and 20-25% in lactating Holsteins. This breed difference is due to body size, the smaller Jersey cows having a large surface area per unit of body weight, lose heat more rapidly than the larger Holstein. Therefore, there is need for a greater rise in heat production to compensate for the increased heat loss.

At the same time feed consumption increased more markedly in cows suddenly exposed for short periods than to those gradually conditioned to increasing cold due probably to acclimatization effects. Here Jerseys showed a greater rise in feed consumption than did Holsteins. Milk production declined more in Jerseys than in Holsteins - more nutrients being required by Jerseys to keep up body heat. Thus, in these cows, the increased heat production came from increased feed consumption and/or increased muscle tonus. Body temperatures remained the same so that increased heat dissipation was balanced by increased heat production.

When the cows were subjected to gradually rising temperatures from 50-105°F. Brody's results showed a surprising reduction of 30-40% in heat production after 80°F. This was associated with rising body temperatures indicating that decreased heat dissipation at the higher temperatures was not balanced sufficiently by the decreased heat production.

The reduction in heat production is notable in that workers have always postulated a rise in metabolism at high temperatures in accordance with Van't Hoff's law and some workers, e.g., McConnell (28) and Dubois (29) have found in man that heat production does increase markedly at the higher temperatures.

With the rise in body temperature and decline in heat production, there is a fall in milk production and feed consumption, with a decline in the animal's heat increment which, says Brody, may amount to 25% of the total heat production. Dempsey and Astwood (19) have demonstrated in the rat that environmental temperature depresses thyroxine production, at high temperatures by 80%. The 'basal metabolism' in thyroidectomized animals is 40% below normal and if the effects on rats may be used to explain the fall in heat production in cows then increasing temperatures up to 105°F. may reduce their thyroxine 80% and, therefore, the heat production by 32% ($.8 \times 40\%$). Thus, the decline in milk production, feed consumption and thyroid activity would explain most of the fall in heat production. Physiological wisdom by the cow makes it reduce its heat load as much as possible by a reduction in metabolism and heat increments.

On the basis of the reactions of their experimental cows to declining and increasing temperatures using 50°F. as a base, Brody et al conclude that the zone of minimum heat production in lactating dairy cows is 40-60°F. This is the first attempt in cows at defining the actual location of the temperature range of thermoneutrality. Jerseys were affected most by cold temperatures, and Holsteins by high temperatures. However, the initial starting point was 50°F. If any other temperature had been taken a different picture may have occurred because of the effects of acclimatization. In Brody's experiments control cows which were subjected to short periods of hot or cold temperatures the effects were much more marked than for experimental cows, and even the latter when brought back to 50°F. from 4°F. took some few weeks to return to their former 50°F. level.

Bonsma believes that Friesians having a larger appetite than Jerseys are affected more by high temperatures, which is what Brody has found - a greater depression of appetite in the Friesians than the Jerseys. On the other hand, in the cold the feed consumption of Holsteins does not need to be increased as

much as for the Jerseys, because of the difference in size.

In temperate climates the dairy cow may not have any great difficulty in getting rid of the heat from its activity and productivity. There may be times when a hyperthermic stage is reached in summer but the time of exposure would not be very great - the time factor is just as important as the height of temperature rise. In the tropics, however, a different situation exists. The solar heat load may be very great and since air temperature is very high, elimination of heat by radiation, conduction and convection is limited. Cows, being poorly sweating animals, increase their respiration rate markedly in order to increase evaporative loss of heat. Mention has been made before of the enormous heat load which may be imposed on an animal by the sun over and above its normal heat production. The effect of this solar heat load would be to set Brody's thermal-neutrality zones at a much lower level, as it seems that the cattle beasts' early response to an excessive heat load, whether from difficulty of eliminating heat just from high air temperature in itself, as with Brody's experiments, or from difficulty in getting rid of absorbed solar radiation, as with Bonsma's observations, is to cut down on its heat production and various heat increments.

2. EFFECT OF CLIMATE ON BODY TEMPERATURE OF CATTLE.

Dukes (58) places the normal body temperature of cattle at $101.1 \pm 0.5^{\circ}\text{F}$. Brody (6) gives 101.0. This is a fairly stable characteristic of homeotherms and only begins to rise when a state of hyperthermy exists. In humans there is rarely, except in very extreme cases, a rise in body temperature with air temperature, but with cattle it will be seen that body temperatures do rise and at quite early a stage.

The literature regarding body temperature of cattle may be divided into 2 broad sections.

(a) Body temperature in heat controlled room.

(b) Experiments in the field.

(a) Heat controlled experiments.

Hays (59) in 1926, working with Jersey cows in a controlled temperature room found that fat percentage and metabolism began to rise at 70°F. He gives no data on body temperature, but seeing that the rise in fat percentage has been found in other experiments (Brody) to be the stage when body temperature begins to rise then perhaps in Hays' trial body temperatures began to rise around about 70°F. This is lower than what other workers have found.

Regan and Richardson (60) observed that the effect of increasing air temperature - in a room maintained at constant humidity, 60 per cent R.H. and air movement 50' per minute - was to cause a rise in body temperature between 70-80°F.; a more marked rise after 80°F. These workers used three pairs of Jerseys, Guernseys and Holsteins. Body temperature of the Jerseys rose well after the Holsteins. They give the following data showing average rise in body temperature with increasing air temperature.

<u>Room Temp. °F.</u>	<u>Rectal Temp. °F.</u>
40.	101.0
50	101.0
60	101.0
70	101.3
80	101.8
85	102.2
90	102.7
95	103.7
100	105.1

Rieck and Lee (61) (62) in 1948, working with four pure-bred Jersey cows subjected them twice a week for 10 weeks to varying combinations of air temperature and somewhat unusually high combinations of humidity. Four calves were also subjected to the same procedure. The cattle were exposed for seven hours and were fed just before entering. Air movement was controlled at 60 ft/min.

Effect of Air Temperature on the Body Temperature
of Jersey Cows and Calves at a Constant Humidity
12 gr. cub/ft. (Adapted from Rieck & Lee's Data)

<u>Air T. °F.</u>	<u>Body Temp. °F.</u>	
	<u>Cows.</u>	<u>Calves.</u>
85	102.3	103.0
90	101.9	103.8
95	102.4	103.7
100	103.4	104.7
105	104.4	104.9
110	103.8	

Effect of Humidity at Constant Temp. 105°F.

<u>Absolute Humidity</u> <u>(gr/cub/ft.)</u>		
6	101.5	104.2
8	101.6	104.4
10	103.0	105.3
12	104.4	105.9
14	104.7	106.9
16	105.8	

This shows how body temperature rises with air temperature - in calves there is an earlier and more rapid initial rise though, as their graphs show, they attain a more stable, higher equilibrium than cows exposed to the same conditions.

Humidity increases, they state, had much less effect on calves than cows as shown by the increase in body temperature with increase in humidities. However, at the lowest humidity of 6 gr. per cubic foot the calves were already in a distressed condition, so that humidity appears to affect calves just as much as, or even more than, cows. The effect of humidity on the cows can be judged from the figures where an increased of 2 gr. per cubic foot of humidity at 105°F. has a greater effect on body temperature than an increase of 5°F. at 12 gr. per cubic foot. At lower temperatures and humidities, cows showed after an initial small rise an equilibrium, though at higher combinations there was no sign of equilibrium.

Brody et al (56) (57) in their series of papers on environmental physiology, have been able to define the critical temperatures of Jersey and Holstein cows quite well. Increasing temperature from 50-105°F. caused the rectal temperature to rise between 70 and 80°F. but more steeply in Holsteins than Jerseys. The

temperature of the Jerseys at 105°F. averaged 106°F. , and that of the Holsteins 108°F. Holsteins being larger cattle have difficulty in eliminating heat and thus the rise in body temperature due to early 'bottling up' of heat will take effect earlier in larger cows and rise to a higher level.

Decreasing this temperature from $50-40^{\circ}\text{F.}$ resulted in no change in body temperature, in either the Jerseys or Holsteins. There was a difference in other reactions to the cold but they were sufficient changes, to enable the specific dynamic action of increased feed intake and increasing diversion of nutrients normally intended for milk production to be diverted and used as fuel, to keep up body heat. That body temperatures did not change even as low as 40°F. shows how well adapted cattle are to withstand cold. However, this constancy of body temperature is only attained at the expense of increased heat production beginning at 40°F. , increased feed consumption, and a decline in milk production, so that the economic aspects have made themselves felt at temperatures of 40°F. Increasing temperatures from $60-80^{\circ}\text{F.}$ increases heat production, body temperature remains constant. Above 80°F. the body temperature rose and heat production declined. Thus, $70-80^{\circ}\text{F.}$ may be taken as the upper critical temperature for body temperature depending on breed and size of cow. The region of the lower critical temperature - where body temperature starts to fall again has not been determined. However, from the economic aspect the effects of falling temperature make themselves felt quite early - well before any fall in body temperature takes place, whenever that may be.

(b) Field Experiments.

Rhoad (63) (64), in Louisiana, carried out observations on the body temperature of four genetic types of cattle being used in that region to evolve a heat adaptive animal. These were:-

1. Pure-bred Aberdeen Angus.
2. $\frac{1}{4}$ Angus - $\frac{3}{4}$ Brahman.
3. $\frac{1}{2}$ Angus - $\frac{1}{2}$ Brahman.
4. Pure-bred Brahman.

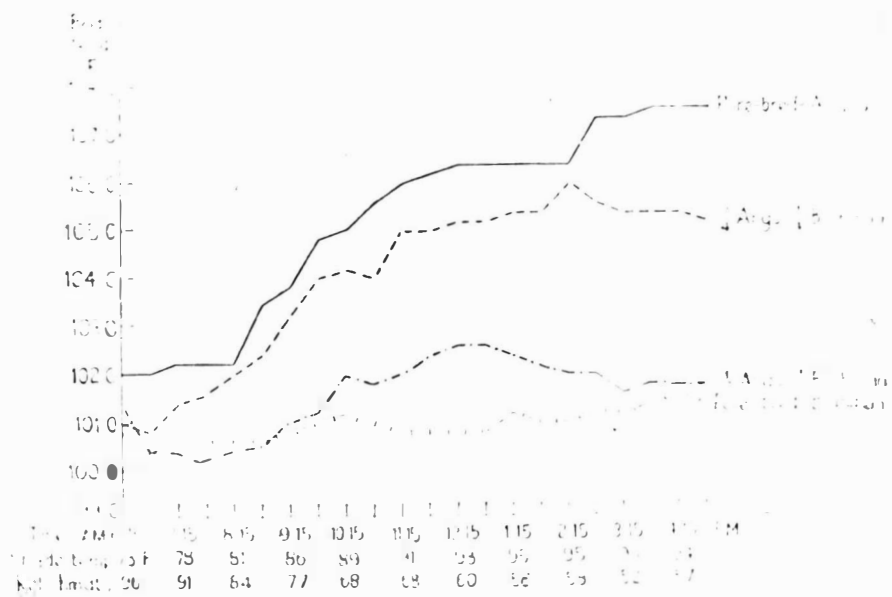


Fig. 5. Effect of air temperature and humidity on body temperature of exotic and native cattle.

Rhoads.

Readings were taken out in the open field and under a shade every half hour of the day.

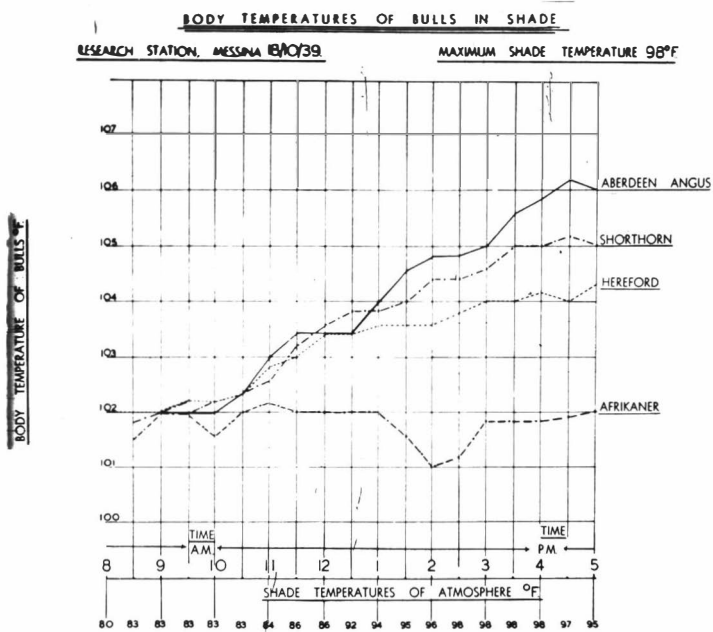
He found as atmospheric temperatures increase above 50°F. there is a general and significant increase in rectal temperature within each genetic type and the difference between each type was highly significant. At 80°F. the body temperature of the Aberdeen Angus and $\frac{3}{4}$ Angus $\frac{1}{4}$ Brahman was significantly increased when exposed to the sun but it was not until 90° that the $\frac{1}{2}$ Brahman and pure-bred Brahman began to have a rising body temperature due to solar radiation. The following is an extract from Rhoad's data:

Mean Rectal Temperatures of Cows in Shade and Sun °F.

Shade Temp. °F.	Cows held in	Pure-bred Angus	$\frac{3}{4}$ Angus $\frac{1}{4}$ Brahman	$\frac{1}{2}$ Angus $\frac{1}{2}$ Brahman	Pure-bred Brahman.
86-95	Sun	104.0	103.4	101.8	101.3
	Shade	102.8	101.9	100.9	101.0
76-85	Sun	102.4	102.4	101.9	101.1
	Shade	101.7	101.4	101.0	101.0

Fig 5 shows quite clearly the marked rise in the Angus and $\frac{1}{4}$ Brahman Angus compared with the other two genetic types. Also the diagram shows how, with falling relative humidities at the higher temperatures the body temperature of the $\frac{1}{2}$ Angus $\frac{1}{2}$ Brahman and pure-bred Brahman, begins to decline. Is this due to better evaporative loss in the Brahman with lower humidity even though air temperature is still quite high? Rhoad does claim that the evaporative loss is greater in these latter two breeds. He also concluded that the tropical climatic conditions were within the range of thermal neutrality for $\frac{1}{2}$ bred Brahman and pure-bred Brahman, but definitely not so for the former two types. It can also be seen how with rising temperature the $\frac{1}{2}$ Bred Brahman and pure-bred Brahman tended to decrease in body temperature for a time until a steady value was obtained and with still further rises in temperature, it began to rise.

For much of his work Rhoad (65) (66) devised a test for adaptability - the Heat Tolerance Test. Animals were allowed out into an open paddock provided with pens and a chute. Only hot,



ig. 6. Body temperature of bulls in the shade -
exotics and indigenous types.

Messina

clear days were chosen and body temperatures were taken in the morning and afternoon. For deriving his heat tolerance coefficient he uses the following formula.

$$A = 100 - 10 (B.T. - 101.0)$$

A = adaptability coefficient; 101.0 = Average normal body temperature.

B.T. = Body temperature found in test and 10 is a factor for converting degrees deviation from normal to a unit basis.

Perfect adaptability when A = 100.

This provides a ready field method for determining the heat tolerance of an animal and several workers have used it. The following table shows H.T.C. data for various breeds. Jerseys come next to Brahman in order of merit.

SCALE OF HEAT TOLERANCE AS DETERMINED BY IBERIA
HEAT TOLERANCE TEST 1944 (Rhoad).

Breeding	Number of animals	Number of tests	H.T.C.
Pure-bred Brahman	7	18	89
$\frac{1}{2}$ Brahman $\frac{1}{2}$ Angus	18	67	84
Pure Santa Gertrudis	7	21	82
$\frac{1}{2}$ Africander $\frac{1}{2}$ Angus	22	64	80
Pure-bred Jersey	34	34	79
Grade Hereford	12	12	73
Pure-bred Aberdeen Angus	31	69	59

Bonsma (67), South Africa, has carried out large field experiments comparing the influence of climate upon exotic breeds and the Africander and first generation cross bred cattle

Fig. 6 shows how the body temperature of four bulls rise in the shade with rising air temperatures. Note how the Africander was little affected by rising air temperature, whereas with the Aberdeen Angus, Shorthorn and Hereford, the body temperatures began to rise at 80°F. Much of the effects of solar radiation would not be affecting the animals directly because these readings were taken in the shade, but this field trial is surprisingly

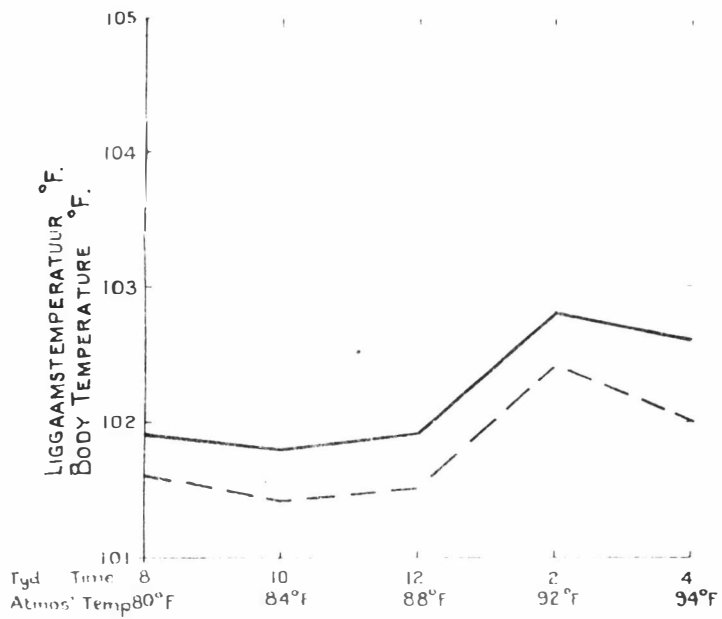


fig. 6b. The effect of environmental temperature on the body temperature of woolly and glossy coated temperate cattle - Bonsma.

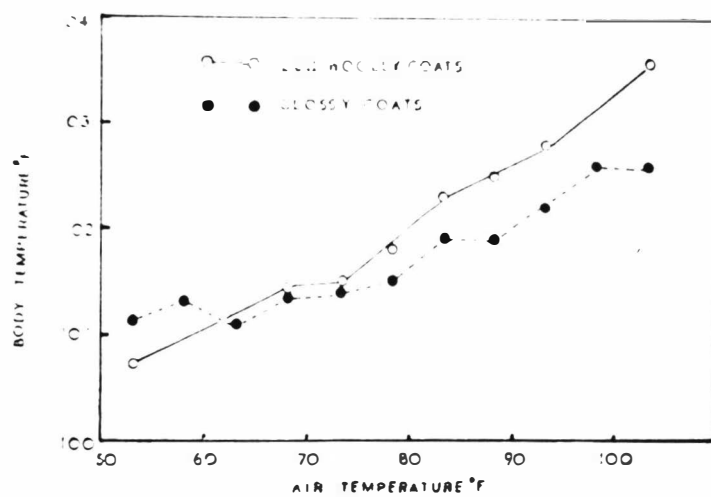


Fig. 6

close to Brody's experiments where the latter found the body temperature of Jersey and Holstein cows began to rise at about 80°F. Rhoad showed that the B.T. of the pure-bred Angus began to rise markedly at 80°F. but this was while the animal was in the sun and radiation was intense.

Kendall (68) working on a small sample of Friesians and Zebus in Tanganyika, found that Zebus showed little rise in body temperature from morning (mean air temp. 68.6°F.) to mid-afternoon (mean air temp. 80.6°F.). Friesians, however, showed a greater rise while cross-breds showed rises of an intermediate order.

French (69), another South African worker, reports that rectal temperatures of Zebu cattle are slightly below those of high grade Ayrshire and Holstein grades, but this difference becomes much greater at midday.

Bonsma and Pretorious (67), 1943, have gone to great lengths to stress the importance of the type of coat as influencing an animal's reaction to heat. If an animal possesses a dense woolly coat then it will readily become hyperthermic at high air temperatures and solar radiations. They maintain that even within a breed there are woolly animals and smooth-coated animals. They show how the woolly-coated animals react much earlier and have a higher body temperature than smooth-coated animals exposed to the same conditions. When under shade, woolly animals still show a higher body temperature but the rise in body temperature does not take place until air temperature reaches 88°F.

Bonsma (30) has also carried out heat tolerance tests using Rhoad's formula. Readings were taken morning and afternoon once a week for 4 years on various breeds of cattle. Work done by his division indicates that an animal's H.T.C. increases with age, especially after the second year. If a calf has a high degree of resistance and can tolerate during its first year high air temperatures, then its powers of resistance to tropical conditions will be high. The higher the H.T.C. of an animal in its first year the better will it grow and thrive as an adult

under the prevailing conditions and Bonsma (70) advocates this as a method of selection in the Tropics. Hammond also maintains that the power of heat regulation gradually develops as the animal grows older.

The following table adapted from Bonsma (30), shows how H.T.C. of four Aberdeen Angus heifers changes with age. In the case of Africander cattle the differences are not so great.

Age	0-1 yr.	1-2 yrs.	2-3 yrs.	3-4 yrs.
Av. B.T. at air temps. above 85°F. - (°F.)	103.3	102.5	101.6	101.6
H.T.C.	77	85	94	94

Even within a breed the H.T.C. will vary with the type of coat.

Baker and Black (71) in a recent report give the following data for heat tolerance on a large number of female crossbred cattle.

Brahman x Angus	Heifers				Mature Cows			
	Yearlings		2 yr olds		Dry		Lactating	
	No.	H.T.C.	No.	H.T.C.	No.	H.T.C.	No.	H.T.C.
$\frac{1}{2}$ B.	12	81.25	11	86.45	13	87.77	32	84.66
$\frac{1}{4}$ B.	84	80.06	63	85.46	23	89.31	49	83.63
$\frac{3}{8}$ B.	47	80.98	32	86.34	10	88.85	15	84.80
$\frac{1}{2}$ Afric-Ang	37	77.49	29	85.96	13	89.12	23	82.48
Total or mean	180	79.85	135	85.90	95	88.90	119	83.80

It can be seen that as a group the 95 dry cows have the highest H.T.C., next came the 135 2 yr. olds, then the 119 lactating cows and lastly, the 180 yearlings which were the lowest. This illustrates that heat tolerance varies with age and physiological status of mature cows.

Gaalaas (72) is another worker who has used a heat tolerance coefficient to measure differences between cattle. He used as a formula $HT = 100 - 14 (BT - 101)$ and calculated the BT somewhat

differently to Rhoad and Bonsma.

In Rhoad's formula the factor 10 is used merely to remove the decimal from the result in parenthesis. In this manner a whole number coefficient on a scale of 100 is obtained. Rhoad criticizes Gaalaas' use of the factor 14. Gaalaas (73) assumed that a body temperature of 108 at 90°F. indicated zero efficiency while 101°F. at 90° meant 100% efficiency. Note that Gaalaas changed this factor 10 to 14 on an assumption. Later in correspondence with Rhoad, Gaalaas states "that a factor 14 was found necessary because his cows had access to shade instead of requiring them to be held in the sun. The factor 14 is large enough to correct for the observed average difference in body temperature."

Rhoad (73) after a survey of Gaalaas' earlier work published in 1945 agrees that the use of 14 was justified but argued against Gaalaas for using it in his paper in 1947 without experimental data to substantiate it.

Gaalaas' heat tolerance coefficient was determined by first calculating the body temperature at 90° air temperature from Linear regression equations. If at 90° the calculated B.T. was 108°F. then the H.T.C. would be zero, if it was 101 the H.T.C. = 100. Since there is a known regression of body temperature on air temperature (Gaalaas, 1945) it was considered that calculating the body temperature at 90°F. from regression formula would be more accurate than using the average body temperature within a specified air temperature range as did Rhoad and Bonsma. This method also permits the use of all readings made.

Rhoad's method is sound where there is consistently high air temperatures but would be of little use in a temperate climate such as New Zealand where air temperatures in our dairying areas seldom reaches above 85°F. The method of Gaalaas could, however, be used, provided sufficient readings were taken to derive the regression equation of air temperature and body temperature.

Gaalaas used this H.T.C. to answer several questions. He wanted to know if the body temperature is stable from year to year and does the age of the animal, stage of gestation, or lactation,

affect the body reaction and are there real differences between individuals, or groups of cows.

By an analysis of variance on his calculated H.T. figures he found little difference in the heat tolerance of the herd from year to year. Analysed in age groups, however, he found a significant difference between the 2-3 year age grade, but older groups showed no significant difference. The 2 year olds showed the lowest H.T.C. and the three year olds the highest. It was a stable characteristic at 4 years but not at 2-3 years. This confirms in part Bonsma's assertion that the H.T.C. changes with age especially after the second year.

On the basis of analysing in sire groups Gaalaas found significant differences in mean sire groups at 2-3 years of age, but little difference over that age. The results of the sire on the heat tolerance of his daughters would therefore appear to be negligible except at certain ages. The H.T. at 2 years of age would have little value in predicting the H.T. at 6 years. Bonsma (74) believed a high heat tolerance in the first year or so will enable an animal to withstand climatic conditions as mature animal, i.e., high H.T. will persist and increase, yet with Gaalaas' results the heat tolerance differences tend to even out as the animal's reach maturity. Gaalaas' work was carried out under less extreme conditions than those of Bonsma, and he dealt with dairy cattle, Jerseys and Holsteins, whereas Bonsma worked with many breeds and used the different hairy coated animals to stress his heat tolerance findings. Whether such coat differences exist amongst pedigree herds of dairy cattle even under good management conditions is not known.

Differences between the average H.T. of cows when milking and when dry were not significant and there was apparently little difference of H.T. when milking and gestating. This is another surprising factor when we remember the large heat increment of feeding and the 60% of increase in heat production caused by lactation (Brody). Under high air temperatures this should tend to

make the animal more readily hyperthermic, set the upper critical temperatures at lower level than for a dry cow. Brody had one dry Holstein cow in the experimental chamber and although it did not show the marked body temperature rise with air temperature as did lactating Holsteins, it also started to rise about 80°F. However, with one animal not much reliance can be based on this. There is perhaps significance in that the lactating cows begin the decline in milk production at 80°F. so that soon they are also virtually dry. The effects of air temperature then, between dry and lactating cows, may not be shown up so well when dealing with body temperature, as it would with the resultant effects of milk production taken into account.

On the other hand McDowall and Hilder (75) at Beltsville found at 65°F. that there was no difference in body temperature of dry or lactating cows. At 90-100°F. little change was noted in temperatures of dry cows, but there were definite increases in the lactating group. Greatest rises in rectal temperature were associated with greatest feed intake in both dry and lactating cows.

These heat tolerance tests take into account only one measurable climatic factor, i.e., air temperature. Rieck and Lee's results show that humidity also accentuates the thermal stress increasing with increasing air temperature. Seath and Miller (76) have carried out one of the few pieces of field work involving humidities. They found over a period of 2 years with 77 Holsteins and 43 Jerseys that air temperature was the major cause of increases in body temperature. On the basis of multiple regression equations they found 1°F. rise in air temperature was 13-15 times as effective in raising body temperature as 1% change in relative humidity. This is contrary to the findings of Rieck and Lee but the experiments were widely separated in method of approach and the latter workers' combinations of humidity were somewhat unusual. However, they did use the more correct absolute humidity rather than relative humidity. Bonsma (30) on the basis of Seath and Miller's results does not regard humidity of very great importance in response of cattle to

climate. Manressa et al (77) in the Phillippines noted that with air temperature some 24.9°C a reduction in relative humidity from 82 to 75% caused a fall in body temperature of Holsteins. Seath and Miller (78), 1946, in another paper, with 3 Jerseys and 3 Holsteins, took readings for 3 days - when cows entered the pasture, when entered the shade, one hour after in the shade, one in the mid-afternoon and in the milking shed at night. Atmospheric temperatures ranged from 73.0°F . at 5.45 a.m. to 86.7°F . at 2 p.m. Body temperatures rose when air temperature was about 80°F . and cows soon sought the shade.

Comparing the reactions of Jerseys and Holsteins to temperature, Seath and Miller (79) found that Holsteins averaged higher then Jerseys in body temperature, and the rate of increase of body temperature as a result of air temperature was greater for Holsteins and Jerseys. This has since been confirmed by Brody (13). Their 1944 data show that an increase in humidity tended to slightly increase the body temperature and respiration rate of Jerseys with an opposite effect on Holsteins but concluded even so that changes in air temperature causes much greater effect than changes in humidity. In each year attempts were made to estimate the percentage of the body surface of Holsteins which was white but they failed to show any relationship between the amount of white and heat tolerance, but this may have been overshadowed by more important factors such as body size.

Gaalaas, 1945, (80) analysed results of observations on body temperature and respiration of Jersey cattle. Regardless of the season of the year the average body temperature and respiration rate per minute were considerably higher in the afternoon than in the morning. Manressa and Erce (80) in the Phillippines found the afternoon temperatures of Jersey, Holsteins and Indian Nellore cattle was significantly higher than the morning temperatures. The daily afternoon temperatures of the Jerseys were not significantly different from the Indian cattle but that of Holsteins was different. Even so, the

Jerseys were not as successful as the Indian cattle so that other factors such as decreased feed intake with the Jerseys, perhaps caused their lesser adaptation.

Kriss (81) working with dry cows found that body temperatures were fairly stable until mid-afternoon when they began to rise slightly.

Duckworth and Rattray (82) studied diurnal variations with Holstein Zebu calves. Two peaks of body temperature were observed, one at noon and one in the evening.

Minnet (83) took hourly observations over 24 hours on hill bulls and sheep and showed that the body temperature started to rise at 6 a.m., followed an upward trend to early evening, and then gradually fell to a minimum between 1 and 4 a.m.

Gaalaas (80) found a wide range of body temperature for individual cows. Below 70°F. body temperature showed no relation with air temperature $r = 0.08$. Above 70°F. the relationship was marked $r = 0.59$ and over the full range of air temperatures 33-95°F., $r = 0.57$. Between the range of air temperature 50-60°F. 17 cows had each 13 sets of readings and the average body temperature was 101.06 with a standard deviation of 0.46. Range was 99.0 - 102.3°F. Regardless of the high body temperatures and respiration rates only a few cases of acute distress as evidenced by panting and drooling at the mouth occurred.

Seath and Miller (76) using partial correlations and holding humidity constant, found correlation between air temperature and body temperature + 0.67 for 1944 and 0.534 for 1945. Correlation for air temperature and respiration rate was 0.748 for 1944 and 0.353 for 1945.

Seath and Miller (84) worked out the repeatability of body temperature observations using 20 milking Holsteins on 14 consecutive days. Temperatures taken out in the paddock and in the barn after the cows had been moved up for milking showed no significant difference. Increasing the number of observations on an animal causes a gradual reduction in temporary variance and an increase in the proportion of the total variance which is

genetically caused by permanent differences between cows. Repeatability for 14 days was 0.288. Observations over 6 or 7 days did not increase the accuracy and they concluded that observations on 6 - 7 warm days plus respiration rate measurements could be used as a basis of selection for a high degree of heat tolerance.

Seath (85) studying the records of body temperature and respiration rate of 2 separate dairy herds found that the intra class correlations on warmer days were better than if all days were taken. Using 8 warmer days repeatability of individual body temperature of some cows was .152 in 1944 and .385 in 1945. Estimates of heritability based on sire progeny differences were 15.1% and 30.9% for the two years.

Besides the influence of climate there are other factors which influence body temperature. Stage of gestation will have an effect. Blaxter and Price, 1945, (86) have found that during pregnancy increases in body temperature were apparent after the 6th week before calving, increases ranging from 0.75 to 1.25°F.

Summary.

1. High air temperatures influence the body temperature of cattle to a marked degree, the effect being greatest with temperate breeds and least with tropical breeds.
2. Calves cannot withstand as high a temperature as cows.
3. About 80°F. appears the upper critical temperature for cattle as far as body temperature is concerned.
4. The heat tolerance test has been used by various workers as a simple field test to determine relative tolerance to heat of different cattle. Tropical cattle possesses the highest heat tolerance coefficient and among the temperate breeds the Jerseys have the best and the Angus cattle the least H.T.C.

3. THE EFFECT OF CLIMATE ON RESPIRATION RATE OF CATTLE.

(a) Controlled Experiments.

Regan and Richardson (60), kept 3 pairs of Jerseys and Holsteins and Guernseys in a large room with temperature controlled from 40 - 100°F. The following data from their trial

show how respiration rate rises with air temperature.

<u>Room T. °F.</u>	<u>Resp./min.</u>	<u>Rectal temp.</u>
40	12	101.0
50	17	101.0
60	28	101.0
70	42	101.3
80	56	101.8
85	70	102.2
90	88	102.7
95	106	103.7
100	124	105.1

Note that the respiration rate begins to rise well before any rise in body temperature takes place. This is a characteristic of cattle. The respiration rate closely followed Vant Hoff's law for chemical reactions and was approximately doubled for every increase of 18°F. rising from 12-124 respirations per minute between 40 - 100°F. This Vant Hoff effect has been found to hold true by many other workers - Brody (6), 1945; Kleiber and Regan (27), 1935; Blaxter and Price (86), 1945; and Rhoad (87), 1936.

Bartlett (88) subjected 2 cows to an experimental room heated to about 80°F., but neither humidity or air movement was controlled. Two other cows were kept at ordinary air temperature and the two pairs of animals were changed over after a time. Body temperatures tended to rise above 80°F. and respiration rates increased with higher temperatures, being about 17 - 26 at temperatures of 50°F. and 36 - 50 respirations per minute at 75 - 87°F.

Kleiber and Regan (27) had two cows in a hot room with humidity controlled at 50%. Respiration rates rose with air temperature following Vant Hoff's law. A mask was fitted over the muzzles of the cows. Breathing cold air in a hot environment markedly decreased rate of respiration, ventilation rate and increased the depth of breathing. Breathing warm air in a cold

environment had no effect on any of these three measures. They concluded that cows decrease the depth of breathing in a hot environment, this increases the dead space per breath and facilitates maximum ventilation of the lungs, without causing alkalosis effects which result if there is excessive alveolar ventilation.

Rieck and Lee (61) (62) mentioned previously, found with cows that the respiration rate for a mean ante-room temperature was 25 respirations per minute, rising up to 150 per minute at higher temperature and humidity combinations in the hot room.

Effect of Air Temperatures and Humidity on Cows and Calves

Exposed for 7 Hours (Adapted from Rieck and Lee).

<u>Humidity content of</u> <u>12/cub.ft.</u> <u>Air T. °F.</u>	<u>Resp./Min.</u>	
	<u>Cows</u>	<u>Calves.</u>
85	55	90
90	60	148
95	80	155
100	110	190
105	135	190
110	130	-
 % increase over mean rate of 50-70°F. for air temp. of 105°F.		
	440	805
 Temperature constant at 105°F. Humidity (gr. per cub. ft.).		
6	47	160
8	65	175
10	100	190
12	135	185
14	145	205
16	150	-
 % increase over mean rate at 2-6 gr/cub. ft. for humidity of 14 gr/cub. ft.		
	480	876

In calves the rises in respiration rate were more striking. The above summary of their data, shows how great is the increase in respiration rate with air temperature. The same is true for humidity, increases appearing to be more marked with calves than with cows, though Rieck and Lee say that humidity had a greater effect on cows than on calves. A two gr. per cubic foot increase in any one case does show a greater increase for cows than calves but even at the lowest humidity 6 gr. per cubic

foot, calves respiration rate is already at a high level so that humidity must have a greater effect on calves than on cows. Increases in respiration rate proceeded any rise in body temperature. Respirating minute volume rose with air temperature not as rapidly as the rate so that tidal volume was reduced. On exposure to the various temperatures respiration rates of calves showed more rapid initial rise and also higher constant values than cows.

Brody, et al (13) found that increasing air temperatures from 50-105°F. increased respiration rate. There was a difference between Holsteins and Jerseys. The visible rise in respiration rate began at about 60°F. with Holsteins, was steepest between 70-80°F. and at 95-105°F. reached a ceiling of 3-4 times the level at 50°F. (20-30). The visible rise in Jerseys began at about 70°F. and at 100°F. reached a ceiling of 5-6 times the level at 50°F. Now it has already been noted that the body temperatures of these Jerseys did not rise as high or as quickly as did those of the Holsteins. Was it because the Jerseys were able to keep themselves cooler by having a greater respiration rate and greater evaporation cooling? Decreasing environmental temperatures from 50-40°F. (56) resulted in a reduction in respiration rate to about $\frac{1}{4}$ of that at 50°F. At these low temperatures there was no evidence of a breed difference in respiratory response.

(b) Field Experiments.

Rhoad (63) (64), comparing Aberdeen Angus, $\frac{3}{4}$ Angus and $\frac{1}{4}$ Brahman, $\frac{1}{2}$ Angus Brahman, and Pure-bred Brahman found within each of the four genetic types a regular increase in the rate of respiration from the lower to the higher temperatures - being greatest in the first two types. In the sun the increases were more marked but it was not until 85-90°F. that the pure-bred Brahman began to increase its respiration and then not to any great extent as shown in the following table

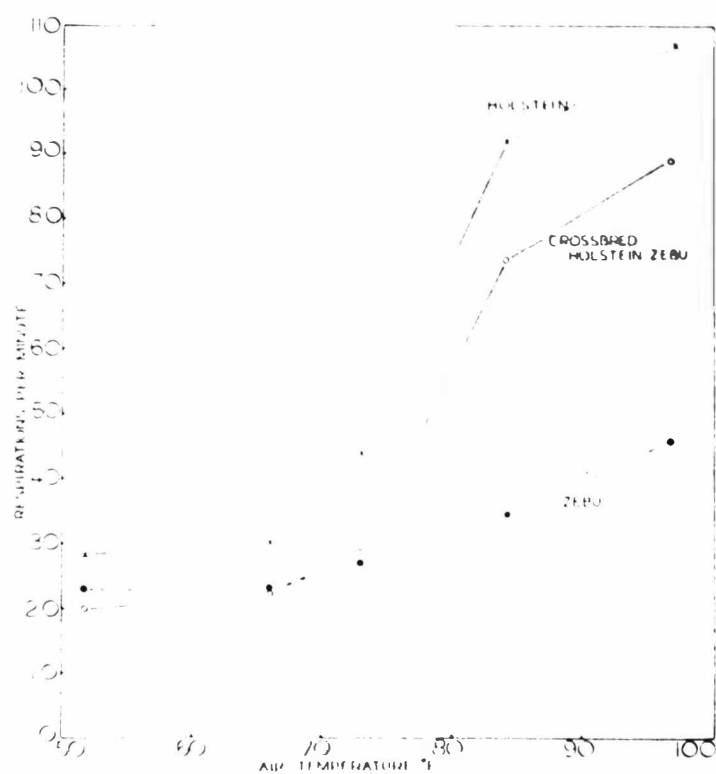


fig. 8. The effect of air temperature on respiration rate of Holstein, Holstein x Zebu and Zebu cattle. - Rhoad.

Respirations/Minute.

Shade Temp °F.	Cows Held	Angus.	$\frac{3}{4}$ A. $\frac{1}{4}$ B	$\frac{1}{2}$ A. B.	Pure Brahman.
86 - 95	Sun Shade	102.2 88.9	105.4 88.0	55.1 44.8	36.8 32.7
76 - 85	Sun Shade	88.3 67.6	74.2 31.8	37.1 31.8	28.7 25.5

That the number of respirations per minute of the pure-bred Angus cow did not surpass that of the $\frac{3}{4}$ Angus, while held in the sun, was due to panting which lowered the rate but increased the depth of breathing. This tends to cause excessive loss of CO₂ leading to alkalosis.

While in Brazil in 1936 Rhoad (87) used Holsteins, Holstein-Zebu crossbreds and two Zebus. His results on respiration rates are shown in Fig. 8.

The normal respiration rate is the same for all groups. There was a slight increase between 51-66°F. for the Holsteins but it was not until 73°F. that a large increase was observed in all animals except Zebus. This range of 22°F., Rhoad attributes to normal physical regulation in which energy loss is not detrimental to normal functions of production and growth. Further increases in temperature above 73°F. caused large increases in respiration rate in all animals except the Zebus. This increase above 73°F. indicated, says Rhoad, an increased metabolic rate and considerable loss of energy due to the muscular activity of breathing. Zebus did not show any marked increase in respiration rate at any stage even up to 95°F. The energy expended in physical regulation and increased metabolism at the higher air temperatures is energy that, at comfortable air temperatures, could be used more profitably for productive processes. Rhoad's statement of an increase in metabolism at the higher temperatures has been shown by Brody (13) to be incorrect but possibly there is an increased energy expenditure with high respiratory activity, but not enough to cause a rise.

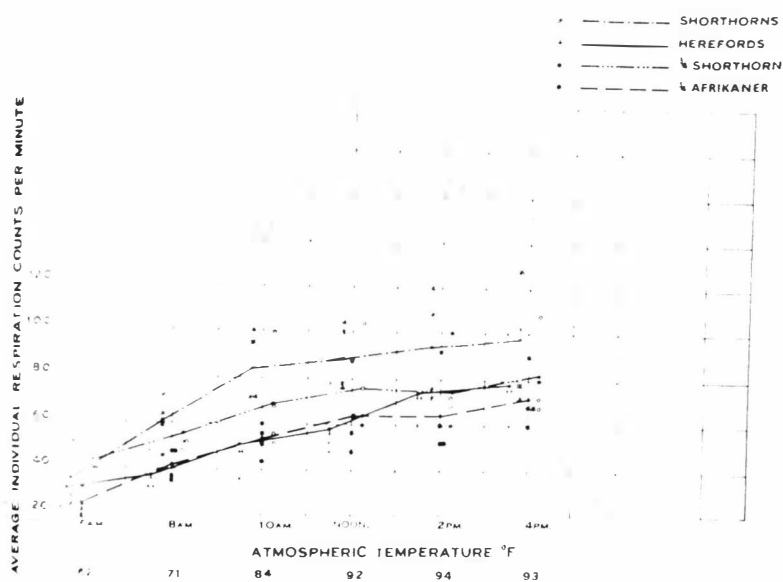


Fig. 9. Respiration rates of calves of various breeds exposed to high air temperatures. - Brody.

in metabolism which Rhoad and Hays believed took place.

Magee (89) working with a goat got a rise in metabolism below 55°F. and above 70° and attributed the rise in metabolism to energy expended in panting.

During the hot summer months Rhoad found that the pure-bred cattle would often seek the shade for the greater part of the day. Even while in the shade the cows did not lay down, but remained standing so as to facilitate respiratory movements and in this way may expend more energy than the Zebus, which were quietly grazing out in the sun. This difference in respiratory activity is probably related in part to the hairy coat difference but Rhoad found no correlation between hair length and respiration counts. Rhoad, 1938, carried out similar work with different cattle breeds and noted the effect of high temperature and increasing respiration rates.

French (69) in Tanganyika, showed that Zebu and Sanga breeds are little influenced by rises in temperature but that the higher the zebu is graded to the Ayreshire the greater is the influence of temperature on respiration rates.

Bonsma (90), in South Africa, has carried out similar work to Rhoad comparing Africander to exotic breeds. He shows how average respiration counts of calves increase as the environmental temperature rises. Early in the morning there is little variation in the average respiration counts per minute between different individuals belonging to the same or to different breeds. As temperature rises the average respiration counts begin to vary more between different individuals and after a continuous stimulation of the respiratory centre the rhythmical functioning of respiration discontinues and the average respiration counts between individuals even of the same breed vary greatly. - Fig. 9.

Average respirations per minute taken on cattle at 12 noon to 2 p.m. every fortnight throughout the year show that mature animals belonging to the exotic breeds respire at an increased rate at midday for the greater part of the year. The

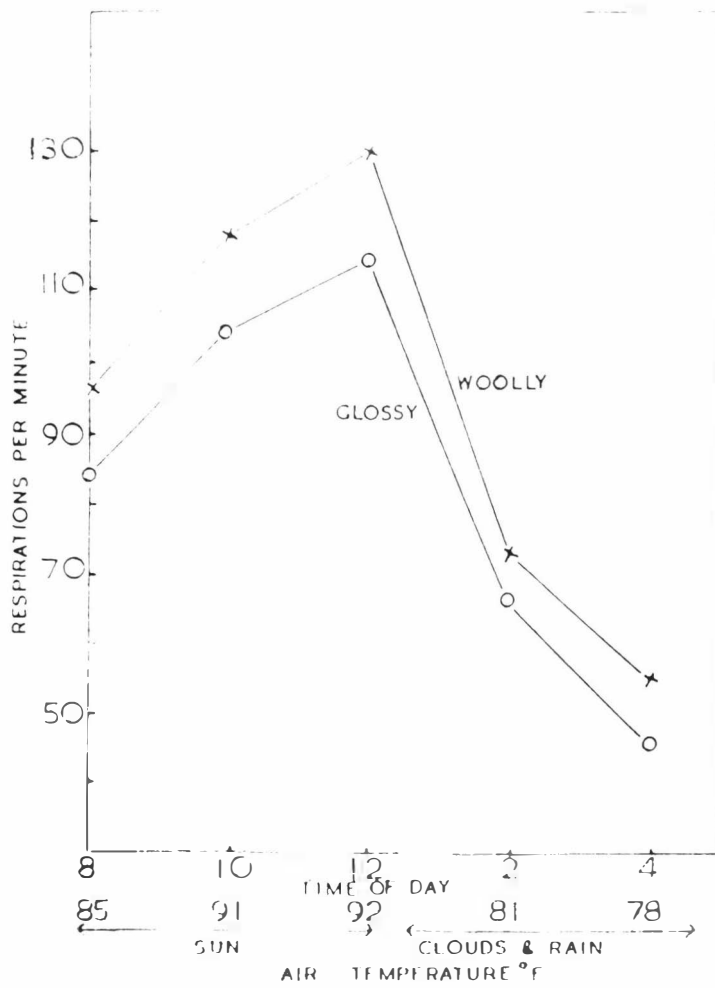


Fig. 10. The effect of air temperature on the respiration rate of woolly and glossy coated cattle and the effect of sunshine, cloud and rain. - Consma.

differences between the average respiration rates per minute of cattle belonging to the exotic beef breeds and the respiration rate in Africanders, increases markedly as soon as the dry bulb thermometer registers a temperature above 70°F.

Effect of Air Temperature on Respiration Rates of
Temperate, Tropical and Cross-bred Cattle -
Adapted from Bonsma (1940).

<u>Shade Temp.</u> <u>°F.</u>	<u>Respirations per minute.</u>				
	Herefd.	Angus	Shthorn.	Afric.	Afric.- Shthorn.
80	49	65	92	48	39
84	71	74	112	54	39
90	85	95	141	59	42
94	98	116	112	71	48

Bonsma and Pretories, (67), have shown the effect of coat colour on the respiration rate and the findings are similar to those found for body temperature, i.e., the dull woolly coated animals showed a higher respiratory rate and a greater rise than the smooth coated animals. Shade slowed down the respiratory rate of both woolly and smooth coated cattle. - Fig. 10.

Seath and Miller (79) comparing Jersey and Holstein cows over two years found that differences between breeds on the basis of respiration rates were small and not consistent as between years, though respiration rates increased with increases in air temperature. Humidity tended to slightly increase respiration rates in the Jerseys and decrease it in the Holsteins.

In another experiment with 3 Jerseys and 3 Holsteins, Seath and Miller (78) found respiration rates increased throughout the day and even though animals sought the shade early in the morning respiration rate and body temperature still tended to increase.

In analysing the effect of temperature and humidity on respiration rate, Seath and Miller (76) found 1°F. change in air temperature had from 41-43 times as much effect as 1% change in relative humidity. On a partial correlation basis with air temperature held constant an increase in humidity slightly lowered the respiration rate. Blaxter (91) believes this to

be an artifact due to the statistical treatment of the data and remembering Rieck and Lee's results this is quite likely the reason for the anomaly.

Repeatability estimates on 20 cows for 14 consecutive days (Seath and Miller (85)) yielded 0.36 and 0.446 for outside and inside a barn. If 8 of the warmer days were taken then the estimates were 0.42 and 0.48. As with body temperature their analysis showed that increasing the number of observations above 6 or 7 did not increase the efficiency of obtaining an accurate estimate of the reactions of animals necessary for selection for tolerance against heat.

In a survey of the records of 21 cows over two years, Seath (84) found repeatabilities on 8 warmer days to be 0.64 for respiration rate. This is a higher estimate than shown in the previous paper. Estimates of heritability based on sire progeny differences were 76.6% and 84.3% for the two years, but these are hard to explain as body temperature heritability estimates were only 15-30%. Possibly the statistical treatment of the data has once again brought forward this result and Seath himself admits that the estimate is faulty.

Gaalaas (80) analysed the relationship between air temperature and respiration rates of Jersey cattle. Respiration rates were always higher in the afternoon regardless of the month of the year. Over 3000 readings of respiration rate were taken at various temperatures. His data indicates how the average respiration rate began to increase at a lower air temperature than body temperature - 51°F. The rate continued to increase slowly as the air temperature rose to 67°F. and then began to increase more rapidly. There was great variability in the respiration rate of individuals, the extent increasing as air temperature rise. Below 69°F. the range was 8-78 per minute; above 69°F. the range was 16-127 per minute, but for most cows the values lay between 16 and 28.

For 17 cows 13 readings were taken between 50-60°F. and the normal respiration rate was found to be 22 ± 6 per minute. Dukes (58), gives average respiration rate as 20 per minute and so does Bonsma (90). The correlation between air temperature and respiration rate, Gaalaas found to be $r = 0.77$ over the full range of air temperatures 33-95°F.

Summarizing.

1. The respiration of cattle increases with environmental temperature. This increase takes place well before any rise in body temperature, usually at about 60-70°F.

2. The rate of increase follows the Vant' Hoff's law.

3. Though not fully clear as yet, increases in humidity tend to accentuate respiration rate response. Further work perhaps by Brody, may finally clear up the relative importance of humidity.

4. On the basis of a large number of observations, normal respiration rates between 50-60°F. has been found to be 22 ± 6 per minute but great individual variations occur.

5. With exotic breeds compared with indigenous breeds in the tropics, the former have a marked increase in respiration rate with air temperature - more so with woolly coated exotics whereas the effects on indigenous breeds are only slight. What then, is the avenue of evaporative loss in the latter case - sweat gland activity or osmotic moisture loss? More will be said about this point later. It is important to note here that exotic breeds rely very greatly on evaporative loss of heat via the respiratory tract to regulate heat balance and that at high air temperatures this method is inefficient and hyperthermy ensues with fall in heat production, depressed milk and feed consumption.

6. Even within the temperate breeds there are differences as measured by differences in respiratory response to air temperature.

4. THE INFLUENCE OF CLIMATE ON PULSE RATE OF CATTLE.

Dukes (58), gives a range of 40-60 beats per minute for pulse rate of cattle, and Fuller (92), on the basis of previous literature and his own observations gives the variation in heart rates of dairy cows as high as 38-96 beats per minute. These figures do not apply to the variation met within an individual but rather to the range in which most of the heart rates of healthy dairy cows fall. Work by Alfredson and Sykes (93) on many breeds of dairy cattle agreed with those of Fuller.

Pulse rates of cows are subject to wide variations and factors other than temperature, humidity, etc., must be considered first.

Blaxter (94), found that most reliable method of recording heart beat was by direct auscultation as various movements result in not allowing sufficient time to palpate the arteries. Even the placing of a stethoscope on the chest wall caused nervous symptoms with a rise in pulse rate.

Lying and standing, Blaxter found, caused a difference in pulse rate; 5-7 beats higher when standing than with lying. Brody (6) states that the increase in pulse rate on standing was 3% for a heavy steer.

Rumination has a small accelerating effect on pulse rate - about two beats per minute increase. (Blaxter). This worker also recorded at 15 minute intervals before, during and after feeding and found a considerable increase especially during the later stages of a meal. This increase from a heavy meal may be very large - 50 beats before the meal and 90 beats at the end - an increase of 66%. After the conclusion of the meal pulse rates dropped rapidly but not necessarily to their former level. Although all cows showed an increase in heart rate during eating, some cows showed a greater response than others and it was not abnormal to find pulse rates up to 100 per minute. A continuous decline in heart beat throughout the night, of approximately one beat per minute, was also found to occur. It has long been observed that pulse rate roughly parallels the

level of metabolism. Murlin and Greer (95) concluded that pulse rate followed metabolism. Brody (56) (57), as will be elaborated shortly, has also found this to be so with cattle.

Ritzman and Benedict (51) found that steers on various levels of feeding between submaintenance to well fed, had various pulse rate levels, the well fed group having the highest pulse.

Kelly and Rupel (96) with a large scale experiment also found that pulse rates varied from 60 beats per minute when animals were at rest, to as high as 96 per minute when they were feeding.

Blaxter (97) carried out an experiment which showed that during the last 12 weeks of pregnancy there was a 15-40% increase in pulse rate. Over short periods during lactation the milk yields were positively correlated with their resting heart rate. An increase of 10 beats per minute was associated with an increase in milk yield of $2\frac{1}{2}$ - 2 gallons per week. This may have been caused by increased food intake with high levels of production.

Thomas (100) found that pulse rate was higher in early lactation and any rapid decrease in heart rate was accompanied by a rapid decrease in milk production. He gives increases of heart rate prior to parturition as follows:

70 to 90 days before calving	65 beats per minute.
30 to 50 days before calving	72 beats per minute.
0 to 10 days before calving	92 beats per minute.

He also stated that pulse rate during oestrus is more rapid than immediately before or after.

Ritzman and Benedict (51) noted a greater pulse rate in lactating animals due possibly to higher caloric intake.

(a) Experiments within Heat Controlled rooms.

Regan and Richardson (60) found that as the temperature rose from 40°F. to 100°F. pulse rates of the cows decreased from 72-57 beats per minute. On the other hand Rieck and Lee (61) found the effect of air temperature on pulse rate was slight and inconsistent, but an increase in humidity was accompanied by some increase in pulse rate. With calves this effect of

humidity was absent. Ritzman and Benedict, 1938, also found pulse rate tended to fall with air temperatures, but the results were not uniform. Similarly Regan and Freckborne (99) found that pulse rates if anything tended to fall with air temperature.

Brody et al, with recent work have shown that with increasing air temperatures above 80°F. the pulse rate of Jerseys declined even at the maximum temperature of 105°F. With Holsteins the pulse rate declined from 80-95°F. and rose thereafter. Chamber temperatures below 40°F. (56) caused pulse rate to rise until at 40°F. the rise was 8% of the 50°F, level. Smith (98) also, reports that pulse rates rise at low air temperatures.

In Brody's work minimum pulse rates occurred between 40 and 60°F. and showed the same trends as heat production, thus confirming Murlin and Greer's observations that pulse rate tended to follow metabolism. Increasing air temperatures from 60 - 80°F. caused a slight increase in pulse rates. Brody (6) agreed with the results of Regan and Richardson (60) that pulse rate decreased with rising temperature. Cows being, as he claimed, poorly sweating species, would derive no benefit from an increased blood supply in the superficial regions indicating that thermal conduction in the peripheral regions through increased blood flow was not a major factor in the adaption of cattle to hot temperatures. Efficient sweating species show a rise in pulse rate with air temperature. This rise will serve three purposes, firstly it will help raise the skin temperature, secondly, it will alter the pattern of heat distribution - more will be lost from the hands and feet, and thirdly, there will be a plentiful supply of raw materials for sweat gland activity.

Cattle, on the other hand, apparently do not make use of increasing heat loss by alterations in skin temperature or in regulating heat loss from the extremities. With poorly functioning sweat glands, and a dry skin, large volumes of blood in the superficial tissues would be a hindrance rather than a help - (Brody), because it would be exposed to the heating effects of

environment. Driving the blood into the interior would overcome this danger of intake of heat.

However, in Brody's more recent work, as air temperatures rise from 60 - 80°F. pulse rate rose and only after 80°F. did the rate decline. Possibly this initial rise was the counterpart of the rise which takes place in man. However, unlike man, after 80°F., heat production declines and with it, pulse rates. Thus the fall in pulse rates is perhaps due more to the fall in heat production than a defense mechanism against intake of heat via the blood stream with large volumes of blood in the exterior, as Brody first postulated. Also, the rise in pulse, 60 - 80°F., is in accordance with the theory of heat loss, i.e., increasing skin temperature so as to increase the temperature difference and also to facilitate loss from those regions of small diameter. Regan and Richardson, and Rieck and Lee, fed their cows just before subjecting them to short periods of high temperatures and the decline in pulse rate noted especially in the former authors' work, may have been due to the observed decline in pulse rate after a meal. On the other hand, Brody's et al (55) experiments were on cows subjected to prolonged periods of high temperatures, and the cows were fed twice daily and they showed quite definitely that pulse rates fall with increasing air temperatures above 80°F. As humidity was at a constant 60 R.H during these trials the exact role of humidity on pulse rate of cows is still not certain. In pigs (101) and (102) and sheep (103), high humidity accentuates the rise in pulse rates.

(b) Field Experiments.

Seath and Miller (78) working with three Jerseys and three Holsteins during the summer of 1945 at Louisiana, found cows entered the shade soon after entering the paddock and pulse rates showed little change throughout the day. In a comparison between the reactions of Jerseys and Holsteins in the field, these same workers found no difference between the breeds and results were not consistent over the two years. In another paper

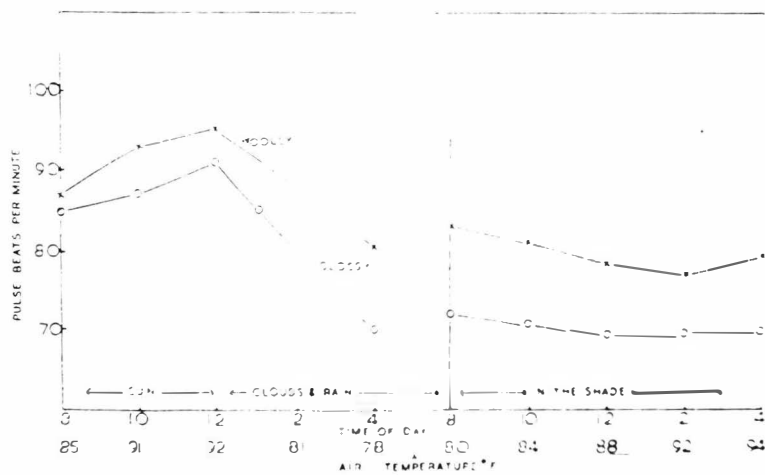


Fig. 11.

The effect of air temperature, sunshine, cloud, rain, and shade on pulse rates of glossy and matte control cattle -
 Monoma.

describing the relative importance of humidity and air movement on pulse rates Seath and Miller (79) found that pulse rates were less affected by either of the two climatic factors, than was body temperature or respiration rate. Correlation between pulse rate and air temperature independent of humidity was $r = 0.195$ and for humidity and pulse rate independent of air temperature $r = 0.07$. The range of temperature for the two years was:-

1944 65 - 93°F.

1945 75 - 91°F.

Bonsma and Pretorius (67) in South Africa, have observed the pulse rates of cattle under tropical conditions. In the shade the pulse rate tended to decline as temperature rose. Out in the open sun, however, pulse rates rose quite markedly, more so in woolly coated animals, and then began to decline sharply in both types when air temperature reached about 92°F. This being a field experiment may be a rough counterpart of Brody's finding. The rise in pulse when in the sun up to 92°F. and then the rapid fall may represent the pyrexial point where heat production and therefore pulse rates begin to decline.

As with respiration rate and body temperature the pulse rates of woolly coated animals are higher than smooth coated animals. Fig. 11.

Summarizing.

1. The heart rate of an animal is influenced by stage of lactation, gestation, feeding, nervous disturbances, time of the day, rumination and posture.

2. Some of the more recent work gives more certain evidence that pulse rates tend to follow heat production. Above about 80°F. both tend to decrease and at cold temperatures both tend to increase.

3. There is still doubt as to whether the cow uses an increase in pulse rate to facilitate heat loss, as happens in man and other sweating animals.

4. The effect of humidity on pulse rate has not yet been thoroughly investigated in cattle. Among other species, humidity

does tend to accentuate pulse rate disturbances.

5. THE EFFECT OF CLIMATIC ELEMENTS ON BLOOD OF CATTLE.

The influence of high environmental temperature on physiological reactions in general, and on blood composition in particular, depends on many factors, but mostly on moisture loss by sweating. We have noted previously how man, a profusely sweating species, on exposure to high environmental temperatures, tends to become dehydrated with a consequent reduction in serum volume. This increases the dry blood residue. With cattle, however, the moisture loss is believed to be relatively low, and also there is some evidence (Brody) that cows tend rather to be hydrated at high air temperatures and urine volume is increased, instead of decreased as in man, so that the concentration of blood constituents should tend to decrease. "Sweating" types of cattle - Indian breeds, may tend to react like man, but the literature is sparse regarding influence of temperature on Indian breeds and is often confused by having European breeds in the discussion as well.

(a) Controlled Experiments.

The only observations on blood composition under controlled conditions have been carried out by Rieck and Lee (61) and Brody (104) et al. The former found with Jersey cows at high air temperatures a marked fall in inorganic phosphate to 2.95 mg. per 100 ml. blood from 4.96, and a small drop in serum calcium from 10.58 mg. per 100 ml. blood to 8.64. A decrease in blood sugar from 55.22 mg. per 100 ml. blood to 44.5, was in no way correlated with rises of temperature or humidity. Mean red cell count showed no significant variation. With calves blood calcium phosphorus, sugar and erithrocyte levels, were unaffected.

On the other hand, Brody found that blood inorganic phosphorus increased as temperatures rose above 85°F. Calcium declined somewhat, but due more to advancing lactation than to temperatures. There was little or no effect on haemoglobin, magnesium, plasma protein, or glucose. Values for CO₂

seemed to decline definitely after 85°F. The most marked change, Brody found, was the creatinine which rose to high levels. Though having no data on creatinine level of the blood, a possible explanation of this rise was thought to be due to a damming up of creatinine as a result of reduced metabolism.

(b) Field Experiments.

Duckworth and Rattray (105) have reviewed the literature on the haematology and *Bos Taurus* and *Bos Indicus* cattle. Many workers have claimed higher erythrocyte counts in tropical breeds and also high leucocyte counts, and Duckworth and Rattray in their experiments with $\frac{3}{4}$ bred Holstein cattle have substantiated these claims.

Manressa et al (106) (107), working in the Philippines, reports that haemoglobin levels could be used as a guide in evaluating adaptability of the animals to given environmental conditions. Native Philippine and Nellore oxen have higher haemoglobin levels than imported exotic breeds. Crosses between indigenous and exotics resulted in intermediate values. These indexes of Nellore cattle are not significantly different from those of the exotic breeds in their own country, but imported stock all show the decline. This suggests that high air temperature depresses haemoglobin levels and Manressa et al took hourly samples of blood for a 24 hour period on 6 consecutive days and found a negative correlation between air temperature and haemoglobin levels throughout the day, in Nellore cattle.

A further study showed that the number of red blood cells, specific gravity of the blood, and phosphorus calcium ratios in the blood, have a positive relation to the ability of animals to adapt themselves to hot temperature conditions. The higher values of these factors were found in those animals of greatest adaptability. On the other hand, uric acid, serum phosphate, and size of red blood cells were inversely correlated to adaptability.

Bonsma (90), South Africa, without giving any evidence states that high temperatures cause a fall in haemoglobin index

if body temperature rises at high air temperature. Also blood sugar content, alkalinity, and the non-protein nitrogen levels, are higher than in temperate climates. The serum calcium is also high, perhaps due to a plentiful supply of vitamin D with the abundant sunshine causing increased absorption of calcium. Bonsma also talks about the blood chlorides which decrease at high temperatures.

Bisschop (108) at Onderstepoort, South Africa, on the basis of two years work reports that Africander cattle have higher red cell counts and show higher values for haemoglobin and red precipitate than do the Freisian and Red Poll cattle. He also noted the same tendency for some of the other chemical constituents.

Summarizing.

1. Tropical breeds of cattle have more erithrocytes and leucocytes than temperate breeds.

2. The literature as a whole does not give a clear cut determination of the influence of climatic elements on blood composition. Some few of the claims have not always been backed by experimental data. Great variability in the results seems to be a major factor clouding the work. The blood picture aspect of environmental physiology has not received as much attention as other sections.

6. AFFECT OF CLIMATIC ELEMENTS ON MILK PRODUCTION AND MILK COMPOSITION OF CATTLE.

There are many factors causing variations in milk production and milk composition. Some are due to hereditary differences and others are connected with management and feeding. These may be briefly listed as follows:-

1. Breed.
2. Individuality.
3. Size within the breed.
4. Age
5. Feed
6. Effect of disease.
7. Condition at calving.

8. Length of dry period.
9. Effect of Pregnancy.
10. Month of calving.
11. Intervals between milkings, frequency of milkings, etc.

The present section is concerned more with the variations caused by climatic elements, temperature, radiation and humidity - not with the whole field of factors causing variation.

(a) Seasonal Effects.

Brooks (109) conducted a well planned experiment in which one wing of a barn was kept at 55°F. and the other wing was allowed to reach air temperatures which was about 40°F. He found that there was a lower fat % from cows in the higher temperature portion of the barn.

Eccles (110) worked on 240 lactation records and found that regardless of when lactation began the fat percentage was lowest in summer. White and Judkins, 1918, studied 49 cows over 7½ years and concluded that milk test was lower in the summer than in the winter and that this variation was due to a seasonal trend.

Ragsdale and Turner (111), 1922, analysed the records of 3763 Guernseys, 219 Jerseys and 95 Holsteins. Monthly milk fats plotted against time follow a gradually rising trend with a peak in the winter, and then declining during spring and summer. They concluded that when different seasons of the year are accompanied by varying temperatures, such as ordinarily prevail throughout the greater portion of U.S.A., the influence of season upon the fat percentage is greater than that due to advance of lactation.

Ragsdale and Brody (112), 1922, used 10 cows and arranged an experiment as well as they were able, to try and find out the relationship between temperature and fat percentage of milk uninfluenced by other factors. Plotting the average fat percentage for the group for 24 hours periods against the average mean temperature of the corresponding 24 hour period they showed that fat percentage increased 0.2% for every

10°F. lowering of temperature. However, they used outside temperature readings, whereas the cows were sometimes kept inside during storms and cool nights.

Clothier (113) had earlier disputed claims that season influenced fat percentage and believed that the difference was due to differences in summer and winter feeding.

Hays (59) analysed data for a herd of Jersey cows at Missouri and also kept two cows under controlled temperature conditions. With this controlled experiment, the object was to subject two similar cows to a constant temperature until the percentage of fat in the milk seemed at a constant level and then to repeat the operation several times at 10°F. intervals of temperature. In this latter experiment he noted that the lowest testing milk occurred between 68-70°F. Above 70°F. fat test began to rise due, reasoned Hays, to increased metabolism. For a range of 65°F. from 27-92°F. an average increase of 0.095% in fat percentage occurred for each 10°F. lowering of temperature. For the outside data fat percentage rose 0.189% for each 10°F. lowering of temperature for a temperature range of 45°F., 27-72°F. This latter figure is in close agreement to that derived by Ragsdale and Brody, 1922.

Brooks (114) studied the question of the influence of temperature on percentage of B.F. in cows milk when such factors as stage of lactation, and gestation, condition of the animal, feeding, and breed differences, were eliminated. A total of 409 lactation records were taken from a Kansas herd over a period of 15 years. Monthly average B.F. percentage plotted against mean monthly temperature, no allowance being made from time of calving, showed a correlation of $r = -0.872$. Separation of the data into the 4 breeds, Jersey, Guernsey, Aryeshire and Holstein, showed the same trend. When the data was sorted into groups corresponding to season of calving, summer, spring, autumn, winter, it was found that irrespective of the stage of lactation, high B.F. percentages occurred in the winter and low ones in the

summer. On the basis of his evidence, Brooks claimed that environmental temperature exerted a greater effect on fat percentage than does stage of lactation.

Harrlass (117) divided 18 Black Pied Lowland cows at the height of lactation into 3 groups. Group one grazed day and night, Group II and III were housed at night and during the day respectively. Each group alternated during subsequent periods. During the first period the highest milk yield and lowest fat % was recorded for days of the highest air temperature. He concluded that cows should be protected from extremes of temperature.

In a winter experiment 6 cows were kept in a heated byre at 6 different temperatures. The highest milk yield occurred in the medium byre temperature, 15-16°C. High (24°C.) and low (6°C.) temperatures lowered yield. Low temperatures increased fat %. He gives the temperature range for both milk and fat production as 10 to 16°C.

Weitzel and Barrett (115), Wisconsin, found that changes in temperature did not appear to affect milk production on two herds of cows - one, in an open pen byre, and the other in an insulated tie stall byre. Weitzel and Heizer (116) added a warm pen byre to the warm insulated tie byre, and to the cold uninsulated byre and found that in the warm tie and pen byres the production of F.C.M. increased with increasing mean weekly outside temperatures. But in the cold byre there was no such relationship.

Heineman (118) worked on milk collected from an area around Springfield, in U.S.A., to a central milk depot. Most of the cows were Jerseys. Correlations were derived for monthly intervals, from mean daily milk composition and mean daily air temperatures. A relationship was shown between air temperature and total solids of separated milk, r ranging from -0.062 to -0.758, average for year -0.4413. For fat % r ranged from -0.258 to -0.838 - average -0.657. There was an average increase of 0.093% fat in the whole milk for each 10°F. decrease in

air temperatures.

Espe (119) summarises the results of many workers concerning seasonal trends in B.F. percentage and concludes that due to changes other than feeding, cows usually test from 15-20% lower in the summer than in the winter. Cows which calve in the autumn, will have their test maintained in the summer and possibly increased because of advancing lactation.

(b) High and Low Temperatures.

This inverse relationship between temperature and B.F. test does not hold at very high temperatures. Hays (59) got a rise in metabolism above 70°F. Regan and Richardson (60) under controlled conditions noted a rise in fat percentage above 85°F. with a fall in milk yield. S.N.F. content decreased from 8.26 to 7.58 and casein from 2.26 to 1.81%. Up to 95°F. composition of butterfat as judged by iodine values and Reichert-Meissel values appeared fairly constant, but above this temperature it tended to become more unsaturated and to contain less of the lower fatty acids. They suggest that at the higher temperatures the usual milk precursors are not supplied to the mammary gland either at the same level or the same rate.

Bartlett (88) kept 2 cows in a hot room at 80°F. and 2 control cows under ordinary conditions at about 40°F. During the course of the experiment the two groups of cows were changed over. High temperatures reduced milk yield by 0.16 lb/day over a three month period and fat % 0.04/day, neither change being significant. A decrease in S.N.F. of 0.15 lb/day was statistically significant. He concluded that S.N.F. may be reduced by high air temperatures, but as the temperatures (80°F.) were higher than English summer conditions, then high temperature is not the only factor responsible for low quality summer milk. However, this experiment was on a very small scale, but does provide partial confirmation for Regan and Richardson's work on the decline in S.N.F. content.

Ragsdale (120) found that high temperatures increased fat percentage. This was accomplished by reduced milk production and feed consumption. They attributed the rise to be due, in

part, to temperature and in part to the fall in the milk production. They believe the mechanism involved in milk fat production tends to be more persistent, less depressed, by unfavourable conditions than the mechanisms involved in producing total milk. Hence, the tendency under certain conditions, for fat percentage to increase when total milk production decreases.

Decreasing temperatures from 50-40°F., Ragsdale et al (121) found that a rise in butterfat percentage occurred - more so in the Jerseys than in the Holsteins. Jerseys increased their feed consumption and decreased their milk production to a greater extent than the Holsteins. The fat percentage rise is associated in part with milk yield decline regardless of the causative factors, high or low temperature. They concluded that the lowest butterfat percentage occurred between 60 and 80°F. rising on either side of this. Cobble and Ragsdale (124) reported that temperatures above 80°F. increased fat %, chlorides and total solids. S.N.F., lactose and N. showed a downward trend at these levels.

Rieck and Lees (61), contrary to Brody's conclusions, could find no affect on the butterfat content of the milk, either per centage or total. At high humidities and air temperatures the S.N.F. percentage increased by 0.69. The fact that their animals were subjected once a week to hot conditions for 7 hours, has probably not been long enough to have allowed the full effects of high temperatures to become evident in fat percentage.

Lee (9) in another paper reports that a 7 hour exposure caused little effect on milk production or fat % but continuous exposure brought about a decline in milk production and a rise fat %.

Sinko and Minnet (122) found that wetting buffaloes 2 hours before milking was essential to keep up production when air temperature ranged from 70-113°F.

King (123) got a positive correlation between morning body temperature of 38 cows and B.F. percentage rise. If

body temperature increased in the morning 99.6 - 100.9°F. B.F. % rose 3.5 to 3.8% but S.N.F. decreased from 8.77 to 8.71%. A similar relationship was found with evening readings on hot days.

Regan (125) noted how milk production and S.N.F. content of milk was lowered by air temperatures above 80°F.

Thus, there is a somewhat confused picture on the literature regarding the effect of air temperature as such, and season as such, in butterfat percentage. The general trend with work involving seasonal changes in butterfat per cent. seem to be that the high summer temperatures do have a considerable effect in causing a low butterfat percentage in spite of the classic work of Eckles (127), and Eckles and Palmer (128), that a result of underfeeding is a rise in fat percentage of milk, because the cow is forced to call on body reserves, and the well known fact that stage of lactation affects the B.F. percentage.

A fall in feed consumption causes a fall in milk production also, so that the rise in fat is due in part to fall in milk yield. This helps to explain the observations of Regan and Richardson (60), Hays (59), Brody (120), Regan and Mead (128), that high temperatures cause a falling off in milk production and a rise in fat percentage. These two factors are also in all cases accompanied by a reduction in feed intake so that the starvation effects are arising here also. In all these controlled experiments cows at approximately the same stage of lactation were used. At low temperatures on the other hand, with Brody's work, feed intake is increased, milk production decreases and fat percentage rises. Heat production in this case rises also so that increasing nutrients are being diverted from milk production to increase metabolism and keep up body heat.

Dice (129), at North Dakota, compared cows wintered in a warm barn, and another group wintered outside with open sheds to shelter them from wind and rain and found that there was littl

difference in milk production between the two groups. On the basis of his evidence he concluded that the cows wintered outside did not use the nutrients fed them to maintain body temperature and the feed cost of maintenance was not increased. This is contrary to Brody's findings that low temperature decreased milk production and increased feed consumption. Dice (130) in 1942, found, however, that dairy heifers left in an open shed did not grow as well as heifers kept in a dairy barn. Waters (131) at Missouri, reported that beef cattle wintered out-of-doors did better than when conventionally housed and Armsby (132) could set no reason why "a cow might not be subjected to low temperatures without increasing metabolism for the sake of heat production solely." Brody (56) has also disproved this assertion. Many writers of popular articles have remarked that cows are affected more by high air temperatures than by lower ones. Regan (133), Brody (134), Geddes (135).

As noted above many workers have, under controlled conditions observed a fall in milk production at high temperatures, and Brody et al found a similar, though not so marked, fall at low temperatures. From Brody's results it appears that milk yield is maximal and at greatest economy - as judged by lowest heat production, pulse rate and a reasonable level of fat percentage (remembering they found it was lowest between 60 - 80°F) - around about 50°F. At temperatures higher or lower than 50°F. milk yield appears to decrease with a drastic decline at 80°F. The depressing effect on milk yield with increasing temperature is apparently greater than with decreasing temperatures. Holsteins were affected more by high temperatures and least by low temperatures than Jerseys. This 50°F. optimum level, however, is but a first range approximation and will have to be confirmed by other experiments. There does not appear to be much doubt that the critical high temperature for milk and butterfat production, and feed consumption is 80°F. But the evidence for a low critical temperature level is meagre and only Brody's work gives any data. Such data suggests that

there does not appear a sharp critical low temperature - the changes are gradual.

Bonsma (55), has observed that feed consumption and milk production decrease in exotic breeds kept in the tropics. He gives no evidence to support this. The amount of heat generated in the body is directly proportional to the quantity of fodder concerned. An animal which readily becomes hyperthermic will automatically eat less so that the metabolic heat generated will be less, and under such conditions exotic breeds which have been accustomed to a high degree of feeding are affected most. Bonsma uses this explanation to point out the success of **Jerseys** in the Southern States of America where it is hot and dry. Jersey cows are a small breed and supposedly eats less than, say, a Holstein and, therefore, says Bonsma, is less susceptible to overheating when the atmospheric temperature rises.

Brody also speaks of the "physiological wisdom" of the cow subjected to high air temperatures in cutting down feed intake, heat production and milk production at high air temperatures. Feed consumption like milk production has a specific dynamic effect. It is not clear if there are two causal factors in the depression of milk production at high temperatures. One due to declining feed consumption and the other to the effect of temperature directly on the milk producing mechanisms. This could be done by observing the production of cows on a limited feed intake both at, say, 50°F. and 90°F.

Summarizing.

1. Seasonal factors tend to reduce butterfat percentage during the summer, quite apart from the effects of other factors.

2. At very high temperatures B.F. percentage is increased; some, e.g., Hays, attributes this to increased metabolism, others to reduced feed intake and others again, with a combination of reduced feed intake and reduced milk production.

Brody has shown that this fall in milk production and rise in B.F. percentage is accompanied by reduced feed intake, reduced heat production, reduced pulse rate, increased respiration rate,

and increased body temperature.

3. Uncontrolled experiments seem to indicate that cold temperatures do not cause much change in milk production, though B.F. percentage rises. Brody, in a well controlled experiment found low temperatures caused a rise in fat percentage, but a decline in milk production, a rise in heat production, and feed consumption, a rise in pulse rate, a fall in respiration rate, and a stable body temperature. The rise in fat percentage is associated in part with the fall in milk production apart from any direct effect on fat percentage of temperature.

7. INFLUENCE OF SOLAR RADIATION ON CATTLE AND THE INFLUENCE OF THE HAIRY COAT.

Solar radiation includes rays of three different wavelengths namely: 1. Long rays - infra red or heat rays.

2. Rays of medium wavelengths - light waves.

3. Short wave or ultra violet invisible rays.

Radiation, as has been mentioned previously, is a variable factor fluctuating with season, the altitude of the sun, midday intensities or direct solar radiation, length of days, number of hours with bright sunshine, cloudiness, etc. The direct effect of solar radiation is two-fold, first there is the chemical effect, sunburn and eye mucous membrane injuries and the heating effect. Only the latter will be dealt with, in detail.

Riemerschmid (136) made a solar survey of South Africa and compared the results with the radiation experienced in Europe.

1. Angle of incidence of solar rays - distinctly larger in South Africa.

2. Midday intensities - little difference.

3. Length of days. Days in South Africa are shorter during the summer but longer during the winter, than in Europe

4. Number of hours with bright sunshine. South Africa has many more hours with bright sunshine during the whole

year, but particularly during winter.

5. Monthly total amount of sun and sky radiation incident on horizontal surface. In summer equal, or slightly greater amounts in South Africa, but much larger in winter.

6. Yearly total much greater for inland stations of South Africa than on the lowlands of Europe.

Thus, all told, differences in the intensity of radiation is not as great as one might first believe, but there are other factors which cause radiation to be a major climatic element for cattle in South Africa and that is, the exposure to comparatively large amounts of radiation through the year, rather than but for a few short weeks, as in temperate climates, and also the simultaneous influence of other climatic factors, such as air temperature, humidity and wind.

Rhoad, (137) using a photoelectric cell took measurements at zero angles of incidence to the sun because the animal body offers all degrees of incidence to the sun. Reflections were measured by reversing the light target. Regression lines showing the relationship between reflection and incidence indicated that the greatest reflection was for the native Brahman breed and light coloured Jerseys were next. Variations in coat colour of Brahman and Jerseys is considerable and it was found that the reflection from each individual varied directly with the intensity of pigmentation of the coat. Brahman and Jerseys having a lighter coloured coat, reflect a greater proportion of the light rays, than do darker coloured cattle.

Reflection values for black cattle, Angus and crosses of Angus with Brahman and also Africander crosses with Angus, showed no great difference. Any small difference there was, Rhoad attributes to glossy or dull coats. Since there is varying degrees of heat tolerance with these black exotic pure-breds and crosses with Brahmans and yet no very great difference in radiation reflection, difference in heat tolerances between these cattle must be due to other physiological reasons - e.g.,

sweating ability or diffusion water transpiration.

Bonsma and Pretorius (67) used a similar type of photo-electric cell for measuring incident and reflected radiation. Using different coloured coats of Africander and Jersey cattle they showed that the Africander reflected a greater proportion of the incident sunlight at any season of the year, than did the Jerseys, though in the summer, reflection values were higher for both breeds. This was, no doubt, due to the smoother, shorter hair adapted in the summertime. As with Rhoad more sunlight was reflected by light coloured than by darker coloured animals. Bonsma and Pretorius claimed that Jerseys have a yellow carotene-like pigment in the skin which may serve as a protective mechanism. They also state that black hair or hide reflects ultra violet radiation very well and black breeds are best adapted in those regions where short wave radiation is intense, as for example, at a high altitude or where mists are frequent. Africander cattle have a light coloured coat and a black hide and perhaps this is the ideal combination, as hide colour is just as important as hair colour.

Measurements made of the skin thickness of various breeds, by Bonsma (74) show that Africander breeds have a thicker skin than exotic breeds. The thinner the skin, he believes, the greater is the amount of heat absorbed which results in overheating of the body.

Riemerschmid (136) measured the incident and reflected radiation from a bull by means of a solarimeter and then immediately afterwards, the bull was covered with a dead hide of the same colour and the measurements were made again. The results showed that there was little difference in reflection and proved that the absorption on the hairy coat of cattle does not depend on the state of the underlying skin and that the difference in the hairy coat of a living animal or dead hide, with regard to smoothness or glossiness, results in only minute differences in absorption if the colour in both cases is similar. Readings made on the bull after he had been fighting hard, showed no

difference from the dead skin. Measurements were thereafter made on hides spread on the ground. This was done because a living animal is not large enough to cover the whole area from which the instrument receives radiation.

Readings were taken on 2 oxen with brown hides of different types. One hide was from an Africander which was smooth and glossy, and the other was from a Sussex-Africander hide, which was rougher and less glossy. There was only a small difference in absorption of the two hides. This is contrary to Bonsma's findings that dull coats absorbed more solar radiation than did smoother ones. Rhoad also asserts that this may cause differences between similar coloured animals. When the direction of the hair was taken into consideration, Riemerschmid found no very great difference again between hairs pointed towards the sun or away from the sun at high sun altitudes, but the absorption decreases rapidly at low sun altitudes.

Riemerschmid and Elder, (138) found the mean absorptivity was 49% for white Zebus, 78% for red Africander, and 89% for a black Aberdeen Angus. Differences due to direction of the hair were again tested and found not to cause much difference and no appreciable difference was noted between the absorptivity of autumn and winter coats of two Africander beasts. Hair ruffled or smoothed down showed no difference. This is again contrary to Bonsma's 1943 findings that there was a difference in reflectivity of woolly and smooth coated cattle.

Clipping of the animal reduced the absorption percentage but this may have been due to a change in colour consequent to clipping.

From the results of readings made of incident radiation from the sun, sky and ground and the various absorption components, Riemerschmid (36) calculated that the total amount of radiation absorbed during a whole mid-summer day on the body surface of a bull, was 20,000 Calories. Smaller sized cattle would absorb less because of smaller surface area - would

absorb probably 17,000 Calories.

According to Forbes (139) the heat production of a bull of 1000 lb. L.W. on mixed rations amounts to 9,600 Calories per day. Thus, comparing this with 17,000 Calories absorbed it can be seen that solar heat load is over double that derived by the animal from its normal body metabolism. Riemerschmid states that given similar clear days, the same amount of heat load would occur in mid-summer in central Europe. In mid-winter the difference between the two regions would be much greater.

Kelly and Ittner (12) (140) compared the effectiveness of various shades in reducing the solar heat load. The four shades tested were, a wood slate roof, hay covered shade, aluminium and corrugated iron shades. Tests made of radiation incident on a flat plate radiometer showed that at midday the solid shades reduced the sun and sky radiation by 65% and the wood slate shade reduced it 55%. Riemerschmid (136) arrived at similar figures when she measured the radiation under a large tree and an artificial shade made of branches on top of a frame. The reduction was 60-70% of total incoming radiation.

While an animal standing in the shadow of a shade is protected from the direct rays of the sun it is still receiving and giving energy to the surroundings. Kelly and Ittner, studied the reactions of three Hereford heifers under the shades. Those animals under the hay and aluminium appeared cooler and more comfortable than under the other two types. However, body temperatures and respiration rates were still high.

They worked out the heat exchange by radiation and convection of the cattle in the shade and in the sun.

Heat Exchange of three Hereford Steers.

	<u>Unshaded Cow</u>	<u>Shaded Cow.</u>
Heat exchange by radiation per hour	- 604 Cals	+ 85 Cals.
Heat exchange by convection per hour.	+ 464 "	+ 109 "
	- 140	+ 194

The unshaded cow received 604 Calories more per hour by radiation than she emitted by radiation. The cow under the shade is emitting 85 Calories per hour more by radiation than she is receiving. This is only an approximation considering cows as flat surfaces, i.e., flat back, sides and belly, when, in fact, these areas are curved. The reason for the greater loss by convection from the cow in the sun is because of the greater surface temperature. Average surface temperature in the sun being 130°F. and 104°F. in the shade. The unshaded animal must lose a total of 334 Calories per hour more than the shaded cow to be as comfortable by vaporization. This is equivalent to the evaporation of 1.3 lb. of water per hour. Air temperature during this trial at midday averaged about 100°F.

For a 15 hour day the total heat absorbed by radiation by the unshaded cow is only 9060 Calories and this includes radiation from solar sources and also from the surroundings. This figure is markedly lower than that calculated by Riemerschmid. This latter work was carried out in California. No information is available of the solar radiation comparisons between South Africa and California to enable one to judge if the difference is due to amount and intensity of solar radiation. Also, Kelly and Ittner's method of arriving at radiation exchange involved the use of a Stephen-Boltzman constant and an emissivity constant borrowed from data on pigs, so that this may be another reason for the discrepancy. Again, two different coloured animals were used. Herefords being red and the bull used by Riemerschmid being brown. There is a size difference also. However, even so, the animals have to eliminate both the solar heat load and the normal heat production to remain comfortable, and at high air temperatures and heat loads we have seen how cattle have poor methods of dissipating heat.

Bonsma (30) reviews much of his previous work and that of others and concludes that both the infra red rays and light rays are effectively reflected by white, yellow or reddish

brown hair, but not by black hair. The short wave ultra violet rays are in turn effectively resisted by yellow, reddish brown and black hides. A white, yellow or red coat with a black hide is the ideal combination and is the combination one finds amongst tropical breeds. Bonsma advocates that breeders in the tropics should select for hide colours with a view to breeding animals which are well adapted - this to replace the present colour selection because of colour or taste.

Bonsma (55) has shown that even in the winter in South Africa the regulation of body temperature is difficult in the exotic breeds. Although solar radiation had diminished by 3-4 pm. there was still a rise in body temperature of bulls belonging to the exotic beef breeds. Thus, during the earlier part of the day, when solar energy was high, these animals accumulated an excessive amount of surplus heat which could not be expelled immediately.

Not only is the colour of the coat important in the heat exchange of an animal with its environment but also the quality of the coat. The loss by radiation and convection of heat from the body and evaporation of moisture are dependent on the quality of the coat.

According to Bonsma (30) smooth-coated animals have mainly primary hair-follicles - from which straight hair emerges - and have better developed sweat and sebaceous glands and lose more moisture from the hide as a result of evaporation. Bonsma gives no evidence concerning sweat and sebaceous glands. Further, animals with furry coats have hides with two kinds of hair follicles, primary and secondary - from which curly hair develops. This curly hair forms a mat over the body surface and little evaporation of moisture takes place

Bonsma (141) claimed work which showed that the ratio of primary to secondary follicles in the skin does not alter with nutrition. The object of his breeding policy was to select for hair which does not felt and for a hide containing primary

follicles only.

Bonsma (67) has taken samples of hair from young calves, dampened them with water and rubbed them between the hands. The hair of smooth-coated animals will rub away while that of the woolly-coated types will cake or felt. A calf with such a woolly coat will not shed its hair early and has a reduced growth rate compared with those calves which do shed their hair early. The woolly coated animals suffer from the effects of overheating much more readily and therefore reduce intake and metabolism and growth is retarded. The entire coats of 8 adult British beef breed cattle, belonging to both smooth and woolly coated animals were clipped. Those from the smooth-coated cattle averaged 14 ozs., those from the woolly-coated animals averaged 52 ozs. The former subjected to a felting test could be pulled apart with a pressure of 4 lbs. - the latter only with a pressure of 25 lbs. Also winter coats of Shorthorn heifers (600 lbs.) weighed 505 gms. compared with 129 gms. for Africander heifers of the same weight. Summer coats weighed 303 and 30 gms. respectively. Bonsma (142) took the hair samples on the 10th rib halfway down because in that position the hair is shed approximately halfway through the shedding process.

Hair diameter measurements, also carried out by Bonsma indicates that the hair diameter of Shorthorn cattle average 30 μ compared with 53 μ for Africander cattle. In many Africander cattle it was found impossible to find curly hairs. In smooth coated exotic animals, it was possible to separate the two types of hair but impossible to separate in the woolly coated exotics because the average hair diameter was so small. Hair of the woolly breed is longer, of more variable but lesser thickness than those of the Africander breeds.

The confirmation of the animal also plays a part in radiating heat and several factors distinguish *Bos indicus* from *Bos taurus* - Brody (6).

1. Indian cattle have excellent heat radiators, enormous dewlaps and sheath or navel flap in females and long ears. Their bodies tend to be small with consequent large surface area per unit of body weight and the hair is short and coat smooth and light coloured.

2. Indian cattle are supposed to sweat to a certain extent, whereas European cattle are supposed not to sweat.

8. THE SKIN TEMPERATURE OF CATTLE AND ITS RELATION TO THE THERMAL ENVIRONMENT.

The great usefulness of skin temperature has been in interpreting the data in regard to regulation of body temperature through control of heat loss. Little is known of the factors affecting skin temperature of cattle, perhaps due to the technical difficulty of measuring skin temperature.

Pitzman and Benedict (51) took skin temperature readings on 6 positions over the body in fasting steer, steers on maintenance rations, and steers on one half maintenance.

Air Temps. 14-18°C.

Fasting steers	27.5°C.
Half maintenance steers	32.0°C.
Maintenance steers.	33.6°C.

This evidence suggested that skin temperature rises with the nutritive level.

Wood and Hill (143) found that a fattening ox may gain 1 lb. or 3 lbs. live weight per day. The former can emit 17,000 Calories and the latter, 22,000 Calories as heat. Since skin temperature bears a definite relation to ease of heat loss a relationship between skin temperature and fattening capacity was investigated. They found that the animals which were good "doers" had an average skin temperature which was lower than the bad "doers."

Bonsma (55) reports that when atmospheric temperature is 90°F. the skin temperatures of animals out in the sun varies from 115-120°F. The thinner the skin, the greater the amount of heat which penetrates the skin. Bonsma stated that if water is poured over the body an immediate drop in body temperature and respiration rate occurs. Skin temperature dropped from

117 to 102°F. No data is given to support these statements.

Quinlan and Riemerschmid (144) when investigating skin temperatures of the scrotum, measured the temperature on an area of the flank from which the hair had been clipped. The bull was placed at right angles to the sun so that one side was exposed to the direct rays of the sun while the other was shaded. Mean values of skin in the sun were 98.6°F. and in the shade 96.7°F. over an air temperature range of 65 - 91°F. Correlations of air and skin temperature were very high. $r = 0.9$ in the sun and 0.94 in the shade. An increase of 1°F. in air temperature resulted in an average increase of 0.28°F. skin temperature in the sun and 0.31°F. on the shaded side of the body. The difference between sunny and shady areas was significant. The correlation of body and skin temperatures were also very high, $r = 0.76$ in the sun, and 0.91 in the shade. They state that the range of body temperature was too small, 101 to 103.5°F., to find a definite correlation between body temperature and air temperature.

Lee et al (145) measured skin temperature taking several readings over the body of a pig, goat and sheep under winter conditions, air temperature range -10.4 - +69.8°F. Equilibrium in skin temperature after a change to a different environment temperature was quickly established with the goat but more slowly with the sow. All three maintained their skin temperature near 80°F. even when air temperature was at freezing or below. Skin temperature of sheep was warmer than that of the goat or pig under all conditions. This would be due probably to the nature of the protective coat and the thickness of the air layer.

Riemerschmid and Quinlan (146) took skin temperature readings on the shaded side of the body near the stifle at air temperatures 50 - 77°F. and at high air temperatures 77 - 104°F. Mean skin temperature values were 92.3°F. at low temperature and 97.7°F. at high air temperatures.

Placing the bull in a cooling chamber at 39.2°F. resulted in a slight fall in skin temperature but showed a steady

increase during the day with a maximum of 95°F. at an air temperature of 39.2°F. After this peak it decreased continually while the bull remained in the chamber. After placing him in a room at a higher temperature the skin temperature increased by 3.6°F. to 95.9°F. in an hour. The bull shivered a good deal while in the cold chamber. Skin and body temperature showed no correlation.

The fact that over a temperature range of 54°F. air temperature the mean skin temperature only ranged 3.6°F. illustrates that the mechanism of regulating against heat loss is very efficient and thereby the skin temperature is kept within a narrow range. Lee's results also show that skin temperature varies little over a wide air temperature range.

Rudzinski (147), a German worker at Zurich, studying the influence of air temperature on skin temperature gives the following conclusion:

"The skin temperature of cows is everywhere lower than the temperature inside the body." The air temperature is not given but from the above statement the air temperature must have been fairly low and the influence of solar radiation small. High air temperatures and solar radiation can easily make skin temperature exceed body temperature, - Bonsma - Brody.

Rudzinski found that skin temperature varied according to environmental conditions and also with the region of the body. The highest skin temperature was recorded at the anus, next highest on the vagina and udder. The lowest temperature recorded was on the back. This latter seems contrary to work on humans, where the lowest skin temperatures are found on the extremities, and my own observations point to this being true also in cattle.

Skorokodjko et al (148), Russian workers, have reported very good work on skin temperature. They distinguish the zone between the skin and hair surface as being the "individual thermal zone" of the animal. They found a temperature

gradient from the skin surface to the hair surface, and temperature gradually decreased until at five centimetres from the hair surface it was the same as the air temperature. The temperature of the "thermal zone" is governed by such factors as the physiological processes regulating the blood supply to the skin, length and density of the hair. They give the equation $q = \frac{\lambda t_1 - t_2}{u}$ as a measure of the heat exchange from the surface.

q = amount of heat lost per unit area per unit time.

t_1 = skin temperature.

t_2 = hair surface temperature.

u = hair length.

λ = total coefficient of heat exchange.

When the hair is 8.5 mm. long the difference between skin and hair surface temperatures = 5.4°C, $q = 0.85$. When the hair is 19 mm. long the difference is 8.0°C., $q = 0.28$. Therefore, the amount of heat spreading from the hair is inversely proportional to hair length. Bonsma, 1943, found the hair of Africander stock were much shorter than exotic breeds and were, therefore, able to lose more heat.

At the hair surface Skorokodjko found that there was considerable variation in the amount of heat lost depending on the part of the body, air temperature, air movement, and the rate of exchange between the atmosphere and hair.

In 15 cows an area of hair was cut to half its length and in 11 cows it was clipped close. Skin temperatures dropped within 10 seconds by 0.6°C. to 1.6°C. in the respective cases. When an area 2 cms. in diameter was shaved, skin temperature dropped 2°C. When the surrounding hair was cut to 10-13 mm., skin temperature of shaved area dropped 3.1°C. whereas it dropped 1.7°C. when the hair was 16-21 mm. long. When the hair was dense, skin temperature was 1.9°C. higher and hair surface temperature 4.4°C. higher than when the hair was sparse. When the hair was washed with cold water (2°C.) the air temperature 3.1°C., skin temperature dropped 9°C. in 15 minutes.

When the water was warm ($35^{\circ}\text{C}.$) skin temperature was 4° lower in 3 minutes, but had returned to normal in 6 minutes.

When animals of hair length 16 mm. and average density were exposed to a temperature of $-2.4^{\circ}\text{C}.$ for 3 hours, skin temperature dropped 14° . The decrease was gradual and then skin temperature increased slowly, - Riemerschmid (146) obtained somewhat similar results.

The temperature of the peripheral parts varied more than central areas with changes in air temperatures.

Thermal Gradients from the Skin to Hair surface on
different regions of the Cow's body at
 $-2.4^{\circ}\text{C}.$

<u>Region</u>	<u>Temps. of Skin</u> <u>$^{\circ}\text{C}.$</u>	<u>Temp. at $\frac{1}{2}$ Hair</u> <u>Length $^{\circ}\text{C}.$</u>	<u>Temp. at Hair</u> <u>Surface, $^{\circ}\text{C}.$</u>
Cannon bone	7	6	5
Shank	8	6	5
Belly	23.8	15.8	14.5

Kelly and Ittner (12) (140) in an experiment comparing various shades for cattle, took skin temperature measurements on Herefords while in the sun and in the shade. In the shade, surface temperatures averaged $104^{\circ}\text{F}.$ and in the sun, $124^{\circ}\text{F}.$ with air temperatures $100^{\circ}\text{F}.$ This skin temperature in the sun is well above the $110-117^{\circ}\text{F}.$ postulated by Bonsma for cattle exposed to the sun at $90^{\circ}\text{F}.$

9. VAPORIZATION LOSS THROUGH THE SKIN OF MAN.

Water may pass through the skin by diffusion, or appear on the surface of the skin as a result of the activity of sweat glands in the skin.

Whitehouse et al (149) carried out experiments with human subjects and concluded that all the moisture given off from the skin during rest under ordinary conditions of temperature, was diffusion water. They showed how osmotic loss increased rapidly as skin temperature rose but with a sufficient rise a stage was reached when sweating interrupts the process. The increase with air temperature was believed to result from vasodilation. They also showed that the effect of raising the humidity of the air was not very marked except at high

temperatures. Raising humidity raised the skin temperature and this increased the osmotic loss nearly as much as humidity decreased it. Pinson (11) measured the amount of diffusion of water through an inactivated area of skin. He showed that when sweat glands were inactivated, moisture never appears on the surface of the skin. He also showed that cutaneous diffusion of water approximately doubles for every rise of 18°F. and that the rate of blood flow through the skin appears to have no effect in the rate of diffusion except so far as it affects skin temperature.

Rothman and Felsher (150) found that keratinisation of the epidermis is associated with considerable dehydration since the malpighian layer contains 70-80% of water, whereas the water content of the horny layer does not exceed 30%.

Burch and Winsor (151) studied the rate of diffusion of water through living and dead human skin, and found that the stratum corneum served as a barrier to diffusion water loss. Living and dead skin (152) showed no difference at given temperatures in rate of diffusion nor was there a difference found between negro and white skin, thus showing that pigmentation had no effect. At 75°F. and 50% R.H. the average loss of diffusion water from human skin was 0.09 mg/sq. cm/min.

These experiments have all been performed on human subjects. No such comparable work has been carried out with cattle. We do not know if there is a diffusion restraining layer or if the rate of loss increases with air temperature.

In view of the fact that cattle are poorly sweating species with few recorded incidences of visible sweat secretion diffusion water loss may be an important cause of difference between breeds of cattle.

10. VAPORIZATION LOSS THROUGH THE SKIN OF CATTLE.

Living animals differ from inanimate objects in being able to dissipate heat by way of evaporation of moisture. At high air temperatures when losses of heat by radiation, conduction and convection becomes difficult, the animal must

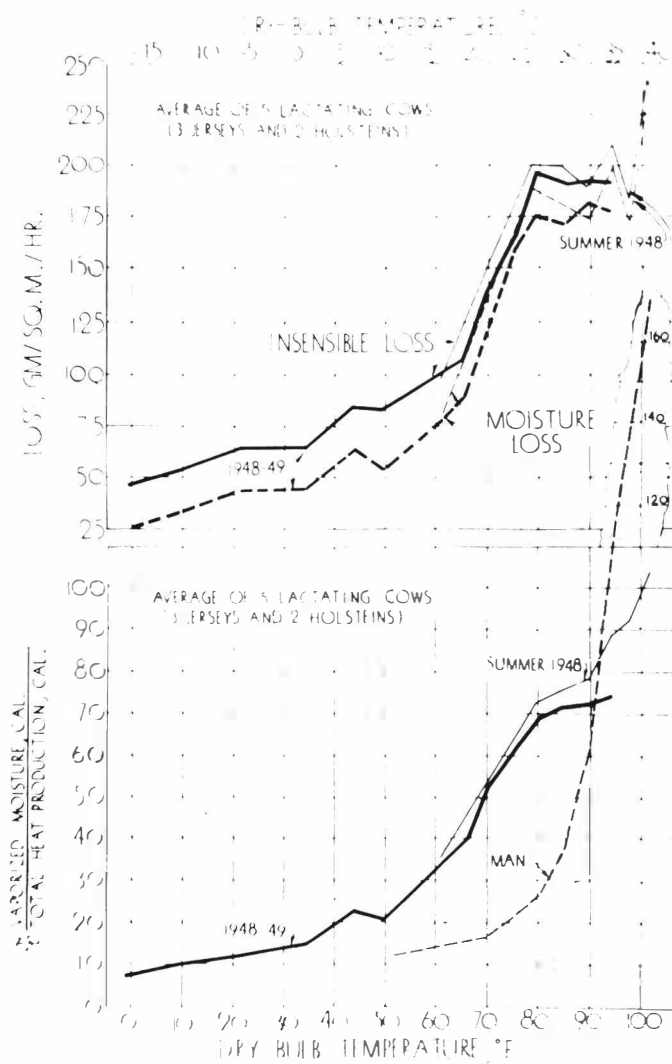


Fig. 12.(a) Loss of moisture by cattle at various air temperatures.

(b) The percentage of vaporized moisture of the total heat production of man and cattle.

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rely on cooling by way of evaporation. Also at very high temperatures the body absorbs heat from the environment by radiation, etc., plus that absorbed from solar radiation. Thus, it has to dissipate not only its normal body heat, but also that absorbed from the environment.

As the environmental temperature approaches skin temperature heat dissipation is shifted from radiation, conductions, and convection, to vapourization. However, a striking difference is seen in this respect, between man, say, a profusely sweating species, and cattle which have a poor sweating apparatus, as shown in Fig. 12.

A sharp break occurs for man at about 84°F. which, according to Kuno (45) is the sweating threshold in man. Up to this temperature evaporation of diffusion or osmotic water increases until at 84°F. it represents 35% of the total heat dissipated. After this vaporization rises steadily until at 95°F. it represents 100% of the total heat dissipated, while at 104°F. it represents 200% because of heat that is absorbed from the environment.

The curve for heat dissipation is quite different for poorly sweating species. No sharp break occurs at any temperature. To compensate somewhat for the inefficiency of sweating these poorly sweating animals increase their respiration rates markedly. There is great controversy in the literature as to whether cattle sweat. Evidence for vaporization loss is limited.

Freeborne et al (153), 1934, used inverted petri dishes on the bottoms of which were fastened filter papers impregnated with calcium chloride, and these were attached to the rump and sides of Jersey cattle. At 84°F. these areas - 35.67 square inches - gave off 333.23 mlgms. of water per hour. Then the right rump was treated with commercial fly spray. After a few days the sprayed areas lost moisture at the rate of 180 mlgms. per hour, due to the oil in the spray. Transposing the data on these small areas to the total area, they arrived at a

figure of 414 gms. of moisture loss per hr. at 84°F. from the entire surface. Calculating further this rate is responsible for the dissipation of 5699 C. a day at 84°F. of 60% R.H. Data obtained in a respiration chamber showed the total daily dissipation of heat to be 17,920 Calories. Hence, loss of heat by evaporation is 32% of the total heat loss. Spraying reduces this to 17.2%. This figure of 32% is remarkably close to the 35% of evaporation loss for man, at 84°F.

Regan and Richardson (60) used a similar technique with 2 Jersey cows and calculated that at 84°F. and 60% R.H. each cow transpired from her surface 1 lb. or 454 gm. per hour.

Rieck and Lee (61) found that the observed water loss was always much ~~greater~~ than could be accounted for by respiratory evaporation. At the lowest temperature used, 85°F., the non-respiratory evaporative loss was 454 g. per hour.

The results of these 3 groups of workers are in very close agreement. Rieck and Lee claimed that if, as Brody (61) states, the rate of water loss by diffusion is constant then the major part of the extra water lost must be by sweat gland activity. However, other workers - Whitehouse et al, - give experimental evidence to the effect that diffusion water loss rises with air temperature and this would account in a large measure for the extra moisture loss at the high temperatures.

Brody et al (44) in a recent refined experiment found no sharp break in the curve of heat dissipation by vaporization. There is a change in the slope of the curve, as seen in Fig. 12, at 55-65°F. which may reflect a rise in the respiration rate. The greatly accelerated evaporative cooling in man above 94°F. reflects his accelerated sweating rate above this temperature. Below 80°F. however, the cow loses more heat by vaporization than does man.

Kuno, previously stated that, at 84°F., man loses 35% of his heat load by means of diffusion water loss. Because his respiration rate varies little with temperature (Bazett (7)) the loss per medium of the respiratory passages would not be very great. Brody's figure, however, shows that at 84°F. the cow loses about 72% of its heat load by vaporization. The work of Freeborne et al, Regan and Richardson, Rieck and Lee,

give 35% of the total heat dissipation at 84°F. as being diffusion water loss from the skin and does not include moisture loss from the respiratory tract. Thus, uniting with Brody's data it appears that, at 84°F. the cow loses 72% of its heat by vaporization of moisture, 35% of this from the skin and the balance - 37% from the respiratory tract.

Richardson (154) found that in man two thirds of the insensible loss came from the skin, $\frac{1}{3}$ from the respiratory passage. With cattle it appears otherwise. However, this conclusion has been reached by deduction only. No true experimental basis exists.

Mitchell and Hamilton (155) reported that in steers, heat loss by vaporization ranged from about 15% of total heat loss at 13°F. to about 42% at 69°F. and that following shearing of the hair, insensible loss decreased by about 20%. Transposing these results to Brody's graph shows a fair agreement.

The cow then, is relying very much on heat loss by evaporation long before its skin temperature equals air temperature (102°F. - Brody). At 102°F. all heat must be lost by evaporation in cows, whereas, in man, 94°F. is the temperature when air and skin temperatures are equal and all heat must be lost by evaporation. However, well before 84°F. the cow loses 70% of its heat load by evaporation.

Why does the cow have to rely to such a large extent on heat loss by evaporation at comparatively early temperatures compared with man? In the case of man there is no hairy coat and heat loss is not hindered by an enveloping air layer as it is in cattle. Also, pulse rate in man rises with air temperature indicating that vasodilation is active. Skin temperature changes and a fine re-adjustment of the circulatory system and the use of the extremities for dissipating heat allows man to make good use of the heat loss avenues of radiation, conduction and convection until skin and air temperature near equilibrium. Cattle, on the other hand, with their hairy coat, decrease in pulse rate, possibly no vasodilation or

circulatory adjustment in the extremities, have poor methods of raising skin temperature and altering the distribution of heat dissipation. Hence, they are not able to make use of the usual avenues of heat loss, even at comparatively low temperatures and have to resort to evaporation.

Workers deplore the fact that cattle are poorly sweating animals and because of this, have poor powers of adaptation to high air temperatures. That cattle are poorly sweating animals may prove to be true, but rather should one deplore the cow's poor thermoregulatory adjustment to quite moderate rises in air temperature, thus causing the animal to resort to evaporation methods at a very early stage so that when higher temperatures are approached, the cow is already relying to a very great extent on evaporation, whereas, man is still using the usual avenues of heat loss and still has the greater part of the evaporation method of heat loss in reserve. This explains his superiority over cattle at higher air temperatures.

Work will have to be carried out to find just what circulatory adjustments do take place in cattle; whether vasodilation is a factor and what is the thermal conductance of the tissues. Although some workers have stressed the importance of coat colour and quality it is probable that the character of the coat is the chief disadvantage of cattle in hot weather and more work needs to be undertaken to study the role of the hairy coat in thermoregulation.

Brody showed that when unit surface area is used as a basis for comparison, differences between Holsteins and Jerseys are small, when size differences in evaporative loss are eliminated. On the basis of body weight, however, (per 1000 lb. L.W.) small cows evaporate more moisture than larger cows. Between 90 and 100°F. a 1000 lb. cow evaporates 2 lb. of moisture per hour, not much above that of man, whose weight is about one tenth that of the cow. At 70°F. man dissipates 18% of the heat produced by evaporation, cows - 50%.

Rhoad (63) used inverted petri dishes technique on the

bodies of pure-bred Angus, $\frac{3}{4}$ Angus $\frac{1}{4}$ Brahman, $\frac{1}{2}$ Angus $\frac{1}{2}$ Brahman and pure-bred Brahman and got the following results:

Mean Weight of Water Transpired per Hour over the

Combined Area of 2 10cm. Petri dishes.

<u>Shade</u> <u>Temp. °F</u>	<u>Pure-bred</u> <u>Angus</u>	<u>$\frac{3}{4}$ A $\frac{1}{4}$ B</u>	<u>$\frac{1}{2}$ A $\frac{1}{2}$ B</u>	<u>Pure-bred</u> <u>Brahman.</u>
86-95	96.5	111.6	183.4	176.2
76-85	79.5	87.6	129.7	112.4
66-85	55.0	50.5	75.2	35.6
46-75	31.0	35.3	33.1	28.5

Within each of the 4 genetic types represented there is a regular and significant increase in the amount of water vaporized through the skin as air temperature rises above 70°F. Brahman types transpired more water than did Angus breeds. Is this because of increased sweat gland activity in the Brahman whose respiration rate does not increase very much even at 90°F?

Water consumption:-

Some heat may also be dissipated by increasing the consumption of water. Regan and Mead (128) placed 3 pairs of Holstein cows for 3 months in a heat controlled room between 40-100°F. R.H. 60%. The water consumption was uniform between 40 and 80°F. Above 80°F. the cows became hyperthermic and decreased their consumption of water. Brody et al (156) got a contrary result to these people. They found that above 70-80°F. water consumption tended to increase. However, the increase was enormously variable within the 6 cows. One Jersey cow increased her consumption from 11 gallons per day at 50° to 43 gallons per day at 100°F. By increasing this water consumption by 30 gallons this cow dissipated 2,850 Calories of heat from the body per day by increasing the water from 60°F. to body temperature of 106°F. This cow's urine output also increased enormously. Now in man, water consumption invariably increases with air temperature, but urine volume always decreases and because of sweating there is a danger of dehydration. With cows, on the other hand, there is a tendency for hydration and increased urine

volume. A possible explanation of the high urine volume, put forward by Brody, is that a decreased secretion of antidiuretic hormone at the high air temperatures takes place and the water consumption was coupled with the urine volume rather than with any thermoregulatory effect. There is no evidence on this and in the meantime it is quite clear that the drinking of large volumes of cool water at high air temperatures helps considerably to cool the body.

Below 50°F. the water consumption tends to parallel the feed consumption. However, whether cattle do increase water at high air temperatures is not certain. Brody's data was on 6 cows, one of these increased her water consumption markedly while in another it declined - between these two there was great variation. A high water intake was associated with a smaller rise in body temperature and a smaller depression of milk production and feed consumption. It appears clear, however, that 80°F. is the critical temperature for water consumption, above this variability is great.

Sweat Glands and Sweating.

Little is known about the histology of bovine skin and it is not yet fully proven whether cattle possess glands that function as sweat glands. Ease of heat loss will depend to a large extent on the functioning of sweat glands.

Gurlt (157) described the sweat glands of European cattle as being small oval sack-like structures. He claimed the cow sweated only from certain surfaces, at the bottom of the ears, the side of the neck, in the flanks. Also, he claimed, that under certain unnamed conditions a general outbreak of sweat could occur all over the body.

Ellenburger (158) stated that cow skin is profusely supplied with sweat glands, each gland lying at the side of the hair follicle and having a sac-like lumen.

Yamane and Ono (159), Japanese workers, studied samples taken from 21 body regions of Buffaloes, Zebus and Dutch Friesian cattle. They claimed that the skin of the Zebu was

thinner, though the epidermis was thicker, than other cattle, and that hair density was greater and sweat and sebaceous glands were greater in size and number. The Friesians were found to have a poor development of the epidermis and a strong development of the papillary layer. Sweat and skin glands were few and small in number. They claimed that the glands were of the exocrine type and attributed superiority of the Zebu to the greater number of sweat glands per unit area.

Kelly (160) worked with Friesian and Friesian-Zebu crosses and claimed that the Zebu crosses had more sweat glands than the Friesians. Kelly, however, merely compared pieces of skin of crossbreds of $\frac{1}{2}$ Zebu blood with skin cuttings at the same places of crosses with $\frac{1}{4}$ Zebu blood. Kelly, himself, said that the material at his disposal was insufficient to give an accurate comparison.

Burcev (161) studied sweat glands in the ear of a large number of cattle of the Red German breed. He found the number of sweat glands per square millimetre was 4.82 ± 0.049 . The coefficient of variation, however, was large - 37.7%. Age and sex were found to have no effect. Yamane and Ono found that both age and sex had an effect on the number of sweat glands.

According to Zamjatina (162) the number of sweat glands per unit surface area should be constant and hereditary in any particular race. Twelve sections were prepared from the upper corner of the left ear of each of a herd of 300 Simmental and Whiteheaded cows. There were 8.58 sweat glands per square mm. in Simmentals, versus 8.84 in Whiteheaded. Age, he believed, had little effect.

Both Burcev and Zamjatina claimed high correlations between number of sweat glands and milk production. Burcev derived $r = 0.72$ and on little evidence suggested that the small number of sweat glands acts as a recessive. Zamjatina $r = 0.74$. Data from 3 bulls showed that the number of sweat glands and milk production were higher in daughters sired by

bulls with a greater number of sweat glands of large diameter and that cows from crossed matings had more sweat glands, i.e., that heterosis had taken place.

Findley et al (163) on the basis of work with 30 Ayrshire cows found no correlation between the number of sweat glands in the helix of the ear and milk production.

Brody (6) states that Zebu or Brahman cattle have a higher degree of heat tolerance than European cattle, apparently because tropical cattle have more sweat glands than European cattle. Bonsma (55) also claims that the Africander has more sweat glands and that smooth-coated cattle have more sweat and subaceous glands than woolly-coated cattle, but both these authors give no data to support their various claims.

Because of the importance of sweat gland activity for heat regulation in man, the possibility of an existing correlation between the number of sweat glands per surface unit of the skin and the degree of heat tolerance in the various breeds of cattle have been given consideration. But the conclusions are vague. There seems to be more sweat glands per unit area in Zebu cattle than in some European breeds but data on the number per unit area in common European breeds is meagre. Whether the factors for sweat gland numbers are hereditary are dominant and have heterosis effects has been suggested, but no really detailed histological investigation of the number of sweat glands over the entire surface rather than just the ears, has not yet been carried out, and no objective experiment has been done to find out just what are the hereditary implications.

Yang et al (165) made a detailed study of the sweat glands in Ayrshire cows. He concluded that in 3 - 4 year old Ayrshire cows each hair follicle is invariably accompanied by an erector pili muscle, a sweat gland and a sebaceous gland. Thus, the counting of sweat glands is made easier Dry (166) has also found that each hair shaft is accompanied by a sweat gland. The average number of sweat glands per

square cm. of skin as judged from 21 body regions was 1,871 \pm 500. Man, according to Taniguch (167) has about 250 sweat glands per square cm. of skin. Thus, the cow has about 8 times as many sweat glands as man. Per square mm. the number of sweat glands for Ayrshire is much higher than that found by previous workers for other breeds - though these had worked mainly on samples drawn from the ear. The sweat glands observed by these workers are similar to those found in the dog (Speed (168)) and in the sheep (Carter (169)).

Not only is there confusion and insufficient work on the number of sweat glands per unit area but there is controversy concerning whether these glands are eccrine or apocrine in secretion. Yamane and Ono claimed that they were eccrine but others (Yang and Lee) believe that they are apocrine in secretion. Man has the eccrine type and the gland is not necessarily associated with a hair follicle. Large glands beneath the axillae in man resembles the sac-like glands of cattle. Yang found that the glands had a poor capillary blood supply - contrary to the condition in man.

(Eccrine glands are defined by Blakistons Dictionary (190) as "glands which deliver their secretion or excretion to an epithelial surface either directly or by means of ducts".)

Much of this research work is incomplete and it seems that so far we cannot explain the superficial similarity between the hereditary behaviour of heat tolerance and the number of sweat glands per unit area of skin, by assuming that heat regulation takes place by means of these sweat glands. It has not been possible to state an average for the number of sweat glands per unit area because of the wide variation of work which has been carried out, most of it on widely different breeds. On the basis of morphological research, therefore, we cannot tell what is the significance of the so-called sweat glands of cattle. From histological evidence, it appears that cattle have a large number of sweat glands. The question arises as to whether or not these sweat glands are functional.

Yang, on the basis of histological evidence, states that

they are definitely functional although the secreting cycle appears to be a slow one. Wiertz (171) in a review, makes the sweeping statement that "in practice, perspiration in cattle appears only sporadically as for example after heavy work, or in warm stables or during the birth of a calf and even then it is limited primarily to the neck, shoulders and sides. However, one cannot exclude the possibility of a perpetual slow secretion of the respiratory glands not perceptible to the eye." He quotes no literature to support these statements but perhaps he may have had the findings of Gurlt in mind. Some stockmen claim that cattle, after heavy drives become wet, especially in the flanks, neck and shoulders. Lee (9) in another review, concluded that since cattle have such a plentiful supply of sweat glands it was strange that they should not be functional. Investigations have shown that all mammals except rodents, possess morphological apocrine sweat glands. It seems probable that sweat glands response to heat is fairly widespread among mammals but the efficiency and degree of activity varies from species to species reaching a maximum in the horse and man.

Experimental material concerning the function of sweat glands is meagre and many of the claims of sweat gland activity have been rather suppositions than conclusions based on exact experimental data. Freeborne and Berry (153) tried washing an area on two Jersey cows subjected to hot temperatures before and after, with distilled water. The fresh water was examined for chlorides but no chlorides were found. A similar technique used by Regan and Richardson (59) resulted in no trace of chlorides. Both concluded that since human sweat contains chlorides, that at the temperature and humidity of their experiments, cows could not sweat. However, sweating need not necessarily result in excretion of chlorides. Both sets of workers, tried out the wash water technique at about 85°F. which is just at the threshold for sweating in man. It is a pity that the trials had not been repeated at higher

temperatures.

Three sets of workers - Regan and Richardson, Rieck and Lee and Freeborne and Berry, derived much the same result for vaporization loss through the skin of cattle at 85°F. Brody (44) too, seems to arrive at a similar figure.

Comparing the evaporative loss of calves and cows in their reactions to high air temperatures, Rieck and Lee (61) found no difference in the evaporative loss per unit of body weight. In terms of unit surface area, however, the evaporative loss would be less for calves than for cows suggesting lowered efficiency of the 'sweat glands' since the density per unit area in the calf would be greater than in the adult. Here again explanation is based on assumption of sweat gland activity without any precise information as regards their actual functional activity.

Rhoad (64) assumes that if diffusion water loss be taken as remaining constant then the increase in water loss at higher temperatures must be due to sweat gland activity. The Brahman showed the highest transpiration rate and any difference in heat tolerances of the animals may be partly attributed to differences in activity of sweat glands. The same explanation as in Rieck and Lee's work, mentioned earlier, could well apply here and the same criterion of assuming sweat gland activity to explain water loss without exact evidence.

Most species enjoy wading in water in hot weather but for some species, e.g., the pig, access to water or mudwallows is a matter of life or death, in hot weather.

Minnet (172) using buffaloes and Zebu cows tried sprinkling with water at 50-60°F. A heavy artificial shower for 2 hours lowered the body temperature of buffaloes by 2.8°F. in the morning and 1.6° in the afternoon, on the average, while a similar shower for Zebu cows, caused body temperature to fall by only 0.5°F. in the afternoon. With the cows the main effects of the shower was due to the drying - evaporation of water - whereas with the buffaloes the direct application of the water was the

greatest cause of the fall. This may have been the cooling effect on the blood in the superficial tissues and this cooled blood being carried into the interior. However, there is no indication of thermal conductivity and blood flow variations between buffalo and Zebu cattle.

Natural rain was found to have less affect and its affects could be overcome by exercise. Fanning was tried out on buffaloes only and appeared to make little difference.

Seath and Miller (173) used 6 Jersey cows in a 2 x 2 factorial design. Cows were tied out in the sun at midday for a time and then put into a barn. Three were sprinkled with water and three left dry. On the following 2 days fan and no fan and sprinkling with fan and no fan tried out. These differences between test days were confounded with the results of the experiment.

After 2 hours in the sun cows had an average body temperature 2.3°F. higher than normal, and respiration rates were also higher. Sprinkling plus shade markedly decreased body temperature and respiration rate compared with cows that had just shade alone. Fanning greatly increased the cooling of both sprinkled and non-sprinkled cows. Pulse tended to follow similar courses as body temperature and respiration rate, i.e., with better cooling methods the pulse rate also declined to a greater extent. These workers concluded that shade alone, sprinkling alone or combinations of these, all tended to reduce body temperature, respiration rate and pulse rate, but the shade plus sprinkling, plus fan produced the greatest reduction. The fan, they believed, increased the evaporation of sprinkled cows and increased convection loss in the non-sprinkled cows. It is a pity that these workers did not try sprinkling in the sun as compared with sprinkling plus shade, then one would be able to see if the sun caused a more rapid and transitional fall in the physiological measurements. The fact that shade alone was not as effective as shade plus sprinkling suggests a poor sweating mechanism.

Seath and Miller (174) in a previous paper found that shade alone or sprinkling plus shade was effective in reducing body

temperature, respiration rate and pulse rate - sprinkling plus shade being more effective.

Brody (6) in a similar type of experiment got results somewhat at variance to the above workers. Wet sponge blankets were placed over 2 cows, one of these had a strong fan and the other left free. Two other cows were left unblanketed, one with the fan the other without. The fanning in this experiment failed to have any effect on either the blanketed or non-blanketed cows. Indeed, in the non-blanketed cow the fan appeared to increase the respiration rate apparently because of the fanning of hot air over the body. The wet blanket reduced the respiration rate considerably. If the animals sweated, then fanning would be expected to give added comfort to the animal. That it did not achieve this is perhaps indirect evidence of a poor sweat mechanism - no information on pulse rates was given.

Why the cows in Brody's experiment did not derive any benefit from fanning whereas the cattle used by Seath and Miller did, is hard to reconcile. Fanning theoretically is expected to have a desirable effect even in poorly sweating animals provided air temperature is below skin temperature and in both these experiments such was the case. Minnet, however, could observe no benefit for buffaloes when fanned.

In 1948 Seath and Miller (175) reported another trial to find the effect of different types of sprays for cooling down cows. Their previous experiments had noted that cows did not like being hosed down. Several types of sprays were tried under a bamboo constructed shade. The cattle showed a liking for a fine mist-like spray and body temperature and respiration rates tended to return to normal. Yearling heifers also showed some preference for the sprinkler, though did not make as ready use of it as the cows, probably because they were less affected by the high air temperatures which averaged about 90°F. No information was given on pulse rate.

Minnet remarked that though buffaloes liked a heavy artificial hosing down, Zebu cows objected to such treatment.

Kelly and Ittner (12) used sprays under artificial shades in a study of radiation effects. A fine spray did not have such an effect as a coarse one. They observed that cattle had to "learn" the use of a spray, and hosing down several times with a garden hose caused them to use the shower more than they did before. When using the mist spray the cattle were only dampened whereas the coarse spray thoroughly wet the skin. Air temperatures were about 100°F. A drop in body temperature of 2-3°F. and 20 respirations per minute were observed, although Seath and Miller got this drop in body temperature and a greater drop in respiration rate with both coarse and fine sprays.

Kelly and Ittner observed that their cows did not use the spray at night even when night temperatures did not fall below 80°F. It was used mainly late in the morning and most of the afternoon. This would be because of the additional heat load from solar radiation during the daytime and greater need for cooling by evaporation.

From the standpoint of ability to withstand high temperatures, Brody divides homeotherms into 2 classes - sweating species evolved in hot regions, including man, and non-sweating species evolved in cool regions, including European cattle, swine, sheep, and poultry and also laboratory animals which neither sweat nor pant, such as rabbits, rats and mice. These animals, often instinctively wet themselves with saliva and urine.

Bonsma (55) has noted that animals are very often in a state of fever at high air temperatures and salivate freely. As much as 4 gallons of saliva has been collected from exotic bulls out in the sun, whereas 2 gallons have been collected in well-ventilated stables. Under similar conditions Africander and Africander crossbred stock do not salivate at all. Such a loss of saliva seems wasteful as, unlike some animals, e.g., the cat, it is not licked onto the coat where its evaporation would help to cool the body. Rieck and Lee (61) also noted salivation at high air temperatures above 100°F. Individual cows varied but the loss became sometimes excessive, reaching to 1 litre per hr. Brody makes no specific

mention of salivary losses in his recent experiments, but a special pan is provided to collect saliva on a platform used to measure insensible weight loss.

That considerable loss of mineral salts can take place through this excessive salivation at high air temperatures has been shown by Bonsma,(25). The average chemical composition of numerous samples of saliva lost in the attempt to cool the body is as follows:

P ₂ O ₅ %	CuO%	N%	2O%	Na ₂ O%	Ash.
0.0031	0.0153	0.0260	0.0671	0.0710	0,4134

A beast drivelling 3-4 gallons per day could lose up to 1½ ozs. of mineral salts. This would be a vital drain on the mineral resources of the body.

Thus, the literature is on the whole inconclusive regarding vaporisation loss of moisture from cattle. There is evidence that cattle have large numbers of sweat glands, but there is no reliable estimate of the average number per unit area for a sufficient number of breeds to see if there is a difference between Tropical and European breeds in this aspect. Some little evidence tends to show that Tropical breeds do possess more sweat glands than European breeds but the position is by no means certain.

The evidence concerning whether or not these sweat glands of cattle are functional or not is even less meagre and more uncertain. That they are apocrine in type has been agreed upon by several writers. On the basis of the presence of sweat glands some writers have maintained that they would be functional others have postulated sweat gland activity to explain observed evaporative losses greater than could be accounted for, or to explain differences between the reactions of different breeds, but no actual data has been presented which relates to sweat gland activity in itself. Ordinary diffusion water loss can account for a considerable amount of the moisture loss,

though even this aspect of moisture loss in cattle has but little evidence to back it up. Most of the suppositions of evaporative loss have been transposed from evidence with humans.

That there is a difference between Tropical and European cattle exposed to high air temperatures, is quite clear. Because Zebu and Africander types do not respire to any great extent at these high air temperatures does suggest either more efficient diffusion water loss on sweat gland activity or both, in these types. Some say that the conformation of the tropical cattle gives them some measure of superiority. However, such conformation by presenting a larger surface area but assists loss by radiation and convection. But, theoretically, losses by these avenues become smaller and smaller as air temperature rises and air and skin temperatures draw closer to one another. At very high air temperatures the only conceivable way of losing heat must be by way of evaporation of moisture, yet these tropical breeds do not increase respiration rate anywhere near as much as European breeds exposed to the same conditions, so that there must be increased diffusion water loss and/or sweating at these high air temperatures. There can be no other way in which the heat load can be dissipated, yet there is no reference in the literature to anyone having actually seen tropical cattle sweating and only a few references to having seen visible moisture on the hide of European animals. Workers experimenting with both types under hot conditions, have never mentioned signs of visible sweating. The position seems hard to comply with theoretical considerations, i.e., that all heat must be lost by evaporation at high air temperatures, yet the body temperature and respiration rate of Zebu types does not rise to any marked extent and no visible signs of sweating have been reported. The conclusion is that we still cannot say definitely if cattle sweat but on the basis of theory it appears they must sweat and on this basis too many workers have assumed sweat gland activity and referred to it as proven. Thus, frequent

reference is made to sweating tropical cattle and poorly sweating European cattle merely on the basis of circumstantial evidence.

11. ADAPTABILITY.

An animal which is adapted is in harmony with its environment. The climate affects the vegetation, and also regulates the thermal elements in which the animal is to reproduce and thrive. As a result of differences in climatic characteristics the various breeds react differently to environmental stimuli. When transported to a new environment certain individuals within a breed succeed better than others and their ability to adapt is reflected in the growth and production of such animals. European cattle transported to tropical or subtropical areas have difficulty in adapting themselves to the new thermal elements. To be successful, animals in hot climates must have resistance to the thermal components.

(a) Resistance to radiation.

(b) Resistance to air temperature.

(c) Resistance to humidity.

Workers have indicated that the colour of hair and hide are important for an animal to cut down on its solar heat load successfully, and breeding for such characters may well be carried out. Quality and nature of the hairy covering exerts an important effect in an animal's reaction to air temperature. Bonsma has shown how the type of hair coat even within a breed exerts an important influence on the degree of stress which high air temperature and radiation impose upon the animal. An animal's heat tolerance has been shown to increase with age. Young animals which show a high resistance as calves can be selected. However, to be properly adapted the animals must be able to make use of the available forage and this in the tropics is usually sparse, and watering places are far apart. Walking tests have shown up the relative efficient manner in which tropical breeds can walk long distances and in some cases, all day in the blazing sunshine. Bonsma (25) had tried out

the effect of deprivation of water on the various breeds.

With exotic breeds deprivation of water for 48 hours caused a loss of weight of 15% (105 lbs.) whereas Africanders showed a body weight loss of only 1.5%, i.e., 15 lbs.

Adequate nutrition strangely enough, does not answer the problem in the tropics. The feed may be scarce and foraging difficult in the tropics, but even so, the feeding of supplementary fodder will not answer the problem. It is possible for a breed adapted to a warm region to develop normally in a temperate climate, provided it receives adequate feed and shelter during the winter. However, the converse is not true. A cattle breed developed in a cool temperate region will not thrive in the tropics, notwithstanding good feeding. Such animals tend to become hyperthermic too readily, they automatically eat less and so the functions of growth are retarded and adaptation is poor. It is often said a poor rough looking coat on an animal is the result of poor nutrition, however, in the tropics a rough coat can be the cause, rather than the result of, underfeeding. Thus an endeavour should be made to locate each breed in those regions which most closely resemble its original habitat and for hot dry tropical climates those breeds should be selected which are able to adapt themselves under the given conditions.

The seeking of shade and voluntary reduction in food intake by the cessation of grazing are homeothermic mechanisms which ease the heat load placed upon the animal when it is subjected to high air temperatures and more so still, when there is intense solar radiation.

Bonsma (55) carried out grazing observations on Africander, Hereford, Shorthorn and Aberdeen Angus cattle.

The following table adapted from Bonsma et al, illustrates how the Africander is able to graze much longer than the Aberdeen Angus.

	<u>% per day.</u>	
	<u>Grazing</u>	<u>Resting in Shade.</u>
Africander	89	11
Hereford	79	21
Shorthorn	78	22
Aberdeen Angus	75	25

Air temperature ranged from 84 - 100°F. On windy days the animals were restive and did not lie down much. On hot days they grazed against the wind while on cool days they grazed with the wind.

Rhoad (63) worked with Aberdeen Angus and pure-bred Brahman and various crosses between these two extremes. However, during the period of the grazing observations the cows were shut up in an enclosure at night and observations were made for 11 hours of the day only. The Brahman types grazed very much longer than the Angus types and when they rested they did so only in the sun and never sought the shade, whereas the Angus spent nearly half of the eleven hours resting in the shade.

Light breezes increased the time spent grazing and decreased the time the cattle rested.

Seath and Miller (78) took grazing records of six cows subjected to air temperatures of 73-86°F. Good permanent pasture was available and the experiment covered 5 24-hour periods. During two relatively warm days, cows grazed less than two hours during the daytime spending the rest of the time in the shade. At night, on these warm days, they grazed about three times as much as during the day, but even so the total 24-hour grazing period was about one hour less than that for cool days. These workers suggest use of the very best pasture during the day so that what short time the cows do graze is on good pasture. At night when the tendency to forage is stronger they still need reasonably good pastures. A weakness of this experiment was the small number of days and cows used.

The fact that some workers have found that wind alleviates the effect of high temperature to some extent, seems at variance with the experiments described by Brody where wind tended to

have no effect, yet partly supports Seath and Miller's observations that fanning had a beneficial effect.

If an animal is not in thermal equilibrium with its environment, then its metabolism will not be normal and apparently no amount of feeding will stimulate growth. Chronic undernourishment in the unadapted types can be detected in newly born calves. Those born after a summer gestation are puny in the case of unadapted breeds. Bonsma (74) has found that calves born after a South African summer are 20% lighter in weight than if born after the winter in the case of exotic breeds.

Underfeeding results in retardation of growth. Since the function of reproduction is intimately associated with growth, all the animals whose growth had been retarded showed reduced sexual activity and in cases, reproductive organs, Bonsma reports, remain infantile.

Production of meat, milk, etc., are but functions of growth. If the animal is not in thermal equilibrium with its environment, then its metabolism will be reduced and production suffers consequently.

12, LIMITATIONS OF OUR KNOWLEDGE.

This review has had to constantly refer to the physiology of heat regulation as it applies to humans. The reason is that ever so much more is known about this aspect of physiology in humans than in cattle. Indeed, in cattle the work is very meagre and much of the work which has been carried out is but isolated and remote aspects of the problem. This work has not been confirmed and elaborated enough in many cases, by other workers. To try and piece together isolated pieces of evidence to give a complete picture in cattle is difficult as only too easily can the wrong interpretation be made without evidence along the chain to help weld it into a connected picture.

However, more work has been done in this field with cattle than in other classes of livestock. Cattle products in the tropics are in short supply and political influences are perhaps at work intensifying the study of cattle so that a more scientific approach may be made to the development and adaptation of

cattle to hot areas.

Fundamental work is required in the following aspects of heat regulation.

1. Do cattle sweat? If so, what proportion of the total heat dissipation is made by way of sweating, is there a temperature threshold as in man where sweating takes place?

2. Histiological studies on sweat glands needs to be undertaken. What is the distribution over the body and can an index of the average number per unit area be given. Comparative studies need to be made between exotic and tropical breeds to see if this is the reason for the difference between the reactions of the two types to high air temperatures. The innervation and endocrinological response of these glands also needs investigating. The relationship between body temperature and skin temperature regulating sweating rates has been worked out in man, does it necessarily hold for cattle?

3. Vaporization loss through the skin and how it increases with temperature has been elucidated fairly clearly for man, but does the same take place with cattle? Some experiments have been carried out with inverted petri dishes, etc., but there is no way of telling whether such water vapour collected is due to evaporative loss from osmotic moisture or from sweat gland activity. Also we need to know if keratinization influences part of the insensible loss and if there is a diffusion restraining layer in the skin as in humans. Does this evaporation from the skin vary with skin temperature? It has been found to be so in man but we do not know if it happens with cattle.

4. Data on skin temperature with cattle is small. Do the extremities play the same role in heat dissipation in cattle as in humans? How does body temperature, and air temperature, influence skin temperature and what is the relation of skin temperature to evaporative loss either by osmosis or by sweating? How does solar radiation affect skin temperature?

5. Information on the circulatory adjustments is needed. Is vasodilation and constriction of any great importance in

cattle? Is there internal economy of heat during cold weather in cattle? Pulse rate changes in cattle, with rising air temperature, follow a difference course to that in man. What is the real reason for this? Experiments, such as Brody's two in 1945, and 1949, especially that latter one where heat production and pulse rate move together, throw some light on the problem, but this is but one experiment with a few cows measured, with only one variable factor, air temperature.

6. Data on the thermal conductivity of the peripheral tissues and of the hair need to be made. Many workers have noted that hair type, whether long or short, woolly or smooth, may be the reason for difference in reactions of cattle to a given set of conditions. Bonsma, in South Africa, has carried out some work on these lines, but again the work needs extending. Rhoad found no correlation between respiration rate and hair length, yet other workers indicate that length of hair between and within breeds is an important causal agent for differences. Skin temperature and hair surface temperatures need more elaboration. Some Russian workers have worked on some aspects of this, but further work is needed, especially at high temperatures.

7. It must be remembered that heat loss by way of radiation, conduction and convection is important in cattle as well as in man. The partition of the total heat loss by these three avenues, plus that lost by way of evaporation would throw much light on the relative importance of each at varying air temperatures. Again, human research predominates.

8. Solar radiation has been found to exert a major influence on cattle, especially in the tropics and sub-tropics. Whether it is important in temperate climates has not yet been tested experimentally. Data is needed on the intensity of radiation over various seasons of the year and also what are the relative incidence of ultra violet, visible and infra red. Coat and hide colour are important and together with hair quality may help to show that even within a breed the breeding of a heat

tolerant strain may be possible.

Radiation to and from the immediate surroundings of the animal is perhaps important. Just how important in cattle we do not know. The measurement of the emissivity of cattle hide and the environment have yet to be carried out. So does the measurement of radiation intensity received from a typical environment by an animal. It has been found that the maximum of absorption and emission of long wave radiation in humans ranges about 9 μ but we do not know what is the range in which cattle absorb and emit long wave radiation. We do not know if cattle behave as black bodies in the far infra red region. It is quite likely that they do, but no experimental data proves it.

10. The partition between skin and respiratory evaporative loss needs studying. That respiration accounts for a larger proportion than in the case of man is quite probable, but how much so needs investigating. Such work will involve studies on water and energy metabolism. Studies on water metabolism plus respiratory exchange data can be used for the investigation of climatic effects on energy metabolism. Brody has shown how heat production in cattle declines at high temperatures contrary to the effect in humans. Such fundamental work needs confirmation.

11. The effect of heat stress on the endocrine system of the body or conversely the exact role of endocrines in thermoregulation is not very well known at present. What changes take place in the body fluids and the biochemistry of cell reaction with temperature changes; how does the blood react, what is the effect on appetite and alimentary function and how do these link up in the complex system, all need elaborating.

12. The role of the nervous system, the hypothalamus and the thermoreceptors is still largely in the hypothetical stage, even with man.

Housing of cattle, in cold weather and in very hot climates, is a common practise in many countries. In England and America Hammond and Findley (176) report that there are some standards layed down regarding optimum ventilation of cattle byres, but

are little better than rule of thumb methods and are largely empirical. An essential step to formulate the best conditions is an expansion of fundamental knowledge outlined above. Methods of assessing the environment can then be formulated and field experiments carried out to test them.

But perhaps, the most important aspect of the study of environmental physiology of cattle is its application to breeding problems in the tropics. There is great need for guidance and knowledge regarding the usefulness of various classes of stock under tropical conditions. In the past the tendency has been to import cattle from one area to another with the hope of improving productivity without any knowledge of the physiological response of the imported breed to their new environment.

Hammond (176) (178) has carried out a regional survey of cattle types over a portion of Africa. The indications were that there was a gradual morphological transition between one region and the next, that there was no sudden change from Zebu types to European but a series of intermediate types, each adapted to its own climatic environment. There is need, therefore, for a world-wide survey on the structural and functional adaptations of various breeds and types of cattle to their environment.

The marked dwarfing and stunting of European cattle in tropical regions, has often been thought to be caused by poor nutrition. Bonsma approaches the matter from a somewhat different angle, claiming that the stunting is due to poor tolerance to heat. This needs more experimental basis but it would be fundamental to find out, since it may imply that stunting represents a natural adaptation, to unalterable conditions of climate under the influence of which any attempt to affect a permanent increase in productivity by improved breeding or feeding would be doomed to failure.

Attempts in the past to improve production in the tropics have involved importation of improved British breeds and crossing with native stock. Crossbreds were often an improvement

but degeneration or reversion takes place in subsequent generations. The original imported stock themselves frequently showed early signs of degeneration. Studies need to be made of the physiological responses of European breeds imported, or bred in the tropics and also of the mode of inheritance of structural and morphological adaptations to tropical climates of various types of crossbred stock. Such studies will show just how the genes react in the new environment and indicate their mode of inheritance. Already some progress has been made with breeding cattle for tropical environments as seen by the development of the Santa Gertrudis breed by Rhoad (177) and co-workers.

IV. TECHNIQUES OF MEASUREMENT.

The chief difficulty which the environmental physiologist has to face is that of measurement. Perhaps it is because of this very real difficulty that the knowledge of thermoregulation in animals is limited. The difficulties of measurement with man are great enough, but with man the experimental subject can be told about it and can co-operate; this, of course, is impossible with animals. To elaborate on methods of measurement is really the field for one trained in physics and chemistry. Therefore, only the principles will be discussed here with details on some of the simpler methods of measurement.

1. BODY TEMPERATURE.

With cattle the rectal temperature is used to indicate the body temperature. As with most measurements either an indication or a record may be desired.

The principal indicating instrument used for rectal temperature of a farm animal is the simple clinical thermometer. There are three sources of error in using it.

(a) Inaccurate calibration of the thermometer - to calibrate it is a simple matter by standardizing it against a standard thermometer in a water bath.

(b) Use of different depths of insertion. Kriss (81), 1921, found a temperature gradient in rectal temperature in dry cows. The deeper the insertion, the higher the body temperature. He used seven inches to record rectal temperature. Readings were made at 4", 5", 6" and 7". At 4" the reading was 0.8°F. lower than at 6-7". Regan and Richardson (60) used 5", Seath and Miller (76) used 3", Bonsma (55) used 4". However, it is perhaps more important to use the same thermometer at the same depth of insertion of each reading in any experiment, since the research worker is more concerned with differences rather than actual precise determination. The use of a rubber bung at the end of the thermometer will ensure a constant depth of insertion. The instrument should be dipped

in water or smeared with vaseline before insertion and care taken to see that it is not embedded in faecal matter. Defaecation, according to Kriss (81), had no effect on the reading, though Hancock (179) (personal communication) states that it does. Probably the time of insertion is more important here than the emptying of the bowel.

(c) Different Times of Insertion. Here again various workers recommend various times. Kriss - 4 minutes; Seath and Miller - 3 minutes; Bonsma - 4 minutes. Three minutes should be ample time for equilibrium to be obtained, but this will vary with the individual thermometer and each one needs to be tested to find the correct time.

Kriss reports that the drinking of water invariably caused a fall in temperature, but after 2-3 hours, temperature returns to normal. Position, he found, had little effect, though, since it has been shown that the heat production of a standing animal is greater than one lying, one might expect a greater body temperature from a standing animal than from an animal which is lying. Benedict and Ritzman (51) found that plane of nutrition had no effect on body temperature. Kriss noted a slight rise following ingestion of a meal.

For a record of body temperature, mercury thermometers cannot be used and one must use electrical methods, either a resistance thermometer or a thermocouple.

2. SKIN TEMPERATURE.

A resistance thermometer (180) consists of an applicator containing an element whose resistance changes with changes in its temperature. It is connected to an instrument which measures changes in its resistance. The resistance element which varies with the temperature to be measured, is usually made of nickel and wound on an insulating rod, which is encased in a protecting tube.

Another thermal electric method of measuring body or skin temperature is by means of a thermocouple. In 1821, Siebeck (181) found that an electric current flows continuously in a •

closed circuit of 2 dissimilar metals when the junctions of the metals are maintained at different temperatures.

A pair of wires so joined as to produce a thermal e.m.f. when the junctions are at different temperatures is known as a thermocouple, (182). In other words when we have two dissimilar metals forming a circuit and one of the junctions is at freezing point and the other at the temperature of the environment of the skin, an electric current will be set up in proportion to the difference between the temperature of the hot and cold junctions.

The various metals and alloys can be arranged in a series according to the magnitude of their thermoelectric effect when used together in a thermocouple. Therefore, for maximum sensitivity the metals should be chosen from opposite ends of the thermoelectric series.

An alloy which is widely used for thermocouples on account of its general all-round suitability is constantan. This alloy is situated near one end (the negative end) of the series. Metals such as copper, iron and alloys, such as brass and steel, are situated towards the positive end of the series and, therefore, produce a large thermoelectric effect when used with constantan.

Thermocouples can be used for taking rectal temperatures provided a suitable holder for the couple is devised. The holder should be so made that the surrounding temperature is quickly transmitted and the couple and the holder should establish close contact with the walls of the rectum.

There are many sources of error in the use of thermocouples and peculiar to the thermocouple itself are:-

(a) Thermal conductivity of the wires. The thermocouple should conduct as little heat as possible away from the skin. The thermal conductivities of the metals and alloys used varies, and it is a matter of choosing those with low conductivity values. Copper and constantan suit this purpose fairly well.

(b) Mechanical strength. There will always be losses of heat by conduction away from the junction and the correct surface temperature would be that obtained with a hypothetical junction

having no thickness so that in practise the wires must be as thin as possible. There is a practical limit to this. Constantan is fairly strong, but copper yields rather easily to tension.

(c) Chemical corrosion. As the wires will be subjected repeatedly to the corrosive action of moisture on the skin the materials used should be chemically resistant. Stainless steel is the obvious choice. Constantan and brass remain bright for months but iron and copper corrode easily.

Apart from these intrinsic errors there are errors in the use of the couple in taking a skin temperature.

(a) Physiological reactions caused by contact pressure or irritating effect of the instrument. There may be vasomotor actions and stimulation or inhibition of sweat glands or hair erector muscles. It is essential, therefore, that the junction be held at a constant pressure and that there be no irritation.

(b) Physical disturbances of the heat exchanges between the skin and its surroundings. Conduction of heat away from the junction will alter the temperature of the skin at the junction and may disturb the effect of wind and radiation to which the skin is exposed. The errors of this type may be positive or negative according to whether the instrument hinders or assists loss of heat from the skin.

(c) There is difficulty in ensuring that the junction is at the same temperature as the skin. One side is against the skin, the other against the air, or, in the case of cattle, against the hair, which may not be at skin temperature. Errors of this type will always be negative as skin temperature will be higher than air temperature and loss by convection facilitated. When dealing with hairy-coated animals, great care must be taken to avoid disturbing the "local climate." The hair can be lifted up with a piece of wood - poorly conducting - and the junction slid under it and the hair smoothed back into place.

Types of holders for thermocouple wires vary. Some of them are in the form of a pencil with the junction at the tip. Such an arrangement will permit ready conduction of heat along the wires

away from the junction. The conductivity of even poorly conducting metals is much greater than that of air and so the skin must be cooled appreciably by this method. Also, pressure is important for accurate readings. A constant pressure is essential, to ensure that the junction is firmly applied to the skin. If held too loosely a lower temperature will be recorded as air will be under the junction.

Both the above errors may be minimized by having the wire from the junction run along the skin for a small distance before moving away to the recording instrument. This will prevent conduction of heat away from the junction, conduction losses taking place at the point where the wires leave the skin. Also, because of the better holder which can be devised by this means, a more constant pressure can be applied. Elder (183) describes a holder which he found useful for taking skin temperatures of cattle.

Even if the temperature of the skin is not altered by the instrument an error may arise due to the junction being at a different temperature from that of the skin. The junction should be freely supported in air so that contact with the holder does not influence it. Because one side is exposed to the air the temperature of the junction will be between that of the skin and the surrounding air but it will be much closer to that of the skin. Russian workers have shown a temperature gradient from the skin to the hair surface so that the air immediately next to the skin is almost at skin temperature, how much so will depend on the density of the hairy coat. Air is a poor conductor of heat, but even so the skin tissues are a much better conductor. The junctions used are also much better conductors than air, thus the temperature gradient through the skin will be continued almost uninterrupted through the junction and there will be little drop in temperature across it, much less than if we take the temperature drop through air for the same distance. If, however, there is poor contact between the junction and the skin, because perhaps of the presence of occasional hairs under the wire then the heat will have a layer of air to move through before reaching the junction. Because

air is a poor conductor the temperature gradient or drop across this small width of air will be considerable and will be lower than the actual skin temperature before it reaches the junction. According to Elder, such a situation may cause an error of up to 0.5°C . Thus, it is important that good contact be made with the skin.

Elder (183) found that errors due to physiological effects were negligible. Using a thermocouple it took 3 seconds to reach equilibrium and after two minutes the skin temperature remained unaltered. Elder showed that actual constancy of pressure was not important but he quotes other workers who claimed that it was important. It seems certain that a constant pressure should be important otherwise there would be different degrees of contact with the skin over various readings.

To measure the e.m.f. developed by the couple either a direct reading galvanometer, a potentiometer or a recording potentiometer can be used. Elder recommends a galvanometer. This has the advantage of giving a direct reading of temperature. For a constant voltage the galvanometer reading depends on the resistance of the electrical circuit because it registers current and not voltage and variations in the resistance in the thermocouple or instrument will affect the reading. To make these variations small a large resistance is added to the galvanometer but this reduces the sensitivity of the instrument. For really accurate measurements the potentiometer is used. Scott (184) describes one as follows:- "A current is passed through a wire to cause a uniform voltage drop along the wire; any voltage within the range of the instrument can be obtained by moving a sliding contact along the wire, the voltage being proportional to the distance the slider is moved. The thermocouple and galvanometer are connected between the sliding contact and one end of the wire. When the potentiometer voltage equals the thermocouple voltage the galvanometer reads zero and the voltage or temperatures can be read by noting the position of the sliding contact. At the point of balance no current is taken from the thermocouple and for this reason the thermocouple resistance does not affect the readings.

The slide wire has to be calibrated periodically by a standard cell, incorporated in the instrument."

Generally the thermocouple is some distance from the potentiometer and connecting leads are used to join the two. The cold junction - usually melting ice - is placed where the lead wires join the thermocouple wires.

The great advantage of the thermocouples is the ease with which they can be made and provided they are used with care, can be quite accurate. Their chief disadvantage is the care in handling and the need for a cold junction at a constant temperature.

The most accurate method of taking skin temperature is by means of a radiometer. This has been successfully used by Hardy (186) on human beings. A simple form of thermopile consists of a series of thermocouple elements, set in the apex of a hollow cone usually screened from wind by a fluorite or rock salt window and another set of thermojunctions at the temperature of the environment. When the open base is pointed at a radiating surface an e.m.f. develops in the wires and its magnitude depends on the radiation absorbed by the elements. For any given surface the radiation emitted is a function of its temperature, its area, and its emissivity. Area can be corrected for, but emissivity is important. Its determination is very difficult yet it must be known accurately. Findlay (11) states that the difference between an emissivity of 0.954 and 0.980 may cause an error of 0.6°C . in reading the skin temperature. Emissivity of cattle hide has not been determined and this method of measuring skin temperature must await its determination. The thermopile, of course, overcomes the many errors to which thermocouples are subject.

3. MEASUREMENT OF ABSORPTION AND REFLECTION OF SOLAR RADIATION.

Bonsma (67) and Rhoad (137) both used a photoelectric cell to measure the reflection of radiation from different coloured hides.

Bonsma used a western photometer model to measure the

direct intensity of sunlight in foot-candles and at the same time to determine the strength of light reflected from the animal's skin. In order to determine the upper limits of solar radiation, he found it necessary to place a multiplier over the "sensitive eye." This excluded nine tenths of the light from the 'eye'. After incident sunlight was taken the animal is made to stand at right angles to the sun and the sensitive eye is placed against the side of the animal so that no direct sunlight falls on the instrument.

Riemerschmid and Elder (136) used a Moll Gorzinsky solarimeter which consists of a blackened receiving surface built up by a series of thermopile elements covered by two glass domes. The measurements on absorption were made on dead cattle hides and the intensity of reflected radiation measured. They used this type of instrument because it measures total solar radiation and not just the visible, as does the instrument used by Bonsma. Also the glass domes which cover the elements prevent long wave radiation being received from the hide in virtue of its temperature, so what is reflected radiation, is reflected solar radiation. Riemerschmid and Elder criticize the use of photoelectric cells because these instruments have a maximum sensitivity in a certain part of the spectrum, i.e., the light waves. However, the spectral distribution of the incoming sunlight is different from that of the reflected radiation and the ratio for reflection represents two different portions of the spectrum and their ratio does not represent the true reflection of radiation. The solarimeter measures all wave energy not the intensity of just visible sunlight. However, though less accurate, Bonsma's instrument should be quite useful for field studies.

4. MEASUREMENT OF RESPIRATORY RATE.

The two most common methods of observing respiration rate of cattle are:

1. Counting the flank measurements. Each complete inward and outward movement is counted as one complete

respiration. A tally marker used in one hand makes things easier. The rates should be counted for a minute and the process repeated two or three times and the results averaged.

2. By placing the hand in front of the nostril and counting the exhalations. However, this method would only work with quiet animals, it has been noted how the animal's attention can be easily distracted and this may perhaps affect its respiration rate.

Another method described by Findlay (11), employs a stathograph and tambour. This method is suitable for cows which are indoors and restrained by a yoke. The stethograph consists of corrugated rubber tubing closed at one end and a tube leading from the other end passes to a tambour set up on a table. This tambour consists of a diaphragm and moves a pointer as the diaphragm moves up and down. The corrugated tubing is tied around the animal until there is sufficient tension so that the movements of the animal's breathing moves the air in the tubing which passes up to the diaphragm and the movement of the latter communicated to the pointer gives the respiration rate. The pointer can be set up so as to record its movements on a revolving drum or kymograph. This latter consists of an electrically driven drum, with blackened paper on it and the pointer draws a trace on this paper.

Another method is to insert small thermocouples or thermostors in the nostrils - the thermocouple is held on a slight expanding spring in the middle of the nostril. Variations in temperature of inspired and expired air will be displayed as fluctuations in the temperature of the thermocouple. Just how the animal reacts to this arrangements in the nostril Findlay (11) does not say, but probably the method would have but limited application.

It is often desirable to obtain measures of respirating minute volume and tidal air to supplement respiration rates.

There are three conventional methods of collecting data of this type:

1. The animal may wear a mask connected with a dry gasometer
2. The animal may use the closed circuit spiographic mask.
3. Or, may use the open circuit method involving a spirometer

These three methods involve expensive equipment and are used principally to determine the energy metabolism. Brody describes the closed circuit type as consisting of a mask over the mouth and nostrils of the subject and connected to an oxygen spirometer and measuring the rate of oxygen consumption by the rate of decline of the oxygen bell. Its advantage is its simplicity and economy of operation, there being no gas analysis involved. However, it has several disadvantages.

1. It furnishes oxygen consumption only, so that no respiratory quotient is obtained, which is essential for determining the invisible weight loss and for determining heat production.

2. The exhaled CH_4 is not absorbed by the carbon dioxide absorbers - soda lime - so that this may result in an error in oxygen consumption data.

3. The efficiency of the soda lime as absorbers of carbon dioxide and water may change with temperature.

The open circuit apparatus provides complete respiratory exchange data and allows the animal to breath the same air as the experimental conditions. However, the supplementary equipment needed for gas analysis from the various absorbers is complicated and costly.

5. MEASUREMENT OF THE HEART RATE AND BLOOD PRESSURE.

There are various positions over the animal where pulse rate may be determined by simple palpation. In cattle the four main positions are:

1. The submaxillary artery below the angle of the jaw.
2. The metacarpal artery on the back of the fore fetlock.
3. The femoral artery on the inside of the hind leg above the hock.
4. The tibial artery running down the underside of the tail.

The last one is very convenient to use. A stopwatch and tally counter are needed, taking readings over half or minute intervals repeated two or three times.

Beakley and Findlay (185) have described an elaborate method for taking pulse rates for cattle in an experimental room. It involves a modification of electrocardiograph methods used for humans, but because of the hairy coat and muscle movements, the instrument used for humans had to be set up to overcome these faults. A rubber strap with pieces of copperfoil gummed to its surface is connected by separate wires to a terminal board and strapped around the chest of the animal. Contact between the copperfoil and skin is made by shaving the hair and applying soft soap to the skin and foil. The leads from the copperfoil are led off to an amplifier circuit and the pulse rate recorded on the kymograph.

Blood pressure can be measured with a sphygmomanometer. This, as described by Findlay (11) "consists of a hollow compressing cuff, a mercury or water manometer and an inflating pump with an exhaust valve." The cuff is strapped to the tail of the cow and inflated just above the pressure necessary to obliterate the pulse. The cuff is then slowly depressed using the exhaust valve until the pulse below the cuff can be detected by auscultation. The pressure at this point, the systolic pressure, is read on the manometer. If the cuff is still further deflated the reading gives the diastolic pressure. The cuff pressure can be found at which the column of water in the manometer oscillates up and down. Each complete oscillation represents one pulse beat and the instrument can be used to record pulse rates.

6. MEASUREMENT OF SWEATING AND EVAPORATIVE LOSS.

Loss of moisture from the respiratory tract can only be found by applying a mask over the animal's face and connected by one way valves to a gasometer or spirometer and the gases metered and collected. From wet and dry bulb readings on the inspired and expired air and from the volume of air passed an estimate of the evaporative loss by this pathway can be made.

For detection of sweating many coloured reactions are used. Guttman (187) used quinizarin mixed with anhydrous sodium carbonate and rice starch as an indicator of sweating. The powder is finally dusted over the skin giving a faint violet colour. Sweat appears as dark violet spots.

Randal (188) applied dilute solution (3% I_2 in alcohol) to the test area. This gives a characteristic starch iodine reaction when ordinary starch-containing papers are pressed lightly over the area. The activity of the gland is shown by a blue-black spot and its size varies with the intensity of sweating.

Minor (189) painted the skin with a solution of iodine in castor oil and ethanol, until it was uniformly yellow. When the skin was dry it was powdered with fine starch until uniformly white. Sweating shows up as black spots on a white background.

The estimate of total evaporative loss involves data on oxygen consumption, carbon dioxide production, methane production pulmonary ventilation rate and metabolic weight loss as measured by open circuit respiratory exchange apparatus. Insensible weight loss is an invisible loss and Brody (44) defines it as the difference between the weight of gases and vapours given off by the body and those absorbed by the body.

There is given off from the body water vapour, carbon dioxide and methane - absorbed is oxygen, i.e.-

$$\text{invisible loss} = (H_2O) + (CO_2 + CH_4) - O_2$$

Evaporative loss (H_2O) = Insensible loss - ($CO_2 + CH_4$) - O_2 and the expression ($CO_2 + CH_4$) - O_2 Brody terms the metabolic weight loss factor.

The modern method of determining insensible weight loss is to weigh the animal on a sensitive balance. The animal is placed on the platform of the balance and a counter weight placed with it and the time interval taken for the balance to centralize. Urine and faeces are collected in a pail which is immediately returned to the scale platform and saliva

collected in a pan attached to the platform.

Together with respiratory exchange data this material on insensible weight loss is used to compute moisture evaporation. Brody has shown that near 100°F. moisture evaporation is virtually equal to insensible weight loss, because the metabolic weight loss factor in the above equation approaches zero.

This is because at 100°F. feed consumption is reduced and little methane is therefore produced. Under the depressed feed intake the respiratory quotient tends to approach 0.73 when the weight of CO₂ produced equals the weight of O₂ consumed. At lower temperatures correction will have to be made to the insensible loss to allow for a different respiratory quotient production before moisture loss can be determined. Brody states that, at 100°F., the heat production of the animal can be computed by multiplying the weight of water vaporized by the latent heat of vaporization. At 102°F. air temperature equals skin temperature and all heat must be lost by way of vaporization. However, in cattle the body temperature is rising at these high temperatures and consequently there is an accumulation of heat within the body so that heat dissipated at 102°F. need not necessarily equal the heat production. In man with a normal body temperature, when air and skin temperature equal, 94°F., then heat dissipation by vaporization would equal heat production.

Also, with cattle, some heat is lost by warming water which the animal consumes and according to Brody, this is considerable at high temperatures. However, the heat loss by evaporation of a unit weight of water at the skin is about 15 times greater than that lost by warming the unit weight of water by drinking.

Measurement of cutaneous loss from small areas have been carried out with cattle by Regan and Richardson (60), Freeborne (153) et al, and Rhoad (64). They used petri dishes with calcium chloride papers in them. However, the isolated area

is subjected to conditions of temperature and humidity different from the rest of the body. Also the evaporative loss cannot be partitioned between that due to osmotic loss and due to true sweating. Kuno overcame the first two objections by using a cup with two side valves and a middle tube containing a thermocouple. Air is led in and out of the side tubes and the volume and water content of the incoming and outgoing air streams noted and the evaporative loss may then be computed.

7. METHODS OF MEASURING THE THERMAL ELEMENTS OF CLIMATE.

(a) Air Temperature.

Usually assessed by means of mercury thermometers which must be set up in a screen in an open space to protect the bulb of the thermometer from direct solar radiation and at the same time permit free circulation of air.

(b) Air Humidity.

This, in meteorological work, is determined from wet and dry bulb temperatures. The dry bulb is the ordinary thermometer as for (a) above. The wet bulb is a similar thermometer but with the bulb covered by muslin saturated with water. The evaporation of water absorbs heat from the bulb and so lowers its temperature. This will fluctuate with air currents but in practice prior to reading, a small fan is turned. From the wet and dry bulb temperature readings, the relative humidity vapour pressure or absolute humidity may be obtained from charts and tables published by various meteorological offices.

(c) Air Movement.

The most common method is by way of finely balanced cups on a spindle and a system of cogs and shafts so arranged that the rotation of the vanes can be recorded on a chart.

(d) Solar Radiation.

Total sun and sky radiation can be measured by means of a flat plate radiometer. This consists of a series of thermojunctions covered by two glass domes, to prevent any radiation from the surroundings to reach the elements, and the rest of the cold junctions may be lead indoors and the whole

arrangement connected up to give the amount of energy falling in gram calories/cm/sec². on a revolving graph. The thermopile elements exposed to the sun are set up in the centre of a large white disc - the latter cuts out reflected radiation from below. Direct sky radiation may be obtained by setting up a separate disk with a large steel hand about 1½" wide over the disk in such a way that its shadow will fall over the elements no matter what is the sun's altitude. The subtraction of the one set of readings from the other, will give reflected sky radiation. The whole arrangement is usually set up on top of a high building.

B. EXPERIMENTAL.

I. INTRODUCTION

Research in environmental physiology involves three separate approaches. Firstly, research on the fundamental physiological mechanisms of heat regulation, secondly, to formulate the best methods of assessing animal reactions to climate stress, and thirdly, methods such as showers, sprinklers, shade barns, etc. on the one hand, and breeding on the other, to help reduce the direct affects of climate.

The second approach occupies the work of this section. When dealing with cattle, methods must be worked out to allow workers to gauge the effect of climate on the individual animal. The clinical thermometer is well known for its use in indicating body temperature, but many worship the arrow on the thermometer, a reading above indicating fever. However, perhaps the chief attribute of life is variability and this applies strongly to body temperature and other measurements of the animal's internal environment. The normal temperature of animals is extremely hard to define because of this variability and a reading above what is popularly though as normal, may not necessarily mean adverse conditions within the animal.

Cattle respond quickly to increasing air temperatures by a rise in respiration rate. How useful is this as an indicator of thermal stress and what variability is associated with it? Pulse rates in man along with the clinical thermometer is used to indicate body health. Is it a useful indicator in cattle? With these 3 measures we have a diurnal trend, a difference due to gestation, lactation, exercise, etc. How may these be held constant or allowed for in order to assess the effect of climate alone? That is the problem.

Skin temperature plays an important role in heat regulation, but this varies with various regions of the body and with emotional stimuli. To find the average body temperature is a difficult task but because of the importance of skin

II. METHOD OF PROCEDURE.

(a) Stock.

The only animals available at the time the experimental work started, March 1950, were rising two year old identical twin heifers. Six pairs were picked with varying coat colours. Bonsma's work in South Africa lead to the choosing of different coloured sets. It would have been more desirable to have mature cows as experimental animals because of the greater heat production due to lactation, though at this period of the year this would probably be greatly reduced through the cows falling off rapidly in production. However, milking stock were all on experiments, and could not be used.

These six pairs were used for all the 'outside' measurements. Three of these pairs, 55/58, 25/26, 49/50, were subsequently used for the diurnal trial. One of the pairs, T55/58, which had dried off very early in lactation and another dry three year old cow were used for skin temperature work in October.

(b) Skin temperature apparatus.

For much of the early work, Dominion Physical Laboratories kindly supplied on loan a portable Tinsley potentiometer and four types of thermocouples. These were:

1. Bow type - The holder resembles a hacksaw frame with 33 S.W.G. copper constantan wire joined at the centre of the bow. This type had a series of pulleys and a spring so that adjustments could be made to vary the tension on the wire.

2. Hypodermic needle thermocouple - 45 S.W.G. enamelled copper constantan wires, soldered at the end of a hypodermic needle.

3. Plastic probe thermocouple - A thin tinned copper disc at the end of which was attached two enamelled wires 45 S.W.G. copper constantan.

temperature it must be found.

These four measures are commonly used to assess animal reactions to climate but we do not know their relative importance or if there are others which would serve the purpose better. A great deal of research will have to be carried out to find just how one may determine an animal's reaction to heat and cold. Unless one can do this then there will be no true scientific approach to the third aspect of the general research programme, that of negotiating the effects of climate.

Object of this Section:

Information on the body temperature, respiration rate, pulse rate and skin temperature of New Zealand cattle is limited. In order to find what variation there is in these respective measures under fairly normal conditions, measurements were taken on several cows over the course of the year. One of the great difficulties of using such measurements is the technique involved and a standard procedure was aimed at with all fair measures. Once such data and methods of measurement has been worked out then there will be a fund of information available for any work which may be started in the future, to find how production is related directly to the climatic thermal elements. A necessary preliminary, however, is to know what is the best time to measure, how to measure, and how to interpret results in the light of factors other than climate affecting these various measurements.

4. Disc type thermocouple 32 S.W.G. enamelled constantan and 40 S.W.G. copper soft soldered at the centre of a tinned copper disk.

The cold junction was composed of a thermosflask filled with paraffin oil with terminals, thermometer and a wire plunger which worked up and down and served to stir and mix the paraffin thoroughly.

Later, in early July, the D.P.L. recalled the Tinsley potentiometer and another one was not available until the end of August. This was a much more robust machine, the Cambridge portable potentiometer workshop model. Further work on skin temperatures designed to find out the effect of clipping the hair, and how skin temperature varied over the body, necessitated the making of more suitable holder than the bow type holder supplied by D.P.L. This latter worked very well but the arms of the bow are wide apart, suitable for taking readings on the trunk of the animal but impracticable on the legs of the animal. The new holder was but a smaller edition of the bow type and 33 S.W.G. copper constantan wire was used. All the above 4 thermocouples were calibrated by D.P.L. and found to be accurate to 0.1°C.

(c) Body temperature.

A review of the literature on methods of measuring body temperature showed that workers used various depths and times of insertion of clinical thermometers. A temperature gradient has been observed by Kriss. However, it was considered that so long as the same depth and time of insertion was used for all readings, the important effect of differences with which one was primarily interested in, would show up. Consequently, ordinary clinical thermometers were purchased, having a thickened bulb of the type used for infants. Care was taken to see that they were accompanied by an N.P.L. certificate and on purchase were calibrated by Dr. Dolby, D.R.I., who found most of them accurate to within 1°F.

A rubber bung was fitted over the end of the thermometer and

a strong cord tied around it and used to fashion a loop to give ease of handling the thermometer. When inserted up to the rubber bung the depth of insertion was 3 inches.

As regards times of insertion each thermometer was tried out to see the shortest time it took to reach equilibrium. This ranged between 2 and 3 minutes.

(d) Respiration rate.

This was measured by counting flank movements using a tally counter and a stopwatch. The animal must be standing quite still and not have its attention distracted. Two or three half minute intervals were taken, during the time that the rectal thermometer was being held in position.

(e) Pulse rates.

Palpation of the femoral and tibial artery was the method whereby pulse rates were recorded. Some cows have a femoral artery which is deeper in the tissues than in others and the tibial artery has to be used. Of course, when the cow is lying down as was often the case, when the stock were in the feeding barn, the only accessible artery is the tibial.

(f) General procedure.

The procedure used for taking readings outside was to take three days per fortnight over the months April, May and June. Towards the end of March work began on types of thermocouples and positions necessary for routine skin temperature work. This was continued during the first set of three days observations and because of the time taken with this preliminary skin temperature work the number of observations were not as many as was planned. In analysing the data by means of complete analysis of variance, therefore, these first three day readings have been omitted to permit ease of calculation. However, analyses of variance at the end of each set of 3 days were prepared and this was carried out also for the first set.

The stock for the outside data were handled in the D.R.I. weighing yards. Each heifer was placed in a chute and all

measurements were taken there. After the preliminary work the hip region was used for skin temperature. A small area was shaved and three readings per position were taken. Then, rectal temperature and respiration rate were taken and finally pulse rates. Each member of a twin pair followed her mate. It took approximately 5 minutes to take all the measurements on one cow, after some experience, and the whole 12 with a good run could be done in just a little over an hour.

The whole process was done four times a day so that there were 4 readings per cow per day with five measurements, viz., air temperature, body temperature, skin temperature, respiration rate and pulse rate. Air temperature was recorded with an ordinary mercury thermometer hung up in the shade near the man operating the potentiometer. Because of the difficulty in holding the thermocouple on the animal and at the same time adjusting the potentiometer, a D.R.I. technician or college student was employed. His job was to operate the potentiometer and record the various readings in a notebook.

(g) Diurnal Experiment.

The D.R.I. feeding barn was used to house 3 pairs of twins. Several days preliminary trial was necessary to accustom the cows to the routine to staying indoors for a 24 hour period. The experimental period consisted of 7 days. For the first 4 days readings were taken of air temperature, body temperature, respiration rate and pulse rate, every hour from 9 a.m. to 10 p.m. then every 2 hours until 6 a.m. and then every hour till 9 a.m. of the next morning. During this time readings were taken whether the cows were lying or standing. Differences were noticed in the various measures depending on the position of the cow. Then readings every hour during the day was changed to readings every 2 hours so as not to disturb the cows so much. Cows in this latter period were all made to stand at least quarter of an hour before readings were taken and it took on an average of about half an hour to take all readings. This

meant that the cows would be on their feet $\frac{3}{4}$ of an hour every hour, which would not allow them enough rest during the day if readings were to be taken every hour and with all cows standing.

The cows were fed silage and hay ad lib and 3 lbs. of mixed meal per day. At the conclusion of a 24 hour period the cows were let out into the paddock until 8 a.m. of the next day when they were brought in and made ready for the next 24 hour period. They were well bedded down with straw, and water was available in drinking cups, though they never made any great use of these.

(h) Skin temperature.

The acquisition of a new type of potentiometer, necessitated it being tested to see how the technique was to be changed. With the Tinsley machine the cold junction varied with air temperature, though not very markedly. This necessitated additional calculation in transposing millivolts to $^{\circ}\text{F}$.

D.P.L. had kindly supplied a graph for doing this, which was subsequently worked up into a table for easier working. Thus, a cold junction temperature of, say, 50°F . had to be transposed to millivolts, this added to the dial reading and the sum transposed back to $^{\circ}\text{F}$. to give the skin temperature reading. This was both time consuming and a source of error in the instrument, for the thermometer reading in the cold junction could change quite a bit while taking just one reading with the thermocouple and may have been a factor making the Tinsley very sensitive and tricky to use.

Experience and practical advice, caused a change over to a cold junction consisting of crushed ice in a thermos flask. Thus, the dial reading on the potentiometer was the skin temperature reading in millivolts. Just one transposing process was therefore necessary.

Each potentiometer could be read to a $\frac{1}{1000\text{th}}$ of a millivolt. As the graph supplied by D.P.L. could only be read to 2 decimal places, millivolt readings were taken to 3 decimal places and when transposing the figures were read to the nearest 2 decimals.

In the literature some workers shave the hair, others attempt to take skin temperature readings by parting the hair and sliding the thermocouple along the skin.

Three cows were placed in the feeding barn, 8 positions were chosen, on about the same spot in each animals, and readings were taken on each of 8 positions on each cow. For the first set of readings, the hair was parted with a piece of wood and the thermocouple placed on the skin thus exposed. Next, the hair was clipped with the scissors as close to the skin as possible and the complete set of readings carried out again. Then each small area was shaved and the readings repeated. This data was subject to analysis of variance technique and on the results of this, the same three animals were used and 22 positions were taken over each animal, each position being marked with red raddle. Readings were carried out as in the first method, i.e., by not clipping or shaving the hair. The first part of the trial was carried over 2 days; for the latter part there were morning and afternoon readings on 6 days. Air temperature and body temperature were recorded before doing each cow.

III SOURCES AND TREATMENT OF DATA:

A. Preliminary work with skin temperature measurements.

To find out how repeatable were the readings on any one position intra class correlation analysis was used. (Snedecor (190)). This method enabled one to see which positions gave the most consistent results.

B. Outside data.

Because of heavy rain and breakdowns with the thermocouple wires, skin temperature data was not as great as for the other measurements. Each set of 3 days was analysed by analysis of variance technique. At the end of the series the whole of the data was analysed in a complete analysis of variance for each measurement. Each analysis was of the special 'time' series type as outlined by Wilm (192). This allows the proper testing of some aspects, of the analysis by appropriate error or inter-

action mean square, but not of others.

Next, to test how the various readings were useful as a method intra class correlation technique was again resorted to. These repeatability estimates were worked out in 3 different ways according to 3 different questions posed.

For the 5 variables involved, correlations were worked out for all possible combinations. At first this was done within each day and ignoring cows. To see if all the correlations for any two variables during various days belonged to the same population they were transposed to Fisher's (z) quantities. (Snedecor, (190)). Then the correlations were worked out on a within cow basis and the test for population again carried out and average correlations derived.

Three of the highest correlations:-

Air temperature and respiration rate.
Air temperature and skin temperature.
Skin temperature and respiration rate.

were tested to see if they fitted best a curvilinear or linear regression line. Linear graphs were then prepared for each cow and the total for each regression and then an analysis of errors of estimate from average regression within groups were carried out, to see if there were differences among the lot regressions.

Because it was desirable to find out which of the measurements were most useful as a measurement of reaction to temperature further work was done with the pulse rate data. Pulse rate did not seem to be strongly correlated with anything and partial correlation and multiple regression analysis (Pearson and Bennet (191)) was used to see whether pulse rates were strongly correlated with something else when the influence of other variables were held constant.

C. Diurnal data.

Because of the slight change in procedure after the first few days, the two separate 'time' analysis of variance were prepared for each variable.

Correlations within cows, for all possible combinations for all variables were worked out and tested to see if a set belonged to a common population, and if so, average correlations

were derived. Graphs were prepared showing variation throughout the day.

D. Skin Temperature Data.

Analyses of variance were applied to all the data.

IV. RESULTS.

A. PRELIMINARY SKIN TEMPERATURE WORK.

Of the 4 types of thermocouples supplied, two of them were impracticable. The hypodermic needle type would give a tissue temperature rather than a skin temperature. To avoid losses of heat by conduction it had to be slid along under the skin for a considerable distance. Not only did the animal object strongly, but the needle was too fragile and soon broke.

The disk with very thin wires attached was also impracticable. The disk had to be taped onto the skin with strips of sticking plaster and the wires were very fragile and broke easily. For swift work in a routine set of readings, this type of thermocouple junction was useless.

There remained the plastic probe and the "hacksaw" types. The following table illustrates the differences between the two.

TABLE 1.

Mv Readings Using Two Different Types of Thermocouples

Cow	"Hacksaw" Dial Reading Mvs.	"Contact" Dial Reading Mvs.
Vanilla	.605	.435
Yale	.625	.500
Virginia	.625	.495
Vanilla	.590	.468
Yale	.628	.529
Virginia	.569	.540
Yerle	.569	.538
T17	.638	.480
T18	.588	.526

The readings were taken on the same position on each cow. After 3 cows the thermocouples were changed and the same three cows

measured again and then the next 3 cows were done. This was to avoid having any changes in air temperature over a period of time affecting the skin temperature. It can be seen how the contact thermocouple gave a very much lower reading. This was probably due to insufficient pressure and to loss of heat by conduction - along the wires leading up through the plastic tube, and also the influence of the plastic holder itself.

To test whether even with the "hacksaw" type of thermocouple there was a loss of heat by conduction the thermocouple was held in the same position for a period and dial readings noted as fast as the operator could work the machine. The following table shows the results.

TABLE 2.
Effect of keeping the junction on same position

Cow No.	Dial Reading Mvs.	Cow No.	Dial Reading. Mvs.
T25	.614	T26	.595
	.594		.565
	.600		.559
	.592		.544
	.598		.538
	.599		.520
	.592		.530
	.595		.542
	.587		.535
	.571		.520

Next, to test whether the cold junction needed pumping after every reading or at the beginning of a series of readings the following data was obtained on positions on a man's arm. The trial was repeated with the operator and subject changing around.

TABLE 3.
Effect of using the pump in the cold junction of
dial readings of Potentiometer
Mvs.

No Pump	Pump	No Pump	Pump
.491	.508	.471	.432
.480	.500	.470	.438
.480	.500	.471	.428
.480	.498	.467	.430
.478	.500	.453	.436
.470	.502	.436	.441
.468	.495	.422	.443
.478	.495	.432	.444
.468	.500	.423	.441
.465	.500	.423	.445

Position effect:-

1. Six twins were used to take skin temperature measurements on 3 shaved points, 12 readings per position were taken, taking the thermocouple off the position each time and working the pump, and then going to the next position until all 36 readings on the one cow were completed.

2. Next nine positions on the right hand side of the six animals were chosen. The thermocouple was applied to each of the nine positions in sequence and then repeated twice.

3. In other trials, five of the best of the above 9 positions were taken with 6 cows, 6 readings per position, during the morning and repeated in the afternoon.

4. Two of the best positions were taken, the thurl and hip, 6 readings per position with 6 cows in the morning and 12 in the afternoon.

5. The same two positions were used, 3 readings per position, 12 cows, repeated morning and afternoon.

6. Two positions, 3 readings per position, repeated 3 times in the one day - 12 cows.

The table shown on the following page, shows the intra class correlations which were obtained from these several trials.

Discussion:

The left and right hip positions gave the best repeatability whereas the back did not give as good results. With the hips and the "hacksaw" thermocouple, better tension could be obtained because of the curvature of the body in this region. With the back position, especially in some animals which are broad across the back, the curvature is not so great. It is desirable to have the junction buried into the skin to about half its depth. Total correlations were calculated, using all positions and all subgroups. These were very high indicating variation within the subgroups, was no-where near as great as variations between subgroups because of different positions and different cows. These first readings were taken under fairly uniform weather

TABLE 4.

Intra class correlations for Skin Temperature
using various positions.

Trial	Cows used	Posi- tions	Reading/ Position	r_i		Combining
1	6	1 2 3	12	.918 .927 .783		.998
2	6	1 2 3 4 5 6 7 8 9	3	.900 .669 .056 N.S .850 .477* .693 .811* .530* .713		.943
3	12	1 2 3 4 5	6	a.m. .846 .998 .793 .716 .760	p.m. .852 .316* .754 .792 -.250 N.S	
4	6	1 2	6	.540 .777		
	12	1 2	3		.876 .862 .953 .664	
5	12	1 2	3	.825 .849	.914 .967	.970 .958
6	12	1 2	3	.713 .849	.833 .687 .761 .936	.871 .946
All highly significant at 1% level except those marked: * significant at 5% level. N.S. non-significant at 5% level.						

conditions with overcast skies, no rain or wind. Thus satisfied that good repeatability could be obtained provided due care was taken, the next step was to find which positions over the body gave the best results with the object of narrowing down the number of positions until a final one could be selected which could be used as a routine test along with the other measurements of body temperature, respiration rate and pulse rate.

First 9 of the positions were taken and then from these 5, then 2. Some positions give a poor r , eg., position 3 in the 2nd trial, which was down on the leg. Such positions are difficult to place the holder in the same place at each reading. Poor curvature of the body and particularly movements of the animals affect the repeatability. The total r is quite high due, probably to large mean differences in skin temperature from one position to another being a greater effect on the total variance than variations within readings on the same position.

During the afternoon when the above 9 positions were being tested the clouds cleared away and it became very hot. Air temperatures in the morning were 62°F., in the afternoon 70°F. There was noticed a drop in skin temperature when clouds passed over the sun. This was probably due to the cloud shading the direct solar radiation. Readings taken in direct sunlight should be shaded from the direct sunlight by the hand or arm, otherwise the reading will be a higher one than the true skin temperature. However, the hand should be well away from the junction, otherwise the junction may receive radiation from the hand in virtue of its temperature. But just the small area around the junction is shaded in direct sunlight, the rest of the animal is exposed and this probably raises skin temperature all over the body. Clouds will shade the whole body causing a corresponding drop.

The next day with 5 positions similar effect of sun and cloud were noticed, skin temperatures rising up to 100°F. The morning was cloudy giving fairly good results for all readings. The first position was the thurl region which was shaded from the sun by the position of the animal. Number two, the hip position was markedly affected by differences in sun and cloud in the afternoon giving a poor r . The shoulder, No. 5, was like the thurl, shaded, yet the repeatability was negative, showing that the variation within subgroups was greater than between subgroups means. This is a case in point where intra class correlations may be misleading, where there is good repeatability within subgroups, but because the readings are much the same on this

position for all animals the total range of variation is not very great and the subgroup means are all very much the same in magnitude.

Thurl and hip regions were used in No. 4 part of the trial. During the morning it was sunny for a time then it became overcast and rained in the afternoon. Two different operators of the potentiometer were used, one in the morning, and one in the afternoon. The morning operator took a lengthy time to obtain equilibrium, whereas the more experienced operator, in the afternoon, took but a short time to take a reading. We noticed in the early stages with this thermocouple and potentiometer, low skin temperature shows a progressive fall with time (see Table 2). The morning operator was new to the job and probably this caused the morning r_1 to be lower than the afternoon. Also care must be taken to use the stirrer or pump in the cold junction before each reading or this will cause lower skin temperature (see Table 3). In the afternoon with heavy rain, skin temperatures dropped to as low as 80°F. Three readings per position instead of 6 gave quite good results, but the lower r_1 for the hip in the afternoon may have been due to raindrops striking the junction. The thurl region was less liable to this influence as it was protected more by the man using the holder. On the whole, although rain caused lower skin temperatures, repeatability of readings was moderately good; but readings should preferably not be taken when it is raining hard, because of rain striking the junction and water seeping into the terminals of the holder, cold junction, and instrument, causing conduction leakage.

On the last two days, the same two positions were taken with all the cows and 3 readings per position taken. Repeatability was good on the whole. However, one cannot stress enough the importance of extreme care. The potentiometer was a more sensitive instrument than the purpose warranted and was hard to reach equilibrium; what with movements of the animal and conduction leakages, etc. This tended to extend the time taken to reach equilibrium, and lowered the temperature. Correct pumping

was essential always and care had to be taken to see that the holder was always placed in approximately the same place at each reading, and that the correct tension is applied to the wire so that pressure is uniform.

As a result of this preliminary work it was decided in subsequent routine observations that the hip region be used, the area being shaved and three readings taken on the position.

B. OUTSIDE DATA.

(a) Skin temperature.

There were, all told, 15 days spread over 3 months for routine outside measurements. The first 3 days work was still being carried out for positions and repeatability estimates for skin temperature and during the last 3 days skin temperature could not be taken because the potentiometer had to be returned to D.P.L. Each set of 3 days was analysed by analysis of variance. Three readings per position were taken and these averaged.

The analysis of variance for the first set is as follows:

TABLE 5.

Analysis of Variance for Skin Temperature - first set
of 3 days.

Source	df	S.S.	M.S.	F
Total	143	365.86		
B Animals (A)	11	23.97	2.18	N.S.
B Twin Pair}	5	11.28	2.26	N.S.
W Twin Pair}	6	11.69	1.95	
B Days (D)	2	147.76	73.88	**
D x A	22	22.99	1.04	N.S.
Twin P x Day}	10	15.69	1.57	N.S.
W.T. P x Day}	12	7.30	0.61	
Within days on individuals (error)	108	171.14	1.58	
N.S. = non significant. ** = significant at 1% level.				

This is an experimental replicated in time and is analysed by the method proposed by Wilm. It is typically an analysis used for a split plot design. The sum of squares is divided into two main portions, that associated with animals and that associated with days. In a typical split plot analysis each major part has its own experimental error. In the above, days has its own experimental error, the between animal variance not being subject to any treatment has no experimental error of its own. In the above analysis it can be seen that there is a highly significant difference between days, but no significance in the day x animal interaction, i.e., animals all reacted in a similar manner each day. The experimental error used to test this in the between days on individual mean square.

Now the variance for animals has the following components associated with it $\delta_A^2 + \delta_{DA}^2 + \delta^2$.

If one was to use as in an ordinary analysis, the error term for testing animals we would in effect be testing:

$$\frac{\delta_A^2 + \delta_{DA}^2 + \delta^2}{\delta^2} = 0$$

i.e. the null hypothesis being tested that $\delta_A^2 + \delta_{DA}^2$ is 0. This does not mean very much because of the interaction component. The correct test for animals to see if δ_A^2 is significant or not is zero, is:

$$\frac{\delta_A^2 + \delta_{DA}^2 + \delta^2}{\delta_{DA}^2 + \delta^2}$$

However, if the interaction δ_{DA}^2 does not contribute a significant amount to the animal mean square that the first test with δ^2 would be quite in order. In the given analysis the δ_{DA}^2 is non-significant and when using δ^2 to test differences between animals, the result is non-significant.

The between animals variance and interaction associated with animals, degrees of freedom are split into between and within twin pairs. This indicates whether twins react together or not.

The second and third set of analyses are given below.

Degrees of freedom do not correspond because on one day stock had to be brought to the weighing yards some considerable distance and it took some time for them to settle down.

TABLE 6.

Analysis of Variance for Skin Temperature.

Second and Third set of 3 days.

Source	d. f.		M. S. & F.			
	2	3	2	F	3	F
Total	131	119				
<u>B Animals (A)</u>	11	11	3.26	**	12.76	N. S.
B. Twin P }	5	5	6.01	**	15.39	N. S.
W. Twin P }	6	6	0.98		10.57	
<u>B. Days (D)</u>	2	2	1.92	N. S.	175.45	**
D. x A.	22	22	1.06	N. S.	2.09	N. S.
T. P. x D.	10	10	1.00	N. S.	2.23	N. S.
W. T. P. x D.	12	12	1.11		1.98	
Within days on individuals	96	84	1.08		8.65	
<p>N. S. = non-significant.</p> <p>** = highly significant 1% level.</p> <p>The same method of testing various mean squares is as before.</p>						

The final analysis for skin temperature is for twelve cows, seven complete days, i.e., days with all the readings per day.

TABLE 7.

Total Analysis of Variance of Skin Temperature.

Source	d.f.	M.S.	F
<u>B Animals (A)</u>	11	4.76	N.S.
B. Twin P.	5	6.34	N.S.
W. Twin P.	6	3.45	
Total	11		
<u>B. Days (D)</u>	6	142.54	**
D. x A	66	2.50	**
D. x T.P.	30	2.17	N.S.
D. x W.T.P.	36	2.77	
Total	83		
<u>B. Readings (R)</u>	3	87.62	**
R. x A.	33	1.49	N.S.
R. x T.P.	15	2.35	**
R. x W.T.P.	18	0.78	
R. x D.	18	7.40	**
R. x. D. x A.	198	1.41	
Total	335		

N.S. = non-significant.

** = highly significant 1% level

In this analysis there is a further subdivision. In order to see how readings varied and how their association with days and animals reacted, the data was divided to supply this information. As the R. x D. interaction is non-significant it does not contribute a significant amount to the animal variance. The reverse is the case for D. x A. interaction which is highly significant. The appropriate test for animals therefore, is the D. x A. mean square and, as can be seen when this test is applied, the variance due to animals is non-significant.

The Range, Mean, Standard Deviation and Coefficient for these four analyses on skin temperature are given as follows. The Standard Deviation is derived from the error variance of each analysis.

	1	2	3	Final
Range °F.	91.4-100.1	84.9-95.7	80.0-96.9	80.0-100.1
Mean °F.	94.99	93.87	92.14	93.80
s	1.25	1.03	2.94	1.18
C.	1.32%	1.09%	3.19%	1.26%

(b) Rectal temperature.

Sets of days were analysed separately with a final analysis of variance on the whole of the data.

Set 1. 2 days, 5 readings per cow all together.

2. 3 days, 12 readings per cow all together.

3. 3 days, 11 readings per cow all together.

4. 3 days, 11 readings per cow all together.

5. 3 days, 12 readings per cow all together.

Total Analysis: 12 cows for 10 complete days, i.e., days with 4 readings per day.

The results for the 5 analyses of variance for each set of days is shown in Table 8 (to be seen on following page).

The final analysis for all data is as follows:-

TABLE 10.

Total Analysis of Variance for Body Temperature.

Source	d.f.	M.S.	F.
Total	479		
<u>B. Animals (A)</u>	11	1.90	**
B.T.P.	5	3.22	N.S.
W.T.P.	6	0.80	
<u>B. Days (D)</u>	9	1.17	**
D x A	99	0.22	**
T.P x D	45	0.34	**
W.T.P. x D.	54	0.11	
<u>B. Readings (R)</u>	3	7.48	**
R. x D.	27	0.18	**
R. x A.	33	0.04	N.S.
R. x T.P.	15	0.08	**
R. x W.T.P.	18	0.01	
D. x A. x R.	279	0.05	

Range = 100.6
103.8

\bar{x} = 101.8
s = .22
C = .22%

\bar{x} = mean
s = Std. deviation
C = coefficient of
variation.

TABLE 8.

Analysis of Variance for Body Temperature. 5 sets of days

Source	d.f.					M.S.F.									
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Total	59	143	131	143	143	M.S.	F	M.S.	F	M.S.	F	M.S.	F	M.S.	F
<u>B Animals</u>	11	11	11	11	11	.125	*	.37	**	.45	**	.85	**	1.70	**
B Twin P.	5	5	5	5	5	.19	N.S	.69	*	.61	N.S	1.60	*	2.88	N.S
W.T.P.	6	6	6	6	6	.08		.11		.32		.22		.72	
<u>B Days.</u>	1	2	2	2	2	3.34	**	.66	**	.87	**	2.69	**	.22	N.S
D. x A.	11	22	22	22	22	.08	N.S	.10	N.S	.08	N.S.	.03	N.S.	.26	
T.P x D	5	10	10	10	10	.12	N.S	.13	N.S.	.13	N.S	.02	N.S	.29	N.S
W.T.P x D	6	12	12	12	12	.04		.08		.03		.05		.23	
Error	36	108	96	108	108	.06		.11		.08		.17		.10	
N.S. = non significant. * = significant 5% level. ** = highly significant 1% level															

TABLE 9.

The Range, Mean, Standard Deviation and Coefficient of Variation for
Body Temperature.

	1	2	3	4	5
Range °F.	101.1-102.5	101.0-102.8	101.1-102.6	100.6-102.7	100.8-103.0
Mean °F.	101.8	101.8	101.8	101.7	101.9
S	.24	.33	.28	.41	.31
C	.24%	.32%	.28%	.40%	.30%

c. Respiration Rates.

The number of readings per cow as for body temperature.

The following table shows the five separate sets of analyses:

TABLE 11.

Analyses of Variance for Respiration Rates - 5 sets of days.

Source	d.f.					1		2		3		4		5	
	1	2	3	4	5	M.S.	F	M.S.	F	M.S.	F	M.S.	F	M.S.	F
Total	59	143	131	143	143										
<u>B Animals</u>	11	11	11	11	11	66.3	*	484.0	**	133.0	**	222.0	N.S.	95.3	**
B.T.P.	5	5	5	5	5	108.0	N.S.	1027.0	**	263.6	**	450.0	**	200.8	**
W.T.P.	6	6	6	6	6	31.3		31.8		24.3		31.8		7.0	
<u>B Days.</u>	1	2	2	2	2	317.0	**	378.5	**	243.5	**	1707.5	**	558.0	**
D. x A.	11	22	22	22	22	31.1	N.S.	21.5	N.S.	26.4	N.S.	43.0	N.S.	16.6	N.S.
T.P x D	5	10	10	10	10	55.6	*	7.4	N.S.	34.7	N.S.	68.2	N.S.	25.1	N.S.
W.T.P x D	6	12	12	12	12	10.8		33.3		19.5		22.0		9.5	
Error	36	108	96	108	108	24.16		29.3		23.6		137.6		25.0	

N.S. = non significant.

* = significant 5% level.

** = highly significant 1% level.

The final analysis is as follows:-

TABLE 12.

Total Analysis of Variance for Respiration Rate.

Source	d.f.	M.S.	F.
<u>B. Animals</u>	11	545.54	**
B.T.P.	5	1145.47	**
W.T.P.	6	45.66	
<u>B. Days</u>	9	2992.00	**
D. x A.	99	49.03	**
T.P. x D.	45	89.75	**
W.T.P. x D.	54	15.09	
<u>B. Readings</u>	3	367.50	**
R. x A.	33	25.63	N.S.
R. x T.P.	15	42.87	*
R. x W.T.P.	18	11.27	
R. x D.	27	305.11	**
R. x D. x A.	297	30.11	
Total	479		

TABLE 13.

Range, Mean, Standard Deviation and Coefficient
of Variation for all analyses on Respiration Rate.

	1	2	3	4	5	Total
Range (resp/ min.)	22-52	25-60	28-62	18-75	18-56	18-75
Mean (resp/ min.)	37.73	41.72	38.25	31.14	25.63	34.26
s	4.91	5.41	4.81	11.73	5.00	5.48
C	13.01%	12.96%	12.58%	37.66%	19.50%	15.99%

d. Pulse Rates:-

The number of readings per cow as for body temperature and respiration rate.

TABLE 14.

Analyses of Variance for Pulse Rates - 5 sets of days

Source.	d.f.					1		2		3		4		5	
	1	2	3	4	5	M.S.	F	M.S.	F	M.S.	F	M.S.	F.	M.S.	F
Total	59	143	131	143	143										
<u>B Animals</u>	11	11	11	11	11	158.9	**	402.1	**	233.1	**	436.9	**	788.0	**
B.T.P.	5	5	5	5	5	309.8	**	840.0	**	465.8	**	905.0	**	1377.0	**
W.T.P.	6	6	6	6	6	33.1		37.1		39.1		46.8		297.5	
<u>B Days.</u>	1	2	2	2	2	44.0	N.S.	529.5	**	40.5	*	104.5	**	124.0	N.S.
D. x A.	11	22	22	22	22	21.4	N.S.	12.9	N.S.	39.4	**	13.7	N.S.	509.5	**
T.P. x D.	5	10	10	10	10	30.6	N.S.	12.9	N.S.	66.8	N.S.	13.8	N.S.	27.5	N.S.
W.T.P x D.	6	12	12	12	12	13.6		10.0		16.6		13.8		70.5	
Error	36	108	96	108	108	28.7		14.1		9.18		13.9		124.9	

N.S. = non significant.

** = significant at 1% level.

* = significant at 5% level.

Final analysis is as follows:

TABLE 15.

Total Analysis of Variance for Pulse Rates

Source	d. f.	M. S.	F
<u>B. Animals</u>	11	1458.36	xx
B. T. P.	5	3065.20	xx
W. T. P.	6	119.34	
<u>B. Days.</u>	9	768.78	xx
D. x A.	99	29.68	xx
D. x T. P.	45	41.07	xx
D. x W. T. P.	54	20.16	
<u>B. Readings.</u>	3	168.34	xx
R. x A.	33	13.27	*
R. x T. P.	15	18.13	N. S.
R. x W. T. P.	18	9.22	
R. x D.	27	53.56	xx
R. x D. x A. (Error)	297	8.37	
Total	479		

TABLE 16.

Range Mean Standard Deviation & Coefficient of Variation for
all Analyses on Pulse Rates

	1	2	3	4	5	Total
Range beats/min	62 - 92	52 - 84	60 - 80	50 - 80	53 - 92	50 - 92
Mean beats/min	74.86	69.40	72.18	64.24	72.86	70.23
s	5.35	3.70	3.02	3.72	11.11	2.89
C	7.15%	5.33%	4.18%	5.79%	15.24%	4.12%

(e) Components of Variance.

To show what proportion of the variance was associated with any source of variation the components of variance for the four final analyses are given in the following table.

TABLE 17.

Components of Variance from Total Analyses for Skin
Temperature, Rectal Temperature, Respiration
Rate and Pulse Rate.

Source of Variation.	Skin Temperature		Rectal Temperature.	
	Actual	%	Actual	%
Animals	0.07	1.17	0.04	19.0
Days	2.79	46.50	0.01	4.8
Readings	0.95	15.9	0.06	28.5
R. x A.	0.49	8.18	0.001	0
R. x D.	0.01	0.16	0.01	4.8
D. x A.	0.27	4.50	0.04	19.0
R. x D. x A	1.41	23.50	0.05	23.8
	<u>Respiration Rate</u>		<u>Pulse Rate</u>	
Animals	12.41	9.83	35.59	51.63
Days	55.58	44.02	14.45	20.97
Readings	0.52	0.41	0.92	1.33
R. x A.	0.00	0	5.33	7.73
R. x D.	22.91	18.14	3.76	5.45
D. x A.	4.73	3.75	0.50	0.73
R. x D. x A.	30.11	23.84	8.37	12.14

(f) Intra-class correlation:

To see how alike readings were from day to day or within a day, intra-class correlations are shown below. These were worked out in three ways to answer three questions.

1. Ignoring differences in the cows reaction to days, all readings were taken for all days for all cows, taking out in the analysis just the between cow variance and working on the within cow variance. This gives a measure of how repeatable

was the skin temperature, say, on each cow. Also, in order to see if the first reading in the day was more constant than the last reading, each of the 4 readings per day were worked out separately.

TABLE 18.

Intra-class Correlations. Method 1.

	Skin Temperature.	Rectal Temperature	Respiration rate.	Pulse rate.
First (morning) Reading	0.068 N.S.	0.111 N.S.	0.007 N.S.	0.421 **
Second (morning) Reading	0.072 N.S.	0.021 N.S.	0.098 N.S.	0.294 **
Third (afternoon) Reading	-0.013 N.S.	-0.039 N.S.	0.033 N.S.	0.378 **
Fourth (afternoon) Reading	0.020 N.S.	0.060 *	0.077 *	0.519 **
N.S. = non significant. * = significant 5% level. ** = significant 1% level.				

2. Because of the non-significance of the first three measurements above, the between day variance was taken out as well as the between cows. This gives a measure of the repeatability of measurements on similar types of days.

TABLE 19.

Intra-class Correlations. Method 2.

	Skin Temperature	Rectal Temperature	Respiration Rate	Pulse Rate.
First Reading	.105 *	.344 **	.279 **	.247 **
Second Reading	.039 N.S.	.283 **	.400 **	.626 **
Third Reading	.133 *	.304 **	.279 **	.749 **
Fourth Reading	.151 **	.304 **	.346 **	.614 **

3. To illustrate how well were the methods of taking the measurement and also how much a cow varies throughout the day,

the data for each cow was taken separately. Since there were four readings on any one day, thus making a sub-group, the between day variance was taken out and worked on the within day variance. This gives a measure of how reliable or how repeatable were the readings for a cow within a day.

TABLE 20.
Intra-Class Correlations. Method 3.

Twin No.	Skin Temperature		Rectal Temperature		Respiration Rate.		Pulse Rate.	
T25	.439	**	.148	N.S.	.406	**	.665	**
T26	.278	*	.117	N.S.	.363	**	.656	**
T55	.337	*	.085	N.S.	.632	**	.758	**
T58	.275	*	.148	N.S.	.525	**	.675	**
T69	.451	**	.133	N.S.	.730	**	.582	**
T70	.659	**	.083	N.S.	.586	**	.649	**
T89	.461	**	.133	N.S.	.585	**	.582	**
T90	.467	**	.083	N.S.	.636	**	.649	**
T31	.542	**	.158	N.S.	.668	**	.448	**
T32	.519	**	.100	N.S.	.607	**	.268	**
T49	.432	**	.508	**	.455	**	.542	**
T 50	.240	N.S.	.468	**	.397	**	.487	**

(g) Correlation Analysis.

The fact that five variables were involved in this work, necessitated an approach to see what variables were strongly associated with one another. Correlation is a measure of how much the variation in one variable is associated with the variation in another and was thus used to test the relationship between the several variables.

First the correlations were analysed for all possible combinations on a within day basis, i.e., because of the difference shown up in the analysis of variance due to days it was thought a closer degree of relationship might be expected within each day. After the correlations were derived all of one groups of r's were analysed by Snedecor's method to see if they all belonged to a common population and, if so, to derive an average correlation. This meant transposing r's to Fisher's "Z" values which have a more normal distribution. It was found that in most cases the r's for any one day did not belong to a common population and, therefore, an average r could not be calculated. Details of this data and tests of probability are given in the Appendix, Table 51.

Next step was to analyse the correlations on a within cow basis and this was more successful

The correlation between skin temperature and air temperature for each cow, test for a common population hypothesis and the deriving of an average r, is shown in Table 21, other correlations are given in the Appendix.

The result is a value of Chi square with 11 degrees of freedom, one less than the number of sample. $\chi^2 = 11.762$. In Snedecor's table Chi square is approximately .40. This means that the chances are quite good of obtaining a similar set of correlations from another set of data, i.e., there is no reason to suspect that the r's were not drawn from a common population. This being so, one may derive their

TABLE 21.

Correlation between Skin Temperature and
Air Temperature.

Test of significance, whether "r's" belong to a common population, and if so, a reasonable average of them.

(Cow) Sample	n = No. of figs/var.	d.f. n-3	r	z	Weighted ^z (n-3)z	Weighted ^{z²} (n-3)z ²
25	33	30	.661	.798	23.940	19.104
26	33	30	.501	.566	16.980	9.570
55	33	30	.818	1.149	34.470	39.606
58	33	30	.736	.925	27.750	25.669
69	33	30	.581	.664	19.920	13.227
70	33	30	.698	.865	25.950	22.447
89	33	30	.587	.626	18.760	11.756
90	33	30	.702	.870	25.100	21.837
31	33	30	.650	.776	23.280	18.065
32	33	30	.674	.818	24.540	20.074
49	33	30	.502	.551	16.530	9.108
50	33	30	.477	.520	15.600	8.112
					272.840	218.575
					Av. z = .758	206.8130
					Av. r = .640	<u>11.762</u>

average value by transposing the average Z. This gives an average correlation between skin temperature and air temperature of $r = .640$. The degrees of freedom is the total $(n-2)$, i.e., 394. Snedecor's table for tests of significance of $r = .640$. 394 d.f. shows that it is well within the 1% level of significance. There is a slight bias in the result derived in this way but the correction necessary causes little reduction in the average r and is hardly justified because the true population r is known only very approximately and the values of r and z are read from a graph inaccurate in the third decimal place. Table 22, page 180, shows all the correlations worked out in this manner.

TABLE 22.
Average Correlations for all Combinations.

X ₁	Skin T.	Skin T.	Skin T.	Skin T.	Air T.	Air T.	Air T.	Rect. T.	Rect. T.	Resp. R.
X ₂	Air T.	Rect. T.	Resp. T.	Pulse R.	Rect. T.	Resp. R.	Pulse R.	Resp. R.	pulse R.	Pulse R.
r	.640	.373	.661	.391	.326	.613	.396	.359	.285	.439

For 394 d.f. Snedecor's table for tests of Significance gives $r \begin{matrix} 5\% \\ .098 \end{matrix} \begin{matrix} 1\% \\ .128 \end{matrix}$. The above are, therefore, highly significant. Individual correlations for each cow are given in the appendix Table 51.

(h) Regression:

Because of the larger size of the correlations skin temperature and air temperature, skin temperature and respiration rate, and air temperature and pulse rate, a regression analysis was made. In a correlation we have 2 variables, X_1 and X_2 or we could designate them X_1 and Y . In the regression equation $\hat{Y} = a + bX$. \hat{Y} is really a coded X . Therefore, a correlation between Y and its regression estimate \hat{Y} is the same as the correlation between X and Y . This means that if Y is uniformly near the regression line then $r_{X_1X_2}$ and its equivalent r_{xy} are close to ± 1 . Thus, in this sense the value of r_{xy} is a measure of the success of estimating Y by means of regression. The size of the 3 correlations mentioned shows that whatever dependent variable is chosen, Y is estimated reasonably well by regression.

With regression there is a dependent variable Y and an independent variable X . Y depends on the value of X .

On plotting some of the data for cows for each of the three correlations it was evident that a straight line would fit the data reasonably well in all cows. However, to statistically determine whether or not there was any curvilinearity of regression, this was calculated using Snedecor's equation fitted, for a second degree polynomial.

$$\hat{Y} = a + bX + c X^2.$$

The hypothesis is set up of linear regression, then the sums of squares of errors of estimate are calculated (i.e., sums of squares of deviations from the regression line) for both linear and curved regression to test the significance of curvilinearity of regression.

From data X and Y are set out and the X values, squared to give a 3rd. variant.

Multiple regression statistics are necessary to calculate the multiple correlation coefficient R .

The following formulae are used to work out the standard partial regression coefficients. Pearson and Bennett (191).

$$b^1_{y1.2} = \frac{r_{y1} - r_{y2} r_{12}}{1 - r_{12}^2}; \quad b^1_{y2.1} = \frac{r_{y2} - r_{y1} r_{12}}{1 - r_{12}^2}$$

Appropriate substitution with the normal correlations worked out in the previous section solves the above equations. To derive the multiple regression coefficient the following equation is used:

$$R^2 = r_{y1} b^1_{y1.2} + r_{y2} b^1_{y2.1}$$

from which, by appropriate substitution, R is derived.

This coefficient like ordinary r measures the success of estimating Y from X_1 and X_2 .

It can be shown by algebra that the square of the ordinary correlation coefficient r is the fraction of the sums of squares of the Y variable, S_y^2 , which is due to regression. Therefore, $1-r^2$ must be the fraction of S_y^2 which is due to errors of estimate. The same applies for the multiple correlation coefficient R.

Thus having derived $b^1_{y1.2}$ and $b^1_{y2.1}$ and R the remainder after linear regression is $(1 - r_{xy}^2) S_y^2$ and the remainder after curved regression is $(1 - R^2) S_y^2$.

The test of curvilinearity of regression then is as follows taking air temperature and skin temperature as the two variables. Degrees of freedom for an ordinary correlation is n-2 for a 3 factor correlation n-3.

TABLE 23.

Test of Significance of Departure from Linear Regression. Air Temperature & Skin Temperature

Source	d.f.	S.S.	M.S.	F.
Deviations from Linear Regression	328	91327.8		
Deviations from Curved Regression	327	91018.3	294	$\frac{294}{309.5} = \text{N.S.}$
Curvilinearity of Regression	1	309.5	309.5	

Thus the hypothesis of linear regression is upheld. This is a total analysis of all data for all cows on skin temperature and

air temperature in the outside measurements.

The analyses for skin temperature and respiration rate and air temperature and respiration rate are as follows:

TABLE 24.

Test of Significance of departure from Linear Regression,
Skin Temperature, and Respiration Rate.

Source	d.f.	S.S.	M.S.	F.
Deviations from Linear Regression	328	15267		
Deviations from Curved Regression	327	4994	15.27	**
Curvilinearity of Regression	1	10273	10273	
<u>Air Temperature and Respiration Rate.</u>				
Deviations from Linear Regression	328	31424		
Deviations from Curved Regression	327	<u>31424</u>		N.S.
Curvilinearity of Regression	1	0		

Tests of curvilinearity were worked out for each cow separately for each of the 3 sets of variables. Their significance is shown below.

TABLE 25.

Significance of individual Curvilinear Regressions

Twin No.	Air Temp. & Resp. R.	Skin T. & Air T.	Skin T. & Resp. R.
T25	**	*	N.S.
26	N.S.	**	
55	**	**	**
58	N.S.	N.S.	N.S.
69	N.S.		N.S.
70	N.S.	**	N.S.
89	N.S.	N.S.	N.S.
90	**	*	**
31	**	N.S.	**
32	N.S.	**	N.S.
49	N.S.		
50	N.S.	**	**
Total Analysis	N.S.	N.S.	**

N.S. = non significant. ** = significant of 1% level.
* = significant of 5% level.

It can be seen that individual cows show a curvilinear relationship within each group. Whereas only in one of them does the final analysis show a significant result, i.e., that for skin temperature and respiration.

The amount of computation necessary to derive the above tables was enormous. It was really a job for a card punching machine rather than an ordinary calculating machine. The liability of errors is considerable and in some cases with individual cows it was impossible to derive a result. This factor together with the opinion that even if there was curvilinearity in the data, it was very slight and a straight line would fit just as well, decided further analysis on a linear basis. Even if it was shown both by plotted graphs and statistical analysis that there was definite curvilinearity, one has the problem of fitting the right type of curve. Some statisticians regard curve fitting an art rather than a science and even when fitted they sometimes do not mean very much.

Linear Regression.

TABLE 26.
Regression Coefficients and value of t for Significance

Twin No.	Air & Skin Temperature.		Air T. & Resp. R.		Skin T & Resp. R	
	b.	t.	b.	t.	b.	t.
25	.434	4.99	0.850	4.72	1.31	3.50
26	.326	13.07	0.947	4.74	1.95	2.63
55	.306	9.79	2.14	5.79	4.57	4.24
58	.273	6.21	1.72	4.88	4.63	4.26
69	.370	12.33	1.01	5.35	2.19	6.98
70	.389	5.47	1.07	5.65	1.88	5.60
89	.258	4.09	1.72	7.47	2.70	4.68
90	.307	5.58	1.55	6.50	3.49	6.34
31	.287	4.76	1.72	5.00	2.14	4.88
32	.393	5.10	1.01	6.34	1.87	6.27
49	.250	3.28	0.798	3.47	2.41	6.16
50	.197	3.03	0.810	3.12	3.18	6.29
Total.	.318	18.77	1.21	17.50	2.42	15.76

These regressions for air and skin temperature, skin temperature and respiration, have 31 degrees of freedom, there being 33 measurements per cow for skin temperature. Although no more skin temperatures were taken in the series, further readings were taken with the other measurements. Thus, for air temperature and respiration rate there were 45 measurements per cow, i. e. , 43 degrees of freedom.

	1% level
t values for 31 d.f.	2.750
t values for 43 d.f.	2.690

It can therefore be seen that all the above regression coefficients are highly significant - testing by Snedecor's method, p. 122.

To state statistically whether the individual cow regressions differed significantly from one another an analysis of errors of estimate for each regression was made. The errors of estimate or deviations from individual regression, had already been worked out in the process of testing the significance of the regressions.

The average regression is an average of the individual lot regressions. The individual lot regressions will have sums of squares of deviations from their own individual regression lines, less than from the average regression line. This is because of the principle of least squares which makes the sum of squares of deviations from their own individual line less than from any other calculated line. Thus, the sum of the individual sums of squares of errors of estimate is smaller than that derived from the average regression. The difference with corresponding degrees of freedom corresponds to the differences between individual regressions and the F value determines whether or not all belong to a common population.

TABLE 27.Analysis of Errors of Estimate from Average Regression.Air and Respiration.

Source	d.f.	S.S. of Errors of Estimate	M.S.
Total (av.) Regression	538	32572	
T25	43	1623	
T26	43	1819	
T55	43	5193	
T58	43	5458	
T69	43	1492	
T70	43	1630	
T89	43	2411	
T90	43	2682	
T31	43	1810	
T32	43	1258	
T49	43	2377	
T50	43	2916	
Sum	516	30660	59.41
Differences among the lot regressions.	22	1912	86.90 F=1.46 N.S

Air Temperature & Skin Temperature.

Total (av.) Regression (sum)	394	996.37	
Individual Regressions	372	951.60	2.56
Differences among the lot regressions	22	44.77	2.03 F = N.S

Skin Temperature & Respiration Rate.

Total (Av.) Regression	394	18500	
Individual Regression (sum).	372	16758	45.05
Differences among lot regressions	22	1742	79.11 F=1.56 N.S

In all three cases when the test is applied it is non-significant. The regression lines all belong to a common population in each case in these data.

(i) Partial Correlations and Multiple Regressions:

Pulse rate was one of the measurements taken but on looking at the ordinary correlations it will be seen that

pulse is not correlated very strongly with anything. Because of the possibility that when pulse is correlated with something, some other variable is also associated and tends to mask or overshadow the true correlation between pulse rate and the chosen variable, further analysis was attempted.

If we have 3 variables X_1 , X_2 and X_3 the correlation between X_1X_2 may be influenced by the fact that X_3 is also correlated to X_1 or X_2 or both. To eliminate the possible effect of X_3 partial correlation analysis is used to test the correlation between X_1 X_2 when the influence of X_3 is removed, i.e., held constant.

A comparison of such partial correlations with the ordinary correlations may reveal that the elimination of other independent variables sometimes reduces the coefficient greatly and sometimes does not change it very much. If the partial is about the same then there is a persistent and separate relationship between X_1 and X_2 , i.e., the relationship is not through one of the other independent factors.

If the partial is much less than the ordinary coefficient then there is an inter-relationship between this independent variable and another which itself was related to X_1 .

Pulse rate could be associated with 4 other variables.

Air Temp.	Skin Temp.	Rect. Temp.	Resp. R.	& Pulse R.
2	3	4	5	1

To trace the effect on pulse rate when first one and then others separately and together, are held constant several steps are necessary.

1. First Order coefficients.

Analysed by the method outlined by Pearson and Bennett (191). Formulae used:-

$$r_{12.3} = \frac{r_{12} - (r_{13})(r_{23})}{\sqrt{1-r_{13}^2} \sqrt{1-r_{23}^2}}$$

In all these partial correlations the average gross correlations worked out and presented before were used in the various equations.

2. Second Order coefficients.

Formulae used:

$$r_{12.34} = \frac{r_{12.3} - (r_{14.3})(r_{24.3})}{\sqrt{1-r_{14.3}^2} \sqrt{1-r_{24.3}^2}}$$

3. Third Order coefficients.

Formulae used:

$$r_{12.345} = \frac{r_{12.34} - r_{15.23} r_{25.34}}{\sqrt{1-r_{15.34}^2} \sqrt{1-r_{25.34}^2}}$$

4. Calculation of multiple coefficients from the partial coefficients.

(a) First order multiple coefficient.

$$R_{1.23}^2 = 1 - (1-r_{13}^2)(1-r_{12.3}^2)$$

(b) Second order multiple coefficient.

$$R_{1.234}^2 = 1 - (1-r_{14}^2)(1-r_{13.4}^2)(1-r_{12.34}^2)$$

(c) Third order multiple coefficient.

$$R_{1.2345}^2 = 1 - (1-r_{15}^2)(1-r_{14.5}^2)(1-r_{13.45}^2)(1-r_{12.345}^2)$$

The square root of each of these gives the multiple correlation coefficient which is a measure of the success of estimating pulse rate from the other 4 variables.

TABLE 28.
Partial & Multiple Correlations.

	Partial Correlations		Multiple Correlation
A. First Order	$r_{12.3}$	= .206	$R_{1.23} = .434$
	$r_{12.4}$	= .335	$R_{1.24} = .428$
	$r_{12.5}$	= .211	
B. Second Order	$r_{12.34}$	= .204	$R_{1.234} = .459$
	$r_{12.25}$	= .162	
	$r_{12.45}$	= .197	
C. Third Order.	$r_{12.345}$	= .164	$R_{1.2345} = .495$

1st Order Partial Correlations	d.f.	n-3 = 393	r = .128	1% lev. sig
2nd " "	" "	n-4 = 392	r = .128	
3rd " "	" "	n-5 = 391	r = .126	

Thus the above partials in the table are all highly significant.

(The $n = 396$ comes from the average gross correlations analysed previously.)

Other partial and multiple correlations used for working out the above table are shown in the Appendix, Table 52.

C. DIURNAL DATA.

(a) First Section.

For the first 4 24-hour periods, measurements were made every hour during the day till 10 p.m. then every 2 hours to 6 a.m. The analysis of variance for this period is as follows:

TABLE 29.

Analyses of Variance for (a) Rectal Temperature

(b) Respiration Rate and (c) Pulse Rate.

Source	d.f	Body Temp		Respiration Rate		Pulse Rate.	
		M.S.	F	M.S.	F	M.S.	F
Total	479						
<u>B. Animals</u>	5	1.76	*	771.40	**	1888	**
B. Twin P.	2	3.67	N.S	1878.00	**	4605	**
W. Twin P.	3	0.48		33.66		76.60	
<u>B. Days.</u>	3	2.26	**	9515	**	375.33	**
Day x A.	15	0.25	**	117.20	**	48.00	**
Day x T.P.	6	0.48	*	191.00	N.S.	68.16	N.S.
Day x W.T.P.	9	0.10		68.00		34.55	
<u>B. Measurements</u>	19	3.41	**	828.68	**	456.15	**
M. x A.	95	0.11	**	95.23	**	12.23	N.S.
M. x T.P.	38	0.17	**	182.02	**	19.11	**
M. x W.T.P.	57	0.06		37.37		7.64	
M. x D.	57	0.24	N.S	227.31	**	46.89	**
M. x D. x A. (Error)	285	0.07		30.30		15.50	

N.S. = non-significant.

* = significant 5% level.

** = highly significant 1% level.

TABLE 30.

Range, Mean, Standard, deviation and coefficient of variation
for Body Temperature, Respiration Rate and Pulse Rate
in the Diurnal Trial.

	Body Temperature.	Respiration Rate.	Pulse Rate.
Range	100.7-103.6	28-102 per min.	72-117/min.
Mean	101.9	64.85 " "	93.67/min.
s	0.26	5.50	3.93
C	0.257	8.48	4.20

For pulse rate the D. x A. interaction is highly significant so that it must be used to test differences between animals. For respiration rates both D. x A. and M. x A. are highly significant. Two questions may be asked:-

1. On days that are similar to those included in this experiment are the measurements likely to have a similar effect if applied to other animals in the population of which these 6 are but a sample?

To test this the Day x A. component of variance is subtracted from the animal mean square and the residual mean square tested by comparison with the M. x A. mean square.

Mean square for animals is an estimate of:-

$$\begin{aligned}
 s_A^2 &= 80s_A^2 + 20s_{DA}^2 + 4s_{AM}^2 + s^2 \\
 s_A^{21} &= s_A^2 - 20 s_{DA}^2 \\
 &= 771.40 - 86.90 \\
 &= 684.50 \\
 F^1 &= \frac{s_A^{21}}{s_{AM}^2} = \frac{684.50}{95.23} = 7.2 \text{ ** d.f. say } 3 \& 90.
 \end{aligned}$$

2. With measurements similar to those on this experiment are the animals liable to react similarly if tested on other days in the total population of days of which the 4

taken in this trial are but a sample?

Mean square for animals -

$$s^2_A = 80s^2_A + 20s^2_{DA} + 4s^2_{AM} + s^2$$

$$s^2_{A1} = s^2_A - 4s^2_{AM}$$

$$= 771.40 - 64.93$$

$$= 706.47$$

$$F' = \frac{s^2_{A1}}{s^2_{DA}} = \frac{706.47}{117.20} = 6.5^{**} \text{ d.f. say 3 and 12.}$$

According to Wilm the calculation of F' and F'' does not follow the mathematical distribution of normal F and one should use fewer degrees of freedom.

Rectal temperature must be treated in a similar manner to answer the questions.

1. On days that are similar to those used in this experiment are the measurements likely to react similarly if used on other animals?

$$s^2_{A'} = 1.76 - .18$$

$$= 1.58$$

$$F' = \frac{1.58}{0.11} = 14.3^{**} \text{ d.f. 3 and 90.}$$

2. With similar measurements are the animals liable to have a similar reaction in body temperature if tested on other days?

$$s^2_{A'} = 1.76 - .04$$

$$= 1.72$$

$$F' = \frac{1.72}{0.25} = 6.9^{**} \text{ d.f. 3 and 12.}$$

(b) Second Section.

During the second session of 3, 24-hour period readings were taken every two hours. Following, in Table 31 is the analyses of variance for this section of the data:

TABLE 31.

Analyses of Variance for (a) Body Temperature (b) Respiration
Rate (c) Pulse Rate, in Diurnal Trial.

Source	d.f	Body Temp.		Resp. Rate		Pulse Rate	
		M.S.	F	M.S.	F	M.S.	F
Total	215						
<u>B. Animals.</u>	5	0.72	**	331.20	**	618.40	**
B.T.P.	2	1.36	N.S.	765.00	**	1523.50	**
W.T.P.	3	0.28		42.00		15.00	
<u>B. Days.</u>	2	0.24	**	880.50	**	868.50	**
D. x A.	10	0.04	N.S.	52.10	N.S.	14.50	N.S.
D. x T.P.	4	0.03	N.S.	101.75	*	20.75	N.S.
D. x W.T.P.	6	0.70		19.00		10.33	
<u>B Measurements</u>	11	2.52	**	1617.91	**	294.90	**
M. x A.	55	0.05	N.S.	48.63	N.S.	10.29	N.S.
M. x T.P.	22	0.06	N.S.	108.09	**	21.13	**
M. x W.T.P.	33	0.05		9.00		3.06	
Days x M.	22	0.06	N.S.	239.95	**	81.27	**
D. x M. x A. (error)	110	0.05		35.82		8.84	

TABLE 32.

Range Mean, Standard Deviation and Coefficient of
of Variation for Body Temperature, Respira-
Rate and Pulse Rate.

	Body Temp.	Resp. Rate	Pulse Rate
Range	100.7-102.7	26 - 88	74-108/minute
Mean	101.6	51.81	91.86
S	0.22	5.98	2.97
C	0.218%	11.54%	3.23%

(c) Correlation Analysis:

These were worked out for all possible combinations, the two sections being treated separately because of the change of technique. Tables No. 33 and 34 are the individual correlations for each cow.

TABLE 33.

Correlations for all combinations. Section (a)
of Air and Body Temperature, Respiration
and Pulse Rate.

Twin No.	Air and Rectal	Air and Resp.	Air and Pulse	Rectal & Resp.	Rectal & Pulse	Resp. & Pulse
55	-.084	.448**	.276**	-.065	.109	.146
58	-.150	.409**	.517**	-.881	.037	-.019
25	.301**	.456**	.393**	.271 *	.535**	.291**
26	.242 *	.448**	.370**	.238 *	.266 *	.377**
49	.267 *	.314**	.309**	.142	.504**	.065
50	.282**	.301**	.267**	.118	.485**	.177
P	.01	.70	.40	.05	.01	.20
Average r		.396 *	.357 *			

** = highly significant 1% level .274, d.f. 84
 (Individual r's).

* = significant 5% level .213, d.f. 84
 (Individual r's).

For average r's d.f. = 504 making them highly significant.

These were tested as before to see whether they belong to a common population or not. As shown, only in the case of Air and Respiration, and Air and Pulse Rate was this found to be so and an average correlation derived.

TABLE 34.

Correlations for all combinations of Air and Body Temperature

Respiration Rate & Pulse Rate

Section B.

Twin No.	Air and Rectal	Air and Resp.	Air and Pulse	Rect. & Resp.	Rect. & Pulse	Resp. & Pulse
55	.134	-.236	.270	-.116	.487**	.017
58	.209	-.343 *	.284	-.128	.444**	.045
25	.304	-.128	.314	-.562**	.484**	-.017
26	.178	-.196	.397 *	-.315	.431**	-.007
49	.348	-.327 *	.368 *	.099	.521**	-.250
50	.353	-.373 *	.355 *	-.027	.563**	-.086
P	.70	.01	.99	.02	.98	.80
Average r	.256**		.333**		.489**	-.051N.S

** 1% level .408 d.f. 37 individual r's.

* 5% level .327 d.f. 37 individual r's.

For averaged r's d.f. = 234. 1% level .171. 5% level .128

Graphs for body temperature, respiration rate and pulse rate with time are shown. As the correlations were not sufficiently high to yield an accurate estimate of a dependent variable by means of regression, regression analysis was not attempted.

A difference was noted between body temperatures taken when the cow was lying or standing. During one day body temperature was taken with cows that were lying and then 15 minutes after they were made to stand. Results are as follows.

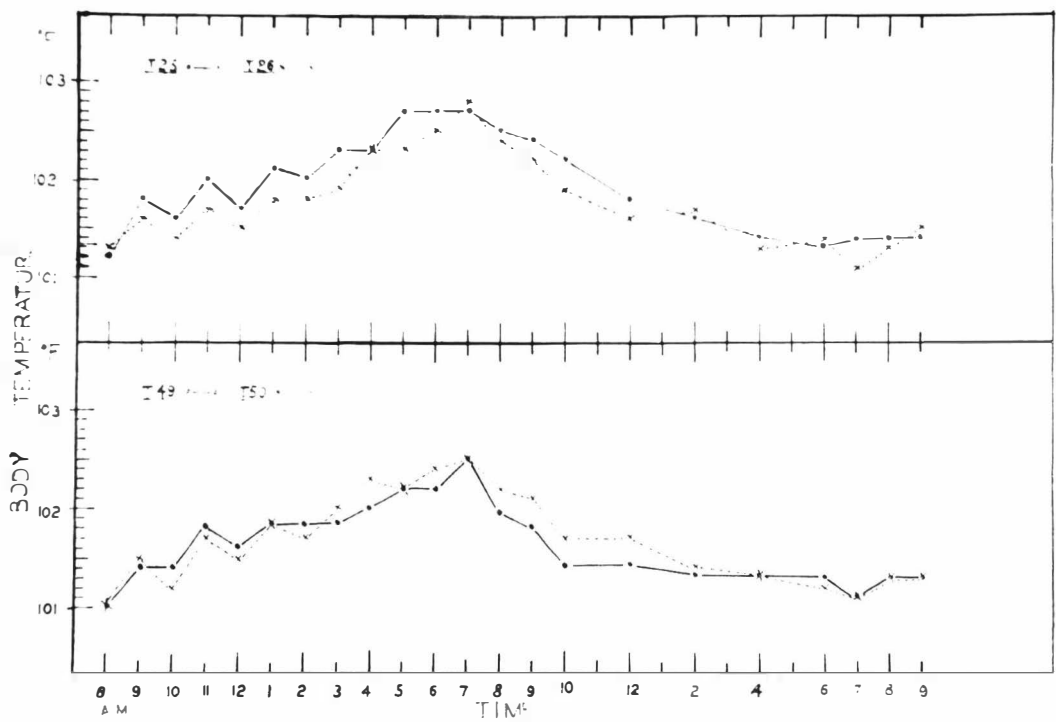
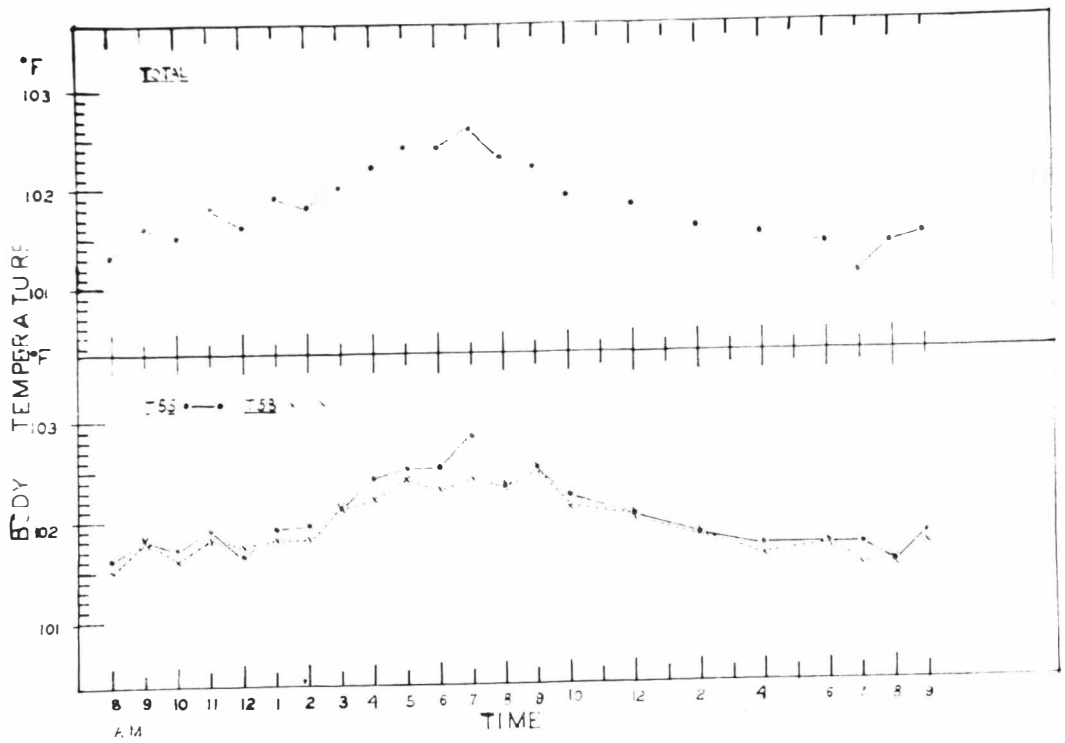


Fig. 15. Diurnal body temperatures.

(a) Total.

(b) Twin pairs plotted together.

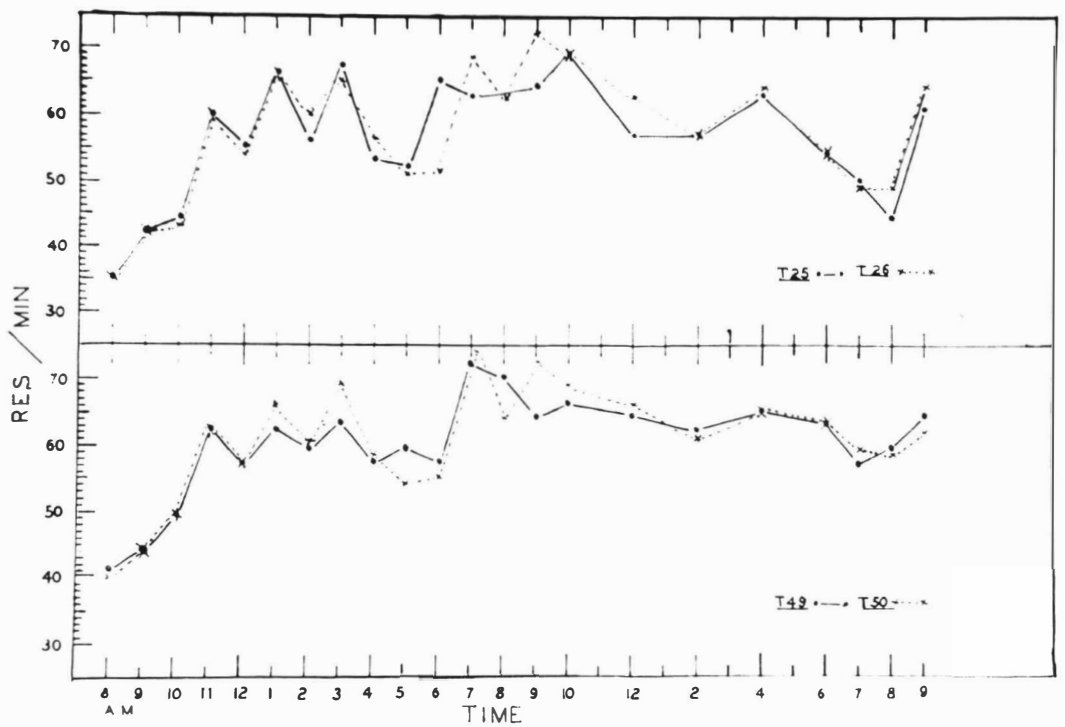
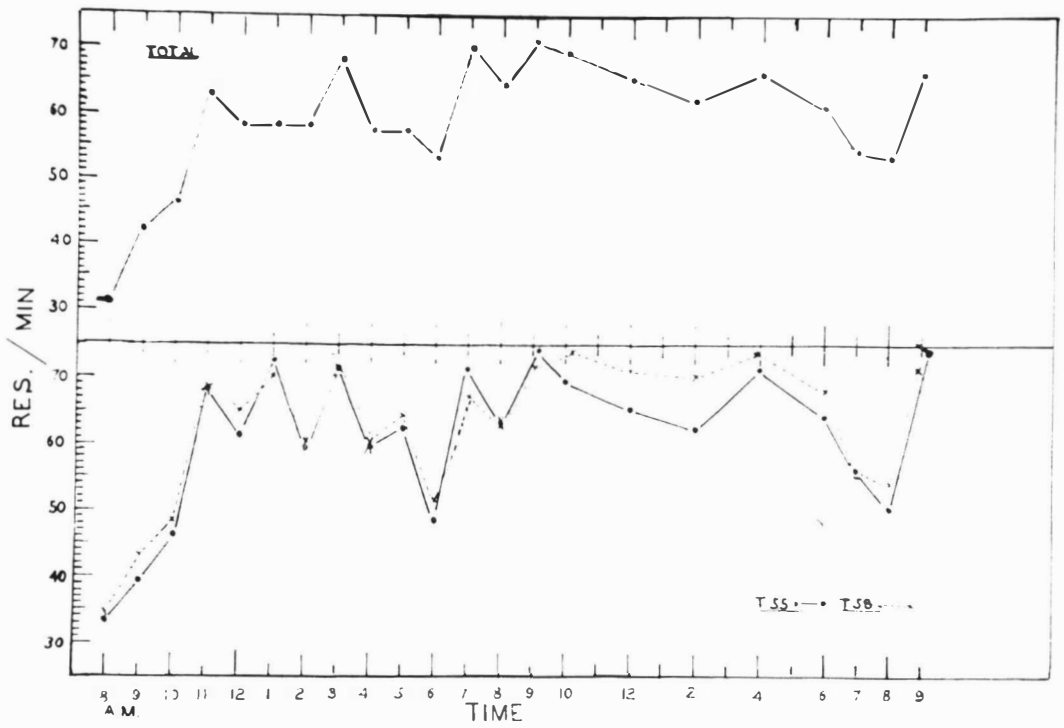


Fig. 16. Diurnal trend in respiration rate of cattle.

(a) Total.

(b) Twins pairs plotted together.

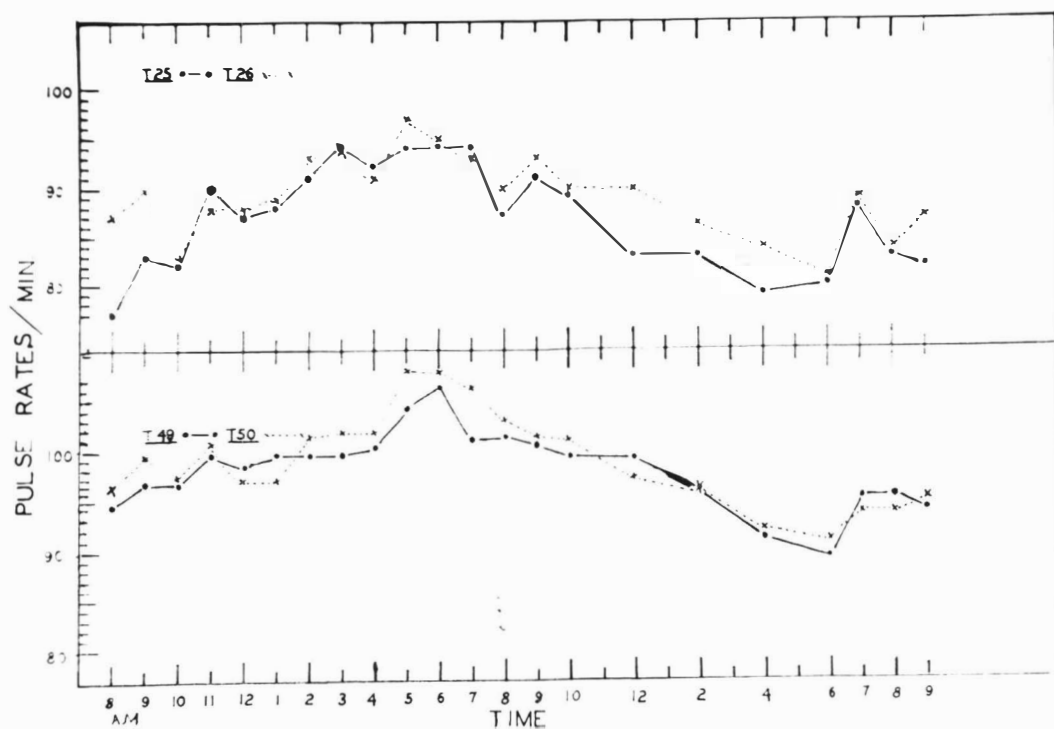
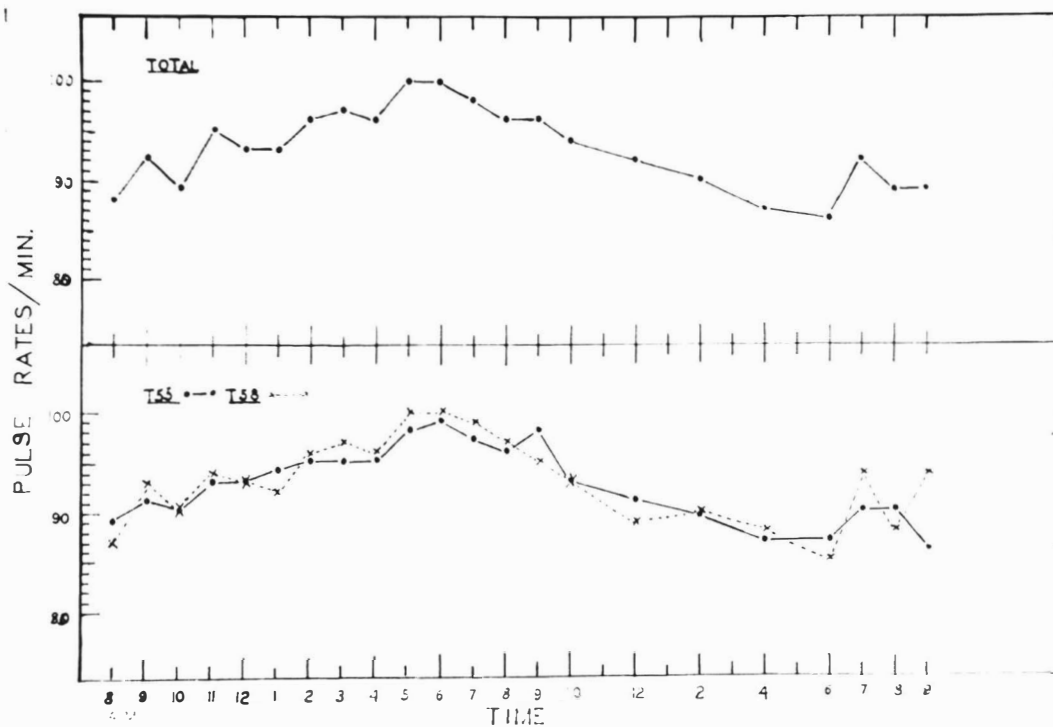


Fig. 17. Diurnal trend in pulse rates of cattle.

(a) Total.

(b) Twin pairs plotted together.

TABLE 35.

Body Temperatures of Cows when Lying and When Standing.

Twin No.	Lying.	Standing 15 minutes	Time
T55	101.7 °F.	101.5	10 a.m.
58	101.3	101.3	
25	101.5	101.0	
26	101.4	101.2	
50	101.0	100.8	
49	101.2(Standing)	101.2	
55	101.8	101.5	12 p.m.
58	101.8	101.4	
25	101.8	101.9	
26	101.5	101.1	
50	101.0	101.3	
49	101.6	101.0	
25	101.9	101.6	2 p.m.
26	102.1	101.5	
50	101.6	101.4	
49	101.5	101.1	

D SKIN TEMPERATURE.

The purchase of a new Cambridge potentiometer necessitated preliminary work once again. The cold junction used this time was melting ice in a thermos flask. It was found that it took about $\frac{1}{4}$ - $\frac{1}{2}$ minute for the junction to reach equilibrium and a stable reading to be obtained on the potentiometer. To see how the readings varied with time the following data was obtained over a period of 5 minutes, the junction being held on the spot all the time and the potentiometer being operated as fast as the operator could work it. This was first tried with the hair on, with the hair clipped, and shaved.

TABLE 36.

Potentiometer reading millivolts with the thermocouple held on the same position.

	Normal	Clipped	Shaved
T21	1.330	1.295	1.260
	1.330	1.295	1.260
	1.330	1.295	1.270
	1.330	1.310	1.270
	1.325	1.310	1.265
	1.310	1.310	1.265
	1.310	1.310	1.270
	1.320	1.310	1.270
	1.310	1.310	1.270
	1.310	1.310	1.270
	1.330	1.310	1.270
	1.330	1.310	1.270
	1.330	1.310	1.270
	1.330	1.305	1.280
	1.325	1.310	1.280
	1.325	1.310	1.280

In comparison with the results obtained with the Tinsley potentiometer there is little or no fall in millivolt readings. With future work, therefore, two readings per position were taken and in nearly all cases the two readings were the same.

(a) Influence of Hair.

Three cows, T55, T58 and T21, were placed in the feeding barn and trials made to see what difference was caused by taking skin temperatures under the following conditions:

- (a) Normal - with hair on.
- (b) Clipped - with hair clipped as close as possible.
- (c) Shaved - with the area shaved with a razor blade.

Eight positions on the right hand side were chosen, on each animal. Three readings per position were taken. The animals were tested once on one day and twice on the following day giving 3 repeats in all.

The following is the analysis of variance on this data.

TABLE 37.

Analysis of Variance of Skin Temperature with the hair on, Hair clipped and Hair Shaved off.

Source	d.f.	M.S.	F
Total	647		
B Animals	2	757.84	N.S.
B Days	1	282.23	N.S.
D. x A.	2	1146.64	**
B Positions	7	175.06	N.S.
P. x A.	14	213.32	N.S.
P. x D.	7	371.94	N.S.
P. x D. x A.	14	345.00	
B Types	2	161.14	**
T. x A.	4	0.71	N.S.
T. x D.	2	3.00	N.S.
T. x P.	14	3.51	N.S.
T. x A. x D.	4	1.20	N.S.
T. x A. x P.	28	2.53	N.S.
T. x D. x P.	14	7.90	*
T. x D. x A. x P.	28	3.37	
Error	504	0.56	

Individual Degrees of Freedom.

B Types:

<u>Subdivided into:</u>	d.f.	M.S.	F
Clipped V. shaved	1	9.87	N.S.
Normal V. (clipped & shaved)	1	312.41	**
T x D x A x P (error for testing)	28	3.37	

Mean of Types °F.

Normal 89.77
Clipped 89.45
Shaved 89.15

Accompanying statistics are:

Range °F. 60.8 - 95.0
Mean. °F. 88.8
s .74
C .838%

(b) Position effect.

On the basis of the above analysis the readings with the hair untouched gives a higher reading. The same three cows were used to try to find if skin temperatures varied over the body. Twenty-two positions were taken on each cow on the right hand side of the body, two readings per position and the average used in the analysis. The trial extended over 6 days, with morning and afternoon readings.

Following is the analysis of variance on the data:

TABLE 38.

Analysis of Variance of Skin Temperature with 22

Positions on each of three animals

Source	d.f.	M.S.	F.
Total	791		
B Animals	2	107.02	
B Days	5	807.56	**
D. x A.	10	48.77	
B Readings	1	19.39	N.S.
R. x A.	2	1.99	N.S.
R. x D.	5	79.70	N.S.
R. x A. x D.	10	24.50	
B Positions.	21	220.63	**
P. x A.	42	4.37	**
P. x D.	105	5.82	**
P. x R.	21	3.11	N.S.
P. x A. x R.	42	1.36	N.S.
P. x A. x D.	210	2.42	N.S.
P. x D. x R.	105	2.85	N.S.
P. x D. x A. x R.	210	2.17	
(Error)			

Accompanying statistics for the above analysis are:-

Range 74.2 - 95.0
Mean 88.3
s 1.47
C 1.7%

For animals there is no appropriate test which would mean very much because of the intricacy of the interactions associated with animals but the object of the trial was to see if there was a difference between positions over the body.

Mean temperature per position is shown in Table 39.

TABLE 39.
Mean Skin Temperature in each of 22 positions.

Position	1	2	3	4	5	6	7	8	9	10	11
Skin T. °F	89.2	82.0	91.2	90.5	90.6	89.6	84.9	82.1	89.0	89.2	89.9

12	13	14	15	16	17	18	19	20	21	22
88.8	89.0	88.8	89.6	90.0	89.0	88.3	84.2	83.3	88.9	90.1

(E) AIR TEMPERATURE CONDITIONS.(a) Outside Data.TABLE 40.

Average readings of skin and body temperature, respiration
Rate & pulse rate at corresponding air temperatures

Air Temp °F	Skin Temp.	Rectal Temp.	Resp. Rate.	Pulse Rate.	No. of Readings/ air Temp
36		100.9	18	56	2
37		101.7	18	68	1
38		101.6	18	64	1
39		101.2	20	60	2
40		100.6	18	55	2
41		101.4	24	67	1
42		100.9	22	63	2
43		101.5	21	56	2
44		101.7	22	62	4
45		101.3	28	64	6
47		101.2	22	70	4
48		101.7	22	70	21
49		101.7	22	70	21
50	90.5	101.6	22	69	14
51	91.0	101.8	27	62	20
52	93.3	101.7	40	67	27
53	91.8	101.6	33	67	31
54	93.3	101.7	30	67	34
55	92.6	101.8	31	68	28
56	93.3	101.8	24	72	40
57	94.7	101.8	36	71	34
58	94.0	101.6	39	69	21
59	93.4	101.8	40	70	23
60	93.7	101.5	38	67	29
61	94.2	101.6	39	69.	16
62	94.9	101.8	39	69	26
63	95.1	101.8	40	70	12
64	96.4	101.5	44	71	16
65	93.3	101.8	41	70	12
66	95.5	102.0	42	70	7
67	96.4	102.2	47	70	4

TABLE 41

Air Temperature Ranges for Outside Measurements.

Day	Air Temperature Range °F.
<div> <div>Set</div> <div> <div>1)</div> <div>2)</div> <div>3)</div> </div> <div>1</div> </div>	57.1 - 64.8
<div> <div>4)</div> <div>5)</div> <div>6)</div> </div> <div>2</div>	57.0 - 67.2
<div> <div>7)</div> <div>8)</div> <div>9)</div> </div> <div>3</div>	51.3 - 62.3
<div> <div>10)</div> <div>11)</div> <div>12)</div> </div> <div>4</div>	36.0 - 58.0
<div> <div>13)</div> <div>14)</div> <div>15)</div> </div> <div>5</div>	46.0 - 58.4

(b) Diurnal Air Temperature.TABLE 42.Air Temperature Ranges for Diurnal Trial.

24 hour Period	Air Temp. Range °F.
1	47.0 - 67.0
2	55.0 - 68.0
3	55.1 - 72.0
4	51.2 - 70.3
5	52.8 - 59.0
6	46.2 - 61.0
7	51.9 - 57.5

(c) Skin Temperature.TABLE 43.Air Temperature for the Normal and Clipped and Shaved trial.

Day	Air Temp. Range °F.	Mean Skin Temp. °F.
1	60.1-63.5	87.8
2	60.0-64.0	89.2

For Position effect trial air temperatures were:-

Day	Air Temp. Range °F.	Mean Skin Temp. °F.
1	70.8-74.0	91.8
2	66.5-73.0	90.8
3	61.5-65.5	86.5
4	61.2-66.0	85.9
5	66.5-67.0	86.7
6	71.0-73.9	88.4

V. DISCUSSION OF RESULTS.

B. Outside Measurement.

(a) Skin Temperature.

For the 3 separate analyses of variance for sets of days, only in one of them is there a highly significant difference between animals and also in the same set a highly significant difference between twin pairs. On the other hand, difference between days are highly significant for the sets where there is no significant difference between animals, whereas where there was a significant difference between animals, there was no significant difference between days. Range of air temperatures for this latter set were not so very different from that for the other sets, though there was more sunshine causing high skin temperatures. These cows were chosen with a view to contrasting coat colours which may possibly affect the absorption and reflection of radiation and thereby affect skin temperature. Also different twin pairs may have different types of hair coats which impede or facilitate loss of heat by radiation and convection. If there is a difference between animals and possibly some of this difference may be due to coat colour and coat quality, then one would expect an interaction between days and animals, i.e., that animals reacted differently on different days. In the three days analysis where there is a difference between animals this interaction was not significant. All animals therefore, reacted similarly on each day. However, as there was no difference between days yet a difference between animals some other factor must be the cause of difference. Perhaps an inherent difference between animals in skin temperature. If so then the other two analyses should have shown a significant difference between animals. There seems no adequate explanation why there should be a difference between animals in this one set of 3 days and not in the other two.

That there showed a significant difference between days was to be expected because skin temperature follows air temperature and radiation fairly closely. However, the second

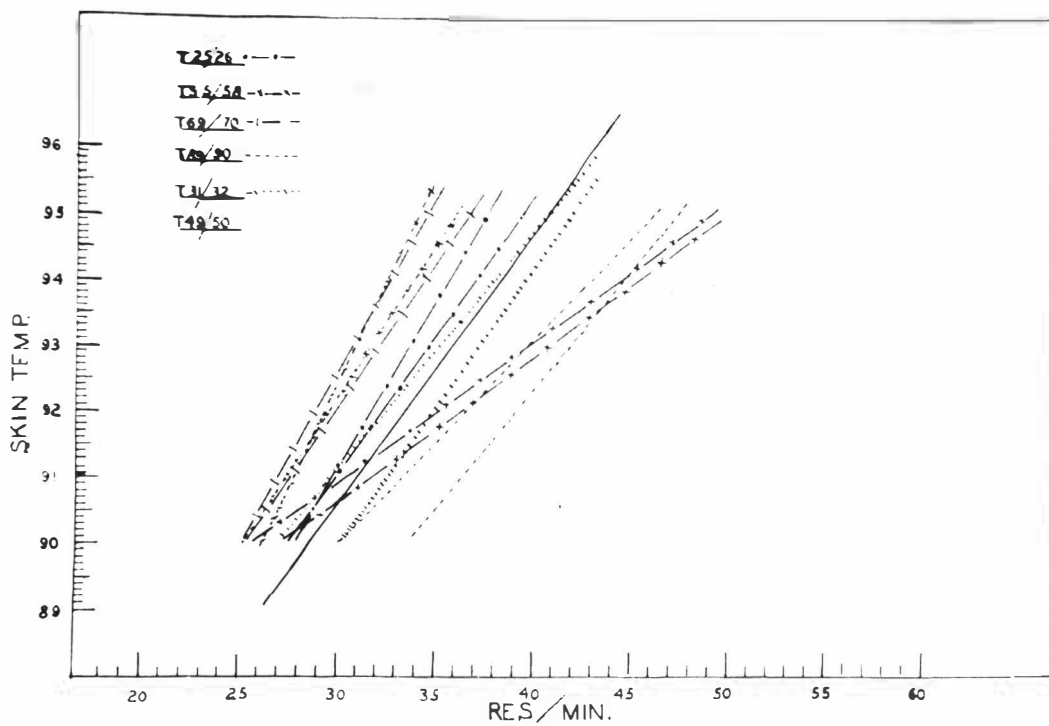
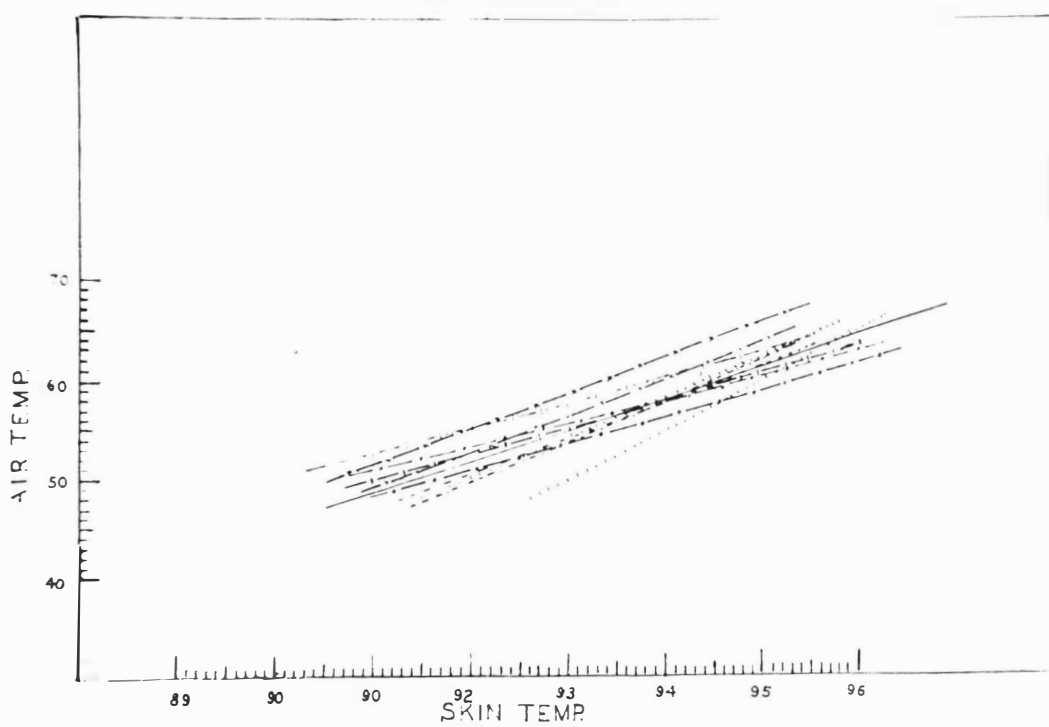
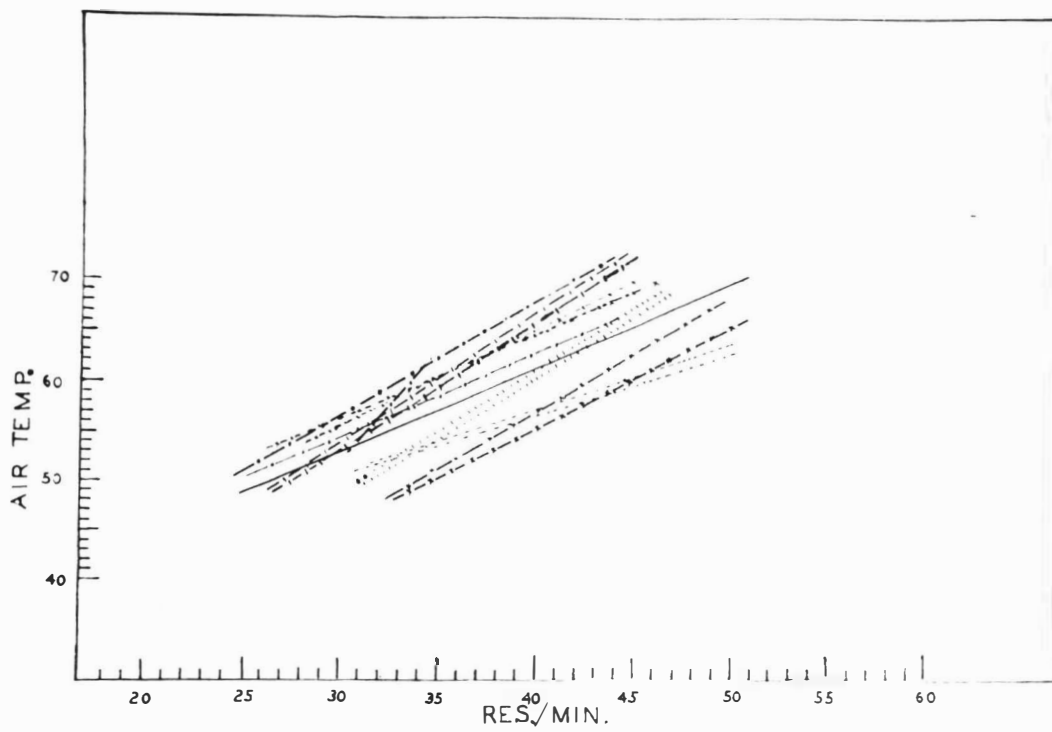


Fig. 18. Total and individual regression lines for:-

- (a) Skin temperature and air temperature.
- (b) Respiration rate and air temperature.
- (c) Respiration rate and skin temperature.



set of 3 days analysis shows no difference between days the greater percentage of the variance has been caused by differences between animals.

An analysis on a large body of data is always more useful both as regards degrees of freedom for error variance and for tests of significance. Randomization and replication which gives an accurate and worthwhile estimate of the experimental error is always to be desired. Thus, the total analysis is a much better indication of the true position than any analysis based on fewer degrees of freedom. However, the shorter analyses were carried out during the course of the experiment to gain any information that may be present.

The total analysis shows that there is no significant difference between animals or between twin pairs in skin temperature. As there was but one position taken on the animal and that area shaved of hair, perhaps differences between animals were not able to be detected. However, the literature indicates that skin temperature of cattle does not change as rapidly as air temperature. That it does change is well shown by Brody's results, but the air temperature and conditions prevailing during this trial, which was during the late autumn and early winter, were not severe enough to cause a difference between animals in skin temperature. Any difference there may be, due to colour and type of hair was not shown up on the basis of this evidence.

It is quite clear that there is a highly significant difference between days. That there is a difference between days in the weather is obvious. On days with bright sunshine the cows had a higher skin temperature than on dull overcast days. The day x animal interaction is highly significant, some days caused some cows to react in a different direction to other cows. For the set analyses, however, this interaction was non-significant. Apparently with the greater range of air temperature for the total analysis this source of variation becomes significant but the range of variation over 3 day

intervals, was not sufficient to cause significance.

It was expected that there would be a highly significant difference between readings. Air temperatures and radiation would bound to increase throughout the day with a maximum in the early afternoon. Thus, skin temperatures would vary from the first to the fourth reading with the variation in hourly weather conditions. Similarly, an interaction between days and readings would be expected. On some days the first reading, say, may be taken under hot sunny conditions, on others, conditions at about this time may be cold and overcast so that on some days readings would vary to what they were on other days.

That there is no interaction between animals and readings and yet a significant interaction between twin pairs and readings is interesting. However, two different error variances are used to test these two factors, for $A. \times R.$, the second order interaction $R. \times D. \times A.$ with a much larger degree of freedom is used for this test of significance. For Twin Pair \times Reading the within Twin Pair \times Reading variance is used for the test with fewer degrees of freedom. However, whether or not animals and readings interact is not of much interest. The major factor is if there was any difference between animals and if there was a difference between days and on interaction between animals and days.

(b) Rectal Temperature.

In all 5 analyses for sets of 3 days and in the final analysis on all the data there is a highly significant difference between animals. Twin pairs do not appear to react together to any marked extent being non-significant in the final analysis. There is a significant difference between days in all analyses except No. 5 set where days was non-significant. Perhaps this may have been due to the fact that this set was carried out at the end of June. At this time body temperature differences caused a larger variation between animals than in the other sets. Advancing pregnancy at different stages caused differences in body temperature between animals.

Although there is a significant difference between days, there was little indication during the course of the trial that body temperatures of cows reacted to any great extent with air temperature. Part of the between day variance would probably be due to the advance of gestation over time causing body temperatures on the whole to increase slightly.

Possibly a slight inherent difference between animals exists but if so one would expect twin pairs to have the same inherent difference but the between pair variance was not significant. Something else was causing the difference between animals and the effects of pregnancy is probably the cause. This would also affect members of a twin pair differently because they do not calve at the same time.

The Day x Animal interaction is non-significant in the set analyses, but is highly significant in the final one. The former being only single sets of 3 days, seeing that air temperature had little effect on body temperature, would not be affected by pregnancy nearly as much as the final analysis which uses the whole time period. Cows body temperature being different in different animals on different days is due mainly to the effects of pregnancy, not to any climatic effect. Correlations between air and rectal $r = .326$ though highly significant due to the large number of degrees of freedom still does not mean very much, as approximately 9% of the total variance is explained by the relationship between these two factors. Some of the twin pairs calved reasonably close together so that this probably caused the Twin P. x Day interaction to be significant.

In the final analysis the between readings variance is highly significant. This was to be expected because of the diurnal trend in body temperature. That readings should be different on different days is probably also due to pregnancy effects.

With one pair of twins, T49 and T50, an interesting

variation on body temperature was noticed. T50 calved approximately 20 hours after the last reading of body temperature was taken.

The following are the body temperatures for both members of the pair, 3 days before T50 calved. T49 calved 13 days after her sister.

<u>Day</u>	<u>T49.</u>	<u>T50.</u>
1	102.1	102.3
	102.3	102.4
	102.7	103.0
	103.0	102.3
2	102.2	102.7
	102.3	102.0
	102.4	102.6
	103.2	102.6
3	102.1	101.2
	102.1	101.4
	102.3	100.7
	102.5	101.0

It can be seen how the pair were very similar in body temperature for the first two days, but on the third day the body temperature of T50 dropped considerably prior to parturition.

Table 44 (on the following page) gives the mean body temperature each day for each animal, and shows how with advance of time, some animals show an increase in body temperature.

Calving dates for these animals are as follows:

Table 45.

Calving Dates of Stock & Dates for the 10 Complete Days of measurement.

Twin No.	Calving Date	Days in the trial & dates.	
		<u>Day</u>	<u>Date</u>
T25	27/7/50		
T26	17/7/50	1	23/4/50
T55	2/7/50	2	27/4/50
T58	11/7/50	3	4/5/50
T69	25/7/50	4	18/5/50
T70	24/8/50	5	19/5/50
T89	8/8/50	6	12/6/50
T90	26/7/50	7	14/6/50
T31	Dry	8	26/6/50
T32	13/9/50	9	27/6/50
T49	12/7/50	10	28/6/50
T50	29/6/50		

TABLE 44.

Body Temperatures of Cows, Mean of 4 Measurements/Day/Cow.

Day		1	2	3	4	5	6	7	8	9	10	Mean
Animal	25	101.8	101.5	101.7	101.7	101.7	101.6	101.3	101.3	101.6	101.2	101.6
	26	101.8	101.7	101.8	101.6	101.7	101.7	101.3	101.8	102.2	101.7	101.7
	55	102.2	101.9	101.7	102.3	102.2	101.9	102.0	102.4	102.4	102.0	102.0
	58	102.3	101.8	101.7	101.9	101.8	102.3	101.9	102.2	102.3	101.9	102.0
	69	102.2	102.1	101.9	102.2	101.8	102.6	102.0	102.6	102.4	101.8	102.2
	70	102.0	101.8	101.9	101.8	101.8	102.3	101.8	101.9	101.9	101.9	101.9
	89	101.7	101.7	101.7	101.5	101.5	101.8	101.6	102.0	101.8	101.6	101.7
	90	101.8	101.6	102.1	101.7	101.5	102.0	101.7	102.1	101.9	101.9	101.8
	31	102.2	101.3	101.5	101.5	101.5	101.5	101.3	101.3	101.3	101.1	101.5
	32	101.7	101.5	101.7	101.8	102.0	101.9	101.4	101.5	101.6	101.5	101.7
Mean	49	101.5	101.6	101.7	101.7	101.6	101.8	101.4	102.8	102.3	102.3	101.9
	50	101.5	101.4	101.6	101.4	101.1	101.9	101.4	102.6	102.1	101.2	101.6
		101.6	101.7	101.8	101.8	101.9	101.9	101.6	102.1	102.0	101.7	

(a) Respiration Rate.

There is a highly significant difference between animals in all the analyses except No. 4. On this set of 3 days air temperatures were low ranging from 36-58°F. Under fairly cool conditions differences between animals in respiration rate is not to be expected. As shown in table 40 it is only at about 50°F. that average respiration rate begins to increase. The range of conditions over the whole trial was great enough for differences in the response of the animals to the need for increasing evaporative loss, to become evident.

A feature of this respiration analysis is that the between twin variance is highly significant, i.e., twin pairs tend to react together very strongly as regards respiration rate.

A highly significant difference between days is indicated in all analyses. Seeing that respiratory response begins at a fairly low air temperature, the air temperature conditions experienced in this trial were sufficient to cause marked differences between days. The day x animal interaction is highly significant only in the final analysis and the same applies to twin pairs x day.

Apparently the range of weather conditions over 3 days close together were not great enough to bring out an interaction, whereas with the final analysis the range of conditions was sufficiently great to make this evident. In the literature great variation was noted in the data of some workers at any given air temperature. That some animals react to higher air temperatures more than do others, under the same conditions, is quite evident because of:

1. differences in body size.
2. colour of the hairy coat.
3. individuality of the animal.

Because of increasing air temperatures and solar radiation throughout the day differences between readings were to be expected as well as in reading x day interaction. The first

reading for example was not always at a low temperature, it ranged from 36-61°F., spread over the 10 days, so that respiration rates in the morning of one day would be totally different to the respiration rates on another morning with different air and radiation conditions.

(d) Pulse Rates:

As with respiration rates, differences between animals is highly significant and twin pairs tend to react together. Pulse rates appear to be an individual characteristic. Remember Fulton's literature on a range of pulse rates of 60-90. This is not so much a range within a cow but the range over which most cows have a pulse rate which is regarded as normal. Some cows may normally have a higher pulse rate than others under similar conditions.

A highly significant difference between days was not expected in part because pulse rates of cattle are believed to be fairly stable over air temperature range 40-60°F. and most of the measurements were taken over this range, the total range being 36-67°F. Above and below 40-60°F. pulse rates according to Brddy, begin to rise, with a fall in pulse rate after 80°F. As the conditions were fairly stable, therefore, a difference between days was not expected from the point of view of environmental effects. However, factors other than temperature can affect pulse rates. The amount of feed eaten and the relation of pulse reading to time of last feed cause differences in pulse rates. Also Bartlett has noted how pulse rate increases with advancing gestation. Both these factors probably contributed to the significant differences between days. It will be noted how, over the short period in the 3 day analyses the D. x A. interaction was non-significant, whereas, in the final analysis it was significant. Over short periods the effects of gestation may not have had time to show up reactions of the cows with days whereas, the total time period would be sufficient for the different stages of gestation and possibly different levels of feeding, remembering what period of the year this trial was carried out,

to affect animals in different ways. This makes the D. x A. interaction highly significant and because it is significant it is used to test the animal variance.

Differences between readings were also not expected from the point of view of climatic effects. Bartlett has noted a slight diurnal variation in pulse rate related possibly more to feeding than a true diurnal trend. However, this feed effect may have caused differences between readings. When the animals were collected from the paddock they were often laying down having grazed some time before. Therefore, by midday, the effect of feed on pulse rate would have decreased. For an hour and a half at midday the cows were allowed out to pasture and then were brought in for the afternoon readings, so that the feed factor would cause a difference here again.

Not only would time since feeding be a factor but the reactions of the animals while in the yards. Nervousness, fighting and general disturbance can alter pulse rate and although the stock were on the whole very quiet and well trained to the routine, disturbances were unavoidable. One twin pair, 49/50, had to be kept separate because of their bunting status in the herd. Feed plus disturbances would obviously vary with different readings on different days.

(e) Components of Variance.

Table 17 of components of variance expressed as percentage shows that day effects accounted for 44% of the total variance in the case of skin temperature and respiration rate. This is a direct effect of climate.

With rectal temperature it can be seen that 28% of the variation is due to diurnal trends - (Readings). The very marked differences between animals in pulse rates even under normal conditions is evident by the fact that the between animal variance accounts for 50% of the total variance. Days does not cause much variation in body temperature, so that these conditions were fairly good for stable body temperature.

The 20% total variance due to animals, explains the significant difference between animals in body temperature, due not so much to temperature effects but to gestation.

Reading variation causes a small part of the total variance in respiration and pulse rate.

(f) Intra class correlation.

Repeatability estimates worked out so as to give the repeatability of a measurement taken at each of the four readings, when day effects are ignored, show poor results for skin and rectal temperature and respiration rate. Pulse rate - a more stable characteristic - shows quite good repeatability at any reading. Body temperatures are fairly stable especially when the variation caused by readings is eliminated by calculating correlations for each reading separately. Days accounted for only 4.8% of the total variance in body temperature. In spite of this the repeatability within cows of body temperature is still almost negative when worked out on a total:-

Between cows

With cows

basis. Apparently Day effects does have an effect because its elimination in No. 2 series of correlations cuts out gestation effects. The 19% of the variance due to Day x Animal interaction would also be a contributing factor.

Ignoring differences between days for skin temperature and respiration rate when we have noted already the large relative effect of days, will obviously give a poor correlation.

When the between day variance is eliminated, correlation for all cows shows a better estimate than before for all measurements, though skin temperature is still fairly low. It is not clear why, after between day variance is taken out for skin temperature (where days causes 44% of the total variance) that repeatability of skin temperature should still be low. However, the fact that the total analysis of variance showed no difference between animals, taking out between animal variance does not eliminate a significant part of the variance, the variation is

still largely within the animals - (subgroups) so that this may serve to explain why repeatability estimates are low for skin temperature.

When the animal's readings within a day are taken as a subgroup so that the correlations are intra day for each cow, the repeatability is highly significant in nearly all cows except those for rectal temperature. However, a large intraclass correlation (.99) indicates little variation within the subclass so that except in the case of pulse rate these correlations are on the whole fairly low.

Seath and Miller have worked out a repeatability estimate for body temperature and respiration in a manner similar to the first series. They derived a much better estimate than the present set. However, their data was for 14 consecutive days, whereas the days here were spread over 3 months, so that days would be more random sample of the population of days, perhaps causing a greater effect than in Seath and Miller's work. Also, their air temperature conditions ranged about 80-95°F. so that animal reactions would be marked, in contrast to the present trial.

On similar types of days repeatability estimates are better and for rectal temperature and respiration rate agree well with Seath and Miller's estimates.

The third series of correlations gives an estimate of the various measurements as a method. The subgroup in this case is the four readings in one day. It can be seen that the method of taking pulse rates gives fairly good reproducible results. Respiration too is quite good though there is considerable variation within the subgroups due to varying air temperature throughout the day causing respiration rates to vary. Rectal temperature in this series show non-significance probably because of the diurnal trend, although one twin pair, 49/50, show quite a good correlation. Later work showed that the diurnal trend within this pair was not so marked. Also, this pair was the closest to calving and

body temperature remained consistently high throughout the day in the later stages. Skin temperatures, though significant are fairly small. Variation in sunshine and cloudiness throughout the day would not help towards a high correlation.

(g) Correlation Analysis.

The degree of relationship between two variables is given by the statistic r . The statistic squared r^2 represents the proportion of the total variance which can be explained by the relationship. Thus, even though the correlation for all possible combinations for the outside data are highly significant the proportion of the total variance explained by the relationship is small. Even for the 3 larger r 's, air and respiration, air and skin temperature, skin temperature and respiration rate, when squared the respective r 's explain at the most, 40% of the variance. 60% of the variance remains unexplained.

However, compared with the results of overseas workers with field experiments (Gaalaas $r = .77$) the correlation between air and respiration is quite good. $r = .613$. Overseas data has been collected under much better conditions and the correlation is higher, as would be expected.

Reimerschmid obtained r between skin temperature and air temperature of 0.9 in the sun. The present result under New Zealand conditions of .640 is not so high but neither were the air temperature or intensity of radiation.

Skin temperature and respiration $r = .661$ is the highest correlation obtained. That there is a fairly close relationship is interesting. Possibly the increase in skin temperature which occurs with rising air temperature, (r - skin and air .640) causes the thermoreceptors on the skin to bring about a reflex action and the heat loss by way of the evaporation method is increased. It has been remarked that it is strange that loss of heat by way of evaporation should be relied upon at such an early stage. Loss of heat by way of radiation and conduction is apparently not assisted in these early stages by way of vasodilation and reduction of thermal conductivity of

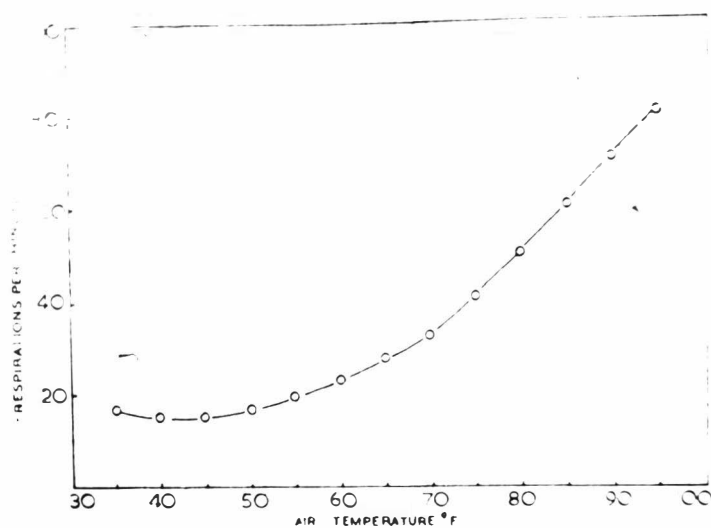


FIG. 14
 A regression curve ($Y = 17.867 - 2.504X + 0.577X^2$) relating
 respiration rate and air temperature for Jersey cows.
 (Adapted from Gaalaas, 1948)

Fig. 14. Regression curve relating respiration rate
 to air temperature for Jersey cows.
 Gaalaas.

the tissues.

(h) Regression Analysis.

The relationship between air temperature and skin temperature, and between air temperature and respiration rate were proven on the basis of the total analysis, to be linear whereas the total analysis for the relationship between skin temperature and air respiration rate is significantly curvilinear. However, on an individual cow basis we find in all three cases that there are some that are curvilinear and some that are not. Plotting some of the data roughly on a graph also showed that a straight line would fit the data reasonably well. On the other hand, a curvilinear relationship may exist but looking at some of the plotted groups it is evident that if there is curvilinearity according to statistical proof then it is only slightly curvilinear. Also, once curvilinearity is established there is the problem of what mathematical formulae should be used to fit the data and many of these merely fit the curve without the curve meaning very much.

Gaalaas found a distinct curvilinear relationship between air temperature and respiration. The present data does not show such a relationship on a total analysis. However, Gaalaas' results were derived from nearly 4000 individual measurements over several years and over a very much wider range of air temperatures than in the present series. On looking at his graph one sees that the relationship is almost linear for the air temperature range for which the present data measurements were taken so that possibly a linear relationship is justified. However, the data is too few, the evidence not precise enough, the air temperature range tested not wide enough, to permit any definite statement about linearity on non-linearity of these relationships in this trial.

Linear regression coefficients are given for the three relationships tested for curvilinearity both for individual cows and for the total data available in each case. All are high significant.

Regression coefficient b for total relationships are:

(1) Air temperature and skin temperature.....0.318

(2) Air temperature and respiration rate.....1.210

(3) Skin temperature and respiration rate.....2.420

(1) means that 1°F. increase in air temperature causes, on the average 0.31°F. increase in skin temperature. (Riemerschmid, 0.28°F. in the sun and 0.31°F. in the shade).

(2) means that 1°F. increase in air temperature causes an average increase of 1.21 respirations per minute.

(3) means that 1°F. increase in skin temperature causes an average increase of 2.42 respirations per minute.

From one, it can be seen that although skin temperature increases with increase in air temperature, yet it does so, at a lesser rate, thus decreasing the difference at the skin interface making it harder to lose heat by radiation, conduction and convection.

That there is a rapid rise in respiration rate with air temperature, especially after 67° (Gaalaas) and 70°F. (Brody) has been noted. Possibly this may act by way of skin temperature but the tie-up between 2 and 3 above does not assist the theory that air temperature may increase respiration rate by way of increasing skin temperature, setting the thermoreceptors in motion and thus increasing respiration rate. If so, then the increase in respiration rate with 1°F. increase in air temperature and 1°F. increase in skin temperature should be on a par. The regression coefficient for air and skin temperature shows a lag in skin temperature rise. The temperature of the air breathed by the cow may increase its respiration rate (Kleiber and Regan) in the first instance but when skin temperature has slowly risen enough to set the thermoreceptors in action, there is an impetus to the respiration rate because of a more urgent warning to the brain centres and consequently increased heat loss by way of evaporation.

Evidence is presented to see whether the individual

linear regressions belong to a common population or not and it is seen that in all 3 cases they do belong to the same population.

(i) Partial Correlation and Multiple Regression Analysis.

Pulse rate was one of the variables measured. Just what is the significance of pulse rate in the physiology of heat regulation in cattle is not known. In an endeavour to see what was the relationship between pulse rate and the other variables which are known to play a role in heat loss, partial and multiple correlation analysis was attempted. Ordinary or gross correlation between pulse rate and air temperature when first 1, 2 and finally 3 of the variables are held constant, are all smaller than the gross correlations between air temperature and pulse rate $r = .396$. This shows that pulse rate is not strongly related to air temperature and there is virtually no connection. The $r = .396$ between air and pulse is higher than the partial correlations because the relationship between air and pulse is indirect, and it is more apparent than real. When skin temperature, body temperature and respiration rate are held constant the correlation between air and pulse is very small - .164 - which is useless even though statistically this figure is highly significant. It can be seen as first, just one variable is held constant and the influence of the other 2 still permitted to hold sway the partial r is higher than when all 3 variables are held constant. Thus, the apparent r between air and pulse is negligible when the interrelations and complex interactions of the effects of other variables is held constant. Air and skin for instance, are correlated somewhat strongly and this influences the correlation between air and pulse. When skin temperature is held constant there is an immediate reduction from 0.396 to .206. The other factors react in a similar manner.

To see if the addition of possible associated variables could provide a better estimate of pulse rate multiple regression analysis was attempted to see how well the

multiple correlation improved when first one, then two, then three variables are added to the test. Multiple correlation like ordinary gross correlations gives a measure of the success of determining the dependant variable, in this case pulse rate, by means of any other independent variable or variables. It was for this reason that these multiple correlations were calculated. It can be seen that $R_{1.2345} = .495$, is higher than if only two or three variables are used. and is higher than the gross correlations of pulse rate with anything else. But R^2 is the proportion of the total variation in pulse rate which is explained by these factors and it can be seen that $.495^2$ still leaves most of the variation in pulse rate unaccounted for.

Partial correlation analysis has shown, therefore, that pulse rate is not correlated strongly with other variables and multiple correlation coefficients although increasing slightly the amount of variation in pulse rate, accounted for by the given variables, still leaves the bulk of the variance to be due to other unknown factors.

That there is no relationship between pulse rate and air temperature seems clear over the range of air temperatures studied. Higher air temperatures above 80°F. depresses pulse rate in cattle, (Brody) and increases pulse rate in man (Bazett). With Brody's data between an air temperature range 40-60°F. there is a constant pulse rate with a slight increase between 60 and 80°F. The present data also shows pulse rate to have little relationship with air temperature; Vasodilation and increased radiation and convection loss with increasing air temperature does not seem to be in operation to any noticeable extent in cattle.

C. Diurnal Test.

(a) Body Temperatures.

In both analyses a highly significant difference between animals is established confirming the outside data.

Twin pairs do not react together though the number of animals leaves small degrees of freedom for testing between twin pairs. There is also a highly significant difference between days and between measurements. That there should be a difference between measurements is obvious from the diurnal trend shown in the graphs. Days x animals and measurement x animals are significant in the first analysis but not in the second. That different animals should have a different body temperature at different times of measurement, is not evident from the graphs as the peak of body temperature comes at about the same time for all animals. During the first four days covered by the first analysis, however, cows which had been standing for some time had a lower body temperature than cows which were lying, which may have brought about this interaction. Also this may have caused the D. x A. interaction to be significant.

(b) Respiration Rate.

As with outside data a highly significant difference between animals and also between twin pair was found. In both analyses, days and measurements are highly significant, which was to be expected because of the different air temperature from day to day and also within a 24 hour period.

Respiration rates were different in different animals at the same time, however (M. x A.) it was noticed that a cow which was eating or had her attention distracted, had a much lower respiration rate than even her twin sister who was just standing or lying quietly, undisturbed. This would cause animals to vary in respiration rates at any one time, regardless of air temperature. There was also a measurement x day interaction, Since respiration rate follows air temperature fairly closely, it is not surprising that this interaction is significant as air temperatures at one time of measurement would not be the same every day.

(c) Pulse rates.

As with the outside data there is a highly significant

difference between animals, twin pairs, days and measurements. Day x measurements interaction is significant in both analyses. Nervous upsets plus variation in feed intake at different times of the day could possibly account for this interaction. Although Measurements x animals is non-significant, in both analyses the twin pair x measurement is highly significant. This may be partly due to pulse rates being a strong characteristic of twin pairs and different twin pairs have a different pulse rate at different measurements. 49/50, for example, were consistently higher than the other twin pairs.

A feature of pulse rates throughout this trial was the marked increase which the animals showed when placed within the barn compared with outside data. The range of pulse rates outside was 50-92, mean 70.23, s 2.89. Within the barn the range was 72-117, mean 93.67, s 3.93. The animals were very quiet and were not any trouble to get into the barn nervousness did not appear to be a factor over the whole period. These animals were not as close to calving at this time 23/6/50 - 4/7/50 as when some of the outside data was taken, yet pulse rates were surprisingly high. Why this was so is difficult to explain. The only factor which may help to explain this high pulse rate was that the cows within the barn had ad lib feeding - of silage and hay with a daily ration of meal. The continuous eating at intervals throughout the day up to midnight may have caused the pulse rates to be quite high. There may not have been a sufficiently long interval between feeds for the pulse rate to fall to normal post feeding level, before the cows started eating again. With the highest pulse rates of 100-117 beats per minute obtained from twins 49/50 it was noted that these occurred while the animals were eating. Pulse rates after midnight tended to fall almost to normal levels in twins 25/26 which ate very little during the early morning, but 49/50 being great foragers, as seen since under grazing observations, would eat quite a lot in comparison with the others during the period after midnight. The graphs show for all cows a distinct

diurnal trend.

(d) Correlations.

None of the r 's are very large and only in a few cases do a series of correlations for individual cows all belong to the same population. Air and rectal temperature shows virtually no correlations, body temperatures vary throughout the day and so does air temperature, but the rise and fall of body temperature is independent of air temperature. Air and respiration shows a highly significant correlation in the first 4 days and all belong to a common population, $r = .396$. This is much smaller than the outside estimate of $r_{AR} = .612$. In the last 3 days there is virtually no r between air and respiration. In the latter 3 days the cows were tested every 2 hours. Most times the cows were lying down when the attendant walked into the shed. They were all then made to stand for quarter of an hour before the first reading was taken. T49, however, would hear the attendant and often be already on her feet. As she was the last cow to be measured it was $\frac{1}{2}-\frac{3}{4}$ of an hour before her respiration rate was taken. These last 3 days show a negative correlation between air and respiration except T49 which has a positive r and of the same order of size as for the first four days. Now it had been noticed all throughout this trial how a cow's respiration rate would be very low if her attention was distracted or if she was eating. The fall in respiration rate would be very marked. Thus, disturbing the cows and making them stand decreased their respiration rates except in the case of T49. The time interval for this cow was sufficient to permit her to look about, perhaps eat a little and settle down so that her respiration rate tended to be higher than the others when it was time to take her readings. This factor of distraction was not so marked at every reading in the first 4 days as cows were not disturbed so much, but this factor operated for all cows at different times of measurement, which probably causes the correlation to be low. Also in the first 4 days members of a twin pair would not always be doing the

same thing so that variation within twins was considerable. However, the data for the last 3 days show better agreement within twins because both were doing the same thing, due to being made to stand.

Why air and pulse rate should be higher and belong to a common population in the first 4 days and not in the last 3 is not known. The former is on a par with the outside correlation, $r_{AP} = .396$. In the last 3 days air temperatures were much cooler but the change of technique may have had some effect.

The only other correlation of interest is that between rectal and pulse. In the first analysis 55/58 do not show a correlation at all and cause the series to belong to different populations. It was these two cows which, in the first 4 days, were nearly always lying down when body temperatures were taken and these tended to be higher than if the cow had been standing for a time. This made their diurnal variation fairly small, and even when they were made to stand the diurnal trend in this pair was not as marked as in the other two pairs. In the last 3 days the correlation between rectal and pulse all belonged to a common population, $r = .489$. Probably the two hour intervals between readings permitted a better estimate of pulse rate due to less tendency to eat at more frequent intervals, as occurred in the first series.

The change of technique may have sacrificed some of the information on respiration rate and pulse rate but the main object was to obtain an estimate of the diurnal trend in body temperature and at what times the peak and fall occurred. When graphed the data shows that a peak always occurred at 6 p.m. and minimum at 4-6 a.m. The range amounted to $1-1\frac{1}{2}^{\circ}\text{F}$. To have taken readings when some cows were lying and some standing would have probably made the diurnal trend less evident. To have uniformity of treatment it was necessary to take all readings either lying or standing and all were made with the cows standing at least 15 minutes - see Table 35.

Some workers have found that a standing cow has a higher heat production than a lying one - (Brody), Ritzman and Benedict. Whether this should lead to a higher body temperature when standing, or not, is not known. The reverse was found in the present trial. However, a cow which is lying may have the abdominal organs pushed down towards the rear and since such internal organs have a higher temperature this may have caused the rectal temperature reading to be higher.

D. Skin Temperature.

The analysis of variance for determining which method of taking skin temperatures gave the highest skin temperature is self explanatory. All 8 positions on each animal were taken on the trunk region where, according to work on man, skin temperature does not vary very much, hence the non-significance, perhaps, between positions. As there were only 2 days for this test with one degree of freedom for days there was no significant difference between days.

There was no significant difference between skin temperature when the hair was clipped and when it was shaved. The clipping was as close as possible and the local environment, therefore, well exposed. However, there was a highly significant drop in skin temperature of 1.32°F. between normal readings with the hair on and clipped readings.

Work with man shows that skin temperature of the extremities varies more than trunk skin temperatures and that in the cold the temperature of the limbs and digits is lower than the trunk. Russian workers claim similar facts with cattle, though their measurements were taken under very cold conditions. An attempt was made in the present series to see if skin temperature varied over the body, and the results show that skin temperature does vary over the body, being lower on the limbs than on the trunk of the animal. Temperatures near the hooves are $6-7^{\circ}\text{F.}$ lower than parts of the trunk.

The analysis of variance - Table 38 - shows a highly significant difference between the means of positions. Position

x animal was highly significant. Probably this may be due to different hairy coats of the animals, differences in subcutaneous fat, and different blood supply in the superficial tissues, and unavoidable errors in fixing positions in the exact place for all animals. That position x day should be significant was to be expected because day effects are highly significant and since skin temperature is correlated with air temperature, then the temperature on any one position would be expected to vary with variation in air temperature.

E. Summary of Results.

(a) Outside Data.

(1) Skin Temperature.

The measurements were made under moderate air temperatures with no great range and no extreme heat or cold. There was no significant difference between animals in skin temperature. There is a difference in skin temperature of cattle on different days and throughout the day due to different weather conditions particularly solar radiation between and within days. Mean skin temperature 93.8°F. s 1.18.

(2) Rectal Temperature.

Animals differ significantly in body temperature though twin pairs do not show significance. There is a significant difference in body temperature between days, however, it is believed that this day difference is due not to environmental conditions but the effect of advancing pregnancy. The pregnancy effect probably also causes the differences between animals as there was little indication of body temperature varying with air temperature. Mean body temperature $101.8,$ s .22.

(3) Respiration Rate.

Air temperature conditions were sufficient to show a marked difference between animals and also between twin pairs and to cause significant differences between days. This is a direct climatic effect. Mean respiration rate $34.26,$ s 5.98.

(4) Pulse Rates.

The pulse rate of an animal is a strong individual characteristic, difference between animals and twin pairs being highly significant. A difference between days showed up but was not expected because pulse rates show little change with air temperature over the air temperature range tested. However, variations from day to day caused by the effect of feeding and advancing gestation may have caused the significant difference. Mean pulse rate 70.23, s.4.12.

(5) Components of variance show that with skin temperature and respiration rate day effects cause 44% of the total variance. Inherent differences between animals in pulse rates account for 50% of the total variance in pulse rates. Nearly 30% of the variance in body temperature is due to diurnal trends.

(6) Intraclass correlations are small and non-significant except for pulse rates when all readings were taken but day effects ignored. When day effects are taken out the correlations are as follows:-

Rectal Temperature	Respiration	Pulse
$r_i = .309$	$r_i = .324$	$r_i = .559$

This is a measure of the repeatability of readings on similar types of days. Skin temperature on this basis showed low repeatability.

As a measure of the accuracy of the method the 4 readings per day were treated separately for each cow. Average intraclass correlations were as follows:-

Skin Temperature	Respiration Rate	Pulse Rate
$r_i = .425$	$r_i = .550$	$r_i = .580$

Rectal temperature, because of the diurnal trend, showed poor repeatability.

(7) Correlations worked out on a within cow basis all belonged to the same population. Three of the higher correlations are as follows:

Air & Respiration	$r = .613$
Air & Skin Temperature	$r = .640$
Skin Temperature & Resp. Rate	$r = .661$

However, these explain at the most 40% of the variation; 60% is due to other factors.

(8) Curvilinear relationships between air temperature and skin temperature, air temperature and respiration rate, and skin temperature and respiration rate, show non-significance for the first two but not for the latter. On the basis of the fact that significance varies within each section when individual cows are tested and the appearance of the data on graphs, linear relationships are decided upon.

Linear regression coefficients, air and skin temperature $b = .318$, air and respiration $b = 1.21$, Skin T. & Resp. $b = .24$

(9) Partial correlation analysis shows that pulse rate is not correlated very strongly with any other measurement taken. Multiple regression coefficients give a larger R for air temperature and pulse than the ordinary gross correlation. Even so, it is still very small and explains but a small proportion of the total variance. Over the range of air temperatures tested, pulse rate does not appear to yield any information of significance from the point of view of the physiology of heat regulation.

(b) Diurnal Test.

As with outside data a highly significant difference between animals was found for body temperature, respiration rate and pulse rate, the latter two being characteristic of twin pairs also. Also days and measurements are highly significant in all cases.

With respiration rates, a marked fall was noted when animals were eating or had their attention distracted. Pulse rates were very high throughout the trial. It is not clear why they should have been high except perhaps the effect of ad lib feeding and the fact that food was available during the whole of a 24-hour period. With body temperature it was found that there was a higher reading in the lying animal than the standing one. A distinct diurnal trend was found in body temperature with a maximum at 6 p.m. and a minimum at 4 a.m.

Similarly a diurnal trend was found in pulse rates.

(c) Skin Temperature.

When the hair of the animal is left on, the skin temperature is higher than when the hair is clipped or shaved off. The skin temperature of the extremities of 3 cows tested was lower than that found in the trunk region.

VI. CONCLUSION.

At no stage in these experiments was there any sign of stress due to environmental conditions. Whether this would apply to lactating animals with a higher heat production and, therefore, larger heat dissipation, is not known. Probably lactating cows would not be affected by the range or air temperatures available.

Skin temperature measurements showed no difference between animals so that any difference between animals as regards solar radiation and type of hairy coat, did not influence skin temperature. However, it is possible that this may have been brought out if many positions had been tried on each animal. Work within the barn shows how skin temperature varies over the animal body, and how skin temperature is higher with the hair left natural. Mean skin temperature from day to day shows a significant difference. The correlation between air temperature and skin temperature is quite high, showing that environmental conditions largely determine the skin temperature.

Body temperatures of the stock were not influenced by weather conditions experienced in this trial. Pregnancy effects and diurnal variation account for most of the variation in body temperature. Position of the animal is important when taking body temperature measurements.

Respiration rates do vary with air temperature and begin to increase at about 50°F. The correlation between air and respiration rate over the whole range of air temperatures is fairly good. Care must be taken when taking respiration rates to see that the animal is not distracted or has its attention

diverted, otherwise a low respiration rate will be recorded. Respiration rates are significantly different between animals and twin pairs under the same conditions.

Pulse rates are a strong animal characteristic and cause 50% of the variation in the data. A significant difference between days was found but this is probably due more to the effects of feed and advancing gestation, rather than to air conditions. Pulse rates taken inside a dairy barn were extraordinarily high, but it is probable that feed was a causal factor. Pulse rate does not appear to be of much use as a measure of an animal reaction to environmental weather conditions. However, at higher air temperatures it may be of use as an indicator of thermal stress, as some workers - Brody, Regan and Richardson - have showed how pulse rates decline after about 80°F. air temperature. But, the difficulty of controlling the great influence of feed on pulse rate under field conditions, makes the interpretation of pulse rate data unreliable. Under field conditions then there is not much point in taking pulse rate, because of the effects of feed, nervousness, general conditions being unsatisfactory for accurate estimation of the significance of pulse rates.

This work was carried out under fairly cool conditions with a maximum for outside measurements of 67°F. and for indoor measurements of 74°F. Respiration rates were always high at the higher air temperatures, but body temperatures were unaffected.

Further work needs to be taken with cows in milk during the summer months of the year to see if the high air temperatures affect respiration rate, body temperature and skin temperatures. A few readings on lactating cows with air temperatures at 81°F. have been carried out during the summer of 1950-51 but no excessively high respiration rates, skin temperature, and no change in body temperatures, were noted. With the evidence of overseas workers, 80-85°F. is about the upper critical temperature level. New Zealand dairying areas do not attain such high air temperatures, and higher temperatures still are needed to bring

about the resultant animal reactions to high temperatures, so that New Zealand conditions may not be severe enough to cause a rise of body temperature. Not only is the actual air temperature important but the time of exposure is a factor.

However, the necessity for the cow to increase respiration rate quite markedly at temperatures above 50°F. may have some effect on production because of the energy being expended in respiratory movement and possible decreased grazing activity.

But, air temperature is not the only factor involved, solar radiation can influence the heat load to be dissipated and this may be a possible factor under New Zealand conditions. The little work which has been done, indicates that with solar radiation on hot summer days, body temperature does not rise. However, this does not necessarily indicate that solar radiation has no effect. The cow may decrease intake and reduce production to cut down its internal heat load because of heat being absorbed from radiation. There may be something of a balance set up so that body temperature still remains normal. But this does not necessarily mean that solar radiation is unimportant. It may yet prove to be quite an important factor, even under New Zealand conditions. Work needs to be carried out to find the amount and intensity of solar radiation, incident over various parts of New Zealand particularly during the summer months. An estimate of the absorption and reflection of solar radiation on the hides of animals in conjunction with information on radiation incidence and distribution may yield valuable indications as to whether solar radiation is likely to be a factor in New Zealand dairy cow production.

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APPENDIX.

APPENDIX CONTENTS.

- I. Preliminary Skin Temperature Data.
- II. Outside Data.
 - (a) Skin Temperature
 - (b) Body Temperature
 - (c) Respiration Rates
 - (d) Pulse Rates
 - (e) Air Temperatures.
- III. Diurnal Data.
 - (a) Body Temperature
 - (b) Respiration Rates
 - (c) Pulse Rates
 - (d) Air Temperatures.
- IV. Skin Temperature.
 - (a) Normal
 - (b) Clipped
 - (c) Shaved
- V. Skin Temperature - Position Effect.
- VI. Individual Correlation.
- VII. Partial Correlations and Multiple Regression Coefficients.

TABLE. 46.

APPENDIX 1.PRELIMINARY SKIN TEMPERATURE DATA.

Data for determining intra-class correlations.

26th March. a.m.

<u>TWIN NO.</u>	<u>POSITION.</u>			<u>TWIN NO.</u>	<u>POSITION.</u>		
	<u>LEFT HIP.</u>	<u>RIGHT HIP.</u>	<u>BACK.</u>		<u>LEFT HIP.</u>	<u>RIGHT HIP.</u>	<u>BACK.</u>
26	95.0	95.8	95.4	58	92.4	91.6	93.8
	95.4	95.4	95.8		91.0	91.0	92.8
	95.0	95.4	95.8		91.0	91.6	93.3
	95.0	95.4	95.0		92.0	92.8	93.3
	94.6	95.4	95.8		92.0	92.0	93.3
	94.6	95.0	94.6		91.6	92.0	93.3
	95.4	95.4	95.4		91.6	92.4	92.8
	95.0	95.4	95.4		92.4	92.8	93.3
	95.0	95.0	95.4		92.4	92.0	93.3
	95.4	95.4	95.0		92.4	93.3	94.2
	95.0	95.0	95.0		91.6	92.4	94.2
	95.0	94.6	95.0		92.0	92.0	93.8
40	93.7	95.0	94.6	55	94.2	95.4	95.0
	94.2	95.0	94.2		95.0	95.0	95.0
	94.2	94.6	94.6		94.2	95.0	95.0
	93.7	94.6	94.6		94.2	95.4	95.0
	93.7	95.0	95.0		95.0	95.4	95.4
	94.6	95.4	95.0		95.4	95.0	95.4
	94.2	94.2	95.0		95.0	95.4	95.4
	94.2	94.2	95.0		94.2	95.0	95.0
	93.4	94.6	94.6		94.6	95.0	95.0
	94.2	94.6	95.4		95.0	95.0	94.6
	94.2	94.2	95.0		95.4	94.2	95.4
	93.6	95.0	95.4		95.0	95.0	95.0
39	93.8	94.6	95.0				
	93.3	93.8	94.2				
	93.3	94.6	94.2				
	93.3	93.8	94.2				
	93.3	94.6	95.0				
	93.8	94.2	95.0				
	93.8	93.8	94.2				
	93.3	94.2	94.2				
	93.3	94.0	94.2				
	93.3	95.8	94.2				
	93.3	93.8	94.2				
	93.3	95.0	94.6				

APPENDIX I (CONT.)

5th April.

<u>A.M.</u>			<u>P.M.</u>			<u>A.M.</u>			<u>P.M.</u>		
<u>TWIN NO.</u>	<u>THURL</u>	<u>HIP</u>	<u>TWIN NO.</u>	<u>THURL</u>	<u>HIP</u>	<u>TWIN NO.</u>	<u>THURL</u>	<u>HIP</u>	<u>TWIN NO.</u>	<u>THURL</u>	<u>HIP</u>
25	94.8	96.8	25	95.8	95.4	69	94.2	94.6	69	87.2	84.6
	95.0	95.9		95.9	95.4		94.2	95.0		86.8	84.1
	95.8	96.3		95.9	95.0		94.6	95.0		86.4	84.6
	95.0	96.3		95.9	95.9		94.6	94.6		86.4	84.6
	95.0	95.9		94.6	94.6		95.0	94.6		85.4	83.7
	95.4	95.4		95.4	95.9		94.6	95.0		85.4	83.7
49	93.2	95.0	49	91.6	89.8				32	87.6	88.4
	93.7	95.0		92.4	90.2					87.2	88.9
	93.2	95.0		92.4	90.2					88.4	90.2
	93.7	95.4		93.2	90.1					87.6	90.2
	93.7	95.0		92.8	89.8					88.9	90.7
	92.8	95.9		91.6	91.3					89.4	90.7
90	93.7	95.4	90	91.6	90.2				58	90.7	92.0
	95.0	95.0		89.8	88.9					91.3	91.3
	93.7	94.2		90.7	89.4					91.3	89.8
	93.7	94.2		92.4	89.8					90.7	89.8
	94.2	94.2		92.4	90.7					91.3	90.2
	93.2	92.4		92.4	91.6					90.7	90.7
70	93.2	92.4	70	89.8	86.4				31	90.7	90.7
	93.2	92.8		89.4	85.4					90.7	91.3
	92.8	93.2		88.0	84.6					89.4	91.6
	93.2	92.8		88.4	84.6					89.4	91.6
	92.4	92.4		88.0	84.1					90.2	91.3
	93.2	92.4		87.6	82.8					90.2	90.7
26	95.0	95.0	26	93.7	92.8				55	88.4	92.8
	95.1	95.0		92.8	93.2					90.7	92.8
	94.2	94.2		93.7	92.8					91.3	92.8
	94.2	94.2		94.6	94.2					92.8	92.8
	92.4	95.4		95.0	93.2					92.4	92.4
	92.0	94.6		93.2	92.4					92.4	92.0
50	93.7	94.6	50	90.7	91.3						
	93.7	94.6		92.0	92.0						
	92.4	94.2		92.8	92.4						
	93.2	95.0		92.8	93.2						
	94.2	94.6		92.8	92.8						
	93.7	94.6		93.2	93.2						
89	94.6	94.6	89	88.0	82.4						
	95.0	95.0		87.6	83.2						
	94.6	95.0		89.4	83.2						
	95.4	95.9		90.7	84.6						
	95.9	95.9		91.6	83.2						
	95.0	95.4		89.8	82.4						

APPENDIX I. (CONT.)

26th March. p.m.

TWIN NO.

P O S I T I O N.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
25	95.4 96.4 95.0	94.6 95.0 93.8	88.0 83.7 85.4	96.8 87.6 87.6	97.2 96.8 87.6	95.0 94.6 83.8	96.8 96.4 96.0	85.0 95.4 95.8	93.8 94.6 92.8
26	93.7 94.2 93.0	93.7 93.0 92.8	85.4 85.4 83.7	85.4 95.0 94.6	97.6 96.3 96.8	93.2 92.0 93.2	93.7 93.2 92.4	94.6 93.2 92.4	92.0 93.2 91.6
39	95.9 95.4 95.4	95.0 95.0 95.0	81.9 82.4 85.4	96.8 96.3 97.6	96.8 96.3 96.3	94.2 92.4 92.4	95.4 95.9 95.4	95.9 95.4 93.7	96.3 95.9 95.4
40	95.0 95.0 94.8	94.6 92.4 92.4	81.4 83.7 84.6	96.8 96.8 96.8	97.6 96.8 96.8	91.6 89.8 90.7	91.6 93.5 92.6	96.8 95.4 94.8	93.7 93.7 91.3
55	92.2 92.6 93.2	92.0 92.2 93.7	83.5 84.1 84.1	95.4 95.9 95.2	96.8 95.9 96.1	91.3 92.8 90.2	95.0 94.4 93.9	95.7 95.9 95.7	92.8 94.2 94.6
58	93.7 93.7 93.2	92.4 92.8 91.6	84.6 83.2 85.9	95.4 94.6 94.6	96.8 95.6 95.4	91.6 90.2 89.8	94.6 94.2 92.8	92.6 93.7 91.3	91.5 90.2 92.0

APPENDIX I (CONT.)

1st April.

A.M.

P.M.

Twin No.

POSITION.

TWIN NO.

POSITION.

32

1.	2.	3.	4.	5.
92.8	95.9	97.2	92.4	93.2
92.4	96.8	96.8	92.0	94.6
93.2	95.9	97.2	92.0	94.2
93.2	95.9	96.8	93.2	94.6
93.2	95.9	95.9	92.0	95.0
93.2	95.9	95.4	92.4	95.0

25

1.	2.	3.	4.	5.
96.8	97.6	99.3	95.9	95.4
97.2	98.4	99.3	95.9	97.2
96.8	97.4	99.3	95.4	96.3
96.8	97.6	98.4	95.9	95.9
97.2	97.6	98.4	95.9	95.4
97.2	98.9	99.7	96.3	96.3

31

1.	2.	3.	4.	5.
94.6	94.6	96.8	95.0	94.2
93.2	95.0	96.3	94.2	93.7
93.7	95.0	95.4	94.6	93.7
95.0	95.4	95.4	92.4	94.2
95.0	95.9	94.6	93.7	94.6
95.4	96.3	95.4	93.2	93.7

26

1.	2.	3.	4.	5.
95.9	97.2	100.6	95.0	95.4
96.3	96.8	100.1	95.4	96.3
97.2	98.0	100.6	95.4	95.4
97.2	97.6	100.6	95.4	96.3
97.2	97.2	100.1	95.0	96.3
96.8	96.3	98.4	95.0	95.4

49

1.	2.	3.	4.	5.
93.7	93.7	94.6	93.7	93.2
95.0	95.0	93.7	94.6	94.2
95.0	95.0	94.2	95.4	93.7
95.0	94.6	92.8	94.6	93.7
93.7	94.2	92.0	95.0	93.2
94.6	94.6	92.0	95.0	94.6

70

1.	2.	3.	4.	5.
95.9	98.0	97.2	95.0	96.3
95.9	95.4	93.2	93.7	95.4
96.8	96.8	94.6	94.6	97.2
95.9	96.3	96.3	94.2	95.4
95.9	95.9	95.9	95.9	94.6
95.9	95.9	94.6	95.0	95.9

50

1.	2.	3.	4.	5.
92.4	95.0	92.8	93.2	90.7
92.4	93.7	93.7	92.8	92.8
92.8	95.0	93.2	92.4	91.6
92.4	93.7	92.8	92.4	90.7
92.4	93.2	92.8	93.7	91.3
92.4	94.2	92.8	92.4	91.6

69

1.	2.	3.	4.	5.
94.6	93.2	92.8	93.7	95.0
93.2	94.6	94.2	93.7	96.8
93.2	95.0	94.6	93.7	95.9
94.6	97.2	94.6	93.2	96.3
94.2	97.2	95.9	94.2	95.0
94.6	96.8	95.0	94.2	96.3

69

1.	2.	3.	4.	5.
94.6	95.9	93.7	92.8	93.7
96.3	95.4	94.6	93.2	92.8
95.4	94.2	94.2	92.4	94.2
95.4	94.2	94.2	92.8	94.6
95.0	95.0	93.7	93.2	95.0
95.4	95.0	94.2	93.2	95.4

58

1.	2.	3.	4.	5.
96.3	98.0	100.6	93.2	95.4
96.3	97.6	100.1	93.7	95.4
96.3	98.0	100.1	93.7	95.4
95.9	97.6	100.6	93.2	95.9
95.4	95.9	97.2	93.7	95.4
95.0	95.4	95.9	94.6	95.4

70

1.	2.	3.	4.	5.
9.54	9.59	95.4	92.4	95.0
9.59	9.59	95.0	90.2	95.0
9.54	95.0	94.6	92.4	94.2
9.59	95.9	95.4	92.0	94.6
9.59	95.4	94.2	91.6	95.0
9.54	95.9	95.4	91.6	95.9

55

1.	2.	3.	4.	5.
94.2	95.9	96.3	93.7	95.9
94.6	95.9	97.6	94.2	95.9
95.0	96.8	98.9	94.2	95.9
95.0	97.2	98.4	94.2	95.9
94.6	96.8	99.3	93.7	96.3
94.2	96.8	98.4	93.7	96.3

APPENDIX I (CONT.)

5th April.

<u>A.M.</u>			<u>P.M.</u>			<u>P.M.</u>		
<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>	<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>	<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>
25	94.8 95.0 95.9 95.0 95.0 95.4	96.8 95.9 96.3 96.3 95.9 95.4	25	95.9 95.9 95.9 95.9 94.6 95.4	95.4 95.4 95.0 95.9 94.6 95.9	32	87.6 87.2 88.4 87.6 88.9 89.4	88.4 88.9 90.7 90.2 90.7 90.7
48	93.2 93.7 93.2 93.7 93.7 92.8	95.0 95.0 95.0 95.4 95.0 95.9	49	91.6 92.4 92.4 93.2 92.8 91.6	89.8 90.2 90.2 90.1 89.8 91.3	58	90.7 91.3 91.3 90.7 91.3 90.7	92.0 91.3 89.8 89.8 90.2 90.7
90	93.7 95.0 93.7 93.7 94.2 93.2	95.4 95.0 94.2 94.2 94.2 92.4	90	91.6 89.8 90.7 92.4 92.4 92.4	90.2 88.9 89.4 89.8 90.7 91.6	31	90.7 90.7 89.4 89.4 90.2 90.2	90.3 91.3 91.6 91.6 91.3 90.7
70	93.2 93.2 92.8 93.2 92.8 93.2	92.4 92.8 93.2 92.8 92.4 92.4	70	89.8 89.4 88.0 88.4 88.0 87.6	86.4 85.4 84.6 84.6 84.1 82.8	55	88.4 90.7 91.3 92.8 92.4 92.4	92.8 92.8 92.8 92.8 92.4 92.0
26	95.0 95.1 94.2 94.2 92.4 92.0	95.0 95.0 94.2 94.2 95.4 94.6	26	93.7 92.8 93.7 94.6 95.0 93.2	92.8 93.2 92.8 94.2 93.2 92.4			
50	93.7 93.7 92.4 93.2 94.2 93.7	94.6 94.6 94.2 95.0 94.6 94.6	50	90.7 92.0 92.8 92.8 92.8 93.2	91.3 92.0 92.4 93.2 92.8 93.2			
89	94.6 95.0 94.6 95.4 95.9 95.0	94.6 95.0 95.0 95.9 95.9 95.4	89	88.0 87.6 89.4 90.7 91.6 89.8	82.4 83.2 83.2 84.6 83.2 82.4			
69	94.2 94.2 94.6 94.6 95.0 94.6	94.6 95.0 95.0 94.6 94.6 95.0	69	87.2 86.8 86.4 86.4 85.4 85.4	84.6 84.1 84.6 84.6 83.7 83.7			

13th April. P.M.

APPENDIX I (CONTD.)

POSITIONS.

<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>	<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>
55	96.8 95.9 96.8	98.0 98.0 97.6	58	94.6 95.0 94.6	95.0 95.4 95.0
58	97.6 98.4 97.6	99.7 100.1 98.0	55	94.2 94.6 94.6	94.6 94.2 94.2
25	97.6 99.3 99.3	98.0 98.9 98.9	26	95.0 95.0 95.0	95.0 95.0 95.0
26	95.4 95.4 96.3	98.4 97.6 97.6	25	95.9 96.3 96.3	98.4 99.3 99.3
89	98.4 98.0 98.0	99.3 99.3 99.3	89	96.8 96.3 97.2	96.3 96.8 96.3
90	96.3 96.8 96.3	98.9 98.9 98.9	90	95.9 96.3 96.8	95.9 95.4 95.4
70	97.6 98.0 98.4	96.8 97.2 96.8	70	95.9 96.3 96.8	94.6 94.6 94.6
69	99.7 99.3 99.7	98.4 98.4 99.3	69	95.9 96.3 95.9	95.4 95.4 95.0
31	98.0 97.6 96.8	97.6 97.2 97.2	32	93.2 93.7 93.7	92.4 92.8 92.8
32	96.3 96.3 96.8	97.2 97.2 96.3	31	95.4 95.9 95.9	95.0 95.0 95.4
49	97.6 97.2 96.8	97.6 97.6 97.6	49	95.0 95.0 95.0	94.6 94.6 94.6
50	97.2 96.3 96.8	94.6 95.0 95.9	50	95.4 95.4 95.4	93.7 94.6 94.2

APPENDIX I (CONTD.)

POSITIONS.

<u>14th April.</u>	<u>A. M.</u>		<u>P. M.</u>			<u>P. M.</u>		
<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>	<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>	<u>Twin No.</u>	<u>Thurl.</u>	<u>Hip.</u>
58	94.2 94.2 94.2	94.2 94.6 94.2	58	96.3 96.3 99.4	96.8 96.3 95.9	58	94.6 95.0 95.0	95.0 95.0 95.0
55	94.6 95.0 95.0	94.2 94.2 93.7	55	94.6 95.0 95.0	95.4 95.0 95.4	55	94.2 95.4 94.6	93.7 93.7 93.2
25	95.0 94.6 95.0	95.0 95.0 95.0	26	95.4 95.9 95.0	96.3 96.3 96.3	26	95.0 94.6 95.0	95.4 95.0 95.0
26	94.6 94.2 94.6	95.0 95.0 94.6	25	96.8 96.8 96.8	95.4 96.3 95.4	25	95.4 94.6 95.9	94.6 94.6 95.0
90	94.2 94.2 94.2	94.6 95.4 95.0	90	96.3 96.8 96.3	96.8 96.3 95.9	90	95.4 95.9 95.9	94.6 95.0 95.4
89	94.6 94.2 94.2	94.2 94.6 93.7	89	96.3 96.8 96.8	95.9 95.9 95.9	89	96.3 96.8 96.8	95.9 95.4 96.3
70	93.7 93.7 94.2	93.2 92.8 93.2	70	95.0 95.0 95.4	94.2 93.7 94.6	70	93.7 94.2 94.2	93.2 93.2 93.2
69	93.2 93.7 94.6	93.7 94.6 93.7	69	94.2 95.0 95.4	95.0 95.4 95.0	69	95.0 94.6 94.6	94.6 94.2 94.6
32	93.7 93.2 93.2	95.4 95.0 95.0	32	94.2 94.6 94.6	94.6 95.0 95.4	32	95.0 95.0 95.0	95.0 95.4 95.4
31	93.7 94.6 94.6	96.3 96.8 96.3	31	96.8 96.3 97.2	95.0 95.4 95.4	31	96.3 95.9 95.4	96.8 96.8 96.8
49	93.2 93.2 92.8	93.2 93.2 93.2	49	95.0 94.6 95.4	95.4 95.4 96.3	49	95.0 95.4 95.4	95.4 95.4 95.0
50	94.2 94.6 94.6	94.6 94.6 93.7	50	95.0 95.4 95.4	94.6 95.0 95.0	50	95.9 95.4 95.9	94.2 94.2 94.6

TABLE 4/.

APPENDIX II

(a) SKIN TEMPERATURES °F

SETS OF DAYS

		Twin No.											
		25	26	55	58	69	70	89	90	31	32	49	50
23rd April	a.m.	94.6	93.7	94.2	93.7	92.8	92.8	94.2	93.7	95.0	93.7	93.7	94.2
		94.6	92.8	94.2	93.2	93.2	92.4	94.2	93.7	94.6	93.2	94.6	94.2
		94.6	92.8	93.7	93.2	93.2	92.8	94.2	93.7	94.6	93.7	94.2	94.2
	a.m.	96.3	94.6	95.0	95.0	96.3	93.2	96.3	96.8	97.2	96.8	95.9	96.3
		96.3	95.0	94.6	95.4	96.3	92.8	95.9	96.8	97.2	95.9	95.9	95.9
		95.9	94.6	94.6	95.0	96.3	93.7	95.9	96.8	97.2	96.3	95.9	95.9
	p.m.	96.8	96.8	94.8	94.6	95.4	95.9	95.4	95.9	97.6	96.3	95.4	95.0
		97.2	96.3	96.3	94.6	96.3	95.9	95.4	95.4	97.2	96.3	95.4	95.0
		96.8	96.8	96.3	94.6	95.4	96.3	95.4	95.9	97.2	96.8	95.4	95.4
	p.m.	96.8	96.3	96.3	95.4	95.4	94.2	95.0	95.4	95.4	95.4	95.4	95.0
		96.3	95.9	95.4	95.0	95.9	94.6	95.0	95.4	96.3	95.4	95.4	95.4
		96.3	95.4	96.3	94.6	95.9	94.2	95.0	95.4	95.9	95.4	95.4	95.0
27th April	a.m.	94.6	94.6	93.7	93.2	95.0	95.4	93.2	95.0	95.4	95.9	92.4	93.2
		95.0	95.0	93.7	92.8	95.4	96.3	92.8	95.0	96.3	95.4	92.8	93.7
		95.4	94.6	93.7	93.2	95.4	96.3	93.2	95.4	96.3	95.4	92.4	93.7
	a.m.	98.4	95.9	95.9	96.8	96.3	99.7	97.6	97.2	99.3	94.6	95.4	95.4
		97.6	95.9	96.3	96.8	95.9	99.3	98.0	97.2	98.4	94.6	95.4	95.4
		97.6	95.9	96.3	95.0	95.9	98.9	98.0	97.2	98.9	94.6	95.4	94.6
	p.m.	95.9	95.4	95.0	94.6	99.3	96.8	98.4	98.0	98.9	98.0	100.1	99.7
		95.0	95.9	96.3	95.0	98.4	97.2	98.0	98.4	99.3	98.0	100.1	99.3
		94.6	95.4	95.4	95.4	98.0	96.8	96.8	98.4	98.9	98.0	100.1	98.4
	p.m.	97.2	95.9	96.8	96.8	94.6	94.2	95.0	95.4	95.4	95.0	96.3	96.3
		96.8	96.8	95.9	96.8	94.6	94.2	94.6	96.8	96.3	94.6	96.3	96.8
		96.8	95.9	95.9	96.3	95.0	94.6	95.0	95.9	95.9	94.6	95.9	96.8
4th May	a.m.	94.2	92.0	92.4	92.0	92.8	90.7	93.2	93.2	92.0	91.3	92.4	94.2
		94.2	92.4	92.8	92.4	92.8	90.7	93.7	93.2	92.0	91.6	92.8	93.7
		94.2	91.6	92.4	92.4	92.8	90.7	93.2	93.2	92.4	91.6	93.2	94.2
	a.m.	93.7	93.2	93.2	92.0	92.0	93.2	93.2	91.3	92.4	92.0	92.8	93.2
		94.2	92.8	92.8	92.0	92.0	93.2	93.7	91.6	92.0	92.0	92.8	93.2
		94.6	92.8	92.8	92.4	91.3	92.8	93.2	91.6	93.7	92.0	92.8	93.2
	p.m.	94.6	94.6	94.2	93.7	95.0	94.2	94.6	95.0	94.6	93.7	95.0	96.3
		94.6	94.6	94.2	94.6	95.0	94.2	94.6	95.0	94.6	94.2	95.0	96.3
		94.6	94.6	94.2	94.2	95.0	94.2	95.0	95.0	94.6	94.2	95.0	96.3
	p.m.	95.9	93.7	94.2	96.8	92.8	92.8	93.7	95.0	94.2	95.0	96.3	96.3
		95.9	94.2	93.7	96.8	92.4	93.2	93.7	95.4	94.2	95.0	95.4	95.9
		95.9	94.6	93.7	96.8	92.8	92.8	93.7	95.0	94.6	95.0	95.4	96.8

APPENDIX II (CONTD.)

SKIN TEMPERATURES (CONTD.)

		Twin No.											
		25	26	55	58	69	70	89	90	31	32	49	50
17th May	p.m.	91.3	92.0	92.0	92.4	93.2	93.7	93.7	94.2	94.6	95.0	93.7	94.2
		91.3	92.4	92.0	92.8	93.2	93.7	94.2	94.6	95.0	94.2	93.7	94.2
		91.3	92.4	92.0	92.8	92.0	93.2	93.7	94.6	95.0	94.2	93.2	94.6
	p.m.	95.0	95.0	94.6	94.2	94.6	93.7	95.0	94.6	95.0	95.0	94.2	95.0
		95.0	95.4	93.7	94.6	94.6	93.7	95.0	95.0	95.0	95.0	94.2	94.2
		95.0	95.4	94.2	94.6	94.6	94.2	95.4	95.0	95.0	95.0	93.7	94.2
	p.m.	93.7	94.2	94.2	93.2	93.7	92.4	92.8	94.6	94.2	94.6	91.6	94.2
		93.7	94.6	93.7	93.2	93.2	92.4	92.8	94.2	94.2	94.2	92.0	93.7
		93.7	94.6	94.2	93.2	93.2	92.4	93.2	94.2	94.2	94.2	92.0	94.2
18th May	a.m.	92.4	92.0	93.2	92.8	93.7	93.7	93.2	92.8	93.2	93.7	93.7	92.8
		92.4	92.0	92.8	92.8	94.2	92.8	94.2	93.2	94.2	94.2	93.7	92.8
		92.4	92.0	93.7	92.4	93.7	92.8	94.2	93.2	94.2	93.7	93.7	92.8
	a.m.	91.6	92.8	92.8	92.4	95.0	93.7	96.3	93.7	95.9	95.4	95.0	94.2
		91.6	92.8	92.4	92.0	95.0	93.7	96.3	94.6	96.3	95.0	95.4	94.6
		92.0	92.4	92.4	92.4	95.4	93.7	95.9	93.7	95.9	95.0	95.4	94.2
	p.m.	95.4	95.4	95.0	94.6	95.4	93.2	95.0	94.6	95.0	95.0	95.9	94.6
		95.4	95.9	95.4	94.2	95.0	93.2	95.0	94.6	95.0	94.6	95.4	94.2
		94.6	95.9	95.4	94.2	94.6	93.2	94.6	94.6	94.6	94.6	95.9	94.6
	p.m.	92.8	93.2	94.2	94.6	92.8	93.7	94.6	94.2	94.2	94.6	96.8	95.0
		93.2	93.2	93.7	94.6	92.8	93.7	95.4	94.2	93.2	94.2	96.3	95.0
		92.8	93.2	93.7	94.6	92.4	94.6	95.9	94.2	94.2	94.6	96.3	94.6
19th May	a.m.	91.3	93.7	93.8	91.6	92.8	92.0	93.2	92.4	93.2	94.2	94.2	93.2
		91.3	93.2	98.9	91.3	92.8	92.8	93.2	92.4	93.2	94.2	94.2	93.2
		90.7	92.8	99.4	91.3	92.4	92.8	93.7	92.8	93.2	93.7	94.2	94.2
	a.m.	93.2	95.4	93.7	93.2	94.6	93.2	94.6	94.2	93.7	95.4	93.2	95.0
		93.2	95.4	92.8	93.7	94.6	94.2	94.2	94.2	93.2	95.0	93.2	95.0
		93.2	95.4	93.7	92.8	93.7	94.2	94.6	94.2	93.2	95.0	93.7	95.0
	p.m.	95.4	95.4	93.7	93.2	94.6	93.2	94.6	94.2	93.7	95.4	93.2	95.0
		95.0	95.4	92.8	93.7	94.6	94.2	94.2	94.2	93.2	95.0	93.2	95.0
		95.4	95.4	93.7	92.8	93.7	94.2	94.6	94.2	93.2	95.0	93.7	95.0
	p.m.	92.4	93.7	92.4	92.8	92.8	94.2	94.6	95.0	93.7	95.4	93.2	95.0
		92.8	93.7	92.8	93.2	93.7	94.2	94.2	95.0	94.2	94.6	93.7	94.2
		93.2	93.2	92.4	92.4	93.7	94.2	95.0	95.0	93.2	95.4	93.7	94.6

APPENDIX II (CONTD.)

SKIN TEMPERATURES (CONTD.)

		Twin No.											
		25	26	55	58	69	70	89	90	31	32	49	50
12th June	a.m.	92.8	92.4	81.9	89.4	91.3	88.0	91.6	89.8	89.8	88.9	92.8	92.4
		92.4	92.8	81.9	89.8	91.6	88.9	92.0	90.2	90.2	88.4	93.2	92.4
		92.8	92.8	82.4	89.4	92.0	88.9	91.6	91.3	90.2	88.9	93.7	91.6
	a.m.	93.7	94.2	92.4	91.6	91.6	93.7	92.4	92.8	92.0	92.8	89.8	92.4
		93.2	93.7	91.6	92.0	91.6	93.2	92.4	92.8	92.8	92.4	90.2	92.4
		93.2	94.2	92.4	92.0	91.6	93.2	92.4	92.8	92.4	92.8	90.2	92.8
	p.m.	94.2	95.4	92.4	93.7	94.2	91.6	94.2	95.0	93.2	95.0	95.0	95.4
		95.0	95.4	93.2	93.2	94.6	92.4	94.6	95.9	94.2	94.6	94.6	95.0
		94.6	96.3	92.8	93.7	95.4	92.4	94.2	95.9	93.7	95.0	95.0	96.3
	p.m.	95.0	95.0	94.6	95.4	95.4	94.2	92.8	95.4	95.9	94.6	95.9	97.6
		94.6	96.3	95.0	95.4	95.9	93.7	92.8	95.9	95.4	94.2	95.9	98.0
		94.6	96.3	95.4	95.4	96.3	94.2	93.2	95.4	95.4	95.0	95.9	97.6
13th June	p.m.	94.2	95.9	89.8	92.4	93.7	91.6	95.0	94.6	95.0	89.8	95.9	96.8
		94.2	95.9	90.2	93.2	93.7	92.4	95.4	95.0	95.9	89.8	95.4	96.3
		95.0	96.3	90.2	93.2	94.6	90.7	94.6	95.4	95.9	90.2	95.4	96.3
	p.m.	94.6	93.2	94.2	94.2	95.9	92.4	94.6	94.2	94.6	95.4	95.0	96.3
		94.6	95.0	94.2	93.7	96.3	93.2	94.6	93.7	94.6	94.6	94.6	96.3
		95.0	94.6	93.2	92.8	96.3	92.8	95.0	94.6	94.6	94.6	94.2	95.9
14th June	a.m.	87.2	91.6	89.4	89.8	89.8	85.9	88.4	89.4	93.7	88.9	88.9	90.7
		87.2	91.3	88.9	90.2	89.4	85.9	87.6	88.9	93.7	88.4	88.9	90.7
		87.2	91.6	88.9	90.2	89.4	86.4	87.6	88.9	93.7	88.0	88.9	89.8
	a.m.	79.7	88.4	85.4	78.7	88.0	82.8	90.2	90.2	88.9	89.4	90.7	91.3
		79.2	88.4	85.9	79.7	88.0	82.8	90.2	89.8	89.4	89.4	90.7	90.7
		79.2	88.9	85.0	79.7	87.6	83.2	90.7	89.8	88.9	88.9	91.3	90.7
	p.m.	92.4	92.4	93.2	93.2	92.4	91.6	93.2	92.8	92.0	92.8	91.3	92.4
		92.4	92.8	92.4	92.8	92.4	90.7	92.8	92.8	92.8	93.2	90.7	92.4
		92.8	92.8	93.2	91.7	92.4	91.6	93.2	92.4	92.8	92.8	90.7	92.4
	p.m.	92.8	92.4	92.8	92.8	92.4	88.4	93.7	92.0	90.2	85.0	92.4	95.0
		92.8	92.4	93.7	93.7	92.4	88.9	94.2	91.6	89.8	85.4	92.4	95.0
		93.2	92.4	92.8	92.8	92.0	88.0	93.2	92.4	89.8	85.9	92.0	95.0

APPENDIX II

(b) BODY TEMPERATURE °F

DETAILS OF DAYS
(SETS)

Twin No.

	25	26	55	58	69	70	89	90	31	32	49	50
13th April.	102.0 101.8	102.2 102.0	102.2 102.2	102.4 102.4	101.8 102.1	101.9 102.3	101.9 101.7	102.5 102.4	102.2 101.8	101.8 102.0	102.0 102.0	102.1 102.0
14th April.	101.2 101.8 101.6	101.5 101.6 101.8	101.6 101.7 101.7	101.8 102.0 101.2	102.1 102.1 102.1	101.7 101.7 101.9	101.3 101.3 101.6	101.4 101.4 101.9	101.2 101.2 101.8	101.1 101.1 102.0	101.4 101.4 101.9	101.2 101.2 101.7
23rd April.	(101.5 a.m. {101.8 102.1 p.m. {102.0	101.6 101.7 102.1 102.0	102.0 101.8 102.5 102.3	102.3 102.0 102.3 102.7	102.1 102.1 102.3 102.5	102.0 101.7 102.3 102.0	101.7 101.3 101.9 101.8	101.6 101.7 102.1 101.8	101.7 101.8 102.4 102.4	101.4 101.4 102.0 102.0	101.4 101.3 101.9 101.9	101.3 101.3 101.7 101.7
27th April.	(101.2 a.m. {101.6 101.7 p.m. {101.7	101.3 101.5 102.1 102.1	101.8 101.6 102.3 102.1	101.6 101.5 102.2 102.0	102.1 101.2 102.8 102.2	101.6 101.7 102.1 101.7	101.1 101.6 101.8 101.7	101.1 101.6 101.9 101.9	101.0 101.1 101.6 101.6	101.3 101.2 101.9 101.8	101.3 101.4 101.9 102.0	101.0 101.1 101.8 101.6
4th May.	(101.4 a.m. {101.5 102.0 p.m. {101.9	101.3 101.7 102.4 102.0	101.4 101.7 102.2 102.4	101.3 101.5 102.0 102.1	101.6 101.7 102.1 102.2	101.6 101.7 102.1 102.1	101.5 101.5 102.1 102.1	102.0 101.7 102.5 102.2	101.3 101.2 101.5 101.9	101.6 101.4 101.8 102.2	101.6 101.2 101.7 102.2	101.5 101.3 101.7 101.9
17th May.	102.4 102.0 102.0	102.4 102.0 102.0	102.2 102.1 102.1	101.9 101.9 101.8	102.0 102.0 102.0	102.2 101.8 101.9	102.0 102.0 101.8	102.4 101.9 101.9	101.8 101.8 101.7	101.4 102.0 102.1	101.7 102.0 102.0	102.0 101.7 101.9
18th May.	(101.4 a.m. {101.4 102.1 p.m. {102.0	101.2 101.6 102.0 101.7	101.8 102.2 102.6 102.5	101.8 101.6 102.2 102.0	101.9 102.1 102.1 102.6	101.6 101.7 102.0 102.0	101.3 101.5 101.6 101.4	101.4 101.7 102.1 101.8	101.4 101.6 101.5 101.6	101.4 101.8 102.0 102.0	101.2 101.4 102.0 102.2	101.0 101.1 101.6 102.0
19th May.	(101.3 a.m. {101.5 102.0 p.m. {101.8	101.2 101.6 102.0 101.8	102.0 102.0 102.4 102.6	101.6 101.6 102.0 101.9	101.6 101.6 102.1 102.1	101.4 101.5 102.1 102.0	101.3 101.1 101.9 101.6	101.5 101.4 101.9 101.4	101.0 101.5 101.7 101.8	101.6 101.7 102.2 102.3	101.1 101.5 101.8 101.9	101.0 101.0 101.3 101.4
12th June.	(101.4 a.m. {101.5 101.9 p.m. {101.6	101.2 101.5 102.1 102.1	101.5 101.8 102.3 102.0	102.1 102.1 102.5 102.5	102.4 102.7 102.5 102.8	102.0 102.1 102.7 102.5	101.5 101.5 101.8 101.9	101.3 101.9 102.4 102.3	101.0 101.6 101.7 101.9	101.1 102.0 102.0 102.4	101.6 101.4 102.2 102.1	101.5 101.5 102.1 102.6
13th June.	(100.8 a.m. {100.7 101.6 p.m. {101.8	101.1 101.5 101.6 101.9	101.6 101.7 102.0 102.0	101.7 101.5 102.0 101.8	101.5 101.9 102.3 102.5	101.1 101.6 101.6 101.9	101.1 101.6 101.7 101.5	101.4 101.8 101.9 101.8	100.6 100.7 101.5 101.6	100.6 101.2 101.4 101.7	101.4 101.3 102.3 101.4	101.1 101.2 102.6 101.6
14th June.	(101.0 a.m. {101.4 101.6 p.m. {101.1	101.4 101.1 101.3 101.4	101.6 101.7 102.2 102.6	101.3 101.9 102.3 102.1	101.1 101.7 102.4 102.6	101.0 101.4 102.3 102.4	101.1 101.4 102.0 101.9	101.2 101.6 102.1 101.8	101.2 101.0 101.1 101.8	101.2 101.0 101.7 101.9	101.4 101.5 101.7 100.7	101.0 101.5 101.6 101.7

APPENDIX II (CONTD.)
BODY TEMPERATURE (CONTD.)

		<u>Twin No.</u>											
		25	26	55	58	69	70	89	90	31	32	49	50
26th June.	(	101.3	101.6	102.0	102.0	102.3	101.7	101.7	101.8	100.9	101.0	102.1	102.3
a.m.	{	101.0	101.8	102.1	101.9	102.5	101.8	102.0	101.8	101.0	101.4	102.3	102.4
	{	101.0	101.8	102.5	102.4	102.5	102.0	102.0	102.4	101.3	101.7	102.7	103.0
p.m.	{	102.0	102.0	102.9	102.6	103.2	102.2	102.3	102.6	101.7	101.8	103.0	102.8
27th June.	(	101.8	102.4	102.3	102.0	102.5	101.9	101.7	102.1	101.0	101.4	102.2	102.7
a.m.	{	101.8	102.3	102.2	102.4	102.5	101.8	101.8	102.0	101.3	101.6	102.3	102.0
	{	101.6	102.0	102.4	102.3	102.4	102.0	101.8	101.7	101.2	101.6	102.4	102.6
p.m.	{	101.3	102.0	102.6	102.4	102.8	101.9	101.8	102.0	101.4	101.5	103.2	102.6
28th June.	(	100.8	101.4	101.6	101.7	101.8	101.8	101.5	101.9	100.4	101.1	102.1	101.2
a.m.	{	100.8	101.6	101.3	101.6	101.5	101.8	101.4	101.9	100.8	101.5	102.1	101.4
	{	101.6	101.8	102.0	101.8	101.9	101.9	101.7	101.7	101.8	101.6	102.3	100.7
p.m.	{	101.8	102.3	102.6	102.4	102.0	102.0	101.9	102.1	101.6	101.7	102.5	101.0

(c) RESPIRATION RATES/MINUTE.

DETAILS OF DAYS. (SETS)														
Twin No.														
	25	26	55	58	69	70	89	90	31	32	49	50		
13th April.	38	46	32	34	38	32	46	40	36	30	42	40		
	38	34	22	24	36	34	38	32	26	30	40	30		
14th April.	38	46	44	44	48	40	50	38	34	28	38	40		
	38	44	52	40	44	46	44	38	32	32	42	40		
	32	36	34	34	34	40	40	38	36	34	44	44		
23rd April.	(40	42	52	50	40	44	56	48	36	32	42	42		
a.m.	{36	38	54	56	40	42	56	60	44	40	42	42		
	{42	44	58	48	36	42	48	54	40	46	50	40		
p.m.	{32	38	60	50	32	36	60	50	30	34	44	38		
27th April.	(32	34	42	43	33	35	53	52	45	35	37	36		
a.m.	{46	45	57	52	37	43	55	56	37	35	37	41		
	{36	33	60	48	42	41	58	59	42	41	51	51		
p.m.	{31	33	42	39	38	36	40	45	33	31	40	36		
4th May.	(35	39	39	42	30	29	45	52	32	34	39	38		
a.m.	{30	35	42	37	33	35	41	45	35	32	41	40		
	{25	37	34	33	30	33	54	43	36	26	35	47		
p.m.	{36	44	51	56	32	36	58	52	41	40	37	43		
17th May.	34	34	40	42	44	35	45	40	36	40	35	37		
	36	40	37	42	32	33	44	37	33	34	37	35		
	28	34	32	38	36	34	41	37	35	34	37	37		
18th May.	(30	45	45	37	40	47	38	34	34	35	38	39		
a.m.	{31	29	52	36	43	37	49	54	43	35	43	42		
	{45	44	62	55	45	37	44	45	35	33	41	39		
p.m.	{32	35	60	53	33	31	39	41	35	34	42	42		
19th May.	(33	31	33	32	35	42	37	37	30	30	38	38		
a.m.	{34	38	45	51	38	32	42	46	36	37	41	43		
	{33	34	43	37	33	30	42	35	34	37	35	39		
p.m.	{29	33	43	38	35	30	41	35	39	34	37	41		

APPENDIX II (CONTD.)

(c) RESPIRATION RATES/MINUTE (CONTD.)

DETAILS OF DAYS

(SETS)

Twin No.

	25	26	55	58	69	70	89	90	31	32	49	50
12th June.	21 22 46 39	21 21 52 44	20 23 66 56	21 32 75 47	21 33 38 37	20 28 36 31	31 32 44 54	28 44 46 52	23 31 47 46	28 32 45 41	31 29 49 56	28 27 55 52
13th June.	a.m. { 20 19 34 p.m. { 32	18 21 35 33	18 23 39 32	18 24 57 33	19 22 33 34	19 20 25 26	20 28 45 34	21 34 41 44	19 22 36 38	18 21 26 31	24 30 58 45	23 33 60 44
14th June.	a.m. { 18 20 26 p.m. { 27	20 36 35 33	21 24 24 21	19 18 23 29	20 19 26 24	21 19 26 22	26 31 37 40	23 25 29 32	24 21 21 21	21 20 21 24	27 28 30 32	27 28 36 39
26th June.	a.m. { 23 19 27 p.m. { 19	21 23 26 23	19 21 24 18	20 21 18 23	19 22 26 19	23 22 24 21	23 26 25 21	28 31 24 20	19 21 24 22	18 20 21 26	26 30 24 27	21 28 25 26
27th June.	a.m. { 23 25 21 p.m. { 22	24 27 30 24	23 21 24 25	22 23 23 21	22 22 22 22	21 22 22 20	24 27 31 32	25 30 28 29	24 24 25 22	24 25 23 20	27 27 22 30	31 28 26 26
27th June.	a.m. { 22 31 25 p.m. { 24	28 30 22 20	26 37 23 18	27 34 22 18	30 25 27 24	39 44 23 23	39 56 25 26	41 47 28 23	22 26 26 24	26 37 28 23	35 41 32 28	38 44 28 28

(d) PULSE RATES/MINUTE

DETAILS OF DAYS

(SETS)

Twin No.

	25	26	55	58	69	70	89	90	31	32	49	50
13th April.	66 70	68 74	76 68	78 64	82 76	70 76	86 74	92 78	68 70	70 70	86 92	80 78
14th April.	64 62 64	70 68 66	70 74 74	68 78 74	74 84 82	78 78 72	76 82 76	76 74 68	70 74 86	70 70 70	92 78 74	78 80 74
23rd April.	a.m. { 68 64 68 p.m. { 66	68 64 58 66	84 76 78 78	82 82 82 78	78 78 66 70	72 66 68 68	76 76 76 80	80 76 78 78	68 60 68 64	66 66 70 72	82 78 84 74	80 72 80 74
27th April.	a.m. { 66 60 61 p.m. { 61	63 59 63 63	74 73 76 70	67 69 77 78	67 65 74 71	67 57 67 65	74 70 79 72	71 73 76 70	57 52 60 65	62 59 70 65	73 72 80 80	75 78 75 78

APPENDIX II (CONTD.)

(d) PULSE RATES/MINUTE (CONTD.)

SETS OF DAYS

		<u>Twin No.</u>											
		25	26	55	58	69	70	89	90	31	32	49	50
4th May.	a.m.	{ 59	66	71	68	66	62	70	66	57	62	79	70
		{ 60	60	65	67	63	58	66	64	57	58	72	67
		{ 63	52	73	72	67	67	69	70	67	64	77	79
	p.m.	{ 59	64	76	68	69	64	71	69	67	67	79	74
17th May.		64	66	80	70	73	68	72	68	71	70	83	80
		62	60	79	67	73	61	69	68	68	70	81	82
		65	63	81	69	72	67	74	70	64	70	82	83
18th May.		67	67	83	75	78	76	76	74	70	69	76	75
		68	65	71	72	76	70	76	73	68	67	77	80
		67	67	81	75	69	77	74	77	73	71	76	73
		67	66	77	80	76	76	76	69	69	68	78	81
19th May.	a.m.	{ 61	63	80	71	70	67	70	76	58	60	74	74
		{ 62	62	75	74	71	68	73	76	62	66	75	78
		{ 69	69	80	76	76	75	79	79	69	72	73	81
	p.m.	{ 68	68	79	79	74	72	73	76	67	72	77	82
12th June.	a.m.	{ 60	56	70	74	60	58	64	70	56	60	78	77
		{ 55	56	64	71	62	63	71	68	58	57	73	77
		{ 62	59	72	73	68	62	68	78	57	64	72	71
	p.m.	{ 61	61	63	74	63	62	66	71	58	61	74	78
13th June.	a.m.	{ 56	56	64	68	68	67	59	62	54	56	67	71
		{ 56	56	64	64	60	59	60	66	60	60	65	72
		{ 59	55	66	72	64	62	68	70	56	62	78	76
	p.m.	{ 60	58	64	66	64	62	67	68	59	66	74	74
14th June.	a.m.	{ 52	58	62	64	58	58	61	62	53	54	67	70
		{ 50	55	63	62	57	56	60	61	52	55	68	73
		{ 57	64	69	67	60	62	73	70	60	67	76	78
	p.m.	{ 52	60	70	66	68	62	64	68	57	71	75	80
26th June.	a.m.	{ 69	74	88	86	76	70	72	81	58	71	81	88
		{ 64	72	83	83	74	66	75	77	59	64	83	90
		{ 64	70	89	80	71	66	75	74	62	63	77	83
	p.m.	{ 60	68	82	75	69	72	73	77	58	68	82	82
27th June.	a.m.	{ 73	72	82	80	73	70	79	81	60	72	86	87
		{ 71	69	80	76	79	72	75	78	54	68	82	84
		{ 64	71	82	75	80	70	77	81	60	70	82	88
	p.m.	{ 61	73	83	75	78	69	72	78	55	69	81	85
28th June.		66	68	79	78	69	70	72	81	54	67	84	90
		60	65	76	74	74	72	70	79	52	70	89	92
		60	62	76	71	70	72	74	75	64	66	81	83
		61	62	73	70	69	73	73	74	53	67	81	86

APPENDIX II (CONTD.)

(e) AIR TEMPERATURES

SETS OF DAYS

Twin No.

	25	26	55	58	69	70	89	90	31	32	49	50
13th April.	64.8 60.0	63.4 60.7	62.8 60.8	64.0 60.5	63.9 58.8	63.5 59.1	63.0 59.9	64.0 59.5	62.1 58.0	62.0 58.6	61.0 57.5	60.1 56.6
14th April.	58.5 59.5 58.0	58.5 59.4 58.2	58.5 59.7 58.0	58.5 59.6 58.6	58.6 59.0 57.8	58.6 59.0 57.8	59.3 59.1 58.2	59.5 59.7 58.0	57.2 59.0 57.8	58.9 58.8 57.1	59.4 59.5 57.5	59.0 58.8 57.5
23rd April.	{60.5 a.m. {63.6 {67.0 p.m. {69.7	60.7 63.2 66.7 65.6	59.7 62.9 67.2 66.1	59.3 62.7 66.9 65.9	61.0 64.3 66.5 65.1	61.0 64.3 67.2 65.0	61.0 64.2 66.5 65.4	60.9 64.4 66.5 65.8	61.1 64.5 66.8 64.7	61.1 64.8 67.2 65.0	62.2 65.1 66.0 64.6	61.5 65.0 66.3 64.0
27th April.	{57.7 a.m. {60.5 {61.7 p.m. {64.1	58.0 61.3 61.8 63.3	57.0 60.5 62.1 62.8	57.5 61.0 62.5 63.1	59.8 62.5 65.0 62.2	59.0 62.0 64.6 62.4	59.0 62.5 64.4 64.2	58.5 62.3 63.6 64.2	60.0 61.5 66.4 62.4	60.0 61.5 64.4 62.6	60.0 61.0 65.5 63.4	60.0 61.0 64.0 62.5
4th May.	57.3 60.0 61.6 65.0	58.0 60.0 61.5 64.2	59.0 60.3 62.0 62.8	58.8 60.0 61.8 63.5	59.5 61.0 62.0 63.0	59.1 61.0 62.1 63.4	59.2 60.5 62.0 62.7	59.9 60.0 62.4 64.0	58.6 60.8 62.7 63.1	59.0 60.7 62.1 63.7	59.5 60.9 62.1 62.9	59.6 60.3 62.7 63.8
17th May.	60.2 61.5 59.0	60.4 61.1 59.0	61.4 60.7 58.8	60.9 61.0 59.0	62.2 60.2 58.2	61.8 60.2 58.0	62.3 60.3 58.4	62.0 60.7 58.8	61.2 60.2 58.2	62.0 59.9 58.0	61.8 59.3 57.7	61.3 59.9 57.8
18th May.	55.6 55.4 58.7 57.5	55.3 55.4 58.0 57.7	55.2 57.0 59.0 57.6	55.6 55.3 59.0 58.4	55.8 57.2 58.7 57.8	55.8 57.4 58.8 56.5	56.0 57.8 57.4 58.2	55.7 57.6 57.8 58.0	56.0 57.7 57.8 56.8	55.7 58.3 57.8 57.4	55.7 58.2 58.0 57.8	55.7 57.8 58.0 57.6
19th May.	51.3 53.0 54.4 54.6	51.5 53.2 54.6 54.6	51.5 53.0 54.4 54.7	51.3 53.6 54.4 54.7	52.5 53.2 54.6 54.8	52.5 53.2 54.5 54.9	52.7 53.2 54.7 54.7	52.2 53.0 54.6 54.7	53.2 53.3 54.5 54.7	53.0 53.2 54.6 55.0	53.2 53.9 54.5 54.4	53.1 53.7 54.5 54.7
12th June.	50.8 54.0 57.5 57.4	50.2 54.0 57.4 57.5	50.3 55.0 56.8 57.7	50.1 55.9 57.0 57.4	50.0 55.2 57.6 57.6	50.0 55.4 57.7 57.7	49.7 55.9 57.5 57.4	50.0 56.0 57.5 57.4	51.0 56.0 57.8 57.7	51.2 56.3 57.9 57.6	51.1 56.7 57.6 57.4	51.0 56.7 57.9 57.1
13th June.	36.0 42.1 51.2 52.2	36.9 43.0 51.2 52.8	38.0 44.2 51.5 52.5	37.5 43.8 51.3 52.0	38.4 44.1 51.5 52.3	38.9 44.5 51.5 52.5	39.8 44.9 52.0 52.0	39.0 44.9 52.0 52.0	40.0 45.0 51.6 51.7	40.5 45.3 51.3 51.3	41.0 45.4 51.3 51.7	42.0 45.5 52.5 51.7
14th June.	48.8 49.1 54.0 54.0	48.5 50.7 54.0 54.1	48.8 50.1 54.1 54.2	49.0 49.9 54.4 54.3	49.1 50.3 54.2 53.4	49.5 50.7 54.4 53.3	49.7 51.0 54.2 54.0	49.5 51.0 54.0 53.6	50.5 51.2 54.4 53.2	50.0 51.1 54.1 52.9	50.8 51.6 54.0 53.5	50.5 51.4 53.9 53.5

APPENDIX II (CONTD.)

(e) AIR TEMPERATURES (CONTD.)

SETS OF DAYS

Twin No.

	<u>25</u>	<u>26</u>	<u>55</u>	<u>58</u>	<u>69</u>	<u>70</u>	<u>89</u>	<u>90</u>	<u>31</u>	<u>32</u>	<u>49</u>	<u>50</u>
26th June.	46.3	46.0	46.6	46.7	47.3	47.5	46.8	47.0	47.6	47.7	48.0	48.0
	48.5	48.5	48.7	48.9	48.8	48.9	48.8	48.9	48.7	49.0	49.1	49.1
	49.2	49.8	49.5	49.8	49.5	48.9	49.5	49.5	49.5	49.1	49.0	49.0
	48.4	48.5	48.4	48.6	48.6	48.3	48.1	48.6	48.1	48.1	48.1	48.1
27th June.	56.0	56.2	56.0	56.0	56.0	56.0	56.4	56.2	56.2	56.2	56.1	56.3
	56.6	56.6	56.3	56.5	56.5	56.2	56.6	56.6	56.5	56.3	56.2	56.2
	57.3	57.3	57.1	57.1	57.1	57.1	57.0	57.0	57.1	57.1	57.1	57.1
	57.0	57.0	57.0	56.5	56.5	56.5	56.8	56.8	56.8	56.8	56.8	56.8
28th June.	56.5	56.5	56.5	56.5	57.1	57.1	56.0	57.1	56.5	56.8	56.8	56.5
	57.1	57.1	57.1	57.1	58.2	58.4	58.4	58.0	58.2	58.4	57.1	58.2
	56.8	56.8	56.8	56.4	56.5	56.1	56.1	56.1	56.3	56.8	56.3	56.4
	55.6	56.1	55.6	55.5	55.5	55.5	55.5	55.5	55.6	55.5	55.5	55.5

APPENDIX III (CONTD.)

(b) RESPIRATION RATE.

T I M E

Date	Twin No.	9 a.m.	10	11	12	1 p.m.	2	3	4	5	6	7	8	9	10	12	2 a.m.	4	6	7	8	9
23/24th May.	55	29	34	44	54	61	54	79	49	46	36	52	44	72	58	58	40	56	63	47	52	60
	58	30	26	40	64	60	48	78	44	45	40	53	48	64	68	68	46	62	59	60	50	58
	25	34	40	40	46	50	51	60	45	40	39	42	54	59	68	56	48	52	52	46	44	52
	26	36	36	40	46	46	50	48	44	44	40	44	50	60	50	52	40	38	50	42	48	50
	49	28	40	46	53	52	52	48	50	44	48	52	68	50	74	60	50	48	60	56	60	56
	50	28	40	44	50	51	62	60	46	46	44	52	60	76	72	68	50	60	68	56	56	56
25/26th May.	55	44	48	72	96	79	72	84	90	56	68	77	78	85	80	79	79	74	66	43	46	71
	58	44	42	74	94	56	75	68	74	58	76	72	68	78	82	82	73	76	76	44	46	70
	25	40	46	76	76	70	62	54	60	44	70	60	72	72	80	66	72	60	66	42	46	56
	26	40	44	68	60	68	61	61	84	40	68	72	80	80	96	70	84	56	72	42	44	72
	49	48	50	72	60	62	68	66	64	56	64	72	84	64	68	72	69	68	68	52	60	61
	50	48	48	72	68	66	72	70	76	56	64	78	76	72	76	70	70	61	72	56	58	60
26/27th May	55	44	61	68	76	96	102	72	78	79	66	80	74	76	72	54	70	86	94	76	60	91
	58	52	68	74	77	92	92	80	85	86	68	84	72	72	84	84	72	84	90	60	71	95
	25	52	60	66	72	78	80	80	66	72	90	72	79	66	68	59	71	72	61	60	56	72
	26	52	60	66	72	76	72	74	72	61	70	84	65	76	68	70	64	64	60	61	62	66
	49	54	66	66	74	72	74	80	60	68	70	83	74	74	70	61	64	74	61	64	64	68
	50	54	60	66	76	76	74	74	72	64	70	84	66	78	69	70	64	64	60	62	62	66
28/29th May.	55	46	66	86	66	66	66	56	72	66	50	76	88	84	84	74	48	79	72	56	60	80
	58	44	82	82	76	74	78	56	91	60	56	60	82	76	84	68	84	81	90	56	70	66
	25	40	50	56	70	66	74	74	70	53	68	84	76	60	68	70	60	64	61	50	64	61
	26	40	48	64	74	74	71	72	76	60	60	76	82	74	66	76	62	54	70	51	60	66
	49	47	60	62	66	60	65	59	68	68	60	86	90	66	60	76	66	80	70	57	68	66
	50	44	66	66	70	70	68	70	66	50	61	84	76	68	64	60	60	86	72	60	72	67

T I M E

		8 a.m.	10	12	2 p.m.	4	6	8	10	12	2 a.m.	4	6	8
1/2nd June.	55	34	48	45	50	52	42	58	80	56	72	80	74	42
	58	36	46	48	52	48	46	56	84	58	78	78	76	42
	25	32	38	44	46	46	36	60	88	52	52	70	60	36
	26	32	40	42	50	40	38	64	86	52	56	64	58	38
	49	38	48	46	56	56	52	58	62	64	66	66	56	58
	50	36	46	48	54	52	48	60	64	60	60	62	60	52
3/4th June.	55	32	36	48	40	42	40	56	40	58	52	70	44	52
	58	34	36	52	42	40	42	60	40	74	64	64	46	46
	25	40	40	44	40	52	38	52	42	48	46	70	44	40
	26	36	42	40	42	46	38	56	44	46	44	68	42	46
	49	44	36	44	52	50	44	62	60	60	64	56	70	52
	50	40	40	44	48	52	44	58	56	58	66	62	60	56
5/6th June.	55	32	32	44	32	32	32	44	70	76	70	60	36	36
	58	32	34	40	32	36	32	54	76	72	76	68	40	52
	25	34	32	36	36	32	42	50	66	52	52	56	36	48
	26	36	32	36	36	34	40	48	72	72	52	68	36	48
	49	40	40	42	48	48	56	52	66	56	56	64	54	52
	50	44	40	40	44	48	54	52	82	76	60	60	52	52

APPENDIX III (CONTD.)

(c) PULSE RATES.

		T I M E																				
Date	Twin No.	9a.m.	10	11	12	1p.m.	2	3	4	5	6	7	8	9	10	12	2a.m.	4	6	7	8	9
23/24th May.	55	80	91	91	90	88	90	92	90	92	92	96	96	97	96	90	87	84	84	85	84	84
	58	88	88	88	90	90	92	92	92	96	96	92	96	94	83	91	88	84	80	90	84	92
	25	78	81	88	82	82	82	82	80	84	92	94	92	90	90	92	94	80	84	88	78	84
	26	87	84	88	83	88	86	88	80	88	90	87	90	88	88	90	78	92	84	82	80	88
	49	96	89	96	100	96	96	94	95	98	106	105	106	105	104	104	100	82	92	94	96	96
	50	96	88	100	99	100	100	100	104	100	104	106	108	104	104	96	98	100	92	96	98	99
25/26th May.	55	96	96	96	99	95	96	95	94	99	99	100	99	95	88	88	85	86	84	92	97	85
	58	96	96	104	97	100	100	100	94	101	100	102	100	97	93	88	100	90	88	96	96	99
	25	40	46	76	76	70	62	54	60	44	70	60	72	72	80	66	72	60	66	42	46	56
	26	40	44	68	60	68	61	61	80	40	68	72	80	80	96	70	84	56	72	42	44	72
	49	90	100	100	100	101	107	102	104	112	112	100	102	99	102	100	97	92	92	100	101	94
	50	100	101	100	99	88	108	101	103	112	117	116	108	104	101	97	103	92	96	100	100	94
26/27th May.	55	96	92	94	92	96	100	92	96	96	100	94	94	96	94	96	96	91	86	92	96	96
	58	96	93	96	100	88	100	96	97	99	100	96	100	97	92	97	92	88	84	98	84	92
	25	84	83	88	88	88	88	99	96	91	98	88	88	95	88	96	84	80	76	96	91	80
	26	96	88	91	92	88	99	96	95	100	100	98	94	99	88	99	96	84	84	96	76	95
	49	104	98	101	99	101	104	98	99	99	107	100	100	97	103	100	100	96	88	100	94	90
	50	102	98	102	100	99	104	99	98	112	106	101	101	96	109	100	98	88	92	97	92	99
28/29th May.	55	92	82	90	99	96	100	100	96	104	104	96	96	102	88	90	92	84	88	92	84	80
	58	92	88	88	92	90	100	100	95	103	104	104	97	91	92	76	84	85	80	92	83	92
	25	80	74	90	84	92	92	99	101	106	97	96	88	88	86	72	79	74	76	82	74	76
	26	84	80	91	92	92	92	100	88	105	101	96	104	91	91	90	84	88	72	88	80	84
	49	84	92	100	100	96	93	101	98	116	108	100	96	99	103	101	102	90	90	84	90	92
	50	99	91	100	100	102	102	108	101	112	114	102	100	100	103	99	100	92	88	84	88	86

T I M E

		8a.m.	10	12	2p.m.	4	6	8	10	12	2a.m.	4	6	8
1/2nd June.	55	92	100	104	94	104	108	100	100	96	92	88	88	92
	58	91	100	102	94	108	106	104	96	96	94	90	86	90
	25	76	90	94	96	94	92	88	94	96	84	90	74	88
	26	88	90	96	96	96	96	100	92	96	86	84	82	92
	49	94	104	102	102	104	108	108	96	104	96	92	86	94
	50	99	104	100	104	104	106	108	100	100	96	94	88	94
3/4th June.	55	92	84	84	92	92	96	88	92	92	86	88	88	88
	58	88	84	92	96	92	96	88	92	92	86	88	88	88
	25	76	80	92	88	92	88	82	90	88	84	80	84	84
	26	88	80	88	92	92	90	80	88	84	84	84	84	84
	49	92	96	100	98	100	96	98	96	94	92	88	88	92
	50	96	96	100	102	102	100	100	98	96	92	92	88	90
5/6th June.	55	84	84	82	96	96	96	96	96	88	88	88	92	88
	58	82	80	80	88	96	98	96	96	86	88	88	91	88
	25	80	76	72	92	92	92	90	76	84	84	82	88	86
	26	84	76	72	92	92	92	88	84	88	84	80	84	84
	49	92	92	88	92	100	104	96	92	88	90	84	90	92
	50	96	92	84	100	108	108	96	94	88	88	88	92	94

APPENDIX III (CONTD.)

(d) AIR TEMPERATURES.

T I M E

<u>Date</u>	<u>9a.m.</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>1p.m.</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>12</u>	<u>2a.m.</u>	<u>4</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
23/24th May.	47.0	51.0	51.6	60.2	62.0	63.2	67.0	64.3	61.2	54.0	53.3	51.8	52.9	52.2	49.0	51.1	47.7	47.0	50.3	52.0	54.0
25/26th May.	55.0	57.8	62.1	68.0	67.7	67.0	67.0	66.8	66.8	65.3	65.3	63.5	62.4	59.1	58.6	60.8	58.6	57.2	59.8	60.0	62.0
26/27th May.	64.0	66.7	68.8	69.0	69.0	70.2	70.2	72.0	67.0	64.2	58.9	59.0	55.1	55.0	57.1	58.0	60.5	57.8	56.3	60.5	61.5
28/29th May.	53.5	60.4	63.8	65.7	67.1	70.3	70.7	70.0	65.2	61.2	57.7	56.0	56.0	57.2	56.0	57.0	55.9	51.2	58.0	56.9	59.1

T I M E

<u>Date</u>	<u>8a.m.</u>	<u>10</u>	<u>12</u>	<u>2p.m.</u>	<u>4</u>	<u>6</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>2a.m.</u>	<u>4</u>	<u>6</u>	<u>8</u>
1/2nd June.	55.6	55.2	55.6	59.0	59.0	55.6	56.0	58.0	54.6	53.0	52.8	53.0	53.4
3/4th June.	52.0	53.5	55.7	58.7	61.0	54.5	51.0	46.2	47.8	51.0	54.5	56.1	54.8
5/6th June.	52.0	55.1	56.2	57.5	56.8	53.9	52.3	52.2	51.9	52.1	52.5	53.9	55.3

TABLE 49.

APPENDIX IV

SKIN TEMPERATURES

Effect of Hair (a) Normal.
 (b) Clipped.
 (c) Shaved.

(a) NORMAL.

P O S I T I O N S										
Air T.	Date	Twin No.	1	2	3	4	5	6	7	8
61.5	12th Oct.	p.m. 58	92.0 94.2 93.2	90.7 91.6 91.6	93.2 94.2 92.8	93.2 93.2 93.7	92.4 92.8 93.7	90.2 91.6 92.0	87.2 88.0 88.0	92.0 93.2 93.2
62.3		55	88.4 88.4 87.6	93.7 94.2 92.8	95.0 95.0 95.6	79.7 75.2 74.0	66.4 67.8 69.0	61.8 61.8 61.8	92.8 92.8 92.8	89.4 89.3 89.4
61.0		21	91.3 91.3 91.3	92.4 92.4 92.4	91.6 91.6 92.0	93.7 92.0 93.2	91.6 92.0 91.6	92.0 92.0 92.1	83.2 83.2 83.2	91.6 91.6 92.0
63.5	13th Oct.	a.m. 58	91.3 91.3 91.3	89.8 89.8 89.8	91.3 91.3 91.3	90.7 90.7 90.7	91.3 91.3 91.3	90.2 90.2 90.2	90.2 90.2 89.9	91.6 91.6 91.6
60.0		55	90.2 90.7 90.7	88.4 88.4 88.4	91.3 91.3 91.3	89.8 89.8 89.8	88.0 88.0 88.9	90.2 90.2 90.2	89.4 89.4 89.4	89.8 89.8 89.8
61.5		21	89.4 89.4 89.4	90.2 90.2 90.2	90.7 90.7 90.7	91.6 91.6 91.6	90.7 90.7 90.7	91.3 91.3 91.3	88.4 88.9 88.9	92.0 92.0 91.6
64.0		p.m. 58	89.8 89.8 89.8	90.7 90.7 90.7	91.6 91.6 91.6	89.4 89.4 89.4	90.7 90.7 90.7	89.4 89.4 89.4	88.0 88.0 88.0	89.8 89.8 89.8
64.0		55	88.0 88.0 88.0	91.6 91.6 91.6	91.3 91.3 91.3	89.4 89.4 89.4	89.8 89.8 89.8	89.4 89.4 89.4	90.7 90.7 90.7	91.6 91.6 91.6
64.0		21	88.0 88.0 88.0	91.3 91.3 91.3	92.0 92.0 92.0	91.3 91.3 91.3	91.3 91.3 91.3	91.3 90.7 90.7	90.2 90.2 90.2	90.7 90.7 90.7

APPENDIX IV (CONTD.)

SKIN TEMPERATURES (CONTD.)

(b) CLIPPED.

P O S I T I O N S

<u>Air T.</u>	<u>Date</u>	<u>Twin No.</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
61.5	12th Oct.	p.m. 58	92.8 93.2 92.8	90.2 90.2 90.2	91.3 92.4 92.0	90.2 92.4 92.4	90.2 89.4 90.7	92.8 92.8 92.0	86.4 86.4 86.4	92.0 92.0 92.0
63.0		55	92.0 92.0 92.4	91.6 92.0 92.0	94.6 93.7 94.2	67.8 68.2 68.2	66.1 66.1 66.1	61.6 61.8 60.8	89.4 89.4 89.4	89.4 89.4 89.4
61.0		21	91.3 91.3 90.7	91.6 91.6 91.6	89.4 89.4 89.4	90.2 90.7 90.7	91.6 91.6 91.6	89.4 89.4 89.4	86.8 87.6 86.8	88.4 90.7 91.6
63.5	13th Oct.	a.m. 58	89.4 89.4 89.4	88.9 88.9 88.9	89.8 89.8 89.8	90.7 90.7 90.7	88.9 88.9 88.9	89.4 89.4 89.8	88.4 88.4 88.4	89.4 89.4 89.4
60.0		55	88.4 88.4 88.9	87.6 87.6 87.6	90.2 90.2 90.2	88.9 88.9 88.9	89.4 89.4 89.7	89.8 89.8 89.8	87.2 87.2 88.2	87.6 87.6 88.0
61.5		21	88.4 88.4 88.4	89.4 89.4 89.4	89.8 90.2 90.2	90.7 91.3 91.3	90.7 91.7 91.7	90.2 90.2 90.2	89.4 89.4 89.4	89.4 89.4 89.4
64.0		p.m. 58	89.8 89.8 89.8	88.9 88.9 88.9	89.8 89.8 90.2	85.4 85.4 85.4	89.8 89.8 89.8	89.4 89.4 89.4	86.4 86.8 86.8	88.0 88.4 88.4
64.0		55	88.4 88.4 88.4	88.9 88.9 89.4	89.8 89.8 89.8	88.0 88.0 88.0	88.0 88.0 88.0	87.6 87.6 87.6	88.0 88.0 88.0	89.8 89.4 89.4
64.0		21	86.4 86.4 86.4	88.0 88.0 88.0	88.9 88.9 88.4	89.8 89.8 89.8	89.4 89.4 89.4	89.8 89.8 89.8	88.9 88.9 88.9	87.2 87.2 87.6

APPENDIX IV (CONTD.)

SKIN TEMPERATURES (CONTD.)

(c) SHAVED.

P O S I T I O N S

<u>Air T.</u>	<u>Date</u>	<u>Twin No.</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
61.5	12th Oct.	p.m. 58	91.6 92.0 92.4	91.6 91.3 91.6	91.3 92.4 92.8	91.6 91.6 93.2	89.8 89.8 90.7	88.0 90.2 90.2	87.2 87.2 87.2	92.0 92.4 92.4
63.0		55	92.0 92.0 92.0	91.6 92.0 92.0	92.4 92.4 92.8	68.2 68.2 68.2	66.0 65.4 65.4	60.4 62.2 63.1	89.9 88.9 88.9	88.4 88.4 89.4
61.0		21	90.7 90.7 90.7	92.0 92.0 92.0	89.8 89.8 89.8	89.8 89.8 90.7	90.7 90.7 90.7	88.4 88.9 88.0	86.8 87.2 87.2	91.6 90.7 90.7
63.5	13th Oct.	a.m. 58	88.4 88.4 88.4	88.0 88.0 88.0	88.0 88.4 88.9	89.4 89.8 89.4	88.9 89.4 88.9	88.4 88.4 88.9	86.4 86.4 86.8	87.6 87.6 87.6
60.0		55	87.6 88.4 88.4	86.4 86.4 86.8	90.2 89.8 89.8	89.8 89.8 89.8	88.9 88.9 88.9	88.9 88.9 88.9	86.4 86.4 87.2	87.6 87.6 87.6
61.5		21	88.4 88.4 88.4	89.8 89.8 89.8	89.8 89.8 89.8	90.2 90.2 90.2	89.8 89.8 89.8	89.8 89.8 89.8	89.8 89.8 89.8	88.4 88.4 88.4
64.0		p.m. 58	88.4 88.4 88.4	87.2 87.2 87.6	89.8 89.8 89.8	88.4 88.4 88.4	89.4 89.4 89.4	88.9 88.9 89.4	87.6 88.0 88.0	87.6 87.6 88.0
64.0		55	88.0 88.0 88.0	88.9 88.9 88.9	89.8 89.8 89.8	88.0 88.0 88.4	86.4 86.4 86.4	88.0 88.0 88.4	88.0 87.6 87.6	89.4 89.4 89.4
64.0		21	88.0 88.0 88.0	89.4 89.4 89.4	87.2 87.2 87.2	88.9 88.9 88.9	89.4 89.4 89.4	88.0 88.0 88.0	88.4 88.4 88.4	88.0 87.6 88.0

TABLE 50.

APPENDIX V

POSITION EFFECT - SKIN TEMPERATURE °F (NORMAL)

Date	a.m. or p.m.	Twin No.	P O S I T I O N S																				Air T.	Body T.		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			21	22
19th Oct.	a.m.	58	94.6	94.2	93.7	94.2	94.2	89.4	84.6	84.1	91.0	93.2	94.6	94.6	93.2	94.6	94.6	93.7	94.2	94.2	80.2	91.3	92.4	93.7	70.8	100.5
		21	91.3	91.6	93.7	92.6	91.3	88.9	84.1	84.1	90.2	88.4	92.4	91.3	92.0	92.8	91.8	93.2	91.3	90.2	88.0	87.2	93.2	92.4	72.0	100.4
		55	94.2	94.2	95.0	94.6	92.8	89.8	85.4	83.7	92.0	92.0	94.2	92.4	93.2	93.2	94.2	93.7	91.3	93.7	86.4	88.0	93.7	93.7	73.0	100.6
	p.m.	58	91.3	93.2	93.2	93.7	93.7	91.3	91.6	90.2	93.7	92.4	94.2	93.2	92.4	94.6	93.7	93.7	93.7	94.2	89.8	89.8	93.7	92.0	73.0	101.4
		21	90.7	92.0	92.4	94.2	93.7	91.6	90.2	89.4	92.8	92.4	93.7	93.7	91.6	92.8	93.7	92.8	94.6	93.2	88.0	89.2	92.4	93.7	73.8	101.0
		55	91.6	92.4	93.2	93.2	93.7	91.6	88.4	85.0	91.6	92.4	92.8	92.8	92.0	92.4	92.4	94.2	90.7	90.7	86.4	89.4	93.7	92.0	74.0	100.9
20th Oct.	a.m.	58	91.3	90.7	91.6	92.4	90.7	87.2	82.8	80.2	90.7	89.8	91.6	91.6	89.8	90.7	91.6	92.0	89.8	88.4	84.6	82.4	91.6	90.2	66.5	101.0
		21	91.3	92.0	94.2	93.2	93.2	89.8	87.2	83.2	91.6	92.0	91.3	92.8	90.2	89.8	92.0	93.7	92.0	89.8	82.8	84.6	89.8	92.8	68.0	100.7
		55	89.4	90.2	89.4	89.4	89.4	86.8	83.2	83.2	88.4	88.4	89.4	89.8	88.0	89.8	90.7	92.0	88.0	88.0	85.9	86.8	89.8	92.8	70.0	101.0
	p.m.	58	92.8	94.2	94.6	94.2	94.2	90.2	89.8	85.0	92.8	93.2	96.3	91.3	95.0	93.7	94.2	94.2	92.0	91.3	86.8	85.4	91.6	93.7	73.0	101.1
		21	92.4	95.0	95.0	93.2	93.7	92.4	90.2	87.2	92.4	94.2	94.2	93.7	94.2	93.7	93.2	93.2	92.0	91.6	88.9	84.1	92.0	94.6	75.5	101.4
		55	93.7	93.7	95.0	92.8	95.0	93.7	90.2	87.2	93.7	94.2	94.2	93.2	92.4	93.7	93.2	93.2	92.0	91.6	88.9	88.0	88.9	93.2	73.0	101.7
23rd Nov.	a.m.	58	89.8	88.9	89.4	88.9	88.9	89.4	82.4	81.0	88.4	85.9	84.6	85.0	86.4	84.6	85.9	85.0	85.0	87.6	87.4	83.7	86.4	87.6	64.0	101.5
		21	89.8	89.4	91.3	90.7	93.2	90.2	86.4	82.8	86.8	88.0	85.0	87.6	82.4	85.0	86.8	88.4	89.8	88.0	83.2	82.4	84.6	88.0	64.0	101.5
		55	85.4	88.4	89.4	89.8	91.6	84.1	83.2	81.4	88.4	88.0	87.6	86.8	85.9	84.6	85.9	86.8	86.8	86.4	82.4	80.6	86.8	88.9	61.5	101.1
	p.m.	58	87.6	88.4	88.9	89.4	91.3	89.4	82.4	80.2	91.3	89.4	88.0	86.4	87.2	88.0	88.0	88.4	88.4	86.8	81.9	81.9	85.4	88.9	64.0	100.2
		21	86.8	90.2	91.6	89.8	90.2	89.8	84.6	78.0	83.2	86.8	86.8	86.4	84.6	82.8	83.2	87.6	86.4	85.4	77.4	74.8	86.4	85.0	65.5	100.4
		55	86.8	89.4	92.0	90.7	89.8	85.0	85.0	87.0	86.8	87.2	88.9	87.2	85.9	83.2	87.6	89.8	88.0	88.0	79.7	81.9	88.0	88.0	65.0	100.4
24th Nov.	a.m.	58	87.2	88.4	90.7	90.2	90.2	87.2	80.6	77.4	85.9	87.2	86.8	86.4	86.8	88.9	88.9	87.2	85.9	86.8	87.0	79.2	88.0	88.9	61.2	101.4
		21	85.9	85.9	86.8	85.4	85.9	83.7	72.2	78.8	79.2	86.4	88.9	85.4	85.4	83.2	84.1	84.1	85.4	81.9	79.7	75.4	84.6	86.8	61.9	101.1
		55	88.0	88.9	93.2	90.7	93.7	88.9	88.0	82.4	89.8	90.7	90.2	86.8	89.8	90.7	90.7	92.4	90.7	89.4	86.8	83.7	90.7	92.4	62.6	101.2
	p.m.	58	88.4	90.2	90.2	88.4	89.4	89.8	77.2	73.5	87.2	86.4	86.8	85.8	85.9	85.9	88.4	88.4	88.0	89.4	79.7	75.7	87.6	88.0	65.0	101.4
		21	84.1	84.1	88.9	88.0	86.8	82.4	79.2	78.4	84.1	85.9	88.9	85.4	86.4	84.1	85.9	86.8	87.2	83.7	74.2	76.0	81.9	83.7	65.2	101.2
		55	88.0	88.0	88.4	88.0	87.6	85.4	78.7	76.6	87.6	87.2	87.2	85.0	86.8	86.8	89.4	89.4	85.0	85.4	83.2	79.2	88.4	89.4	66.0	101.0
6th Dec.	a.m.	58	88.9	89.8	91.6	91.6	90.7	88.0	85.9	82.4	88.0	87.6	88.4	85.0	89.8	88.4	87.6	89.8	87.6	86.4	83.2	81.0	88.0	88.0	66.5	101.0
		21	87.6	87.6	86.4	87.2	87.2	82.4	85.9	81.0	85.0	86.4	85.0	85.4	86.4	85.9	85.7	89.4	88.4	86.8	79.7	81.7	87.2	90.2	66.5	100.5
		55	90.7	88.4	90.7	90.7	90.7	86.8	86.4	88.0	86.8	86.8	91.6	86.4	89.8	88.4	91.3	90.2	89.8	87.2	84.1	82.6	91.3	91.6	66.5	101.4
	p.m.	58	85.9	87.2	88.0	86.4	85.9	74.7	75.4	75.0	87.2	86.4	86.8	86.8	87.2	86.8	87.2	88.4	85.4	85.4	81.0	80.6	87.6	87.2	66.9	100.9
		21	82.4	87.2	87.2	87.2	87.2	82.8	85.9	81.0	88.9	88.0	86.8	85.4	88.4	86.8	85.9	85.4	84.6	83.2	80.6	82.8	85.0	85.9	67.0	100.4
		55	90.7	88.4	90.7	90.7	90.7	86.8	86.4	81.0	86.8	86.8	91.6	86.4	89.8	88.4	91.3	90.2	89.8	87.2	84.1	82.4	91.3	91.6	67.0	100.8
15th Dec.	a.m.	58	88.4	88.4	90.7	89.8	90.7	85.4	82.8	78.4	89.4	88.9	88.4	88.0	87.6	85.0	85.4	86.4	86.8	86.4	84.1	83.2	83.2	86.8	71.0	101.4
		21	85.9	87.2	91.6	89.4	86.8	86.4	93.2	82.4	89.4	88.4	84.1	88.9	87.6	89.4	88.9	87.2	87.2	86.8	84.6	83.7	88.9	89.8	73.6	100.5
		55	89.8	90.7	90.2	90.7	90.7	90.2	84.6	82.8	88.4	88.4	91.6	88.9	91.6	90.2	90.2	90.7	89.8	88.4	88.0	88.0	89.8	91.6	72.1	100.4
	p.m.	58	88.4	88.0	90.2	88.4	86.8	86.8	85.0	84.6	91.3	89.4	88.9	88.9	90.2	88.0	91.3	90.2	89.4	86.8	86.8	82.8	87.6	89.4	72.0	101.0
		21	89.4	91.6	91.6	89.8	91.3	87.6	85.9	85.0	89.4	90.2	91.6	91.3	89.8	90.2	89.8	86.4	88.4	88.0	86.4	84.1	90.2	90.2	73.6	100.5
		55	89.4	90.7	91.6	88.9	90.2	88.4	87.6	85.4	92.8	91.6	91.6	92.0	88.9	90.2	91.3	92.0	89.8	88.9	86.8	85.4	89.8	90.2	73.9	100.8

TABLE 51.

APPENDIX VI

INDIVIDUAL CORRELATIONS

OUTSIDE DATA

Within Animal Basis.

Twin No.	Air and Skin.	Skin and Rectal.	Skin and Resp.	Skin and Pulse.	Air and Rectal.	Air and Resp.	Air and Pulse.	Rectal and Resp.	Rectal and Pulse.	Resp. and Pulse.
25	.661	.382	.604	.497	.581	.527	.442	.440	.538	.487
26	.501	.585	.427	-.035	.616	.501	.225	.323	.105	.207
55	.818	.277	.649	.360	.198	.619	.420	.399	.408	.433
58	.736	.370	.640	.383	.0278	.533	.439	.342	.477	.487
69	.581	.341	.602	.420	.153	.503	.350	.124	.101	.604
70	.698	.231	.698	.340	.239	.362	.196	.080	.125	.504
89	.587	.288	.605	.671	.406	.764	.537	.382	.107	.501
90	.702	.341	.768	.543	.408	.735	.251	.232	.030	.416
31	.650	.278	.617	.140	.510	.517	.366	.285	.470	.250
32	.674	.406	.735	.429	.242	.677	.374	.446	.588	.405
49	.502	.413	.737	.608	.154	.296	.674	.451	.118	.386
50	.477	.512	.745	.153	.108	.200	.406	.514	.202	.363
<hr/>										
AVERAGES:	.640	.373	.661	.391	.326	.613	.386	.359	.285	.439
PROBABILITY:	.40	.90	.60	.05	.10	.75	.40	.70	.10	.15
Individual χ^2 's d.f.			31	5% .345	1% .444					
Total χ^2 's d.f.			394							

Within Day Basis.

Day

1	.730	.120	.015	-.287	.377	.035	-.132	.015	-.09	.635
2	.331	.290	.328	.065	.272	.069	.085	.084	.300	.449
3	.600	.543	.295	.357	.696	.277	.295	.277	.237	.396
4	.194	-.328	-.079	-.181	.076	.407	-.100	-.041	-.095	.097
5	.669	.239	.341	.191	.532	.422	.519	.396	.084	.441
6	.573	.002	.121	.055	.510	.070	.548	-.061	.303	.461
7			.596		.520	.697	.181	.488	.214	.336
8	.705	.447	.454		.633	.750	.812	.635	.408	.642
9	.616	.253	.334		.563	.505	.476	.079	.308	.526
10					-.121	.252	-.623	.187	.712	.257
11					.025	-.031	-.124	.085	.547	.454
12					-.304	.872	.080	-.079	.230	.723
<hr/>										
d.f.	34	34	34	22	16	46	46	46	46	46
<hr/>										
PROBABILITY:	<.01	.02	<.01	.80	>.01	>.01	>.01	>.01	>.01	.01

TABLE 52.

APPENDIX VII

PARTIAL CORRELATIONS AND MULTIPLE CORRELATION COEFFICIENTS1ST ORDER PARTIAL CORRELATIONS.

$r_{12.3} = .206$
 $r_{12.4} = .335$
 $r_{12.5} = .221$
 $r_{13.2} = .196$
 $r_{13.4} = .321$
 $r_{13.5} = .150$
 $r_{14.2} = .177$
 $r_{14.3} = .162$
 $r_{14.5} = .150$
 $r_{15.2} = .346$
 $r_{15.3} = .262$
 $r_{15.4} = .372$

$r_{24.3} = .101$
 $r_{34.2} = .189$
 $r_{45.2} = .158$
 $r_{53.2} = .490$
 $r_{43.2} = .233$
 $r_{45.2} = .231$
 $r_{35.2} = .490$
 $r_{35.4} = .600$
 $r_{25.3} = .198$
 $r_{25.4} = .469$
 $r_{54.2} = .231$
 $r_{54.3} = .135$

2ND ORDER PARTIALS.

$r_{12.34} = .204$
 $r_{12.35} = .162$
 $r_{12.45} = .197$
 $r_{13.24} = .169$
 $r_{13.25} = .038$
 $r_{13.45} = .132$
 $r_{14.23} = .137$
 $r_{14.25} = .106$
 $r_{14.35} = .131$
 $r_{15.23} = .269$
 $r_{15.24} = .319$
 $r_{15.34} = .246$
 $r_{25.34} = .197$
 $r_{35.24} = .144$
 $r_{45.23} = .138$

3RD ORDER PARTIALS.

$r_{12.345} = .164$
 $r_{13.245} = .124$
 $r_{14.235} = .105$
 $r_{15.234} = .255$

MULTIPLE CORRELATION COEFFICIENTS.

$R_{1.23} = .434$
 $R_{1.24} = .428$
 $R_{1.234} = .459$
 $R_{1.2345} = .495$

All the above worked out by the method proposed by Pearson & Bennett (191). The original gross correlations and the average correlations derived on a within cow basis. Appropriate test of significance of partial correlations is by means of Snedecor (190) tables.