HOT CLIMATES AND HIGH CIVILIZATIONS

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The Problem

Some investigators have expressed the opinion that high civilizations can arise only in "stimulating" climates (1). These are variously defined, but in general it turns out that climates like those of Western Europe and the United States are what the author has in mind. The present distribution of the main centers of western civilization, and the economic backwardness of some tropical countries, are cited in evidence. The great civilizations which have appeared in the past in hot countries are explained by invoking changes of climate within historic times.

The basic premise of the argument is the belief that "the natives of the tropics are dull in thought and slow in action," and that white men who move to the torrid zone deteriorate, so that "after a long sojourn in the tropics, it is hard to spur oneself to the physical effort of a mountain climb and equally hard to think out the steps in a long chain of reasoning....Few people will question the reality of the tropical inertia. It is the same lassitude which every one feels on a hot summer day--the inclination to sit down and dream, the tendency to hesitate before beginning a piece of work, and to refrain from plunging into it in the energetic way which seems natural under more stimulating conditions" (2).

In the light of recent work on the physiology of heat regulation, the basic assumption which has just been stated seems open to question. It is granted that people must do much hard work to build up a great civilization. But hot climates, as they actually exist in the world, are not as such the enemies of hard work, and they do not make particularly for lassitude. It is hot climates plus unsuitable clothing that do the damage, for clothing increases enormously the difficulty of keeping cool, and hence the strain on the heat-regulating mechanisms of the body.

It is the purpose of this paper to present the findings which bear on this one point. No attempt will be made to discuss the countless other influences which affect the growth of civilization.

THE BASIC HEAT EQUATION

The normal temperature of the human body, taken by mouth, is about 98.6°F. In health it varies little, though it may rise temporarily during vigorous exercise, or be temporarily depressed by exposure to cold. Yet heat is being generated throughout life, by chemical processes within the body, and heat is constantly dissipated to, and may be taken up from, the environment, through a number of channels. To account for the observed constancy of body temperature, the total gains and losses must be in approximate balance. This balance is achieved, in spite of wide variations in the quantities involved, through the operation of complex physiological mechanisms.

The factors in the problem and the relations between them can be indicated by symbols, as follows:

Let M = Heat generated within the body by the oxidation of foodstuffs. This is generally called metabolic heat.
W = Mechanical work performed.
E = Heat loss by evaporation.
R = Heat gained or lost by radiation.
V = Heat gained or lost by convection.
D = Heat gained or lost by conduction.
S = Heat gained or lost when body temperature rises or falls; this is called "storage" and is taken as positive when the body is cooling.

$$\text{Then} \quad M - W - E \pm R \pm V \pm D \pm S = 0 \qquad 1.$$

This equation expresses the fact that, over any considerable period of time, heat gains and heat losses are equal. The transformations of energy that it refers to are usually measured in large calories (kg. cal.) per hour. The quantities and mechanism involved are discussed very briefly below (3).

Metabolism. All the energy used by the body is derived ultimately from the oxidation of foodstuffs, and all of it appears ultimately as external mechanical work or as heat. The process is known as metabolism.

It is customary to use the term "basal metabolism" when one speaks of the energy required for the minimum activities of respiration, heartbeat, etc., when the body is fasting and at rest. The term "work metabolism" is used when one speaks of the total energy used by the body when it is at work. Of course work metabolism varies with different tasks, but it always includes the energy needed for heartbeat, respiration etc., for these processes are speeded up above the basal rate by activity, and it would be impractical to distinguish between energy required for the task in hand and that required for life processes.

The basal metabolic rate is about 40 kg. calories per hour per square meter of body surface, for young men, and 6% to 7% less for young women. It may vary up to 15% either way from these figures in healthy individuals. The total area of the body can be calculated from the equation:

$$A = W^{0.425} \times H^{0.725} \times 71.84 \qquad 2.$$

where W is the weight of the subject in kilograms and H is his height in centimeters. Applying this formula, one gets total basal metabolic rates for males of different sizes, as follows:

Height cm.	Weight kg.	Surface Area sq. meters	Total Basal Metabolism per hour	 per 24 hours
150	50	1.43	57.2	1370
170	70	1.8	72	1728
190	90	2.2	88	2112

Work metabolism varies with the task, and also with the worker. A big man uses more calories than a small man, in shovelling a given amount of dirt, because his own body is heavier, and it takes more energy to move it every time he swings the shovel. Average figures for different tasks are given by one authority as follows (4):

Man at rest, awake, sitting up	100 kg cal/hour
Man at light muscular exercise	170 kg cal/hour
Man at severe muscular exercise	450 kg cal/hour

There are two factors, usually of minor importance, which may modify figures for metabolism. After eating, there is a temporary increase in the metabolic rate, whose amount varies with the kind of food eaten. This is called the specific dynamic action of food. Mechanical work done in climbing a hill or compressing a spring transforms part of the energy derived from the oxidation of food into potential energy; it is, therefore, not available to heat the body, and must be subtracted from the total metabolism in calculating heat balance. In many problems, neither of these modifying influences is present.

The overall effect of metabolism is to supply the body with heat, which must be got rid of if the temperature is to remain constant. The rate at which heat is supplied will vary from 50 or 60 kg calories per hour, for a small individual fasting and at rest, to 500 or 600 kg calories per hour, for a large individual at severe exercise.

Storage. When the body as a whole becomes cooler, the heat taken from the tissues is dissipated to the environment. When the temperature of the body increases, there is a failure to dissipate heat to the environment as fast as it is supplied. In either case, one may say that there is a change in the amount of heat stored in the body, and this change is indicated in the heat balance equation by the symbol S, for storage. S takes a positive sign when the body is cooling (for the heat which the body loses is added to the metabolic heat which must be dissipated) and a negative sign when the body is growing warmer. Storage is calculated from changes in the skin temperature, usually measured by thermocouples, and changes in the temperature of the organs deep in the body, measured by rectal thermometer.

Metabolic heat is generated inside the body cavity, and comes to the surface partly by simple conduction through the tissues, and partly borne by the blood, which is heated deep in the body and cooled as it courses through the vessels just below the skin, the heat passing from the blood to the skin and from the skin to the environment. If, for any reason, the amount of heat to be got rid of increases, the surface vessels dilate and carry more blood. The phenomenon is known as vasodilation. For this mechanism as a whole to operate, the skin must be cooler than the deep regions of the body.

The civilized man, accustomed to clothing, usually finds that a skin temperature of 88° to 94°F is associated with comfort. For persons accustomed to nudity, the figure may be a good deal lower. As heat load increases, the skin temperature begins to rise. Sweating sets in when it reaches about 93°. If the heat load is sufficient, it increases further to about 95°, perhaps somewhat more if the person is clothed. Skin temperature then becomes constant, if heat balance is being maintained, through the evaporation of sweat or other agencies. If heat is not thrown off fast enough to the environment, however, to maintain heat balance, the skin temperature will continue to rise. This impedes the flow of heat to the surface from the interior of the body, so that the temperature there rises also. The process continues until the heat load is reduced, or the increase in skin temperature restores equilibrium, by accelerating heat loss to the environment, or such internal temperatures are reached—about 110°F—that the organism perishes.

When the environment is cool, the temperature of the skin is reduced, but unless the cooling is excessive, the inner regions of the body remain at their normal temperature. The mechanisms involved are as follows: As the skin cools the blood vessels under the skin contract, a phenomenon known as vasocontraction. Less blood circulates through them, and as a result the heat transfer from the vital organs via the blood to the surface of the body is reduced. Moreover, as the skin becomes cooler it loses less heat to the environment by radiation and convection, and by hypothesis the conditions are such that there is no sweating. Finally, the temperature of the tissues near the surface is reduced, sometimes to a depth of several centimeters, and they act in a sense as garments for the vital inner organs.

Evaporation. Evaporation always serves to cool the body. It takes three distinct forms: respiratory, for we inhale air at various temperatures and humidities, but expire air that is warm and moist; insensible perspiration, that is to say the sheer drying of the tissues through the skin; and the evaporation of sweat. The first two go on all the time, and together remove an amount of heat from the body, which is variously estimated at from 15 to 30 kg cal per hour (5). Sweating is intermittent, a response to heat load, and can remove much larger quantities of heat, for the latent heat of evaporation of sweat is 580 kg calories per liter, and a man can sweat more than a liter an hour.

Sweating begins when there is need for body cooling, and the amount of sweating is adjusted quite accurately to the need. The fineness of this adjustment improves with acclimatization to a hot environment. The maximum rate of heat removal by this means depends on the amount of sweat available, the temperature and relative humidity of the air, and the amount of air movement. The amount of evaporative cooling of the body that actually takes place in a given time depends also on the amount and kind of clothing worn, for clothing can absorb much sweat, which either does not evaporate at all, or evaporates at a distance from the skin. This subject is discussed further in another section.

Water requirements. Water which leaves the body, as sweat or otherwise, must be replaced. The combined water loss through the lungs and through insensible perspiration has been estimated at about a liter in 24 hours, for a man at light work. For practical purposes, this amount can be lumped with water loss from the evaporation of sweat. The amount of urine which leaves the body varies all the way from $\frac{1}{2}$ liter to 3 liters or more per 24 hours. The more water is lost by sweating, the less there is left to be eliminated through the kidneys; but the amount of urine should not fall below 700cc per day, as this amount is necessary to carry off dissolved solids. The feces carry with them only 150-200cc of water per 24 hours, except in cases of diarrhea; then, however, the amount may be large.

All these water losses, for a man at light work, who is not sweating, may total 2 to $2\frac{1}{2}$ liters per 24 hours. The additional amount of water lost when a man does sweat depends primarily on the amount required to provide evaporative cooling, but this quantity is modified by a factor that represents the efficiency of the process. If some of the sweat falls to the ground and is wasted, or is absorbed by the clothing, a larger total output of sweat will be required, to make up for these losses. The water ration in the French navy in the Mediterranean is 3 liters a day. This allows for moderate sweating. Adolph found that soldiers marching in the California desert, with an air temperature of 96°F, needed as much as 12 quarts of water a day (6). Ordinary requirements in warm climates will vary between these limits.

Sweat contains from 1 to 8 grams of salt per liter, the concentration decreasing with acclimatization to heat, and increasing with the amount of sweat produced. Adolph found that troops in training in the California desert area in summer excreted, on the average, 6.8 grams of salt per day in the urine, and lost 10 to 20 grams per day in the sweat. Salt that is lost from the body must be replaced, or serious consequences ensue. In the man at rest salt deficiency leads, after several days, to extreme weakness; at work, it leads to heat cramps, with less delay.

Radiation. Radiation is the transfer of energy from one point to another by electromagnetic waves. This is the form in which we receive energy from the sun. All objects in nature emit radiation, the amount varying with the fourth power of the absolute temperature of the emitting body. When two bodies exchange radiation, the net flow is from the hotter body to the colder one, and is proportional to the difference between the fourth powers of their absolute temperatures. The hotter the emitting body, the shorter the wave-length of the radiation which it emits.

Natural bodies reflect, transmit and absorb varying proportions of the radiation which falls upon them. One which absorbs all the radiation that falls on it is called a black body; one which reflects all of it and absorbs none is a perfect reflector. The coefficients of absorption and emission are equal, for a particular surface, so a body which absorbs radiation readily will also emit it readily, and a good reflector is a poor emitter.

The human body constantly exchanges radiation with the objects around it, losing heat to them when they are cooler than the surface of the body and gaining heat from them when they are warmer. The net effect in particular cases is often difficult to calculate, for a single problem may involve many surfaces with different characteristics, presented to each other at various angles. According to Robinson, (7) who cites Blum, the white man's skin reflects 30% to 45% of the solar radiation which falls upon it, while the negro's reflects 16% to 19%. At longer wave-lengths light and dark skin behave very much alike, both reflecting little and absorbing much. The few figures that are at hand for clothing indicate that white materials may reflect two thirds of the solar radiation that falls on them, and dark ones from one third to one tenth. The rest is absorbed.

Convection. Convection is the term applied to the heating or cooling of the body by the air around it. Air movement increases the effect, according to the empirical formula.

$$C = .65 \ wv \ (Ts - Ta) \qquad 3.$$

Where C = cooling power in kg calories per square meter of surface per hour
wv = wind velocity in miles per hour
Ts = skin temperature in degrees Fahrenheit
Ta = air temperature in degrees Fahrenheit.

Theoretically one should get zero cooling power with zero air movement, but this condition is never realized in practice, for the movements of respiration stir the air near the body, no matter how quiet the atmosphere seems to be. When Ts = Ta there is no convective heating or cooling, but air movement still contributes to heat balance, because it assists in the evaporation of sweat.

When equation 3. is plotted, it becomes apparent that C increases rapidly with wind velocity up to about 5 m.p.h., then more slowly, and that moderate increases in wind velocity above 10 m.p.h. have little added affect on cooling.

Convective heat exchanges usually have little importance in the wet tropics, for there skin temperatures and air temperatures are not far apart. They can bulk large in deserts, however, for desert air can get very hot in the daytime and very cold at night, and there is a good deal of wind. Under these conditions clothing is an advantage, for it reduces all convective heat exchanges; at the same time its effect in retarding evaporation is of little importance, for desert air is so dry that evaporation takes place readily in spite of clothing.

Conduction. Conduction means the passage of heat through a substance, from one molecule to another, or from one piece of material to another that is in contact with it. Conduction within the human body, from the deeper regions where heat is generated, to the surface where it is dissipated to the environment, has been discussed under storage.

At times conductive heat exchanges between the human body and water, rock, earth, metal, ice or the like assume great practical importance, and one may wish to provide insulating materials which will reduce them to a minimum. These are special problems beyond the scope of this paper.

More often one is concerned with the conduction of heat through clothing. Here the exchange is primarily between the body and the atmosphere, and the mechanisms of radiation, evaporation and convection are involved, but they operate to a considerable degree at the surface of the clothing, and heat passes through the clothing, in either direction, largely by conduction.

Heat passes readily through some materials, with difficulty through others. For any given material, the resistance to heat flow varies directly as the thickness. Resistances to heat flow are additive, and the combined resistance of several layers is equal to the sum of their resistances taken separately. Still air is an excellent insulator. It follows that one is more warmly clad, for a given weight, in several thin layers of clothing than in one thick one, for the air spaces between the layers give additional insulation without weighing anything. The arrangement of layers is immaterial, from the point of view of conduction, but wind disturbs the still air imprisoned in porous fabrics, and a wind-break worn outside therefore diminishes heat losses. By similar reasoning, the coolest clothing is a single layer of thin material. Porosity assists cooling if there is wind, but not otherwise.

Laboratory measurement of heat balance. There have been numberous experimental studies of heat balance in human beings. They show how the avenues of heat exchange, which we have discussed separately, are combined in particular instances, and how each contributes to the total result. A case that has been admirably studied is that of subjects at rest, with a constant metabolic rate of about 50 kg calories per square meter of body surface per hour; and environmental temperature the principal variable, the walls being kept at about the same temperature as the air. The investigators (8) found three zones of thermal adjustment:

1. The zone of body cooling, in which the body as a whole was losing heat, largely by radiation and convection, and skin temperature was falling. The cooler the environment, the more rapidly the changes took place. Heat loss by evaporation was small and fairly constant.

2. The zone of thermal equilibrium, in which there was neither body cooling nor sweating. Heat loss by radiation and convection about balanced heat gain from metabolism, and the finer details of equilibrium were taken care of by variations in the flow of blood through the superficial vessels.

3. The zone of evaporative regulation, in which the temperature of the body was kept from rising by the secretion and evaporation of sweat. The amount of sweat secreted and evaporated increased as the temperature rose, and was quite accurately adjusted at each temperature to the requirements for keeping the body in heat balance. In the zone of evaporative regulation, radiation and convection contributed to the cooling of the body as long as the temperature of the air and the walls was less than that of the skin; when they were at the same temperature as the skin, the exchange by radiation and convection was zero; and when air and walls were warmer than the skin, radiation and convection brought heat to the body instead of cooling it.

Throughtout the experiments, the total heat gains and heat losses for any given temperature, including changes in storage, added up to zero, and the basic heat equation was satisfied. The passages between the three zones were not abrupt, but gradual transitions, and the graphs of the different quantities are reasonably smooth curves, without sharp angles. With other subjects and different conditions one might get somewhat different numerical values, but the succession of zones, and the regulatory mechanisms for each, would be unchanged.

Failure of equilibrium. When heat losses fail to equal heat gains, the body temperature changes. This happens quite often in calorimetry experiments, and is of no great moment, so long as the change is strictly temporary and is a matter of only a few degrees. If the change goes far in either direction, serious results ensue.

On the cold side, subjects become drowsy and stuprous when the rectal temperature falls below 90°F, and death is almost sure to ensue if it falls to 77° (9). On the hot side, the ill effects which follow from excessive heat load, or great but bearable heat load too long continued, may take several forms:

Heat cramps. Muscular cramps may occur when the level of salt in the body falls too low. This is quite likely to happen with intense and prolonged sweating, for sweat is a somewhat salty liquid, and the liquid is usually replaced by drinking fresh water, without regard for replacing the salt that has also been lost. The administration of salted water brings relief.

Heat exhaustion. Vasodilation, with increased peripheral blood flow, is part of the normal mechanism of adaptation to heat stress. If these changes go far, especially in unacclimatized subjects (10), there is much blood at the surface, and this may leave uncomfortably little for venous return to the heart; thus the heart may become embarrassed. The ensuing condition is spoken of as heat exhaustion. The mechanisms involved are discussed further under Skin Temperature, in the next section of this paper.

Heat Pyrexia. When the heat regulating mechanisms are frankly unequal to their task and the stress continues, heat accumulates, body temperature rises, and collapse follows. This condition is heat pyrexia. It is likely to be called heatstroke if it comes on in the shade, and sunstroke if it comes on in the sun. The mechanism is the same in both cases.

Heat pyrexia has been produced experimentally by putting subjects in an environment so hot and humid that heat balance was impossible (11). Pulse rate and rectal temperature rose steadily. Sweating was extremely copious at first, but became depressed after a time. The subjects went through a period of irritability, then became languid, and gradually passed into a stupor. Sweating decreased at about the time of the advent of the stuprous condition. The experiments were then interrupted to avoid permanent harm to the subjects. When these were brought out into cool air the sweating was suddenly restored, then diminished gradually. The pulse fell rapidly. Rectal temperature continued to rise for a few minutes, then fell slowly.

The body temperatures recorded in these experiments went as high as 105°F. Such temperatures can be reached in fever without stupor or suppression of sweating, so apparently body temperature itself is not the cause of the other symptoms, but rather all the symptoms are due to the unremitting stimulus to ever greater heat elimination. When this stimulus is removed sweating begins again, and the other symptoms diminish.

Apparently the highest body temperature from which man can recover is about 110°F (12). In heat pyrexia a temperature over 106° indicates a very grave situation.

EFFECTS OF CLOTHING

The laboratory experiments on heat balance which have been described were first performed with nude male subjects, then repeated with the subjects wearing ordinary street dress (13). The results were qualitatively the same in both cases, but the boundaries between the zones were different. Nude subjects were in a state of thermal neutrality at environmental temperatures between 84° and 89°F. Temperatures below 84° gave rise to body cooling, and temperatures above 89° to sweating and evaporative regulation. When the subjects were clothed the zone of thermal neutrality extended from 77° to 84°F, with body cooling below 77° and sweating above 84°.

Radiation and convection. The use of clothing reduced heat exchanges by radiation and convection at all temperatures. In the zone of body cooling this meant that clothes helped to keep the subjects warm, as might have been expected. In the zone of evaporative regulation the result depended on temperature. When the environment was warmer than the skin, clothes served as insulation and reduced the amount of heat that radiation and convection brought to the body, thereby helping to keep it cool. When the environment was cooler than the skin, clothes interfered with heat loss from the body by radiation and convection, and so added to the amount of sweating required for heat balance.

The relations between radiant heating and evaporative cooling have been explored more fully in other experiments, and are treated in another paragraph.

Evaporation. The effect of clothing on evaporative cooling under conditions of severe heat stress must next be considered. The stress may be due to moderately high temperatures combined with high relative humidity, a condition common in the wet tropics and often called "jungle climate," or to very high temperatures combined with low relative humidity, a condition common in deserts and often called "desert climate." Evaporation is easy in deserts but difficult in jungles, because of the relative humidities that are characteristic of these environments.

In 1942 Winslow, Herrington and Shulman studied the influence of clothing on evaporative cooling, for the Office of the Quartermaster General (14). Subjects worked on a stationary bicycle at 270 kg cal per hour, in a variety of uniforms, under simulated desert and jungle conditions. The results are displayed in the following abbreviated table (Table I).

TABLE I

Effect of Clothing on Evaporation

Simulated Jungle Climate

(Temperature 85°F, Relative Humidity 85%)

Clothing	Total Sweat Secreted gr/hr/man	Evaporative heat loss to air gr/hr/man	Sweat absorbed by clothing gr/hr/man	Evaporative Efficiency %
1) 2-piece HBT uniform, with helmet, pack, gas mask, rifle and leggings	752	232	520	30.9
2) Same, undershirt removed	476	194	282	40.8
3) Same without leggings and stripped to the waist	438	352	86	80.4
4) Nude, wearing only shoes, socks, and athletic supporter.	260	216	44	83.0

Table I (cont.)

Simulated Desert Climate

(Temperature 110°F, Relative Humidity 15%)

Clothing	Total Sweat Secreted gr/hr/man	Evaporative heat loss to air gr/hr/man	Sweat absorbed by clothing gr/hr/man	Evaporative Efficiency %
Combination 1 above	746	550	196	73.7
" 2 above	798	608	190	76.2
" 3 above	596	570	26	95.6
" 4 above	652	642	10	98.0

When we study the changes step by step, we find that the amount of sweat secreted and the amount wasted in the clothing decrease, and the evaporative efficiency increases, each time that a garment is discarded (15). Under simulated jungle conditions, the nude man sweats only about one third as much as the man fully clothed. Nudity also improves evaporative cooling under simulated desert conditions, but the advantage which the nude man enjoys over the man that is clothed is very much less than in jungle.

It follows from these experiments that a man under heat stress can perform a given task with less sweating, and hence with less water to drink, when he is nude than when he is clothed; or alternatively, that he can perform a heavier task without going beyond the capacity of his body to provide enough sweat for evaporative cooling. This is particularly true at high relative humidities.

It will help us to understand these results, if we examine the factors that influence the evaporation of sweat, after it has been secreted. The rate at which sweat will evaporate depends on the temperature and relative humidity of the air. If the air is fully saturated and at the temperature of the skin, no evaporation takes place. This condition is likely to be realized in the air spaces between clothing and body, or between layers of clothing. Then the sweat must soak through the garments to the outer clothing surface before it meets drier air and has a chance to evaporate. But evaporation must take place on the skin, to be of most use. If it takes place from the surface of wet clothing, some of the latent heat of vaporization will be taken from the surrounding air, instead of the body. The more layers of clothing a man wears, the further from the skin evaporation takes place, and the worse the situation becomes. This is why clothing is such a hindrance to body cooling.

This effect is most marked when the atmosphere is very humid; it becomes a matter of minor importance at low relative humidities. Desert air is so dry that moisture evaporates promptly, and to a large extent sweat can be vaporized on the skin, where it has maximum cooling effect, in spite of the presence of garments. Under these conditions little sweat is wasted, the skin remains relatively cool, and the ill effects that follow a rise in skin temperature are largely avoided.

As these experiments show, large volumes of sweat are involved when the body is adapting to severe heat stress. Yet economy of sweat is of great practical importance, for it is possible to fatigue the sweat-secreting mechanism to such a degree that it is no longer able to function adequately. Robinson (16) quotes experiments in which men worked under severe heat stress for six hours, with an initial sweat secretion of 1.4 kg per hour; this had declined by 10% to 80% before the end of the exposure. He states that the decline in sweat secretion was not dependent on falling skin or rectal temperature, dehydration, salt deficiency or lack of acclimatization, and that it did not occur in moderate heat stress, where the mean skin temperature was below 95°F and the rate of sweating was associated with long sustained high skin temperatures and high rates of sweating. As Robinson says, it "is undoubtedly related to the more complete failure of heat regulation occurring in heat stroke."

Radiant heating versus evaporative cooling. During indoor experiments, heat exchanges by radiation can be controlled, so their amount can be calculated, by bringing the walls of the chamber to some desired temperature. In the open one has to consider both radiant heat exchanges with the immediate surroundings, and radiation received from the sun. It is difficult to measure these quantities directly, as they affect the human body, because the angles, times and areas of exposure vary in a most complicated manner. One can, however, discern some of the factors involved, and one can measure the effects of specific exposures on rates of sweating and other physiological variables.

As we have seen, heat exchanges by radiation and convection with the terrestrial surroundings are apt to be of minor importance in a jungle climate, because the temperature of the air and of neighboring objects is not far from that of the skin. Generally the surroundings are cooler than the skin, and the body loses heat to them by radiation and convection. In a desert climate, on the other hand, such exchanges often involve large amounts of heat, with a net heat flow towards the body, for the temperature of the air may be well over 100°F and the surface of the ground may be as hot as 150°F.

Far more important, in either environment, is the effect of the sun's rays as they fall upon the body, or reach it reflected from the ground. The amount of solar radiation received depends on the latitude, the time of year, the time of day, and the condition of the atmosphere.

In jungle climates there is likely to be a good deal of shade and verdure, in deserts very little. The world's jungles tend to be equatorial, whereas some of the principal desert areas are located 20°to 35° from the equator, and receive a maximum of insolation during the summer months.

From these considerations it follows that heat load due to radiation presents a more acute problem in desert climates than in jungles, and the use of clothing to shield the body seems indicated. But we have seen that clothing interfieres with evaporative cooling. Which of these two effects is the more important, in a hot desert climate?

There is some experimental evidence on the subject. Adolph (17) had men sit in the summer sun, in the California desert, fully clothed and again in shorts only, and measured their sweat loss. This averaged 725 grams per hour for men in shorts only, and 480 grams for men fully clothed. The difference, 245 grams per hour, is equivalent to 142 kg calories. This added heat gain, on the part of nude men, was due partly to radiation and partly to convection. The air temperature was 104°F and the wind velocity 14 m.p.h.; applying the formula for convective heat exchanges given on an earlier page, it appears that the heat gain due to convection was 20 to 50 kg calories per hour (18). The rest was due to radiation.

Clothes again appeared to be advantageous, when men walked in the sun instead of sitting; but they were cooler nude than clothed, when they walked in the shade. Robinson attacked the same problem, working in Indiana in summer, with a temperature of 91°F and a relative humidity of 44%, and 2 m.p.h. wind velocity (19). He found that clothed men had a less heat load to bear than nude men, in the sun, as long as the work rate was low; but as soon as the metabolicarate increased this advantage disappeared, and at heavy work the nude men sweated about 200 cc per hour less than the clothed men. In a later series of experiments, designed to determine the most severe conditions under which acclimatized men could maintain heat balance (20), Robinson and his associates found that they could stand higher temperatures in shorts only than when fully clothed. This held true at all the work rates tested. These last extended from 46 to 109 kg cal per M^2/hr.

Some of these experiments point one way, some the other. It appears that, on the whole, clothing is an advantage in the sun in a hot desert climate, unless one is doing hard physical work; then, however, one loses more through interference with evaporation, than one gains by being protected from the rays of the sun. Ethnographic evidence points the same way: peoples who live in hot deserts wear clothes a good deal of the time, but strip when they have hard work to do (21).

It remains to comment on the kind of clothing that is most advantageous. A single layer is cooler than several, and keeps off radiation just as well. Clothes should be loose, with ample apertures. There is no evidence that solar radiation in the tropics has any special or peculiar effect on the central nervous system. A hat should give shade, without cutting off the ventilation necessary for evaporative cooling. One is hotter in some hats than bareheaded.

GEOGRAPHY AND HISTORY

Test Cases. We are now prepared to examine the historical record, as it bears on the development of high civilizations in hot climates.

For the purposes of this discussion, civilization will be defined as the culture of a literate people, with relatively advanced technology and developed government; and a civilization will be considered high, or notable, when it has originated much that others have copied, and has maintained itself for a considerable period. The question is, then, whether such civilizations have developed and persisted in hot climates.

The answer can only be an unqualified affirmative, We have the Sumerian and the ancient Egyptian civilizations, which grew to maturity in countries of high temperature and high radiation, and the Mayan civilization, which developed in a country of high temperature and high humidity. To these one can add certain offshoots of the Indian civilization, which spread into the hot wet climate of Indonesia and flourished there in modified form for centuries. It is unnecessary to bring forward detailed evidence that these have been great civilizations.

Here a reservation is in order. For the purposes of this discussion, it is necessary to emphasize the past, and to dwell on the period when the peoples of the areas we are discussing were acknowledged leaders in the world around them. I do not wish to imply by this that they are now any less worthy of respect. It may be simply that others have caught up with them. The rise and fall of nations is an infinitely complicated topic, and we are here dealing with only one very small part of it. What the real relative standing of nations is today, we shall not know until tomorrow.

Climate. The question is whether the climates of the regions we are considering were formerly much as they are now, or whether they have changed greatly for the worse in historic times. The evidence suggests that there has been no significant change.

In Mesopotamia crops and growing seasons in ancient times were much what they are at present, and ancient references to the weather of this or that month are still notably appropriate (22). Sumeria is the southeastern part of Mesopotamia, and the hottest. It is the place of origin of the civilization which later spread over the whole area.

Egypt may have had a little more moisture in antiquity than it has now, but it seems to have been just as hot, and the climate was similar to that of modern times. We can use evidence from the desert to supplement indications from agriculture and from daily life, for Egypt is simply a long oasis in the Sahara. Now the older rock carvings of the Sahara show a Sudanese fauna: hippopotamus, elephant, giraffe. They can be dated to the second, third and fourth millenia B.C. (23). If the climate of the Sahara then was like that of the Sudan today, or, as appears more likely, was already much like the modern Saharan climate, but with more residual water, the climate of Egypt can hardly have been cooler than it is now.

The case of the Mayan and Indonesian civilizations is simpler, for they were still active in the sixteenth century A.D. We know quite well that there has been no marked change in climate since then. In Java, the stupendous ruins of Borobudur date from the eighth and ninth centuries. The great early creative period of Mayan civilizations extended from the fourth to the ninth century A,D., and its principal locale was the Peten district of Guatemala, a region noted today for its hot steamy climate. We have direct evidence that the climate was the same during the period of Mayan greatness, for the ancient Maya used the trunk of the chicle sapote tree for beams. It is a tree that now exists in the area, and can live only under the climatic conditions that are found there (24).

Thus we have reason to believe that the climate has changed little during historic times, in all the regions we have been considering. Political and economic events are enough to explain the rise and fall of the nations that have rendered these areas famous. Now let us see how their people adapted themselves to climate, in the days of their greatness.

<u>Dress</u>. In another place (25) I have examined in more detail the way of life and the dress of the Sumerians, the ancient Egyptians, the Mayas and the Indonesians. Here a summary must suffice. The ancient Egyptians wore very little, as their statues and tomb-paintings show. The Sumerians of the third millenium B. C. had a kilt as basic costume; this was all that people usually wore indoors, or at hard work. A number of outer garments might be added for more or less formal occasion (26). The Mayas and the Indonesians generally wore nothing above the waist. This appears from the reports of the first European visitors.

Thus, the populations of the regions we are concerned with generally wore nothing above the waist, and not very much below it, in the period when they were doing the arduous work which the creation of a great civilization demands. One must not be misled by remarks about the desert Arab and his voluminous garments. Syria and much of Arabia are cold half the year, as one can learn from Doughty's <u>Arabia Deserts</u> or Musil's <u>Rwalla Bedouin</u>, and the nomad's costume is an admirable compromise, good for cold weather, passable in warm weather, and comfortable for sitting or lying on the ground. The Arabs in the hottest regions strip to a loincloth when there is hard work to be done.

Conclusion. We have examined the physiological mechanisms by which the body adapts itself to a hot environment, and we have studied the effect of clothing. It hinders heat transfer, and in hot climates it usually adds to the burden which the environment imposes on the body, and reduces the amount of work which the wearer can do. We have also reviewed the great civilizations which have arisen and flourished in regions considered, by some modern authorities, to be too hot for hard work. We have seen that climate has probably changed little in these regions, during historic times, but that the populations in the days of their greatness wore very little clothing, especially when they were working.

These findings give no support to the theory that civilization need be confined to a particular type of temperate climate, or that hot climates, as they are actually found on the globe, are intrinsically hostile to high cultural achievement. The findings do fit with the hypothesis that civilization can flourish in hot regions, as far as climate *per se* is concerned, provided people will reduce drastically the amount of clothing they wear.

ENDNOTES

(1) Huntington, 1915, 1945; Semple 1911; Markham 1947.

(2) Huntington 1915, pp. 35, 42, 43.

(3) For a more extended treatment, see Wulsin 1948.

(4) Howell 1941.

(5) Robinson 1949 a, p. 198.

(6) Wulsin 1948, p. 26.

(7) Robinson 1949 a, p. 195.

(8) Gagge, Herrington and Winslow, 1937.

(9) Herrington 1949, p. 264.

(10) Increase in the volume of the circulating blood is involved in acclimatization to heat.

(11) Kuno 1934. The book is hard to obtain, but Kuno's description of heat pyrexia is quoted in Wulsin 1948.

(12) Herrington 1949, p. 267.

(13) Gagge, Winslow and Herrington, 1938.

(14) The report as such has not been published, but the findings are given in Wulsin 1948.

(15) There are unexplained irregularities in the column for evaporative heat loss to air. They may be due to changes in heat flow by radiation and convection, associated with changes in dress; but one cannot be sure, in the absence of a complete partitional study.

(16) Robinson 1949 a, p. 213.

(17) Adolph 1949.

(18) It is impossible to be more precise, for we know neither the exact area exposed to convective cooling, nor the skin temperature, nor whether sun and wind came from the same or different directions.

(19) Quoted in Adolph 1949, p. 332.

(20) Robinson 1949 a, p. 223.

(21) Wulsin 1949, pp. 40, 45, 46.

(22) Meissner 1920, I, p. 186.

(23) Wulsin 1941, Ch. VIII and IX.

(24) Kidder 1950.

(25) Wulsin 1949.

(26) Meissner 1920.

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