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TECHNICAL NOTE No. 65

A SURVEY OF HUMAN BIOMETEOROLOGY

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in collaboration with:

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FOREWORD

During recent years the World Meteorological Organization has been collaborating with the International Society for Biometeorology (ISB) in promoting developments and progress in the fields of common interest. Support of this Society was reaffirmed at the third session of the WMO Commission for Climatology (CCl) (London, 1960), which expressed its appreciation of the activity of ISB and advocated a further and even closer collaboration between meteorologists and biologists both at the national and international levels. The CCl established a Working Group on Human Bioclimatology to co-operate with the appropriate committees of ISB and to help meteorologists to obtain a better knowledge of progress in biometeorology. The membership of this CCl working group is as follows :

H.C. Shellard (U.K.), chairman
K. Buajitti (Thailand)
M.I. Budyko (U.S.S.R.)
H. Cordes (Federal Republic of Germany)
E.G. Davy (Mauritius).

The present Technical Note is the first major result of the co-operation between WMO and ISB. The chapters and sections were drafted by members of ISB who are leading specialists in the respective fields; their names are given in the list of contributors. The text was then referred to the CCl Working Group on Human Bioclimatology for examination and editorial review.

I should like to take this opportunity of thanking Professor F. Sargent II and the other contributors of ISB for having prepared this most valuable survey. Thanks are also due to Mr. H. C. Shellard, chairman of the CCl working group, and the other members of his group for their ready co-operation in the preparation of this publication.

(D.A. Davies)
Secretary-General

A SURVEY OF HUMAN BIOMETEOROLOGY

Summary

This Survey is concerned with the relationship of man to his atmospheric environment. Basically this bond is inexorable and absolute, for man requires that atmospheric surround for his very existence. The relationship that is the subject of human biometeorology, however, extends beyond this vital requirement for oxygen. Human biometeorology studies the influences of the meteorological elements such as temperature, humidity, wind, radiation and atmospheric electricity on man in health and in disease, his adaptability to alterations in the atmospheric environment, the role these changes may play in triggering the onset of disease or even in causing disease, and the use of weather and change of climate in the treatment of human disease.

In Chapters I, II and III, the science of biometeorology is defined, important problems of human biometeorology are considered, and human physiological regulations are discussed. In Chapter IV the influences of the meteorological elements are described. In Chapter V attention is directed to the influences of weather, season, and climate on man in health and disease and on his reactions to drugs.

Man has increasingly become an urban settler and worker. With this urban concentration of habitation, transport and industry has come pollution of the atmospheric environment. This pollution has been damaging to the biota and even to man himself. In Chapter VI there is a review of the importance of biometeorology in urban planning, and in Chapter VII the problems of atmospheric pollution are summarized.

The action of weather and climate on man's domestic animals and on some economically and medically important insects is discussed in Chapter VIII.

Finally in Chapter IX there is a consideration of the use of weather and climate in the treatment of disease.

This Survey has been prepared by members of the International Society of Biometeorology in collaboration with the Working Group on Human Bioclimatology of the WMO Commission for Climatology. The Survey is presented to the meteorologist and the climatologist as a statement of the nature and current state of knowledge in one important atmospheric science. Thus, some of the sections contain authors' biometeorological speculations. These ideas must be tested and it will be the task of some future investigator to report their verity. By these means does any scientist work to achieve deeper understanding of nature.

UNE ETUDE SUR LA BIOMETEOROLOGIE HUMAINE

Résumé

Cette étude traite des relations entre l'homme et le milieu atmosphérique dans lequel il vit. Il s'agit d'un lien essentiellement inexorable et absolu, puisque l'homme a besoin de l'ambiance atmosphérique pour exister. La relation qu'étudie la biométéorologie humaine s'étend cependant au-delà de ce besoin vital d'oxygène. En effet, cette discipline étudie les influences qu'exercent sur l'homme - sain ou malade - les éléments météorologiques tels que la température, l'humidité, le vent, le rayonnement et l'électricité atmosphérique; elle s'intéresse à l'adaptabilité de l'homme aux altérations du milieu atmosphérique, au rôle que ces changements peuvent jouer en déterminant le déclenchement des maladies ou même en provoquant celles-ci, et à l'utilisation des conditions météorologiques et des changements de climat pour le traitement des maladies humaines.

Dans les chapitres I, II et III, les auteurs définissent la science de la biométéorologie, passent en revue les plus importants problèmes de la biométéorologie humaine et traitent des lois physiologiques humaines. Le chapitre IV décrit les effets des éléments météorologiques, tandis que le chapitre V appelle l'attention sur les influences que le temps, les saisons et le climat exercent sur l'homme malade ou bien portant et sur sa façon de réagir aux médicaments.

L'homme devient de plus en plus un habitant et un travailleur des villes. Cette concentration urbaine de l'habitat, des transports et de l'industrie a entraîné une pollution du milieu atmosphérique qui porte préjudice aux organismes vivants et même à l'homme. Le chapitre VI analyse l'importance que la biométéorologie présente pour l'urbanisme, tandis que le chapitre VII expose succinctement les problèmes de la pollution atmosphérique.

Le chapitre VIII est consacré à l'action exercée par le temps et le climat sur les animaux domestiques et sur quelques insectes qui présentent une importance économique et médicale.

Enfin, le chapitre IX étudie l'utilisation des phénomènes météorologiques et climatiques à des fins thérapeutiques.

La présente étude a été préparée par des membres de la Société internationale de biométéorologie, avec la collaboration du Groupe de travail de la bioclimatologie humaine de la Commission de climatologie de l'OMM. S'adressant aux météorologistes et aux climatologistes, elle fait le point des connaissances acquises dans une importante science atmosphérique. De ce fait, certaines parties de l'ouvrage contiennent les spéculations biométéorologiques des auteurs. Ces idées doivent être mises à l'épreuve et ce sera la tâche d'un chercheur de les vérifier par la suite. C'est ainsi que les savants contribuent à approfondir la connaissance de la nature.

ОБЗОРНЫЙ ОЧЕРК ЧЕЛОВЕЧЕСКОЙ БИОМЕТЕОРОЛОГИИ

Резюме

В обзоре разбираются вопросы взаимоотношения человека и окружающей атмосферной среды. Эта связь нерасторжима и всеобъемлюща, так как от атмосферной среды зависит само существование человека. Однако эта зависимость, составляющая предмет человеческой биометеорологии, не ограничивается жизненной потребностью человека в кислороде. Человеческая биометеорология изучает проблемы влияния таких метеорологических элементов, как температура, влажность, ветер, радиация и атмосферное электричество на здоровый и больной организм, его приспособляемость к изменениям атмосферной среды, роль, которую эти изменения могут играть в возникновении болезней и использование погоды и климатических изменений в медицине.

В главах I, II и III дается определение предмета биометеорологии, рассматриваются важные вопросы человеческой биометеорологии и обсуждаются проблемы регуляторных физиологических функций человека. В главе IУ дается описание воздействия метеорологических элементов на человеческий организм. Глава У посвящена влиянию погоды, сезонных изменений и климата на больной и здоровый организм и его реакции на лекарственные вещества.

Жизнь и трудовая деятельность человека все более тесно связывается с городом. Концентрация населения, промышленности и транспорта в городах привели к загрязнению атмосферной среды. Это загрязнение оказывает вредное воздействие на флору и фауну местности и даже на самого человека. Глава УI посвящена роли биометеорологии в городском планировании, и в главе УII дается общий обзор проблем, связанных с загрязнением атмосферы.

В главе УIII рассматриваются проблемы воздействия погоды и климата на домашних животных и некоторые виды насекомых, полезных в экономическом и медицинском отношении.

Наконец, в главе IX обсуждаются вопросы использования погоды и климата в медицине.

Обзор подготовлен членами Международного общества биометеорологии в сотрудничестве с рабочей группой по человеческой биоклиматологии Комиссии по климатологии ВМО. Он предназначен для метеорологов и климатологов и представляет собой очерк современного состояния одной из важных отраслей атмосферных наук. В некоторых разделах излагаются собственные воззрения авторов на проблемы биометеорологии. Эти воззрения требуют экспериментального подтверждения - задача, которой должен будет заняться будущий исследователь этих проблем. Именно таким путем идет ученый, стремясь к более глубокому познанию природы.

ESTUDIO SOBRE BIOMETEOROLOGIA HUMANA

Resumen

Este estudio trata de la relación que existe entre el hombre y el medio atmosférico en que vive. El vínculo es, fundamentalmente, inexorable y absoluto, ya que el hombre necesita el ambiente atmosférico para su existencia. Por otra parte, la relación que estudia la biometeorología humana se extiende más allá de la necesidad vital del hombre por el oxígeno; esta ciencia estudia las influencias de los elementos meteorológicos tales como temperatura, humedad, viento, radiación y electricidad atmosférica en el hombre sano y enfermo, el poder de adaptación del hombre a los cambios del medio atmosférico, la función que estos cambios pueden desempeñar en el desencadenamiento de las enfermedades o incluso en la producción de las mismas, y el uso del tiempo y el cambio de clima en el tratamiento de las enfermedades humanas.

En los Capítulos I, II y III, se define la biometeorología como ciencia, se estudian importantes problemas de biometeorología humana y se examinan las leyes fisiológicas aplicadas al hombre. En el Capítulo IV se describen las influencias de los elementos meteorológicos. En el Capítulo V se señalan las influencias del tiempo, la estación del año y el clima en el hombre sano y enfermo y en sus reacciones ante las drogas.

El hombre se ha convertido, cada vez más, en habitante y trabajador de la ciudad. Con esta concentración de vivienda, transporte e industria ha aparecido la contaminación del ambiente atmosférico, que perjudica la vida de las plantas y los animales e incluso al hombre. En el Capítulo VI se expone una revisión de la importancia de la biometeorología en la planificación urbana, y en el Capítulo VII se resumen los problemas de la contaminación atmosférica.

En el Capítulo VIII se estudia la influencia del tiempo y el clima en los animales domésticos y en algunos insectos importantes desde el punto de vista económico y médico.

Finalmente, en el Capítulo IX, se exponen algunas consideraciones sobre el uso del tiempo y el clima para el tratamiento de las enfermedades.

Este estudio ha sido efectuado por miembros de la Sociedad Internacional de Biometeorología, en colaboración con el Grupo de Trabajo sobre bioclimatología humana, de la Comisión de Climatología de la OMM, y se somete a la consideración de los meteorólogos y climatólogos como una exposición de la naturaleza y del estado actual de los conocimientos humanos en esta importante rama de la ciencia atmosférica. En consecuencia, algunas de las secciones de este estudio contienen razonamientos e ideas propios de los autores que requieren ser verificados y cuya comprobación llevará a cabo más adelante algún investigador, a quien corresponderá informar sobre su autenticidad. De esta manera, cualquier científico puede trabajar y conseguir un conocimiento más profundo de la naturaleza.

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CHAPTER I

DEFINITION OF BIOMETEOROLOGY

Because biometeorology is old as a concept but new as an interdisciplinary science, a firm definition has not yet been formulated. Perhaps, therefore, it would not be inappropriate to cite, first, the definition accepted by the International Society of Biometeorology at its inaugural meeting in 1956 (Tromp, 1963) and, second, the definition more recently adopted by a group of biologists and meteorologists who participated in "The Task Force Planning Conference on Atmospheric Sciences" held in Boston, Massachusetts, in the summer of 1960 (Committee on Atmospheric Sciences, 1962; Sargent, 1963). These contrasting statements, in themselves, demonstrate the conceptual evolution that has taken place in biometeorology during the past few years.

1. STATEMENT OF 1956

Biometeorology comprises the study of the direct and indirect interrelations between the geophysical and geochemical environment of the atmosphere and living organisms, plants, animals and man.

The term "environment" is broadly conceived and includes micro, macro, and cosmic environments in so far as they affect the earth's atmosphere and the diverse physical and chemical factors which comprise these environments. The investigations in these disciplines should be conducted in nature or in the laboratory under as rigidly controlled conditions as possible to describe measurable and reproducible physical, chemical and biological factors which show a sufficiently high statistical correlation with measurable physiological and pathological processes to suggest a valid cause and effect relationship between organism and environment.

2. STATEMENT OF 1960

Biometeorology is a branch of ecology which studies the interrelations between chemical and physical factors of the atmospheric environment and living organisms. This environment ranges from the bottom of the root zone in the soil to the highest atmospheric levels involved in the dissemination of pollen and spores. Not only does biometeorology investigate in the natural atmosphere but also in man-made atmospheres such as those found in buildings, shelters, and in the close ecological systems of submarines and satellites.

3. DIVISIONS OF BIOMETEOROLOGY

According to the organism one studies, it is convenient to recognize such divisions of biometeorology as phytological (plants), zoological (animal other than man), and human biometeorology. For some purposes a more extensive classification may be useful. The interested reader is referred to Tromp (1963) for a consideration of one possible detailed classification of divisions of biometeorology. More recently Sargent (1963) has discussed the nature of general biometeorology. In Chapter II this same author discusses the unique nature of human biometeorology.

CHAPTER II

THE IMPORTANCE OF THE STUDY OF HUMAN BIOMETEOROLOGY

1. THE NATURE OF HUMAN BIOMETEOROLOGY

Biometeorology investigates the effects of the atmosphere on living organisms and the reactions and adjustments made by organisms to change in the atmosphere. Since the atmosphere is but one component of the total environment within which organisms have their being, biometeorology may be thought of as a branch of ecology, for ecology studies the relations of organisms to their whole environment and the interrelations of organisms one with another. On the other hand, meteorology is concerned with measuring the weather and unravelling the causes of atmospheric processes. Consequently, biometeorology may be also thought of as one of the atmospheric sciences. For these reasons biometeorology is an interdisciplinary science : it joins biology, particularly ecology, and meteorology in the study of the system in which organism and environment interact (Sargent, 1963 a).

Because human biology is not merely an extension of the principles of animal biology to man, human biometeorology has a different orientation and content from general biometeorology. From the strictly biological viewpoint man possesses few characteristics which can be identified as unique. To be sure, he can be distinguished anatomically. Functionally, however, human beings differ from other animals more in degree than in kind. We may then ask, as does Medawar (1957), what are the differences between other animals and man? Medawar (1957, p. 138) concludes that "man is unique among animals because of the tremendous weight that tradition has come to have in providing for the continuity, from generation to generation, of the properties to which he owes his biological fitness". Tradition and culture are synonymous in this context. Indeed, culture has become so much a part of man that it is difficult to separate it from his biology (Dobzhansky, 1962). Thus, it can be argued that human biometeorology is distinctly different from general biometeorology because of the nature of human biology. It is distinctive because human biometeorology must be cognizant of the cultural environment.

Organisms demonstrate "biological fitness" if they are endowed with organs, systems and processes which enable them to sustain themselves in and prevail over their environments.* For man there are inborn endowments and the technological creations of his culture. Both have exhibited evolution, but cultural evolution has been the more rapid (Blum, 1963). Both contribute to his biological fitness. Medawar (1957, p. 142) views tradition (or culture) as "a biological instrument by means of which human beings conserve, propagate and enlarge upon those properties to which they owe their present biological fitness and their hope of becoming fitter still".

Biological fitness is greater among organisms that are adaptable than among those that are adapted. Man is adaptable. His adaptability arises from his genetic individuality, his phenotypic plasticity, and his culture. Each human being is a unique combination of genetic traits. One individual is anatomically and functionally, with the exception of monozygous twins, unlike any other (Medawar, 1957). This inborn diversity and the genetical system responsible for maintaining that diversity allows selection to happen with the result

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* Here Medawar's definition of biological fitness is paraphrased (cf. Medawar, 1957, p. 141).

that evolution proceeds. The important selective forces in the environment are weather and climate, food and water shortage, predation, and disease.

Phenotypic plasticity is the alteration in the individual with change in the environment. With excess food the individual becomes fat, with under-nutrition, lean. With repeated exposure to unaccustomed heat or cold, he becomes acclimatized to heat or cold. He also exhibits responsiveness to weather and season. This phenotypic plasticity contributes to intra-individual variability, to the constant changeability of the chemical properties of the blood, the functioning of organs and systems, the reactivity of the organism to stress, and the behaviour of the organism.

The uniqueness of the individual members of a species and the intra-individual variability of each individual together constitute biological variability. The phenomenon is complex. The degree of variability is limited by genetic factors and by physiological regulations. Some of the variability is inherent in the organism, derives from the dynamic equilibrium that characterizes the functioning of self-regulating organisms and thus may be termed system variability. Some of the variability relates to changing environmental circumstances. One of the major problems of human biometeorology is to unravel how much of biological variability is due to system variability, how much is the result of weather, season and climate.

Unlike other animals man is capable of profoundly modifying the atmospheric environment. On the one hand, he has at his disposal numerous devices for supporting and maintaining his health and comfort, e.g. clothing, housing, heating and ventilating machinery, and air conditioning. On the other hand, particulate and gaseous discharges from his technological establishments have succeeded in polluting the atmosphere of urban population centres and have damaged the biota. A question with which human biometeorology must deal is : "Do these cultural modifications of the atmospheric environment assure continued human biological fitness ?"

Human biometeorology thus has two central tasks. The first is to explain the causes of biological variability. The second is to understand how man's ability to modify his atmospheric environment may affect his biological fitness. Since these problems have not been solved, a summary of some of the principal facts and their implications may assist the reader to relate the remainder of the pages of this publication to these tasks.

2. THE PROBLEM OF BIOLOGICAL VARIABILITY

Human beings differ one from another; individuals are different when compared with themselves at different times. The uniqueness of individuals constitutes inter-individual variability; the temporal variability of the individual, intra-individual variability. Both aspects of biological variability can be demonstrated by any feasible measurement; e.g. measurement of anatomical features such as height or weight, of the composition of blood, of the functioning of organs and systems, and of behaviour.

Race and geography

Anthropologists (Garn, 1961) have decided that human beings can be grouped into races. The geographical pattern of these racial groups is distinctive; the several races of man tend to reside in different regions of the world, regions which have contrasting climatic characteristics. As a consequence of this fact, the hypothesis (Baker, 1958, 1960; Barnicott, 1959; Newman, 1961) has been stated that during the course of man's evolution the distinctive racial groups emerged through natural selection, particularly through the action of climate, and that the anatomical, functional, and behavioural differences among these racial groups represent genetic adaptations to the prevailing local climate.

One example of such supposed genetic adaptation is anatomical (Baker, 1958, 1960; Barnicott, 1959; Newman, 1961). The racial groups of the hot climates tend to be linear, i.e. to have a relatively large surface area in proportion to the body mass, whereas the inhabitants of cold climates tend to be stocky, i.e. to have a relatively small surface area in proportion to the body mass. Even with race held constant, there is a remarkable correlation between the mean air temperature and the ratio surface area to body mass. The ratio increases as the temperature rises (Barnicott, 1959; Newman, 1961).

One cannot gainsay the fact. It is the interpretation which is in question. One hypothesis is that the linear type with the greater surface can lose bodily heat more easily and the stocky type with the smaller surface can conserve bodily heat more readily (Barnicott, 1959; Newman, 1961). This interpretation is based on the assumption that surface area plays an important role in the regulation of the heat balance. It does not. There is a large body of data (Scholander, 1955; Wilbur, 1957) that invalidates this assumption. The more significant factors are the rate of production of body heat and the insulation of the outer layer of the body by fat (Scholander, 1957).

Functional differences have also been proposed as evidence of these genetical adaptations. Negroes are more susceptible to frostbite and immersion foot in cold regions than are whites (Barnicott, 1959; Newman, 1961). Inhabitants of cold climates can maintain higher skin temperatures of hands immersed in cold water than individuals from warmer regions (Barnicott, 1959; Newman, 1961). Inhabitants of hot dry climates sleep better in the cold desert night because they can tolerate a greater decrement of skin temperature than newcomers (Barnicott, 1959; Newman, 1961). Inhabitants of hot climates sweat less than sojourners from mid-latitudes (Barnicott, 1959; Newman, 1961). Negroes tolerate humid heat better than whites, for they sweat less and exhibit a lesser elevation of the rectal temperature than do whites (Baker, 1958, 1960).

There is no convincing proof that these functional differences between racial groups do not simply represent phenotypic changes such as acclimatization or habituation, changes which develop within the lifetime of an individual. With acclimatization or habituation individuals from mesothermal regions can develop phenotypic changes comparable to those described as characteristic of inhabitants of extreme climates. White man can acclimatize to cold (Hardy, 1963) and to heat (Hardy, 1963), and with prolonged exposure to heat (weeks other than days) his sweat rate declines after an initial rise (Macpherson, 1961). Length of residence of tropical whites must be critically evaluated when comparing their sweat rates with those of native residents. The weight of the observations on the relative heat tolerance of Negroes and whites fails to support the view that these racial groups possess significantly different tolerance for humid heat (Barnicott, 1959; Newman, 1961).

Physiological and biochemical individuality

Within a homogeneous group of human beings one can readily demonstrate the uniqueness of individuals by physiological and biochemical measurements (Sargent, 1963 b; Williams, 1956, 1958). When a variety of measurements are repeatedly made under standardized conditions, it can be shown (Sargent, 1963 b; Williams, 1958) that the pattern of the mean values for these measurements becomes a characteristic of each individual in the group under study; indeed the pattern is as characteristic as his facial features. For example, some persons have persistently high or low concentrations of certain blood constituents, high or low rates of excretion of metabolic waste products, high or low levels of blood pressure and pulse rate.

The patterns of individuality may be genetic in origin. The genetic factors of an individual probably not only determine his pattern with respect to mean values of biological measurements but also his patterns of reaction to environmental change. For instance, monozygous twins, i.e. individuals who have identical genetic factors, exhibit much less individuality in patterns of physiological and biochemical measurements than do two unrelated persons

(Williams, 1958). Within large populations individuals can be found whose measurements deviate by more than three standard deviations from the population mean. These deviations are disconformities (Williams, 1957). There is ample evidence that many disconformities are genetic (Carter, 1962). Much additional research on human biological variability will, however, have to be undertaken to demonstrate whether patterns of individuality characteristic of most persons are also genetic.

Precision and effectiveness of physiological regulation

The precision of physiological regulation may be measured in terms of inter-individual variability. There is demonstrably a hierarchy of preciseness with which the chemical composition of the blood is regulated (Sargent and Weinman, 1962). Certain constituents of the blood particularly essential for the normal functioning of the body cells are precisely regulated or closely guarded. Other constituents not so essential for the normal functioning of the body are less closely guarded. Furthermore, it is found that the physiological processes which regulate the composition of the blood are more variable than the properties of the blood (Sargent and Weinman, 1962). The regulatory processes show more plasticity than do the properties regulated. These hierarchies of inter-individual variability apply equally to intra-individual variability even though a single individual is generally much less variable than is a group of individuals (Sargent and Weinman, 1962).

Effectiveness of physiological regulation is measured by the capability of the organism to limit change when the environmental circumstances are altered. The ability to preserve the chemistry of the blood and the body temperature, for example, is a function of the adaptability of the organism. Effectiveness and precision of regulation are closely related (Sargent and Weinman, 1963). The properties of the blood that are most closely guarded change least with a sudden alteration of the environment; those least precisely regulated change the most.

Temporal variability

The organism is capable of self-regulation. It can accomplish this regulation because it has sense organs which are capable of detecting alterations in their surroundings and because those surroundings are constantly changing. Two environments constitute the surroundings, the external and the internal. The internal environment is the fluid medium which bathes the cells of the body. The sense organs are so situated that some can detect external environmental change and others internal environmental change. Each detector has a set point, each responds to deviations from that set point. As a consequence of their response, reactions both physiological and behavioural are initiated which seek to correct the deviations. The deviations are never completely corrected. There is constant variation about the set point and this variation - which is limited by the precision and effectiveness of regulation - is system variability. System variability is an inherent characteristic of a self-regulating organism. Females tend to show more system variability than males because during the reproductive period they exhibit the menstrual cycle (Griffith *et al*., 1929; Pucher *et al*., 1934 a, b).

The menstrual cycle is not the only cyclical phenomenon of biological variability. Two others are the 24-hour cycle (circadian rhythm) and the seasonal cycle (Webb and Brown, 1959). These two cycles are characteristic features of the terrestrial environment, of the astronomical relationships of our rotating Earth. Because of the close relationship between organism and environment, the surprising fact is not that these cycles can be demonstrated in living things but rather that they have not been found in all measurements of all organisms. Human beings exhibit fewer circadian and seasonal cycles than do other organisms (Webb and Brown, 1959). This fact may be an expression of the biological principle that more highly evolved organisms are, by virtue of their more effective physiological regulation, relatively freer of their external environment than are lower organisms. Both circadian and seasonal cycles have been ascribed to the action of a biological clock (Webb and Brown, 1959). It has not yet been settled whether the clock is driven endogenously or exogenously. Research in space biology may well eventually provide definitive proof, for in distant space the geophysical orientation of the organism will be significantly altered.

Another component of intra-individual variability is daily variation. The day to day measurement of biological events - blood chemistry, physiological functions, and behaviour reveals that there is limited but never-ending variation. This variation has been ascribed to the effect of weather on the organism (Tromp, 1963). The conclusion that weather "causes" this daily variation is supported more by statistical evidence than by laboratory experiment. Biological events that correlate with meteorological processes are called meteorotropisms. Within a population, certain human beings are more influenced by the weather than others; these persons are weather-sensitive (Tromp, 1963). Weather-sensitive persons usually are individuals with arthritic joints, scars, amputated limbs or breasts, or failing hearts. The meteorotropism of the failing heart to hot humid weather (Burch and DePasquale, 1962) and of the arthritic joint to humid weather with decreasing atmospheric pressure (Hollander and Yeostras, 1963) have been confirmed in the laboratory. A singular fact about meteorotropisms is that they appear to relate more to weather processes (so-called weather types) than to individual meteorological factors such as temperature, humidity, pressure, wind velocity, and so on (Tromp, 1963). Since it is difficult to reproduce weather in the laboratory, progress has been very slow in elucidating these phenomena.

Two assumptions are made in interpreting weather-correlated human biological events. First, it is generally assumed that all of the intra-individual variability is attributable to weather. The contribution of system variability has not been recognized. It must be considered and demonstrated to be non-contributory before the notion of meteorotropism can be generally acceptable. Second, the assumption is generally made that the only variable aspect of man's environment which acts on many people in a population is weather. The cultural environment is equally changeable. Its alterations may influence a large segment of the population. The impact of the cultural environment on human beings is profound. This assumption must be validated, too.

3. CULTURE AND BIOLOGICAL FITNESS

Biological fitness is the capability organisms possess to sustain themselves in and prevail over their environments. It is an adaptive capacity that depends upon precision and effectiveness of physiological and behavioural regulation. This concept of biological fitness is closely related to the view that health is a harmonious blending of bodily functions so that the individual can meet and cope with his environmental challenges (Dubos, 1961; Sargent, 1963 b). When the harmony breaks down, there is disease and death (Dubos, 1961; Sargent, 1963 b).

Amelioration of environmental change

Biological fitness, indeed health, is sustained by preserving adaptive capacity. Adaptive capacity is maintained by repeated environmental challenge from such forces as the organism prevailed over in its evolution, viz. weather and climatic change, scarcity of food and water, predation, and disease. Man's present biological fitness, however, also depends upon cultural tradition and cultural innovation. His health is closely related to the amelioration, reduction and eradication of these natural environmental challenges. Increasingly he lives, works and plays in a constant physical environment regulated technologically so that he is comfortable all the time. This cultural innovation, which began with the discovery of fire, has increasingly come, as Dubos (1961, p. 49) expresses it, "to place him outside the natural order of things". The fundamental problem for human bioclimatology that follows cannot be better stated than in the words of Dubos (1961, p. 49). "By changing the physical world to fit his requirements - or wishes - he has almost done away with need for biological adaptation on his part. He has thus established a biological precedent and is tempting fate, for biological fitness achieved through evolutionary adaptation has been so far the most dependable touchstone of permanent success in the living world."

Pollution of the atmospheric environment

There has been another consequence of man's discovery of fire. This discovery combined with his skill as a maker of tools led to the modern technological era. Man has traditionally used the atmosphere as a sewer for the discharge of gaseous and particulate wastes from his industrial establishments and his mechanical devices which used fossil fuels for energy. The discharge of these wastes has increased so rapidly that now there is widespread atmospheric pollution, particularly over large urban population centres (Anonymous, 1962; Stern, 1962). These pollutants present a novel environmental challenge to all living things. This man-made atmosphere has produced severe damage in communities of plants and lower animals (Stern, 1962). Among human communities there has been increasing discomfort, disease, and death (Stern, 1962). Dubos (1961, p. 140) succinctly states the implication of this cultural innovation : "The one characteristic of our civilization is the rapidity with which it changes all our ways of life, without too much, if any, concern for the long-term effects of the changes. Man can eventually become adapted to almost anything, but adaptation demands more time than is allowed by the increasing tempo at which changes are presently taking place."

4. SUMMARY

These thoughts concerning the importance of the study of human biometeorology have led to a critical examination of the nature of this interdisciplinary science, its basic concepts, and its assumptions. Our conclusions suggest directions that future investigations might profitably follow. It is these directions that show the substantive importance of human biometeorological research.

First, organismic variability constitutes the raw data of human biometeorology. Variability is a natural characteristic of the system that relates organism to environment, but organismic variability is limited by physiological regulation. For man, the environment includes both the atmosphere and the cultural milieu. Both must be investigated in studies of human biometeorology designed to probe and elucidate the effect of environment upon human beings.

Second, human biometeorology cannot limit its study to the atmospheric environment, the customary weather and climate. Human biometeorology must include within its province the cultural environment, for cultural innovations are creating major changes in the physical surroundings within which human beings live. The simple question is, will these innovations make man fitter still?

CHAPTER III

PHYSIOLOGICAL REGULATIONS IN MAN

1. THE SYSTEM MAN-ENVIRONMENT

Man has his being within two environments : the external (or physical) environment and the internal environment. To both he is bound inseparably. Upon the composition of each does his very existence depend. From the external environment man obtains the nutrient energy (fat and carbohydrate) and nutrient raw materials (oxygen, water, protein, minerals, vitamins) required to satisfy the needs of his cells, tissues and organs. His relation to this environment is an open one - he is an open-system - for the energy and nutrients flow through him. As it passes through, he is capable of organizing the heterogeneous material from the external environment into the homogeneous structure we recognize as the human being. The homogeneity is achieved and maintained by regulatory processes which draw on energy stores kept at higher levels than those of the environment. This capacity to achieve homogeneity from heterogeneity is indeed a fundamental characteristic of all living organisms.

The human being is comprised of cells, tissues, and organs bathed in an aqueous milieu called the internal environment. The internal environment is equivalent to the extracellular fluid, the volume of which is about 15 litres. The components of the extracellular fluid are the plasma of the blood, the lymph, and the interstitial fluid. There are about 30 litres of water within the cells, the so-called intracellular water. Thus, nearly 70 per cent of the human being's body weight is water.

2. THE CONCEPT OF HOMEOSTASIS

The healthy functioning of cells, tissues and organs, indeed, of the human organism, is closely dependent upon the physical and chemical properties of the internal environment. The physical properties include temperature, osmotic pressure and specific gravity. Among the chemical properties are the concentration of hydrogen ion (pH), the partial pressure of oxygen, the concentration of the electrolytes (e.g. sodium, potassium, calcium, phosphorus, and chloride) as well as the content of glucose, amino acids, and fats. The health of the human being is linked to the precision with which these physical and chemical properties are regulated. Wide variations of these properties from their usual levels are usually associated with functional deterioration of the organism. The precision of regulation is generally identified by the term <u>homeostasis</u>.

The properties of the internal environment exhibit limited or regulated variability. The descriptive phrase usually employed in this connexion is that the composition of the internal environment varies within certain limits. Actually there is a hierarchical order of variability among the physical and chemical properties of this milieu. The most closely guarded (i.e. regulated) properties and temperature, pH, osmotic pressure, and the concentration of such electrolytes as sodium, potassium and chloride. The least closely guarded properties are the concentration of blood enzymes and the waste products of cellular metabolism. The most closely guarded properties are those most vital to the continued efficient functioning of the organism's cells, tissues, and organs. The least closely guarded are the properties unrelated or non-essential to the healthy conduct of the business of the organism.

The fact that variability of the physical and chemical properties of the internal environment is limited means that this aqueous milieu is in a "steady state". It must be emphasized that the "steady state" is not defined by the average condition of the milieu intérieur but by the limits of variance. Variability within the internal environment is a necessary condition for the effective operation of the processes concerned with physiological regulation. This variability has been called system variability. The processes concerned with physiological regulation are homeostatic mechanisms.

3. HOMEOSTATIC MECHANISMS

Irritability is a fundamental property of living organisms. By irritability we mean responsiveness to environmental change. The change is called a stimulus. An environmental change is not a stimulus unless the magnitude and duration of the change are sufficient to initiate a response. The cells, tissues and organs of the human being respond to environmental change in two ways : First, the change may elicit a response by direct action on cells. For example, a chemical alteration in the internal environment may cause cellular processes to speed up or slow down. Hormones act in this fashion. Second, the environmental change may be detected by particular cells, viz. cells of the nervous system. In this case the response of the organism is indirect in the sense that it is mediated via the nervous system. Both types of reactions by the human organism are fundamental features of the homeostatic mechanisms. We shall first describe how the nervous system functions and then we will examine the endocrine system.

The nervous system

The human organism possesses exquisitely sensitive detectors (organs of special sense) which are specialized to respond to stimuli of certain kinds. Thus there are organs which react to light, sound, chemical change, thermal gradient, pressure, stretch, and so forth. Some organs are situated so as to detect changes in the external environment, others to detect changes in the internal environment.

These detectors or receptors are extensions of nervous tissue from the central nervous system, which is composed of the brain, the brain stem, and the spinal cord. The receptors are either bare nerve endings, e.g. the receptors that detect thermal change are bare nerve endings located in the skin, or highly complex structures such as the eye or ear. The receptor is an energy transducer. Each receptor converts the stimulus to which it is specifically irritable into an electrical impulse which is self-propagated along the extension of nervous tissue, the neuron or nerve fibre (in this case called afferent or sensory neuron), to particular locations within the central nervous system. There are two main groups of centres to which these nerve impulses travel : the reflex centres which are located either in the brain stem or the spinal cord, and the perceptual centres, all of which are situated in the brain. The reflex centre collects information from nerve impulses without the organism's necessarily being aware of it. The perceptual centres collect information from nerve impulses so that there is conscious awareness of the nature and location of the environmental change. Consequent to the arrival of the nerve impulses at the reflex centres reflexes are initiated. Subsequent to the arrival of nerve impulses at the perceptual centre voluntary action may be affected by the organism. Since many neurons go to both reflex centres and perceptual centres, the response of the organism may comprise both an automatic (reflex) act and an awareness of the stimulus. For example, if an unexpectedly very hot object is grasped in the hand, the object is automatically dropped but simultaneously there is awareness of pain in the burned hand.

Reflexes are automatic and involuntary reactions involving muscles or glands within the human organism. The muscular or glandular reactions are brought about by neurons that pass from reflex centres in the central nervous system to these muscles and glands. Nerve impulses travel over these efferent or motor neurons. When the nerve impulses reach the muscles, they change their length and a movement takes place. When the nerve impulses reach the glands, they produce and release a secretory fluid.

Most of the muscles of the human body are either attached to the skeleton or located in the walls of hollow organs and structures such as the gastrointestinal system, the urinary system, and the blood vessels. There are two kinds of glands, the exocrine and the endocrine. The exocrine glands include those associated with the digestive system and with sweating. These glands have ducts and when stimulated discharge secretory products such as saliva or sweat. The endocrine glands have no ducts. They secrete regulatory substances known as hormones directly into the blood stream.

The muscles attached to the skeleton are activated not only by reflexes but also by voluntary decisions. The voluntary action on these muscles is made possible by motor neurons that arise in the brain in the vicinity of the perceptual centres and pass out from the central nervous system to the skeletal muscles. Breathing, for example, is usually an unconscious automatic activity. However, by voluntary decision one can stop breathing, hold one's breath, or breathe faster or slower as one desires.

The endocrine system

Some of the ductless glands of the human body are stimulated by reflexes. Others are stimulated or inhibited by specific chemical changes in their aqueous surroundings. As a result of the stimulation, whether it be chemical or nervous, the endocrine gland secretes a hormone which passes directly into the blood stream. Hormones are complex organic molecules which are carried in the blood to distant cells and organs where they function to regulate metabolic activities of cells, tissues, and organs. Hormones do not initiate bodily processes; rather they regulate the rate at which they proceed. Reactions to environmental change mediated by the endocrine system are slower than those initiated by the nervous system. Nerve impulses travel very rapidly over sensory or motor neurons; much more rapidly than the movement of hormones in the circulatory system.

Hormones from the endocrine glands have a wide variety of actions in the body. They regulate physical and mental growth, cellular metabolic events, the chemical and physical properties of the internal environment, digestive processes, and the functioning of many organs of the body. Consider, for a moment, an illustration of how the endocrine system operates.

Regulation of osmotic pressure of internal environment

The organs concerned are the hypothalamus, a region in the brain stem containing many reflex centres for homeostatic mechanisms; the posterior pituitary gland; and the kidney. The kidney functions to eliminate metabolic waste products and at the same time conserve body water. The kidney is capable of elaborating dilute or concentrated urine depending upon whether or not there is an excess or a deficiency of body water. The problem for the organism is to "direct" the kidney to excrete dilute or concentrated urine. An excess of body water lowers the osmotic pressure of the blood, a deficit of body water raises the osmotic pressure. Changes in the osmotic pressure of the blood are detected by osmoreceptors located in small blood vessels in the hypothalamus. Nerve impulses pass over neurons to the posterior pituitary gland, attached by a stalk to the base of the brain stem, where a hormone known as the antidiuretic hormone is stored. This hormone is discharged into the blood stream and carried to the kidney where it regulates the amount of water excreted as urine. If the blood is concentrated and the osmotic pressure rises, the output of antidiuretic hormone is augmented, and the volume of urine is reduced. With less urine lost, more water is conserved, the blood then becomes less concentrated. The output of antidiuretic hormone is reduced. Thus, there is a dynamic chemical interplay between the brain stem and the kidney and, as a consequence, a steady state with respect to the osmotic pressure of the internal environment is maintained.

A simple model for homeostatic mechanisms

It has been established that environmental change is a necessary condition for effecting physiological regulation and that this environmental change is capable of detection by the human organism. Most changes of the external environment act on the human being through the nervous system; the change is detected by a special sense organ or receptor. Internal environmental changes are detected either by specialized receptors or other cells of the body. Because the human being is an open-system fulfilling many of its needs for nutrient energy and raw materials from the external environment, our model for homeostatic mechanisms must include internal regulation and external regulation.

Internal regulation

Each of the internal receptors has a set-point. Deviations from the set-point are detected and initiate reponses to correct the deviation. Without deviations from these set-points, there would be no regulation. Earlier this variability of the internal environment was termed system variability. Once regulatory processes have been set in motion to correct deviations, it is essential that the organism possess a mechanism for indicating that the deviation has in fact been corrected. This mechanism is nowadays identified as "negative feedback". As the environmental change is corrected, the milieu of the detector approaches its set-point. The detector then ceases to provoke further regulatory responses. Because of the timing of the various stages in the regulatory process, the alterations are generally somewhat over-corrected. This over-correction constitutes a new environmental departure which again initiates regulatory mechanisms. Thus system variability is a continuous alteration of the internal environment. The deviations from detector set-points are never completely corrected, but the regulatory mechanisms make it possible to maintain a "steady state" with the internal environment.

External regulation

The maintenance of the "steady state" within the internal environment requires that the organism continously replenish its limited stores of energy and raw materials from sources in the external environment. Since there is a continuous utilization of these materials, there must be a regular intake. Furthermore, many deviations of the physical and chemical properties of the internal environment cannot be corrected by internal mechanisms alone. For these reasons there is a behavioural component to physiological regulation which involves searching in the external environment for the nutrient energy and nutrient raw materials required to correct deviations. The searching has a vector which orients the organism toward these nutrients. Thus external regulation consists of searching and orientation. The externally located sensory receptors, of course, make this search and orientation effective.

The other behavioural aspect of external regulation that assists the homeostatic mechanisms concerns amelioration of extreme variations of the external environment. These variations are detected by the external receptors and the response is a complex motor process which results in use of clothing and shelter and heating and air-conditioning as means of environmental protection. Animals other than man also engage in a form of environmental protection : they build nests or live in burrows, caves, and under rocks. Many animals move into and out of these shelters depending upon external environmental circumstances. Certainly seeking environmental protection can be viewed as a form of searching and orientation.

The integrative action of homeostatic mechanisms

The human being is not simply a composite of cells, tissues, and organs; he is an integrated unitary organism. The functioning of the organism cannot be predicted from its constituent processes. The organization and interrelationships among the cells, tissues, and organs adds something that cannot be deduced from knowledge of the isolated parts. The outstanding feature of the organism is its operational integration. Cells, tissues, and organs each perform specialized functions, but these parts are made to function holistically by the integrative systems - the nervous system and the endocrine system. These systems provide the guidance for the homeostatic mechanisms. These mechanisms are responsible for the "steady state" maintained in the internal environment amid the vicissitudes of the external environment. The preservation of the "steady state" in the face of environmental challenge is a measure of the effectiveness of physiological regulation.

The human organism can make both immediate and extended adjustments to stressful situations. The immediate homeostatic adjustments are served by the nervous system, the extended homeostatic adjustments by both the nervous and the endocrine system. With repeated exposure to stress or with continuous exposure to a new constellation of environmental circumstances, the organismic reactions change. The magnitude of the disturbance of the "steady state" and the degree of variation in the homeostatic mechanisms gradually diminish. This phenotypic variation is identified as acclimatization if the stress to which the organism has been exposed is meteorological. The variation is the consequence of phenotypic plasticity and is a measure of the adaptive capacity. The human being exhibits great phenotypic plasticity and is considered to be adaptable to a wide range of external environmental circumstances.

When the "steady state" of the internal environment cannot be preserved because the strain on the homeostatic mechanisms is great and disintegration occurs, cellular and organismic functions are disturbed. The organism is said to be diseased. The symptoms of the diseased organism arise both from the attempt of the homeostatic mechanisms to preserve the steady state and from the action of the noxious circumstances on the organism.

4. HOMEOSTATIC MECHANISMS RELATED TO MAN'S ADAPTIVE CAPACITY TO MEET METEOROLOGICAL CHALLENGES

Modern man evolved from a hominid called Australopithecus who lived in the semi-arid steppe climate of East and South Africa. In the million years of his existence on the Earth, man has ranged into and inhabited hot and cold regions, sea-level areas, and the rarified atmospheres of high mountains. We emphasized in Chapter I that this adaptive capacity was in part physiological and in part cultural. In the following paragraphs we shall briefly consider the physiological regulations which contribute to the ability of man to adjust to heat, cold and low partial pressure of oxygen. More detailed discussions of these topics may be found in Chapter IV, Sections 3 and 4, and Chapter V, Section 1.

Thermoregulation

The human being is "warm-blooded". The temperature of his internal environment is regulated close to 37°C. The homeostatic mechanisms serving temperature regulation function to maintain thermal balance, i.e. to balance heat production and heat loss so that this thermal steady state is preserved.

Deviations from the steady state condition are detected by thermally sensitive cells in the hypothalamus of the brain stem. These receptors and the reflex centres to which their afferent neurons pass constitute the temperature regulating centre. Additional information is conveyed to this centre from temperature sensitive receptors located in the deep layers of the skin. By them the centre is informed that the external environment has become hotter or colder. The temperature regulating centre then sets in action homeostatic mechanisms which seek to maintain thermal balance. Since information from the peripheral receptors activates these mechanisms before a detectable change has taken place within the internal environment, we can view the initial phases of the reaction of the organisms as anticipatory. A deviation from the steady state is anticipated, counter-reactions are set in motion to prevent the deviation from developing.

The homeostatic mechanisms activated by the temperature-regulation centre act to conserve body heat (reduce heat loss) when the organism is threatened with cooling and to increase heat dissipation when the organism is threatened with overheating. The regulatory problems are solved by reducing heat loss and increasing heat production in cold environments and increasing heat loss and reducing heat production in hot environments. Both internal and external regulatory processes are utilized. Both nervous and endocrine mechanisms are involved. The neural regulations are served primarily by a division of the nervous system known as the autonomic nervous system. The reflexes regulating the cardiovascular system (heart and blood-vessels), the respiratory system, and sweating are among the components of the autonomic nervous system.

There is a range of ambient temperatures within which the homeostatic mechanisms of thermoregulation are not stressed and within which the rate of resting heat production is minimal. This range of temperatures is the zone of thermoneutrality. For man the zone is narrow - 28° to 30°C for the nude individual and 29° to 31°C for the clothed person. Departures of the ambient temperature beyond the zone of thermoneutrality cause the rate of resting heat production to increase. On the hot side of the zone, mechanisms increasing heat loss are activated; on the cold side, the heat-conserving mechanisms are stimulated.

Mechanisms of heat conservation

The immediate physiological response to cold is reflex vasoconstriction. Two reflex centres are concerned : the temperature regulating centre and the vasomotor centre of the medullary portion of the brain stem. The vasomotor centre is an autonomic centre. Neurons from this centre pass to the muscles in the walls of small arteries and veins under the skin. When the circular muscles surrounding these vessels contract, the calibre of the vessel is reduced, i.e. the vessels constrict. The blood flow in the peripheral regions of the body is reduced. Since this blood carries metabolic heat to the skin for dissipation by radiation and conduction, with peripheral reflex vasoconstriction, radiant and conductive heat loss is reduced and body heat is conserved. Concurrently blood vessels deep in the body vasodilate (their calibre increases); their vasodilation acts to accommodate the volume of blood shifted out of the peripheral regions. Since the accommodation is not perfect, the blood pressure tends to rise secondarily.

With continued exposure to cold, vasomotor reflexes prove incompetent; insufficient heat is conserved. The temperature of the internal environment begins to decline. The thermoregulatory centre now initiates reflex shivering. Nerve impulses travel to skeletal muscles causing them to contract. As a consequence of increased muscular activity, extra metabolic heat is produced. It is this process which is largely responsible for the augmented rate of heat production at ambient temperatures less than 28°C.

Accompanying these vasomotor reactions, there is a decrease in the blood volume which is mainly caused by water moving from the blood to the interstitial spaces. Few significant endocrinological adjustments have been demonstrated in man. There is, for example, only a modest stimulation of the activity of the thyroid gland, the hormone of which (thyroxine) regulates the rate of heat production in the cells and tissues.

Voluntary regulations also develop. The cold individual increases his body movements. This activity further augments heat production.

Mechanisms of accelerating heat loss

Again the immediate reaction to heat is a vasomotor one. There is now reflex vasodilatation of the small arteries and veins under the skin. More blood is shunted to the periphery. More body heat is carried to the body surface for dissipation by radiation and conduction. Accompanying the peripheral vasodilatation there is vasoconstriction of vessels deep in the body. This central vasoconstriction does not completely accommodate the peripheral vasodilatation, and so the blood pressure declines. The heat is reflexly speeded up through a cardiac centre located in the medullary portion of the brain stem. However, the output of blood by the heart (the cardiac output) declines because the volume of blood returned to the heart through the veins is reduced. A more slowly developing compensatory adjustment is an increase in the blood volume brought about by interstitial fluid moving into the blood-vessels.

Small increments of the internal temperature and stimulation of the temperature regulatory centre by afferent impulses from the skin's thermo-receptors initiate reflex sweating. As the sweat evaporates it extracts its heat of vaporization from the body heat stores and thus augments heat loss.

As the temperature of the internal environment rises, metabolic processes are stimulated. More heat is produced. The rate of resting heat production increases. The metabolic effect is partially offset by a reflex relaxation of the skeletal muscles. Muscular heat production is reduced. Furthermore, there is also a decline in voluntary activity. The overheated individual moves slowly, is drowsy, and may sleep more than usual.

Sweating not only increases the loss of body heat but also becomes a threat to the body water. The homeostatic mechanisms related to the regulation of body water thus are set in motion. These mechanisms are endocrinological. The principal glands are the pituitary and adrenal. What these glands accomplish in attempting to maintain the water balance is described in Chapter IV, Section 3.

There is little evidence that in man there is more than a modest reduction in the activitity of the thyroid gland.

Adjustments to low partial pressure of oxygen

The need for a regular supply of oxygen to the cells of the body is the primary reason that the organism is so dependent upon its external atmospheric environment. At sea-level the partial pressure of oxygen (pO_2) is about 150 mm Hg (200 millibars). When the organism migrates to mountains where the pO_2 is sharply reduced, homeostatic mechanisms are set in motion which aim to augment the intake of oxygen so that the continual cellular demands for oxygen can be met. The mechanisms involve the respiratory centre and the bone marrow. The respiratory centre regulates the rate and depth of respiration or breathing. It is in the bone marrow that red blood cells are produced. These cells contain a pigment called haemoglobin which combines with oxygen as the red cells pass through the lungs and carries this oxygen to the tissues where it is released for use by the tissue cells.

The immediate organismic reaction to low pO_2 is respiratory. Chemically sensitive receptors in the large arteries of the neck region detect the low oxygen content of the blood. The nerve impulses act on the respiratory centre to increase the rate and depth of breathing, to bring more oxygen into the lungs. A more slowly developing reaction is hormonal. The low oxygen stimulates the kidney to elaborate a hormone (erythropoietin). This hormone accelerates the rate of production of red cells by the bone marrow. As these extra cells enter the blood stream, its capacity to carry oxygen is increased. At sea-level each cubic millimetre of blood contains about 5 million red blood cells. Among men living in high mountains the figure is about 8 million. In the unacclimatized individual this plethora of blood severely taxes the cardiovascular system and may be one of the factors leading to mountain sickness described in Chapter IV, Section 4.

5. THE BIOMETEOROLOGICAL INDEX

What we might call the biometeorological index - and there are many of them - is really a stochastic model which attempts to describe from experimental observations how the ambient atmospheric environment acts on the human organism. The models are biometeorological, for they combine in equations and nomograms both biological and meteorological data. Some indices are expressed in meteorological terms, e.g. effective temperature, corrected effective temperature, temperature-humidity index, wet-bulb globe temperature index, wind chill, and cooling power; others are expressed physiologically, e.g. predicted four-hour sweat rate and heat stress index (Table III.1).

These indices have two major limitations as models for describing environmental-organismic interactions. In the first place, since the atmosphere is a restless admixture of properties which are never exactly the same, it has been very difficult to develop reliable and realistic models of the weather. It is probable that the organism reacts to changes in the weather and thus, to be of predictive value, the model or index must incorporate the values and rates of change of all those properties of the atmosphere that have an appreciable effect on the organism. There are now numerous indices primarily because none constitutes a generally satisfactory model. In the second place, most of the models have been developed from observations on non-representative populations performing tasks in chambers where the meteorological parameters are precisely controlled. Since weather cannot be simply reproduced in the climatic chamber, the models become descriptive of rather limited situations. They certainly rarely describe with much reliability the atmospheric circumstances commonly summarized in the word "weather". Extension of these models to the reactions of representative populations of ordinary people living in the natural atmospheric environment has not been uniformly successful. Before these indices are widely used as a basis for prediction, it is most desirable that they be extensively tested against the reactions of the common man going about his customary routine in the natural environment. Where such testing has been done, useful results have accrued, and the biometeorological index has become a valuable tool of preventive medicine.

The reader is referred to Hardy (1963) and Sargent and Zaharko (1962) for a more detailed treatment of the topics considered in Chapter III.

TABLE III.1 REPRESENTATIVE BIOMETEOLOGICAL INDICES

Index	Definition	Parameters required to solve equation or nomogram	Derivation of index	Application of index
Effective temperature (E.T.)	Any combination of temperature, humidity and air motion that produces the same thermal sensation as still saturated air of a given temperature.	Dry bulb temperature; wet bulb temperature; wind velocity; knowledge of clothing, i.e. wearing only shorts or customarily dressed.	Chamber experiments.	Prediction of sensation of warmth and physiological strains imposed by atmosphere.
Corrected effective temperature (C.E.T.)	Any combination of radiant temperature, humidity, and air motion that produces the same thermal sensation as still saturated air of a given temperature.	Black globe temperature (temperature registered on thermometer inserted into blackened 6-in. copper sphere); wet bulb temperature; wind velocity; knowledge of clothing.	Globe temperature empirically substituted for dry bulb temperature.	Same as E.T.
Temperature-humidity index (T.H.I.)	An empirical index of atmospheric warmth: T.H.I.= $0.4(t_d + t_w)+15$	Dry bulb temperature (t_d, ^oF); wet bulb temperature (t_w, ^oF)	Empirical.	Prediction of "discomfort" during heat waves.
Wet-bulb globe temperature index (WBGT)	An empirical index of atmospheric warmth: WBGT = $9.7t_w + 0.1t_d + 0.2t_g$	Dry bulb temperature; wet bulb temperature; globe temperature (t_g).	Empirical but extensively tested in field.	Prediction of development of heat disease during hot weather.
Wind chill (K_o)	An empirical equation describing the rate of cooling of a cylinder filled with water, which approximates the cooling effect of the atmosphere $K = (\sqrt{v \times 100} - v + 10.5)(33-t_d)$	Dry bulb temperature (t_d, ^oC); wind velocity (v, m/sec).	Empirical; field tested.	Prediction of clothing requirements for cold weather and occurrence of cold injury, e.g. frostbite.
Cooling power (C.P.)	The rate of heat loss from a katathermometer, a specially constructed alcohol thermometer, the characteristics of which were presumed to simulate man. Numerous empirical equations and nomograms. (See Stone, R. G., Bull. Am. Meteorol. Soc., 24: 295; 327, 1943.)	Rate of cooling of katathermometer; katathermometer constant.	Empirical but extensively tested in field and industry.	Prediction of thermal sensations and physiological reactions to heat.
Predicted Four-Hour Sweat Rate (P4SR)	An empirical index of the stress of atmospheric heat expressed in terms of the strain on thermoregulation, i.e. the sweat rate that the stress will provoke.	Dry-bulb temperature or globe temperature; wet bulb temperature; wind velocity; rate of heat production from physical work.	Chamber experiments; extensively tested in field and industry.	Prediction of physiological reactions to heat.
Heat stress index (H.S.I.)	A theoretical relationship between the thermal load of the atmosphere imposed on a standard man and the resulting thermoregulatory strain expressed as the ratio evaporative heat loss required to maintain thermoregulation to the maximum evaporative capacity of the atmosphere.	Dry bulb temperature; wet bulb temperature; globe temperature; rate of heat production from physical work.	Theoretically derived from chamber experiments; extensively tested in industry.	Prediction of physiological reactions to heat.

CHAPTER IV

THE INFLUENCE OF METEOROLOGICAL FACTORS ON PHYSIOLOGICAL PROCESSES

1. RELATIONS BETWEEN EXTERNAL WEATHER AND THE MICROCLIMATE OF ROOMS AND BUILDINGS

The development of shelter is a natural adaptive device to escape temporary unfavourable environmental conditions. This tool for survival is widespread throughout the animal world in form of cocoons, nests, lairs, dens or through the occupancy of hollow trees or natural caves. Man has extended this protection against unpleasant or dangerous atmospheric states by the invention of the house. Even in its simplest form, just consisting of roof and walls, it produces a marked change between the atmospheric environment indoors and outdoors. Controlled use of fire and mechanical devices has enabled man to make every part of the earth inhabitable, including environments that would be rapidly lethal to man in his original state. Thus the house has become an artificial extension of man's homeostatic system.

There can be a very wide separation between indoor and outdoor values of atmospheric elements, depending on how far the outdoor circumstances are removed from the comfort zone of human beings. Because there is always an interaction between the outer weather states and the air inside the shelter, it is proper to regard the indoor conditions as a special type of microclimate, although some prefer to call it a cryptoclimate.

Housing, if properly constructed, generally eliminates completely all hydrometeors and offers protection from the hazards of lightning. It is usually designed to withstand all but the strongest wind forces; only tornadoes and hurricanes are apt to produce major damages.

Indoor microclimate is determined by the following elements : illumination, temperature (air, wall, floor, ceiling), air motion (draught), relative humidity and vapour pressure, ionization, character of gaseous and solid admixtures to the air. Simultaneous outdoor observations desirable for comparative purposes are air temperature and humidity, solar radiation, cloudiness, wind speed, cooling power, outside wall and roof temperature. Useful for indoor measurements are the Assmann psychrometer, the katathermometer or frigorimeter, windmill type or hot wire anemometers, thermocouples or thermistors for temperatures of surfaces, nuclei and dust counters and gas analysers (Bradtke and Liese, 1952).

Architectural design in various climatic zones is (or at least ought to be) closely related to the climatic environment (Aronin, 1953). In sunny climates small windows and shading devices are called for. Often high buildings with flat roofs in relatively narrow streets expose a minimum amount of surface to the solar radiation. Homes with central patios and shade trees offer comparable advantages. In hot climates properly constructed roofs with adequate natural or artificial ventilation are essential to avoid excessive heat loads. Considerable control of radiative processes in daytime can be accomplished by choice of construction materials and paints. Dark surfaces absorb heat, whereas light surfaces and paints reflect incoming radiation. At night little difference exists in the emissivity of structural materials. Foliage of plants, such as ivy, can also act as interceptor of incoming radiation.

In bright sunshine dark walls and roofs, depending somewhat on wind speeds, can readily have temperatures 15° to 20°C above air temperature. In contrast reflecting surfaces (white paint, fresh aluminium paint, whitewash) will show only from 3° to 7°C higher temperature than the air. An ivy-covered brick wall, exposed to the sun, will only show a temperature excess of 6°C under the foliage, but 10° to 12°C where the wall is bare.

In climates with wide fluctuations of temperature thick walls or insulation with material of poor heat conductivity will mitigate both diurnal and aperiodic swings of temperature. Double windows will reduce heat losses in climates requiring artificial heating. The latter is generally required in areas where outside temperatures drop frequently and for prolonged periods of time below 17°C. Similarly artificial cooling is desirable for temperatures above 32°C, especially if humidities are high. This cooling is now usually produced by refrigeration machinery but where temperatures are high and outdoor humidities are low evaporative cooling may be practical if water supplies for this purpose are available. Cooling is especially indicated for hospitals. It is particularly beneficial for persons with heart and circulatory ailments. In many cases filtered air is indicated for individuals with allergies involving dust and pollen.

The zone of comfort, although somewhat different from one person to another, according to their metabolic rate and the type of clothing worn, comprises a relatively narrow band of temperature, wind speeds, and humidities. With low ventilation the following pairs of values constitute approximate limits of sultriness feelings in normal human beings : 20°C, 85 per cent relative humidity; 25°C, 60 per cent; 30°C, 44 per cent; 35°C, 33 per cent.

In heated houses or apartments, even in cold weather, a certain minimum amount of ventilation is required. Modern space standards require 10 to 12 m^3 per person with a ventilation rate of about 250 litres of air per minute. This corresponds to around 1 1/2 complete air changes per hour. There is in normal construction usually enough leakage of air through walls, window frames and doors to accomplish this. The air change serves to eliminate accumulations of odours and gases, especially CO_2, produced by occupancy. In dwellings where gas or other fuels with open fires are used for heating and cooking dangerous accumulations of CO may occur and require forced ventilation. This is especially true for kitchens where other fumes also develop and excessive heat may be produced. CO concentrations have to be kept below 0.1 parts per million.

Under conditions of outdoor stagnation and a high load of polluting substances, scrubbing or filtration of incoming air may be needed in order to keep obnoxious substances out of houses. This can often simply be accomplished by placing wet sheets over openings. Nebulizing of water is also beneficial in settling dusts and some vapours that may have penetrated indoors. Aerosol loads are generally higher indoors than outdoors, especially in the size range of condensation nuclei. These run in occupied rooms without artificial ventilation about twice as high as outdoors; in rooms where smoking takes place or in kitchens the number can rise to levels 10 to 20 times higher than outdoors. Many of these nuclei are positively charged heavy ions. For coarse dust in contaminated city atmospheres indoor values are generally half of those outdoors. Offices, by virtue of location and use, usually have higher values than homes. Ventilation is not always the best remedy to exchange stale indoor air because the outdoor air may not only contain a higher number of particles, it may also stir up particles which had settled on the floor. This especially is the case when the outdoor air is cold and rushes in at high speed. It will then lift warm air from the floor and in the process raise large numbers of dust particles. This method of airing also contributes, incidentally, to the temperature inversion commonly found in rooms, with low temperatures at the floor and high temperatures near the ceiling. Modern air exhaust systems high up in rooms and proper arrangements of heating and cooling devices can remedy this situation (Brezina and Schmidt, 1937).

Many tests have shown that the number of inert dust particles is almost paralleled by the counts of airborne bacteria. Typical examples show the lowest concentration of these in the open air of rural areas. In the air of industrial regions the numbers are 3 to 5 times larger than in the rural zone. Homes in areas of low contamination generally have an indoor value of twice the amount found outdoors. In crowded trains, offices, and schoolrooms the bacterial counts are usually 5 to 10 times higher than outdoors.

This situation reflects several atmospheric phenomena. One is, of course, the prevalent diffusion, turbulence, and fallout outdoors. Equally, or perhaps even more, important is the disinfectant value of the solar ultra-violet radiation which is completely excluded in indoor environments. In general, natural illumination indoors, even in bright rooms,does not exceed 5 per cent of the outdoor values and, hence, has to be supplemented in many home and work environments by artificial light.

Temperatures can be regulated indoors through a wide range. Thus it is usually found that the diurnal and annual range of temperature indoors is much smaller than outdoors. This is primarily a consequence of higher minima indoors. Even without mechanical heating and cooling devices a building introduces a considerable element of inertia and indoor temperature variations will always lag at least several hours behind outdoor changes. In basements and cellars this lag may be as long as a whole season. This is also well reflected in the fact that bedrooms with an open window at night never reach the minimum temperatures attained outdoors. The temperature difference is usually larger in the cooler season, even if no artificial heating is used, than during warm seasons. Under hot or tropical conditions comfort can often be had through adequate air speeds provided by artificial ventilation. This will raise the cooling power and permit evaporative cooling of the skin. Under extreme conditions, especially with high humidities, mechanical cooling is the only remedy (Landsberg, 1954).

Humidities are generally lower indoors than outdoors, except in rooms where steam-producing operations (such as laundering) take place. This, as well as a number of other properties of indoor environmental conditions, can be best visualized by the use of a temperature-humidity diagram. One type is reproduced in Figure IV.1. It has as major

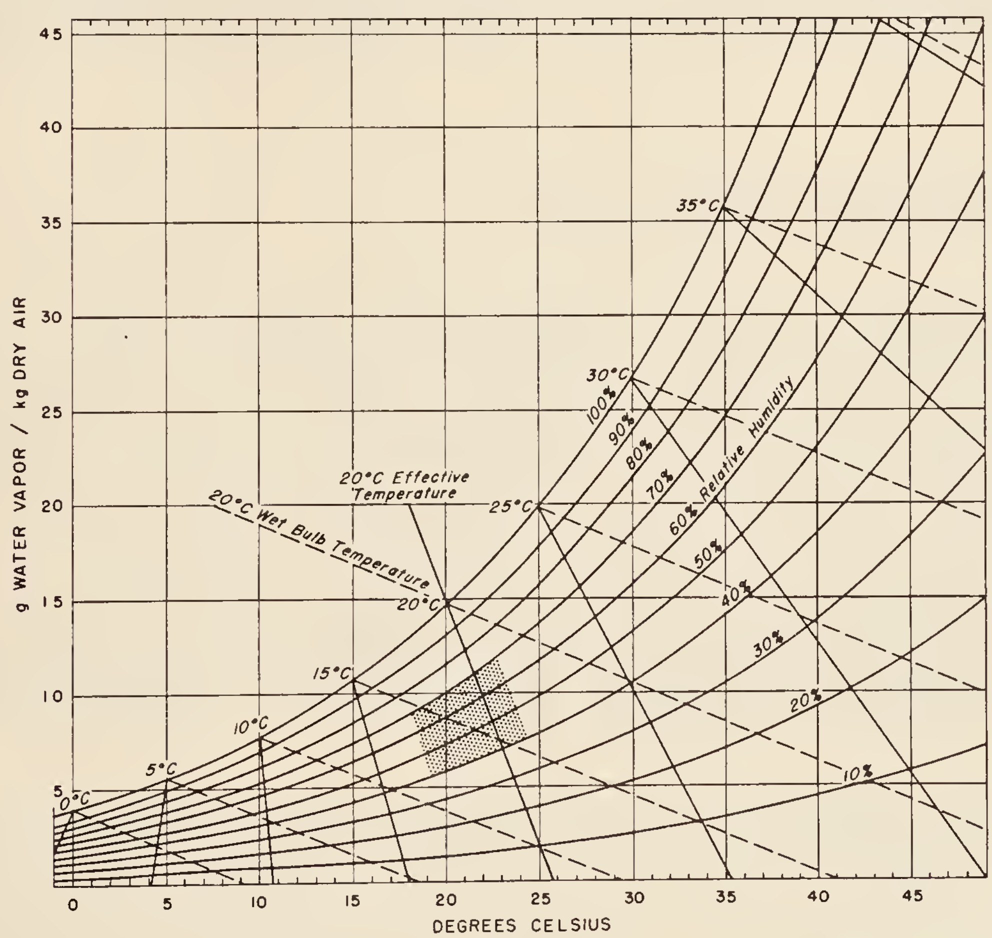

Figure IV.1 - Temperature-humidity diagram

co-ordinate axes the mixing ratio, in g of vapour per kg of dry air, and the dry-bulb temperature °C as abscissa. The curved lines represent the relative humidity in per cent, the slanting lines with shallow slope are wet-bulb thermometer readings and the steep slanting lines are so-called effective temperatures (ET). This term does not designate an actual temperature but is an index which combines temperature, humidity and air motion. It is equivalent, for any combination of these elements to the sensation felt at an identical temperature with calm air and saturation. Effective temperatures around 20°C are considered to represent optimal comfort conditions. On the diagram the usually accepted comfort zone for indoor conditions is cross-hatched. In first approximation, the effective temperature can be obtained from the dry- (t_d) and wet-bulb (t_w) temperature readings, in degrees Celsius, by the formula :

$$ET = 0.4\ (t_d + t_w) + 4.8$$

A diagram of the type shown in Figure 1 also permits an estimate of the change the relative humidity will undergo between outdoors and indoors. If outdoor temperature and humidity and the indoor temperature are known, the indoor humidity, resulting from air exchange, can be derived. This is based on the fact that, if no additional moisture is provided from other sources indoors, the mixing ratio stays constant. For example, for a 5°C temperature and 90 per cent relative humidity outdoors, the mixing ratio is 5g/kg. If the air is warmed indoors to 20°C, at constant mixing ratio (i.e. follow horizontal line 5g/kg in diagram to intersection with dry bulb 20°C abscissa) the relative humidity, corresponding to this set of conditions is found to be about 35 per cent. The extraordinary low relative humidities indoors during the heating season in cold climates are, of course, a well-known phenomenon and one of the most important biometeorological changes produced by dwellings. Conversely an air of high mixing ratio introduced into a cooler inside environment can lead to condensation. This is a condition often found in basements. For example, an outdoor temperature of 25°C with 50 per cent relative humidity (mixing ratio 10g/kg), will result in saturation by cooling to 14°C. This can lead then to the hygienically undesirable condition of mildew.

2. EFFECTS OF NATURAL RADIATION ON MAN

Natural radiations from sun, cosmos, and earth span the wide spectral region from about 10^{-8} to more than 10^{10} cm or from X-rays to very long radio waves. Of these waves, only a few can penetrate certain spectral windows in the otherwise impenetrable atmosphere. Oxygen and ozone absorb all rays below about 0.29 μ. The decrease of solar emission and absorption by water vapour define the upper limit of the solar spectrum near 3 μ. About half of this spectrum is in the visible region, half in the near or solar infra-red. The ultra-violet portion contains only a small fraction of the solar flux. The next window around 4 μ finds no substantial source except in fires and other hot sources. Above 5 μ, the surfaces of man and earth begin to emit radiant heat. The maximum of this emission coincides with the third window of atmospheric transmission situated at 8-14 μ. It is this window which permits measurement of earth and cloud temperatures from weather satellites. A fourth window extends from the millimetre to the metre radio range. This region is closed at the lower end by O_2 and H_2O absorption, and at the other end by ionosphere reflection. This region seems to be of no biological concern.

This leaves us with solar radiation and the long infra-red of our own emission. These rays can (1) heat or cool, and (2) cause photochemical effects. They will do this where they are absorbed, i.e. neither transmitted nor reflected. The avenues of entry are the skin and the eye.

Reflection of human skin is restricted to the visible and nearest infra-red. Up to 40 per cent of solar radiation is reflected by white skin. This reflection constitutes a substantial lessening of heat load for white skin as shown by the faster skin temperature rise of black than of white people suddenly exposed to sun. Reflection of ultra-violet (UV) as well as long infra-red (IR) is minute. Only visible and near IR are transmitted beyond the epidermis; thus solar heating occurs, in part, in the dermis and deeper layers. UV and far IR are absorbed mainly in the horny layer.

High sun through clear air creates about the same heat flow of 1.2-1.4 cal $cm^{-2}min^{-1}$ irrespective of latitude. This radiant heat is fully available to an absorbing surface perpendicular to the sun. Human heat balance consists of gains from metabolism and absorbed solar and long IR radiation, and of losses from outgoing IR, convection and evaporation.

If conditions are too hot and moist, the sun adds to the total heat load. This may lead to heat-strokes, of which the formerly dreaded sunstroke is but a subportion. The head is not more heat sensitive than the rest of the body; the topi or tropical helmet is outdated. Regions of brightness necessitating the use of dark goggles are subtropical deserts and snow fields with clear skies. Tropics and moderate latitudes are less afflicted.

Spectral vision is restricted, at the ultra-violet end, by absorption and scattering in the lens and at the red end by the energy of the light quantum. UV near 0.3 μ causes temporary photochemical inflammation of the eye's cornea. Normal glass windows or glass spectacles protect adequately. This damage is often caused by solar UV reflected from snow. The effect is absent over water since its reflection is high only when the sun is low and thus deficient in UV.

Photochemical actions of the skin are : (1) Vitamin D creation, (2) sunburn, (3) delayed pigmentation, (4) strengthening of the horny layer, (5) immediate pigmentation, (6) early ageing of the skin, and (7) skin cancer. The first two are caused, in nature, by a very small spectral band around 0.3 μ and (3), (4), (6), and (7) are frequent consequences of (2). Only (5) is caused by the long UV around 0.36 μ.

The anti-rachitic Vitamin D_2 is made from natural sterol by UV of $\lambda < 0.31$ μ. This occurs in plants, animals, and men at layers close to the surface. This vitamin is now easily available in food or as a drug. UV may still be important where the vitamin is not readily absorbed by the intestines. Some of the poorly defined health effects of UV irradiation are claimed to be based on Vitamin D production in human skin.

Natural sunburn stems from solar UV around 0.3 μ which penetrates the horny layer and creates a capillary dilating substance in the deeper, living skin layers. The substance is unknown. Since UV action is direct, the time between UV application and visible skin reddening is short. Artificial UV from a mercury lamp contains mainly waves below 0.3 μ which cannot penetrate the horny layer but create another dilating substance in this layer. This substance diffuses into the deeper layers, a process which takes many hours.

Unadapted white skin exposed to a clear June sun at noon at about 50° latitude will show the first trace of reddening after 3 to 20 minutes of exposure. Saturation reddening which corresponds to 10 per cent decrease of reflection of blue-green light is reached after 30 to 70 minutes of exposure. Larger doses yield painful reddening, oedema, and finally, blisters. Blond people react faster and stronger than brunettes; darker races are nearly immune.

The erythema-producing UV is strongly altered by solar altitude and clouds. As a rule more than half of it comes in the form of scattered sky light. For the same solar altitude and with clear sky this UV does not vary much from seashore to land or city; neither the UV dose arriving nor the sunburn produced is different, on land, between 50° latitude and the equator. The increase with height is usually exaggerated. At 60° solar altitude this UV is 45 per cent higher at 3500 m compared to sea-level. A rise of the sun from 40° to 60° above horizon, however, nearly doubles this UV for all stations between sea-level and 3500 m. If noon height of the sun is below 30°, the chances of sunburn become small.

Snow is the only important natural reflector for this UV and causes sunburn under the nose and chin as well as of the eye's cornea. Window-glass, most dry clothes, and vegetation completely attenuate these rays,but most plastics, including many of those used for ski-ing goggles, are permeable.

Protection against sunburn is provided by (1) lowering the dose applied, i.e. shortening exposure time at high sun and clear sky, (2) natural thickening of horny layer, in many people, by UV action, (3) some of the pigments produced in skin, (4) window glass, and (5) skin creams which absorb below 0.32 μ.

Overdose of solar UV leads quickly, after exceeding the minimum reddening dose, to severe erythema,oedema and blistering. Frequent exposure causes early and irreversible skin ageing in the form of wrinkling and loss of skin elasticity. These phenomena are pronounced in blond individuals. Finally, they may be instrumental in producing skin cancer which is restricted to the frequently exposed areas like face and neck, and which is more prevalent in blond people working outdoors.

None of the above UV induced phenomena, except skin reddening, can easily be reproduced with wavelengths below 0.28 μ which do not occur naturally on earth. UV effects caused by mercury lamps and other artificial sources having spectra different from that of the sun have little bearing on solar UV effects. In general, the solar type UV is more dangerous than the shorter wavelengths of artificial origin.

All tests of UV effects on somatic and psychic effects on man, except for the skin, have been made with short-waved UV. All observations on natural sunbaths are coupled with effects of vacation, exercise or rest, temperature stimuli, massage, etc. Natural UV may be beneficial, but nobody has shown it accurately. Damages from UV, however, are well substantiated.

Very short UV mutate or kill certain bacteria and viruses. Whether the same is true for solar UV seems doubtful.

For a more detailed consideration of these topics the reader is referred to the following references : Blum (1955); Buchanan, Heim and Stilson (1960); Buettner (1938); Buettner and Pfeiderer (1940); Howell (1960); Meyer and Seitz (1942); Ronge (1948); and Renbourn (1956, 1962).

3. THE INFLUENCE OF HEAT, HUMIDITY AND WIND ON HUMAN FUNCTIONS

There are three levels of function at which man is affected by the environment. First, there is the purely physical reaction by which the surface of man accepts or rejects the forces of the environment. There is then the physiological response of the body to changes at the surface, transmitted inward directly or through the nervous system. This leads to adjustments of function through reflexes or by consciously controlled activities, together with endocrine changes. The third level is that of cellular and metabolic adaptation.

Since few naked human groups remain it seems most useful to consider man as having an insulating layer of clothing over 80 per cent of his surface. There are then three components to be considered. The first is the surface of clothing with a layer of air between it and the skin. The second is the shell of the body, that is the skin and its subcutaneous tissues through which heat must pass inwards or outwards. Beneath that is the core of the body in which most of the energy of metabolism is released and where heat may be stored. Since clothing is to be dealt with in another section the main considerations at present will relate to the responses of the organism to whatever reaches it through the clothes or directly through the skin.

Physical processes

Heat, atmospheric water vapour and air movement all affect the thermal balance of the human body.

Radiation is accepted or rejected by the skin according to its surface properties and colour. Black skin absorbs up to 44 per cent more solar energy than white skin (Heer, 1952) but the horny layer of white skin transmits 3.5 times more ultraviolet light than that of Negroes. On the other hand, the colour of the skin makes no difference to the radiation outwards from the warmed surface since the long-wave output from the skin is essentially that of a black body at 32°C, whether the skin colour be white, yellow or black. The main wavelengths emitted from the human body are in the far infra-red, at 6 and 9 μ (range 2 - 14 μ) (Hardy and Muschenheim, 1934).

When the skin is smooth, greasy or wet, the reflectivity of the skin is increased so that more physical rejection of short-wave energy takes place. Nearly all reflection has a wavelength of less than 1 μ.

In the sun, orientation, posture and clothing greatly modify the amount of absorption of radiant energy. Radiant energy may reach 1,000 kcal/m^2/hr from the sun near its meridian, together with sky radiation. The human albedo is low but the gain of solar energy is not often above 250 kcal/m^2/hr. Long-wave radiation from heated ground is also absorbed. The heat passes in through the skin the thermal conductivity of which is estimated to be 1.5×10^{-3} cal/cm/sec/°C.

Two forms of convection occur. In still air the skin surface is likely either to heat or cool the air which rises or falls to replace the surface film of air around the body. Forced convection of wind replaces air proportionally to the velocity of the wind. If the wind is at a higher temperature than the body surface, heat will be gained by convection and conduction. If the wind is much cooler than the body surface it increases the energy discharged and may reach a level where wind chill occurs.

Thermal balance is the sum of metabolism $\pm$ radiation $\pm$ convection $\pm$ heat storage - the work performed - vaporization. At rest in a neutral environment all these factors neutralize each other and there is thermal equilibrium, which is likely to be comfortable.

Comfort

Comfort is a feeling state in which a subject has no wish to increase or decrease insulation or to adjust the ambient thermal environment. Most people are comfortable in bed with an air temperature under the bed-clothes of 30°-31°C. Similarly the air layer under street clothes maintains an average skin temperature of 31°-32°C. It is possible to be comfortable, however, even though some parts of the body are at a lower temperature than the average. The feet, hands, nose and ears are usually, during thermal comfort, several degrees below the temperature of the trunk. A sense of freshness is induced when the skin temperature is a little lower than that for warm comfort and the feet in particular may reach temperatures around 25°C, and the hands and nose about 28°C, in the cooler range of the comfort zone.

Tropical peoples accept as comfortable considerably higher levels of air temperature and humidity than are accepted by temperate zone groups. Outdoor workers also tolerate higher temperatures than sedentary indoor workers. Adults at rest appropriately clothed for the environment and not exposed to solar radiation nor to relative humidity above 50 per cent have the following modal comfortable dry-bulb temperatures : cool temperate zone 17°C, temperate zone 23°C, subtropics 25°C, tropics 27°C. It appears that tropical people accept some sweating as a component of comfort. Increase of insulation,work - or radiation-load - lowers the comfort zone.

The effective temperature index used in comfort studies attempts to integrate dry-bulb or globe thermometer temperature with wet-bulb and air velocity. The effective temperature was standardized by subjective comparison of the effects of saturated atmospheres. Probably too much weight has been given to humidity at lower temperatures and to air movement at higher temperatures (Macpherson, 1960).

Thermal imbalance

Imbalance may occur because of changes of metabolic rate or of the thermal environment. This leads to subjective discomfort and to physiological adjustments.

Heat gain is recorded at the skin surface by thermally sensitive receptors. These receptors have no specific anatomical features; they are simply bare nerve endings located in the deep layers of the skin. Some nerves concerned with temperature regulation are stimulated only by wide changes in temperature, others respond to small (0.2°C) gradient changes (Hensel *et al.*, 1960). The difference in temperature between the surface and a zone 1 to 2 mm deeper determines the discharge of thermal receptors. Some receptors react to an outward, others to an inward, thermal gradient. As more heat is applied to the skin, the temperature rises and the frequency of reaction of the nerve cells increases. When the skin surface reaches a temperature of 45°C, pain is felt (Hardy, 1962).

The least thermal increment of skin temperature discriminated by the brain on the information coming from peripheral receptors is less than 1°C. This discrimination depends upon the type of skin involved and the temperature of that skin. If skin is cooled to 4°C the just noticeable difference of temperature is 9°C. When the skin is at 28°C, on the other hand, 0.5°C change can be discriminated, while at a skin temperature of 40°C the noticeable difference is 1°C.

Once afferent nerves have been stimulated, reflex changes occur to adjust the organism to near thermal neutrality, or the perceived temperatures lead to deliberate modification of the environment. Reflexes are mobilized to increase the convection of blood through the skin and increase the potential evaporation from skin. Vasodilatation and sweating do not necessarily go together. If one part of the skin is heated, there is reflex vasodilatation of that zone, together with a spread of increased blood flow to other parts of the skin. The face warms first, after that the hands, and finally the feet become warm by increased blood flow. When all superficial arterioles and capillaries are dilated, the average skin temperature reaches about 33°C. During vasodilatation, heat from the core of the body is brought to the surface where it is dispersed. The output of blood from the heart increases as the peripheral vascular bed enlarges. Vasodilatation reduces the effective insulation offered by the body shell to one-fifth of the maximum insulation during vasoconstriction.

Sweating is reflexly initiated by skin temperatures above 36°C or by 0.2°C rise in the temperature of the heat regulatory centre located in the hypothalmic portion of the brain. There are about 2.3 million eccrine sweat glands in man. Reflex centres concerned with stimulating these glands are located in the spinal cord, in the medulla or through the main control centre of the hypothalamus (Kuno, 1956). It is probable that some cortical influence is also exercised on sweating. A local skin temperature of 28°C inhibits sweat secretion.

The secretion of sweat is not continuous from any one gland. There is activity for a few seconds and then a period of non-secretion. Sweat is a modification of the extracellular fluid of the skin, having less sodium but more potassium and lactate than plasma. Protein is left behind and a watery solution of about 30 to 150 milli-osmolal concentration containing 0.3 per cent to 0.8 per cent solids is secreted. Most of the heat involved in evaporating sweat water comes from the skin, although a little comes from the air if convection is high. The latent heat of evaporation removes thermal energy from the blood which convects heat to the surface. Human sweat rates may reach 3 litres per hour for short periods but in sustained work they rarely exceed 1.2 litres per hour.

The weight lost in sweating during four hours has been used as an index of the physiological strain produced by work in hot environments (Macpherson, 1960). Correction of this index by using, as an exponential function, the ratio of actual to maximum possible evaporation has given the sweat rate better predictive value for assessing thermal stress (Givoni and Belding, 1962).

Water and salt

The process of cooling the skin by sweating has a number of physiological consequences. Water is lost from the body by sweat at three to six times the rate that solids from the extracellular fluid are secreted. Water is drawn first from plasma and extracellular fluid, and later, if not replaced, from cells. In unacclimatized people there is more loss of sodium by sweat than in acclimatized subjects. Sweat sodium falls from 60 - 90 milli-equivalents per litre to 5 - 15 mEq/l. in acclimatized subjects. Sodium depletion results in compensatory physiological changes. The extracellular fluid becomes concentrated but as the sodium content is lowered the volume of fluid that can be retained is reduced. Two consequences follow. First is retention of sodium as well as water by the kidneys. The initial action seems to be intrinsic to the kidneys. Greater loss of salt and water activates the adrenal gland; the hormone aldosterone released causes the kidney to reduce the rate of urinary excretion of sodium. Aldosterone also influences the amount of sodium present in sweat. It seems likely that the low sodium content of sweat in acclimatized subjects is the result of successive episodes of aldosterone release during sweating.

A further endocrine adjustment involving the adrenal gland is a reduction in the excretion of the corticosteroid hormones (17-hydroxycorticosteroids and 17-ketosteroids). This adjustment occurs on acute exposure and it appears also with seasonal temperature changes. Steroid excretion is high in winter and low in summer. Probably this pattern of steroid excretion is bound up with the reduction of metabolism during exposure to heat (Macfarlane, 1963).

The thyroid gland provides the third component of endocrine responses to heat gain. In man the evidence for thyroid depression in summer is not as substantial as it is amongst other animals. This probably comes from human avoidance of uncomfortable conditions, relative to the exposure of animals to the environment. There seems to be little doubt, however, that energy output and thyroid activity in man at rest are reduced by 10 to 15 per cent in the tropics relative to temperate zones; and in the temperate zones during summer relative to winter. This lower production of chemical energy means that less heat need be dissipated by evaporation. In addition, the nervous system contributes to lowering heat production by reducing the drive towards severe muscular exercise and in fact increases the reluctance to perform tasks rapidly or to do more work than necessary.

The distribution of blood from the core of the body to the skin during heating seems not to affect other functions unduly. The upright posture of man, however, results in some pooling of extracellular fluid in the dependent parts, particularly in feet and hands. Swelling of the feet is normal in hot environments and this leads to a sense of turgor and discomfort. In the heat leg veins distend and the flow of blood towards the heart is reduced. This vascular behaviour accounts for the fainting often found in unacclimatized subjects standing in the sun without moving. If blood does not return in sufficient quantity to the heart the cardiac output is reduced, blood pressure falls and unconsciousness supervenes. The subject than lies horizontally and restoration of circulation automatically follows.

Cold

When the surrounding walls or earth and sky are cooler than the skin there is radiation from skin to these regions. A cold sink therefore feels cool from a distance. Cold air convected over the skin also removes heat directly and cold receptors are stimulated. Reflex constriction of peripheral blood vessels follows. This occurs first in the feet, then in the hands and later in the face and trunk. Blood flow through the skin of the nose is reduced more than that of the lips and cheek. Ears are also perfused less actively and all these regions become liable to frostbite.

Blood is redistributed from the skin to the core of the body so that the effective insulation of the body shell is increased. Vasoconstriction leads to increase of insulation since heat flow is reduced when blood flow is low. Insulation by the skin rises from 0.15 clo in warm skin (maximum vasodilatation) to about 0.8 clo in cold skin (maximum vasoconstriction), so that cold feet are insulating against heat loss. The clo unit of insulation is equivalent to the clothes normally worn for office work. 1 clo = 0.18°C m^2 hr $kcal^{-1}$, that is the insulation that will permit 1 kcal to pass per square metre per hour when the skin-air gradient is 0.18°C. Still air has an insulating value of about 1.0 clo. Wind reduces the insulation of air to 0.15 clo. In arctic conditions up to 5 clo may be worn (Newburgh, 1949). Wind, therefore, does not cool well-clothed men even at gale force. Light clothing of 1.0 clo insulation allows rapid cooling in cold air with high wind, and death has often been reported within one or two hours from such exposure, especially when exercise ceased.

Fat also contributes to lowering conductivity, although not as much as was originally thought. Adipose tissue appears to have a considerable blood supply and its insulation is only about twice that of skin or muscle (Burton and Edholm, 1955).

The sensation of cold is recorded in the thalamus and cortex, and this may give rise to action designed to evade the cold. Another line of defence is to increase internal heat production, either by increased muscle tone and shivering or by non-shivering thermogenesis (heat production by chemical processes independent of muscular action). Shivering is a reflex response to cold and it comprises phasic twitching of muscles at 4-12/sec with little external work being performed. It is initiated by skin afferents when the mean skin temperature is 26° to 28°C. This encourages the production of heat by burning carbohydrate. Its efficiency in protecting against heat loss is about 11 per cent. Shivering is not continuous but is intermittent. If a subject is distracted or makes a voluntary effort, shivering can be stopped temporarily. Shivering is also inhibited by low oxygen pressure or raised carbon dioxide, as well as by such agents as magnesium, insulin and aspirin which seem to act centrally. In addition to an increase of heat production by shivering there is chemical thermogenesis without muscle action. This seems almost certainly to be due to adrenalin released from the adrenal gland. In people highly acclimatized to cold, non-shivering thermogenesis adequately supplies heat at temperatures where unacclimatized people shiver violently. The third method of thermal compensation for heat loss in the cold is through the endocrine system. The thyroid is activated through the pituitary gland to release the hormone thyroxine which in turn increases the rate of metabolism. The output of adrenal corticosteroid hormone is increased in the cold also and this is probably concerned with the metabolic processes which release energy.

Habituation and acclimatization

Human subjects moving from one thermal environment to another make a series of adjustments. For both heat or cold the initial phase of resetting body temperature regulation and vascular control takes place in four or five days. Endocrine adjustments begin during that time and reach new levels in two or three weeks. Judgements of comfort, however, may require years before they are fully adjusted to the new environment. Peoples indigenous to hot or cold climates are moderately well acclimatized although the highest level of such adjustment is not reached except by very severe work in the heat or by long exposure to the cold with little clothing (Macpherson, 1960).

Habituation appears to be the inhibition of the reflex responses to heat or cold. This can occur in the spinal cord without reference to the brain. The best examples of habituation are the ability of arctic fishermen to manipulate their lines in freezing conditions without feeling distress. Another is the ability of aborigines to sleep when the skin temperature is low enough to be grossly uncomfortable to urban Europeans or the skin so hot that sleep is not possible for unacclimatized people. Glaser et al. (1959) have shown that if one hand is thrust into ice-cold water for five minutes each day the reflex rise of arterial blood pressure ceases after about 9 to 15 days. At the same time there is a reduction in the subjective sensation of cold until at least the painful component of cooling is lost. It is possible to become habituated to hot and to cold stimuli at the same time if they alternate. In habituation to cold, the slowly acquired inhibition of shivering was demonstrated by Davis and Joy (1962). At 13°C for eight hours daily, five men dressed in shorts shivered continuously in the first week of the experiment. After 30 days they almost ceased to shiver during the daily exposure. Without further habituation this inhibition of shivering persisted through 11 monthly tests.

In spinal cats* it has been shown that daily exposure for five minutes to heat or cold for 30 days after habituation has occurred, leads to retention of the inhibitory reflex pattern (Kozak, Macfarlane and Westerman, 1962). This proves evidence that the nervous system at the level of the spinal cord is modified so that it retains information of previous heat or cold if stimuli have been repeated sufficiently often. This type of memory is not cortical but can occur in the spinal cord. These phenomena probably account for the rapid adjustment of function and feeling made by a cold-temperate subject when he returns to a cool environment after years spent in the tropics (and vice-versa).

Vapour pressure

The humidity of air is important in achieving thermal balance as well as in determining subjective responses to the environment. When evaporative cooling is initiated, that is in man at rest, clothed at air temperatures above 25°C - although significant sweating does not usually occur until about 28°C is reached - the vapour pressure of the air determines the effectiveness of evaporation from the skin. The rate of evaporation is reduced as the water vapour gradient from the skin to air decreases. Vapour pressures above 15 mm Hg (20 mb) become increasingly unpleasant at temperatures over 25°C. In saturated air, sweat is of no use for cooling. In the humid tropics a great deal of sweat is produced without removing heat, since it drips from the body. On the other hand, in low humidities such as those of the desert, sweat evaporates as soon as it is formed and leaves a crust of salts and urea. The sensation of comfort is, therefore, strongly influenced by the rate of evaporation. The skin temperature is a function of this evaporative rate.

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* A spinal cat is an experimental animal in which an operation has been performed so that the brain and spinal cord are surgically separated.

In cool air, also, water vapour affects subjective sensations. At temperatures between 25° and 18°C moist air is distinguished quite readily from dry air. This discrimination is best made at temperatures over 18°C. At lower temperatures less ready discrimination occurs until there is relatively little at an air temperature of 4° to 5°C, when skin receptors and perception fail to distinguish air of 5 per cent relative humidity from air of 30 per cent relative humidity. On the other hand, discrimination can be made between 30 and 70 per cent saturation at near-freezing temperatures and this ability is increased with increasing air temperature. The sensitivity to vapour pressure is most marked, however, when sweating begins, in warm air.

Another aspect of humidity in relation to cold is the subjectively greater apparent cooling power of wet cold air for clothed men than dry cold air. In men without clothes dry cold air caused more shivering and a greater feeling of cold than damp cold air. Wet cold alters the behaviour of clothing, but dry cold could act by drying skin and altering its thermal conductivity.

In meteorological practice, relative humidity is usually recorded. This has a reasonable correlation with human responses to the atmosphere. In the process of evaporative cooling, however, it is the difference in vapour pressure between the surface water of the skin and the air that determines the effectiveness of cooling, and records of vapour pressure are of greater value than relative humidity.

Convection

In the cold deserts of the Antarctic and the hot deserts of the subtropics wind blows almost continuously and it is of considerable thermal importance. In the hot zones it is desirable to let as much wind as possible make contact with the air sheath round the body to remove heated moist air and to encourage evaporation. Desert winds at an air temperature of 38°C or more add heat by conduction, but they encourage evaporation also. In a cold environment, however, the opposite holds. An impermeable insulating layer prevents movement of the warmed air sheath and economizes heat. The disadvantage of too great impermeability of clothing is that if the subject should sweat during work, the sweat freezes inside the wind-proof clothing. A compromise is necessary, in which some air movement takes place to remove surplus water vapour, but not sufficient wind penetrates to dissipate too much of the heat of the insulating air.

In a cold environment sweating occurs with exercise, and the skin temperature in these conditions is much cooler than during thermal sweating. Emotional sweating also has undesirable consequences since it is greatest on hands, feet and forehead, where sweat is readily frozen. A skin temperature of -5° to -10°C (supercooling) is necessary before the skin is frozen.

The amount of heat carried away from the surface of the skin is directly proportional to the square root of the speed of the wind and to the temperature gradient between skin and air. Wind chill is a powerful cause of frostbite to nose and ears as well as to penis and digits.

In addition to the convective component of the wind there is of course direct pressure which is received by mechanoreceptors of the skin. Such compression of the skin is usually not unpleasant unless the wind contains snow, hail, rain or dust. In the cold and hot deserts these suspended materials are frequently present and add abrasion to the hazards of the environment.

4. THE INFLUENCE OF REDUCED PARTIAL OXYGEN PRESSURE IN THE ATMOSPHERE

Every living organism whose metabolism depends on the consumption of oxygen is naturally acclimatized through generations to the particular partial oxygen pressure of the ambient air of its habitat. The physiological functions are in a steady state of harmonious integration in these organisms whatever the partial pressure of oxygen may be. This applies to animals and to men native to sea-level as well as to high altitudes. The situation is quite different, however, if organisms from low altitudes to which they are naturally acclimatized ascend to high altitudes where they find a decreasing oxygen pressure with increasing height. Since oxygen is less readily available at high altitudes, numerous adaptative mechanisms are activated to supply the tissues with the required amount of oxygen. The significance of these adaptative mechanisms is to readjust the impaired efficiency of the body due to the shortage of oxygen in the new environment. Many investigations in man and animals have proved that there is neither an increased nor a decreased oxygen consumption at reduced oxygen partial pressure under standardized conditions of rest and temperature (basal metabolic rate). Therefore, the impairment of the body's efficiency is entirely due to the poor availability of oxygen to the tissues.

A high altitude environment as compared with sea-level (ambient oxygen pressure c. 150 mm Hg) includes, besides the reduced partial oxygen pressure, a lower mean temperature and relative humidity, stronger winds and radiation and a lower ion content in the air. Although all these factors contribute to the change of the biosphere, and in this way to the environmental stress, no doubt exists that the reduced partial oxygen pressure is the most important factor.

The adaptative mechanisms to reduced oxygen pressure (PO_2) are generally classified into two groups :

(a) Those which act along the PO_2 gradient (drop of the partial oxygen pressure between inspired air - alveolar air - arterial blood - mean capillary blood - mixed venous blood).

(b) Those which are present at tissue level and which are related to the cell wall and chemical and enzymatic processes of internal respiration (oxygen consumption).

The drop of the partial oxygen pressure between ambient air and mixed venous blood measured on men fasting and in a recumbent body position is different in natives of sea-level and of high altitudes (Figure IV.2). A high degree of economy exists in the naturally acclimatized natives of high altitudes because the total drop of pressure is much less in these than in natives of sea-level. This economy is attained through several adaptative mechanisms :

(1) Increased sensitivity of the respiratory centre to partial CO_2 pressure in the blood,

(2) Increased pulmonary ventilation,

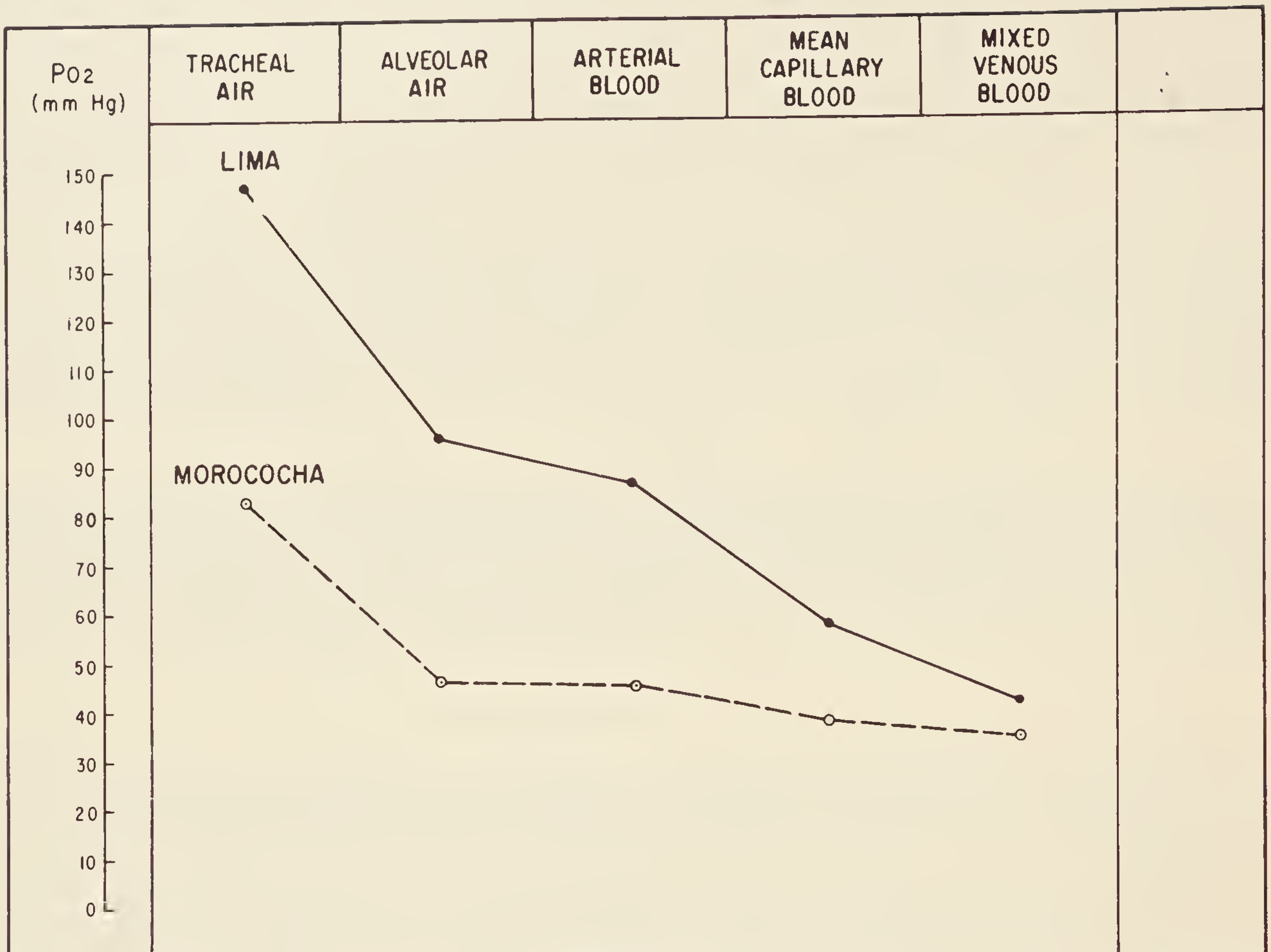
(3) Decreased alveolo-arterial oxygen gradient, which is a greater oxygen diffusing capacity,

(4) Increased production of erythrocytes with increased percentage of red blood cells in the blood while the plasma volume is normal or slightly reduced,

(5) Decreased affinity of haemoglobin for oxygen,

(6) Decreased blood buffer base (bicarbonate buffer) to compensate the decreased partial CO_2 pressure.

The heart rate is increased after ascent but soon normalizes and is decreased after one year. Since the cardiac output also declines there is a decline of the stroke volume.



	MEAN ± S.E. (mm.Hg)						TOTAL DROP
LIMA	147.0 ± 0.09	96.2 ± 0.55	87.3 ± 1.58	57.2 ± 0.46	42.1 ± 0.53		
	50.8	8.9	30.1	15.1		=	104.9
MOROCOCHA	83.4 ± 0.09	46.7 ± 0.36	45.2 ± 0.72	38.3 ± 0.52	34.8 ± 0.54		
	36.7	1.5	6.9	3.5		=	48.6

Figure IV.2

Atmospheric trace elements

The adaptative mechanisms with the cells and tissues are needed because the partial oxygen pressure of the capillary and venous blood is lower in high altitude than in sea-level natives (Figure IV.2). These mechanisms must favour the oxygen diffusion from the blood into the cell and the oxygen utilization in the cell. The mechanisms involved are :

(1) Increased number of capillaries providing a larger surface area to facilitate oxygen diffusion,

(2) Increase in muscle haemoglobin (myoglobin),

(3) Changes in cell enzyme patterns.

Though man and animals at rest at the reduced partial oxygen pressure of high altitudes appear physically fit during the phase of activation of the adaptative mechanisms, physical exercise will reveal to what extent this fitness exists. During the period of acclimatization physical efficiency is reduced as can be demonstrated in exercise tests. Full acclimatization to reduced partial oxygen pressure is reached when the body is as efficient at high altitudes as it is at the ambient pressure to which it is native. This state is called acquired acclimatization. Acquired acclimatization refers not only to work efficiency but to various other functions of the body such as natural resistance to infections; adjustability to meteorological changes, mainly those of temperature; and psychic and intellectual responsiveness.

Recent investigations of Peruvian physiologists at Lima have demonstrated that above a certain altitude c. 4,000 m (ambient oxygen pressure 90 mm Hg) the process of acclimatization of men native to sea-level lasts months and even years and it may well be that the state of full acclimatization is never reached. A new steady state of harmonious integration of all the physiological functions may be achieved but only additional severe stress, e.g. low temperature, will reveal the degree of acquired acclimatization.

The speed and extent of the acclimatization depend on the race, the age, the state of body training and many other factors besides the actual difference between the partial oxygen pressures before and after ascent to high altitudes.

It is said that for a healthy, physically fit and trained Caucasian subject native to sea-level, acclimatization to high altitudes below 3,000 m (ambient oxygen pressure c. 110 mm Hg) takes place without major disturbances and full acclimatization can be reached within four to six weeks. The process of acclimatization is prolonged above 3,000 m and life is impossible above 6,000 m for longer than several months. Even at altitudes of about 2,000 m, unfit, untrained or old people suffer from the same symptoms as fit persons above 3,000 m. At all altitudes acquired acclimatization deteriorates with age.

Pathological symptoms during acclimatization to high altitudes are : hypotonic collapse (if ascent is rapid and combined with environmental heat), sleeplessness, headache, increased excitability; lowered threshold of taste, pain, tendon reflexes; gastro-intestinal disturbances; loss of weight; thyroid deficiency; lung oedema; severe and fatal infections; dysmenorrhea or amenorrhea; psychological and mental disturbances. Acute and chronic mountain sickness is an independent disease unit or syndrome characterized by a symptom complex of vomiting, headache, and physical weakness in the acute form and nervous and psychic symptoms in the chronic form. It is due to an increase of the circulating blood volume following an increase of the number of red blood cells, right ventricular hypertrophy, and low peripheral blood pressure. Treatment of all these pathological states can only be effective if the victim is transported down to lower altitudes with a higher partial oxygen pressure.

Natives of high altitudes may suffer from some of these complaints if they descend to low levels. Acclimatization must take place in these persons in the opposite direction.

For this reason the term "syndrome of vertical climate change", which applies to natives of any altitude moving to higher or lower levels, has been introduced by Monge.

Adaptative mechanisms in animals are similar but wild species which live over wide ranges of altitude show less marked differences in standard parameters, such as red blood cells, when compared with their sea-level relatives. This suggests that other mechanisms are involved, probably at tissue level, which are not yet known. As an example, lactation in domesticated animals and man native to sea-level is poor at high altitudes but sufficient in wild mammals living over wide altitude ranges. The conception rate is reduced or there is infertility, but if conception occurs pregnancy is little affected by altitudes up to 4,000 m and foetuses and newborn are equal in weight to their sea-level counterparts. However, an increased rate of malformation at high altitudes has been found.

In summary, the influence of reduced partial oxygen pressure on all species not native to high altitudes is an imbalance of the steady state of their physiological functions. During the period of acclimatization multiple adaptative mechanisms are activated to achieve a new steady state permitting full efficiency and fitness of the body. The duration and the degree of acclimatization depends on the individual. Full acclimatization can never be reached during residency at altitudes above 4,000 to 4,500 m (ambient oxygen pressure c. 90 to 80 mm Hg).

The reader is referred to Houssay (1955) and Weihe (1963) for more detailes treatment of these topics.

5. THE INFLUENCE OF AIR IONS ON PHYSIOLOGICAL FUNCTIONS

A small air ion consists of a single positively or negatively charged molecule about which cluster 4 to 12 uncharged gaseous molecules. The number of ions in clean outdoor air averages c. 1,200 positive and 1,000 negative ions/cm^3. Any force of a magnitude sufficient to displace electrons from their atomic orbits produces ions, e.g. radiation, heat or mechanical stress; atmospheric pollutants rapidly combine with them and in effect destroy them. Thus in any given environmental situation the small ion density is determined by the momentary equilibrium existing between generative forces and those which tend to consume ions. Predictably, such density is higher on a mountain top than it is in an industrial centre.

Ever since their discovery at the turn of the century, it was suspected that air ions might exert biological effects but for many years indisputable evidence of such action was elusive. Recently, two developments have made it possible to conduct critical tests of air ion action, viz. (1) ion generators capable of producing relatively dense unipolar ionized atmospheres without at the same time producing pollutants and (2) sensitive and accurate ion collectors and micromicroammeters to monitor the ion content of the ambient air during an experiment. Using these aids it has been found that air ions do in fact bring about physiological changes in a variety of living forms. A few examples are cited here to indicate the types and magnitude of elicited reactions.

Under carefully defined conditions gaseous ions of either charge were found to exert a lethal effect on M. pyogenes (Krueger, Smith and Go, 1957), Neurospora (Fuerst, 1955), Esch. coli (Kingdon, 1960) and Penicillium (Pratt and Barnard, 1960). The order of magnitude of this action was small and the underlying mechanism is not as yet understood. The flight activity of the blowfly was increased in air containing an excess of positive air ions while negative ions had no observable effect (Edwards, 1960).

With higher plants, positively or negatively charged air ions evoked an altogether different response; namely, stimulation of growth. This has been demonstrated with oats, barley and lettuce plants maintained in washed sand culture and supplied with a chemically defined nutrient solution under uniform conditions of lighting, temperature and humidity (Krueger, Kotaka and Andriese, 1962). After three to four weeks of exposure to moderately dense concentrations of positive or negative ions, the plants exhibited some 60 to 110 per cent increase in elongation of aerial parts and 70 to 600 per cent increase in dry weight of the aerial parts compared to controls grown in ordinary air. During this period of treatment the current flow to ground was as high as 6.4×10^{-12} amp/plant compared to $< 3 \times 10^{-15}$ amp/plant in the controls. Chemical analysis of ion-treated plants revealed no significant alteration in composition as measured by the content of total nitrogen, protein, total sugars or reducing sugars per gm of dry weight.

When the effects of air ions were tested with mammalian cell lines maintained in tissue culture, the results depended upon the ionic charge : proliferation of connective tissue cells and human heart cells was slowed by positive ions and accelerated by negative ions (Worden, 1961). This same tendency of positive ions to inhibit or depress physiological activity and of negative ions to facilitate it applies to mammalian cells organized into tissues.

In a study of the tracheas of small mammals exposed to air ions and of excised tracheal strips it was found that positive ions produced decreased ciliary activity, contracture of the tracheal wall, increased susceptibility of the tissue to trauma, constriction of the small blood-vessels and increased rate of respiration (Krueger and Smith, 1960). All five effects were seen in the living animal and the first three in the isolated tracheal strip. Negative air ions reversed these effects. Further experimentation established CO_2^+ and O_2^- respectively as the physiologically active agents in positively and negatively ionized air. Studies of gaseous ion effects on tissue enzyme systems disclosed that O_2^- ions act directly on cytochrome oxidase and thereby stimulate certain metabolic functions.

Later it was observed that all the tracheal effects attributed to CO_2^+ could be duplicated by the injection of the neurohormone 5-hydroxytryptamine (5-HT). The 5-HT effects, like those resulting from positive ion action, could be reversed by treatment with O_2^-. On the basis of these facts it was postulated that the physiological changes occurring when the mammalian trachea is exposed to positive air ions are due to the release of free 5-HT from the bound state. Experimentally, negative air ions which reverse these changes, decreased 5-HT levels in excised strips of rabbit trachea and in the trachea of living mice; in guinea pigs there was an increase in the urinary excretion of 5-hydroxyindoleacetic acid (5-HIAA), the specific metabolite of 5-HT.

Support for the 5-HT hypothesis was derived from observations on the effects of drugs which alter tissue levels of 5-HT. Iproniazid raises 5-HT levels and produced physiological changes mimicking those elicited by CO_2^+. Reserpine lowers 5-HT levels and the resultant functional changes closely resembled those produced by O_2^-.

Recently it was observed that the inhalation of CO_2^+ significantly increased the blood level of 5-HT and this rise was accompanied by a series of functional changes identical with those evoked by the injection of 5-HT or the administration of iproniazid (Krueger, Andriese and Kotaka, 1963). During prolonged exposure to CO_2^+ some animals developed an illness characterized by enteric and pulmonary lesions that can be reasonably ascribed to the increased level of 5-HT in the blood.

Certain air ion effects noted in man are compatible with the 5-HT hypothesis. For example, Minehart, David and Kornblueh (1958) have observed that negatively ionized air exerts remarkable pain-relieving and sedating effects on burned patients. It has been established that the excretion of 5-hydroxyindoleacetic acid rises in burned patients, reflecting an increase in available 5-HT. 5-HT itself is a potent pain-inducing agent and may well account for some of the discomfort and pain experienced by burned patients. The relief of pain occurring as a result of negative air ion therapy can then be ascribed to the increased rate of conversion of 5-HT to 5-HIAA by the action of O_2^-. This same mechanism may apply to the observations of Kornblueh, Piersol and Speicher (1958), who treated pollinosis successfully with negative ions. Another example is found in the work of Winsor and Beckett (1958) who tested the response of volunteers to the inhalation of positive ions and negative ions. The patients who inhaled positive ions complained of nasal obstruction, sore throat, husky voice, headaches and dizziness, and their maximal breathing capacity was reduced by approximately 30 per cent; those inhaling negative ions showed little change. These signs and symptoms may be caused by the local accumulation of 5-HT in the upper respiratory tract.

Several attempts have been made to determine whether air ions influence performance or behaviour in humans. The results were affirmative in some studies e.g., Slote, Knoll, Rheinstein (1962) and negative in others, e.g. Chiles, Cleveland and Fox (1960). The writer's impression of the reported data is that air ions can affect performance under specified conditions.

In Russia, Tchijevsky and Vasiliev and their colleagues (e.g. Tchijevsky, 1960) have done a great deal of work on the biological effects of gaseous ions and have concluded that air ions exert their influence in two ways : (1) reflexly through pulmonary receptors and (2) through humoral transmission of some unspecified agent. It is possible that the humoral agent actually is 5-HT.

Frey (1959) has developed the theory that stress is a pre-condition for the appearance of air ion effects and that ions alter physiological functions through their influence on the adrenal gland.

Erban (1959) tested the response of normal humans to unipolar ionized atmospheres administered for one hour three times a week for eight weeks. He observed no significant alterations in the blood picture, electrolyte balance or sedimentation rate. Those individuals inhaling positive ions underwent a gradual increase in blood pressure, blood globulins and excretion of 17-ketosteroids. Blood albumins dropped, as did total and free cholesterol. With negative ions the only shifts noted were a slight rise in blood albumins, an increase in excretion of 17-ketosteroids and a decrease in globulins.

To sum up, there is convincing evidence that air ions produce physiological changes in bacteria, fungi, higher plants and in mammalian cells maintained in tissue culture. Similarly, they affect the functioning of mammalian cells organized into tissues and in intact animals and humans evoke a variety of physiological responses for some of which biochemical mechanisms are becoming established. In the experiments conducted so far, CO_2^+ and O_2^- appear to be the only biologically active ions and the changes they produce are usually moderate. It is clear from the available experimental data that the type of reaction elicited by ions is determined by the nature of the gas being ionized, by the sign of the charge and by the essential properties of the biological substrate.

6. THE IMPORTANCE IN BIOMETEOROLOGY OF FLUCTUATIONS IN THE ATMOSPHERIC ELECTRICITY FIELD

Atmospheric electricity is part of man's external environment; Alexander von Humboldt referred to it in his definition of "climate". We must distinguish two things when we study the significance in biometeorology of fluctuations in the atmospheric-electrical field : (1) their possible use as indices in a study of a large number of biotropic weather situations and (2) their possible direct effects on the human body.

The number of atmospheric electrical parameters and their manifestations as functions of time and place is so great that we must first of all decide which are of primary interest. We can limit the field to a considerable extent if we set the following two conditions : first, the relevant atmospheric-electrical elements must stand in an unequivocal relation to those weather situations which affect the human body; second, we must be sure that the atmospheric-electrical element is physically capable of reaching the human body and of penetrating it to some extent or of inducing physical movements in it (e.g. shift currents), for a physiological reaction would otherwise be quite out of the question.

Weather and atmospheric electricity

An analysis by Reiter (1960, 1962, 1963) of the relevant elements and varieties of atmospheric electricity showed that quick variations (fluctuations) of the atmospheric-electricity field are of significance, viz. fluctuations of the static field,as manifested through precipitation and discharges in shower and storm clouds; and the electrical vector of electromagnetic waves of atmospheric origin "atmospherics" ranging from the lowest frequencies to around 50 kHz. Where suitable recording methods are used, from the frequency and intensity of the impulses of atmospherics, we can calculate atmospheric instability in a radius of some 100 km.

Research over a period of several years (Reiter, 1960) allows several conclusions regarding the relation of atmospherics to weather. Those meteorological movements leading to stabilization of the atmospheric layers cause the impulse frequency of atmospherics to decrease. In contrast, processes leading to instability cause the frequency to rise. The lowest values of atmospherics are obtained in anticyclonic weather, while high impulse frequencies of atmospherics are registered during cyclonic weather, particularly during the first days of cyclonic weather periods, during cyclogenesis, or in trough situations.

Biological effects of atmospheric electricity

In recent years several experiments have been carried out, the object of which was to show whether electrical field alterations caused biological reactions. The principal findings will now be summarized. For a full account, the reader is referred to R. Reiter (1960, 1962, 1963).

Experiments with plants. When colonies of *Bacterium casei* were exposed for several hours to an artificial electrical alternating field of some Hz (partly sine-form and partly distorted), König and Krempl-Lamprecht (1959) observed that the bacteria multiplied in proportion to the period of exposure. The field strengths of 0.01-1 V/cm simulated low frequency atmospherics (cf. Schumann and König, 1954). Comparable results were obtained with the yeast fungi, *Saccharomyces cervisiae*. These investigators found that, within one week, wheat germs growing in the electrical alternating field became 23 per cent longer than control plants.

Experiments with insects. Weather influences the general behaviour of the honey bee (Schuà, 1950). On days with increased atmospherics, more bees failed to return to the hive than during other weather situations (Becker, 1958). There is a striking parallelism between sucking capacity of bees and the main disturbances of the static electrical field of the air which develop before storms and with the passage of shower clouds (Schuà, 1951). Under carefully controlled conditions bees avoid the part of their hive containing an electrical alternating field of 15 V/cm field strength and a frequency of 5-10 kHz (Schuà, 1954 a; Lecomte, 1954).

The skin-shedding time of the plant louse, Mysus persicae Sulz, exposed to an artificial electrical alternating field (0.5-25 Hz, 0.3-0.03 V/cm), falls in high electrical field strengths and rises in low (Haine and König, 1960). These low frequencies are comparable to atmospherics observed in nature (König and Krempl-Lamprecht, 1959).

Experiments with mammals. The relationship between atmospherics and the nesting behaviour of the hamster has been critically studied by Schuà (1953, 1954 b). Six animals were housed singly in glass cages in an artificially air-conditioned room from which daylight was excluded. On each cage was mounted an antenna. After several weeks of acclimatization the antenna was placed directly over each animal's nest. On the antenna of three cages an alternating electrical field of up to 10 kHz was impressed. (The frequency did not influence the results.) Its strength at the nest ranged between 1 and 9 V/cm. Within less than 48 hours the experimental hamsters had moved their nests and fodder outside the electrical field. Each time the antenna was moved over a new nesting site, an escape reaction was resumed.

When mothers and their broods were similarly studied in low field strengths down to 0.1 V/cm and in frequencies near 10 kHz produced by rectangular oscillations from a cathode-ray tube, the hamsters, within 24 hours, dragged their young far from the field, dismantled the original nest and rebuilt it near the young, and transported the fodder to the new site.

These experiments of Schuà convincingly demonstrate that electrical alternating fields, with amplitudes and frequencies comparable to those found in nature, have a direct biological effect.

Mice exposed to an electrical alternating field exhibit increased oxygen consumption and excretion of carbon dioxide and the resting metabolic rate rises (Sundermann, 1954).

To investigate whether low field strengths can affect the pH of tissues, Reiter (1953, 1954) exposed guinea-pigs to two different types of alternating fields activated between condenser plates : (1) rectangular oscillations from a cathode-ray tube, with impulse frequencies between 50 Hz and 100 kHz and field strengths between 0.1 and 10 V/cm; and (2) natural atmospheric impulses amplified by a receiver and converted into voltage fluctuations, with field strength varying between 0.1 and 10 V/cm and basic frequency varying between 2 and 50 kHz.

An examination of models and dead animals showed that the electrical fields used in the experiment did not affect the pH reading. In each of the numerous measurements on living animals, there was a characteristic deviation in the pH of tissue of 0.02 to 0.1 units from the control value whenever that part of the animal in which the pH of tissue was measured was in the alternating field. In many cases, after the field was switched on, the initial acidification was followed by alkalization. Strong variations of pH were frequent too. After the field had been switched off, the pH value levelled off and tended to approach the old control position. The field amplitude played only a secondary role.

Experiments on humans. So far, few experiments have been made on humans, and then only on a very limited number of subjects. Mention must be made of the observation of Kampik and Reiter (1948) that the typical "weather pains" of amputated persons can manifest themselves in a short-wave diathermic field, and in artificial alternating fields of around 100 Hz and about 100 V/cm field strength. Sundermann (1954) exposed 17 human subjects to an electrical condenser alternating field (10 - 5,000 Hz, 50 - 150 V/cm) and discovered, in four cases, increased blood coagulability. König and Ankermüller (1960) reported that low-frequency atmospherics (3 - 10 Hz, some V/cm) had some effect on the reaction time of some humans.

By and large, current knowledge about the direct effects of electrical alternating fields on man is still sparse and does not admit of final judgements. Nevertheless, we must seriously regard fluctuations of the atmospheric-electricity field, as found in nature in conjunction with the weather, as likely causal factors in regard to the human organism's reactions, particularly in the light of the unequivocal results of certain experiments with animals.

In conclusion, reference must be made to the great importance of atmospherics and other atmospheric electricity field fluctuations as indices for biotropic weather situations (cf. Reiter 1960, 1963). Table IV.1 summarizes a statistical study of one million individual data on human reactions to increased atmospherics.

TABLE IV.1

REACTIONS OF MAN TO INCREASED ATMOSPHERICS

Phenomenon observed	Percentage increase over days with low atmospherics
Complaints of brain patients	30
Complaints of amputation cases	50
Chronic patients' pains	100
Polio admissions	6
Births	11
Deaths	20
Traffic accidents	70
Work accidents	20
Mining accidents	12
Prolongation of the reaction time	6

7. THE INFLUENCE OF TRACE ELEMENTS OF THE ATMOSPHERE

Nitrogen, oxygen, argon and water vapour constitute more than 99.9 per cent of the atmospheric gases. Besides these there is a great variety of others, present in considerably lower concentrations, known as "trace substances" (Tromp, 1963). A list of some substances is given in rough order of the observed amounts in Table IV.2. Most of the data given are based on a limited number of analyses. The range of concentration may differ considerably depending on weather conditions, geographical position, season and other factors.

The interest that biometeorology takes in these atmospheric constituents originates from one or more of the following aspects. They may :

(a) contribute to the supply of material for metabolic processes,

(b) control the action of some other, e.g. physical, factors of biological importance,

(c) exert a stimulus to some biological functions by their presence in variable amounts or conditions,

(d) serve as an indicator for events in our environment.

Role in metabolic processes

In spite of the considerable quantity of air breathed daily (approximately 24 m^3 by volume or 29 kg by weight), none of the atmospheric trace substances involved in human metabolism is inhaled in functionally significant amounts. For some time a presumptive role of airborne iodine was discussed for the geographic distribution of endemic goitre seemed to be correlated with the pattern of the abundance of this element in air. The hypothesis had to be abandoned, however, when it became obvious that high iodine concentrations found years ago in the air of certain regions were caused by carbonizing of seaweed in some coastal districts (Caver, 1939).

Control of other physical factors

While carbon dioxide plays some part in hindering heat radiation from the earth's surface into space, the most impressive example of biologically important indirect effects of a trace substance is the screening of ultra-violet sun rays by the stratospheric ozone layer. Ozone is continually formed by very short-wave solar radiation, the level of maximum concentration building up at heights between 18 and 30 km. The lower atmosphere is thus shielded from the short ultra-violet rays which are highly destructive to living matter. The solar spectrum is sharply cut off at about 290 m μ, leaving just enough UV radiation of moderate quantum energy for vital photochemical processes.

Another kind of indirect effect originating from minute admixtures to atmospheric air is the formation of aerosols, especially of condensation nuclei. Substances active in this regard include the NH_4 ion, mineral salts from the oceans, and reaction products of ozone and other oxidizing agents. The number of condensation nuclei available influences the development of mist, fog and clouds.

Action on biological processes

Such phenomena as the sensitivity of many people to weather changes or the outbreak of certain diseases obviously related to meteorological conditions have sometimes been tentatively explained by changes in the concentration level of trace substances in the air. For example, the suction exerted on soil gases, such as radon or ammonia, by falling atmospheric pressure generally augments their concentrations near ground. None of the substances considered, however, has shown any physiological effect when inhaled in amounts occurring naturally. Another approach is based on the movement of some air constituents from the upper atmosphere. Ozone, which is formed in a stratospheric layer, has several properties suggesting its participation in biotropic effects of weather and climate. The ozone content of the

TABLE IV.2

ATMOSPHERIC TRACE ELEMENTS

Substance	Range of concentration related to dry air	
	pphm = 10^{-6} vol. %	ug/cm^3
Carbon dioxide	20,000 - 60,000	390,000 - 1,180,000
Neon	1,800	16,200
Krypton	100	3,730
Sulphur dioxide	0 - 100	0 - 2,850
Methane	2,200	1,570
Chloride	-	0 - 1,000 *
Helium	524	935
Sulphate	-	0 - 700 *
Xenon	8	470
Ozone	0 - 4.7	0 - 100
Dinitrogen-oxide	(50)	(38)
Ammonia	0 - 9	0 - 65 *
Magnesium	-	0 - 65 *
Hydrogen	50	44.5
Nitrogen-dioxide	0 - 2	0 - 41.2
Formaldehyde	0 - 0.45	0 - 6 *
Hydrogen-peroxide	0 (0.02)	0 (0.34)
Iodine	0.003 - 0.04	0.05 - 0.6
	$10.^{-18}$ vol. %	10^{-15} g/cbm
Radon^{222}	2 - 10	20 - 100

* Values gained by analysis of condensate on a cooled surface exposed to air. Conversion to concentration figures is based on the doubtful assumption that water vapour and nuclei are sampled in proportional amounts.

biosphere varies widely. Its correlations with meteorological factors are governed mainly by the fact that there is an ozone source in the upper atmosphere, and a sink on the earth's surface. By reaction with oxidizable matter and partly by catalytic actions, ozone is destroyed in the surface layers of the atmosphere. The more or less pronounced daily rhythm of ozone values with a maximum in the early afternoon and a minimum near sunrise, as well as the differences in average local ozone concentration, correspond well with the patterns of wind velocity and of vertical exchange intensity. Even the effects of air mass, season, humidity, temperature, etc. on ozone concentration may be explained, at least to a great extent, by this reciprocal action of transport and destruction. Some possibility of additional ozone formation in the lower atmosphere by electric discharges cannot, however, be ruled out at present. It may be responsible for part of the high concentrations sometimes found around thunderstorms. Another source of tropospheric ozone, detected when searching for the causes of "smog", will be mentioned elsewhere in this publication (cf. Chapter IV, Section 8).

As to the biological effects of ozone, a highly irritating and even toxic action is observed at concentrations only about five times above those naturally occurring (Freebairn, 1959). Very little, however, is known about possible influences of lower concentrations. Numerous subjective observations (Currie, 1946) have been presented to support the notion of a supposed control of human autonomic functions by changes in the natural level of ozone and other oxidizing substances. These reports have failed to find general acceptance. The indoor behaviour of ozone levels, dropping almost to zero even in moderately ventilated rooms, yields a strong argument against causal connexions of ozone concentrations with the phenomena of weather sensitivity. On the other hand, serum mineral changes characteristic of a readjustment of autonomic nerve functions have been found when applying artificially produced levels of 60-80 $\mu g/m^3$ to patients (Hermann and Heine, 1952). Experiments of this kind not only suffer from the usual difficulties on analysing biological regulatory processes of subtle nature, but are hampered by a considerably lower threshold of smell found for artificial ozone as compared with that for natural ozone.

Recent findings have shown that gaseous trace substances may potentiate their biological activity when adsorbed to suitable aerosol particles (Amdur, 1961). This may possibly provide a clue to overcome some of the difficulties and contradictions mentioned above. Ozone and nitrous oxides have a tendency to react with or to annex to compounds containing unsaturated carbon bonds, thereby forming particles with oxidizing properties. Even atmospheric carbon dioxide has recently been shown to adhere to certain nuclei to a degree depending on air mass conditions (Stetter, 1960).

Finally, the presence of numerous odorous substances in free air must not be forgotten. Though probably acting predominantly on a psychical basis, their role in mediating pleasant and refreshing sensations is an important example of stimuli originating from trace substances in the atmosphere.

Role as environmental indicators

Much information of biometeorologic concern may be gained by measuring the variation in concentration of some trace substance in the air. For instance, the advent of air from higher atmospheric regions is indicated by a rise in ozone level, whereas a drop of ozone amount to nearly zero points to the existence of a barrier to vertical exchange above the observer. Air masses originating from the sea may be identified by high levels of hygroscopic salt nuclei, those coming over continental areas, in contrast, will contain particles of dry mineral dust.

Some inferences on the origin of air and on the presence of natural or pollutant admixtures may also be made from determinations of the so-called "acidity (pH) of air". Actually, this term refers to the acidity of the condensate obtained by cooling the air below its dewpoint.

8. AIR POLLUTANTS AND THEIR EFFECTS

A series of dramatic episodes in which high concentrations of air pollutants were associated with excess mortality and sickness has left us in no doubt that there are acute effects of air pollution on health. Among the places where such episodes have occurred are three which are notorious : the Meuse Valley in Belgium; Donora, Pennsylvania, and London. Although it was suspected that there might also be long-term danger to health from lower concentrations, the true extent of the problem of chronic chest disease was realized only after advances in hygiene and the treatment of hitherto fatal infections with antibiotics had enabled many more people to survive to the age when chronic disease manifests itself.

The question of the association between air pollution and chronic chest disease is a complex one. The problem is to distinguish between the effects of many adverse circumstances surrounding those who live in towns - circumstances which vary from place to place in much the same way as does air pollution. Overcrowding, exposure to infections, inadequate diet, poor understanding of the principles of hygiene, bad housing, and bad conditions of employment are all likely to undermine health even in the absence of pollution, though pollution is always present in areas where such conditions prevail. To what extent can air pollution be blamed ? The questions of individual susceptibility to certain pollutants, and of the role of smoking, complicate matters even further. Research is made difficult by the often insidious onset of chronic chest diseases and the confusion existing in their nomenclature. A short account of the nature of urban air pollution and a summary of its effects is all that can be given here, but details of the many epidemiological and experimental studies on this subject, and references to all the wide range of subjects included in air pollution research, will be found in the following books listed in the bibliography : Anonymous (1961); Green and Lane (1951); Lawther, Martin and Wilkins (1962); Magill, Holden and Ackley (1956); and Stern (1962).

Factors influencing the concentration of air pollutants

The presence of air pollutants in concentrations sufficient to affect man's health and welfare depends on the balance between the sources from which they arise and the factors favourable to their dilution and dispersion. These factors include the height of the chimney stack, the buoyancy of the plume, to topography of the surrounding landscape and the meteorological conditions. If chimney gases are hot and therefore buoyant, and if they are emitted at high velocity from tall stacks, they can, under normal weather conditions, be expected to rise and be diluted so rapidly that they never reach the ground in harmful concentrations. Unfortunately, these conditions are not always fulfilled; either the plume does not rise, or the chimney stack is too short, or the weather is unfavourable. Particularly unfavourable is calm anticyclonic weather in which clear skies and the consequent loss of heat by radiation encourage the formation of a stable layer of air near the ground; pollution emitted into this layer is prevented from rising by the presence of a belt of warmer air above, so that it accumulates at ground level.

The sources of pollutants

Excluding naturally-occurring pollutants such as pollens, spores, bacteria and dust raised from the ground by wind, air pollution arises from four main types of source : fuel combustion, industrial processes, road traffic and the burning of waste.

Combustion of fuels. Fuels may be used for heating or for the industrial production of power. The availability of fuels in different parts of the world means that each area may have a characteristic pollution problem. There are three classes of fuel : solid fuels, liquid (oil) fuels and gas.

Solid fuels : (1) lignite, peat, wood, etc.
(2) soft or bituminous coal
(3) hard coal or anthracite
(4) manufactured solid fuels such as coke.

The solid fuels give rise to different types of pollution according to the conditions of combustion. If low temperatures or inadequate air supplies or both are permitted (and these are unavoidable on some appliances, particularly the open domestic grate) combustion is incomplete and very fine black particulate matter predominates. With high temperatures and an adequate air supply, little particulate matter need be emitted. Whatever the combustion conditions, most of the sulphur in the fuel will be emitted, mainly as gaseous sulphur dioxide. A small percentage forms sulphuric acid mist.

Liquid fuels : (1) oil distillates
(2) oil residues
(3) coal-tar fuel.

Incomplete combustion of oil fuel giving rise to a visible plume should rarely occur, though some fine particles are always emitted. Sulphur dioxide and sulphuric acid mist arise as with solid fuel. The amount of sulphur varies not only according to the source of the oil but with the fraction of the distillate; residual oils may contain a high proportion (4 per cent or more) of sulphur. Coal-tar fuel contains little sulphur.

Gas : (1) natural gas
(2) manufactured gas.

Natural gas presents no pollution problems; manufactured gas may contain a small proportion of sulphur but is otherwise clean in use. The main pollution problem here arises in the course of manufacture.

Industrial processes. In some industrial processes substances other than the products of combustion are emitted to pollute the air in the surrounding community. The problems in such cases are essentially those of industrial hygiene. Examples of substances which have given rise to community pollution problems are hydrochloric acid, chlorine, hydrogen sulphide, fluorides, beryllium, and various substances having an offensive odour. Even when man's health is not directly affected there can be important economic effects from damage to materials, vegetation and livestock.

Road traffic. Diesel exhaust contains oxides of nitrogen, and black smoke is also emitted if the engine is overloaded or badly maintained. Petrol (gasoline) engines give out a mixture of hydrocarbons (unburnt or partly burnt fuel), carbon monoxide and oxides of nitrogen, and also lead compounds if lead is present as an additive in the fuel. In certain circumstances complex photochemical reactions can occur between the components of exhaust gases, giving rise to toxic compounds. The classic example of this occurs in the Los Angeles basin in the United States, where stagnation of the air over the coastal plain allows exhaust gases from the vast number of cars in the area to accumulate, and eye irritation and plant damage are common in the summer months. This phenomenon is not necessarily confined to southern California; it may be expected to occur wherever the same set of circumstances exists. This is an entirely different problem from the pollution of urban communities burning solid fuel (particularly bituminous coal), and it is perhaps unfortunate that the same word, "smog", has been applied to pollution of both kinds.

Incineration of waste. The problems raised by the burning of waste are akin to those due to the burning of solid fuel; with high temperatures and adequate air supply there can be complete combustion, though the variability of the material presents difficulties. Incomplete combustion leads to the production of many very irritating and potentially harmful compounds. Sulphur is not usually present, but the fumes given off in these low-temperature combustion processes contain hydrocarbons, aldehydes and other organic compounds; the fumes are usually too cool to rise far above the ground.

Physical and chemical characteristics of pollutants

Despite the diversity of the various sources listed above they may lead to very similar forms of pollution, apart from substances derived from specific industrial processes. Generally, pollutants fall into two classes; particulate matter (including liquid droplets) and gases.

Particulate matter (solids and liquids). Particulate matter needs to be specified by size as well as by composition; particle size is important because it is one of the factors controlling the ultimate fate of the pollutant.

Large particles, i.e. particles with a diameter of 20 microns and over (many are over 100 microns) have an appreciable falling speed and come to the ground near the source, often constituting a serious nuisance. This kind of pollution, known as "dustfall" or "deposited matter", is usually composed of ash particles; unburnt fuel can also be present. The products of partial combustion characteristic of small installations are unlikely to occur since large particles can only become airborne in hot flue gases passing at high velocity up tall chimneys. Pollution of this sort is therefore commonest in industrial areas. The particles can be removed from stack gases by dust-arresting equipment, and from ventilating systems by air filters; they are prevented from entering the finer passages of the lungs by the natural protective mechanisms of the respiratory tract.

Small particles may comprise particles of the same nature as those described above, plus the very large contribution from incomplete combustion of fuels in small installations - in particular, the open domestic grate burning bituminous coal. The low exit-velocity of the gases from such installations prevents the emission of large particles, but any particles which are small enough (under about 5 microns) will remain in and travel with the air wherever it goes. The word "smoke" has been used to describe this fine suspended material. Its removal from stack gases presents difficulties, since it passes through the ordinary types of arrester; electrostatic precipitation is the method usually employed, but as the size of particle falls below one micron the efficiency of collection falls off rapidly. There is of course no way of cleaning these fine particles from the domestic chimney plume, and the only satisfactory way to reduce smoke formation is to substitute hard coal or coke for bituminous coal and burn it efficiently in well-designed appliances. This is the principle underlying the Clean Air Act which has been in force in Great Britain since 1956.

Because of their small size, individual particles in this range are invisible to the naked eye and their presence is often unsuspected. They are found indoors and out and they pass through air filters in ordinary ventilation systems which remove larger particles.

The composition of typical urban smoke in coal-burning areas

There is a high proportion of submicron particles of carbon and tarry hydrocarbons, often present as fine aggregates. Even in the absence of these products of incomplete combustion, and irrespective of whether coal is burnt or not, fine particles are still found, notably ash particles and crystalline sulphates, sulphuric acid in droplet form, and particles of unburnt fuel. The liquid components may be absorbed on the solid particles.

Effects of fine suspended particulate matter or "smoke"

(1) Particles in this size range can be inhaled and reach the finest lung passages, where they may be retained. If irritant particles are present they may affect the tissues and cause or exacerbate lung disease.

(2) They adhere to any surface (even vertical and downward-facing ones) with which they are brought into contact, causing soiling.

(3) They scatter light so as to cause haze, thus impairing visibility and reducing the amount of sunlight reaching the earth. A given mass of small particles scatters very much more light than the same mass of larger ones.

(4) Carcinogenic substances are present as components of the finely-divided particulate matter and may be retained and have some effect in causing lung cancer. In this connexion the relative roles of smoking and of air pollutants are difficult to assess.

Gases

Sulphur dioxide is considered the most important of the gaseous pollutants. It is highly soluble in body fluids, acting as an irritant to which certain persons are more sensitive than others. Plants and animals vary in susceptibility according to the species. It is corrosive to many materials.

Carbon monoxide occurs in engine exhaust gases. It forms a complex with haemoglobin and is potentially lethal. It attains an equilibrium level in the blood and although intermittent exposures to the moderate concentrations found in towns are not thought to have any permanent effect, this is the one pollutant which in the general atmosphere frequently exceeds the maximum allowable concentration set for industry.

Oxides of nitrogen are also found in vehicle exhausts. Nitric oxide, like carbon monoxide, forms a complex with haemoglobin, while nitrogen dioxide in high concentrations is capable of producing acute respiratory distress. These oxides play an important part in the formation of Los Angeles smog.

Ozone and oxidants together form another important component of the Los Angeles type of pollution causing damage to plants. Ozone destroys rubber by causing it to crack.

The need for town planning

It should be remembered that we can avoid much unnecessary suffering and damage to our health and our surroundings by designing and siting factories and dwellings to give the best possible opportunities for the harmless dilution and dispersal of pollutants, until the time comes when technological progress makes air pollution a thing of the past. (See also Chapter VI.)

CHAPTER V

THE INFLUENCE OF WEATHER AND CLIMATE ON MAN

1. THE INFLUENCE OF WEATHER AND CLIMATE ON HEALTHY MAN

Though the weather can influence physiological functions of healthy man and may be one of the factors causing daily fluctuations of physiological functions, it is not easy to analyse the factors and determine the pure effects of weather. On the other hand, climatic effects are well manifested in acclimatization. Many characteristic differences of physiological functions are found between acclimatized and non-acclimatized people. Evidence of acclimatization is revealed in seasonal variations in physiological functions and metabolism in people who are living in the temperate zone of the earth. The effects are especially striking in Japan where there are marked seasonal swings in the meteorological factors. Thus seasonal changes in functions and metabolism will be dealt with in this section.

Seasonal variations in body temperature

The body temperature is generally believed to remain at a constant level throughout the year. Actually, however, it may change a little, within 0.5°C, according to the season. For one year Ogata (1949) measured the basal rectal temperature of three subjects living in Manchuria. The rectal temperature tended to decrease in summer and in August was sometimes lower by about 0.5°C than that in winter. The extremely large range of diurnal variation of atmospheric temperature may have been a cause of this decrease in summer, for people generally go to bed lightly clad on hot summer nights and the body may be cooled by a large decrease of atmospheric temperature in the morning. A similar seasonal variation in rectal temperature was observed in Kumamoto, Japan, where the range of atmospheric temperature variation is comparable to that in Manchuria, but not in Beppu, where the range is not so great (Ogata, 1949).

Seasonal variation in thermoregulatory functions

Thermoregulation is achieved principally by reactions of skin vessels, sweating and heat production (cf. Chapter III; Chapter IV, Section 3). Related changes appear in blood properties.

Skin circulation and skin temperature. Alterations in skin temperature reflect changes in the circulation through the skin. The distribution of temperature over the surface of the body and the mean skin temperature varies with the season (Yoshimura, 1960). With a decrease in the environmental temperature, the skin temperature in the limbs falls while the trunk skin is maintained at about the same temperature (Figure V.1). Since alterations of temperature distribution from season to season are presumed to be mainly effected by changes in skin circulation, it follows that the circulation in the limbs decreases, and the depth of shell for heat elimination over the body increases in cold seasons. By this means conservation of body heat is achieved. In warm seasons the regional variations of skin temperature tend to disappear. An increased cutaneous circulation facilitates the elimination of bodily heat by physical processes. Moreover, a high skin temperature induced by increased circulation will promote sweating.

Similar changes in skin circulation have been observed in a subject who changed his residence temporarily from a warm to a cold room or vice versa. However, the reaction in skin circulation to the same thermal stress is somewhat different according to season. To explain these variations, the effect of acclimatization should be considered. For example, persons acclimatized to cold are able to maintain a smaller core and deeper shell than those not acclimatized and can tolerate cold by diminished heat loss (Carlson, et al. 1953). Even when environmental conditions at the time of measurement are held constant, the cold shell increased during winter acclimatization but decreased in the summer (Yoshimura, 1960).

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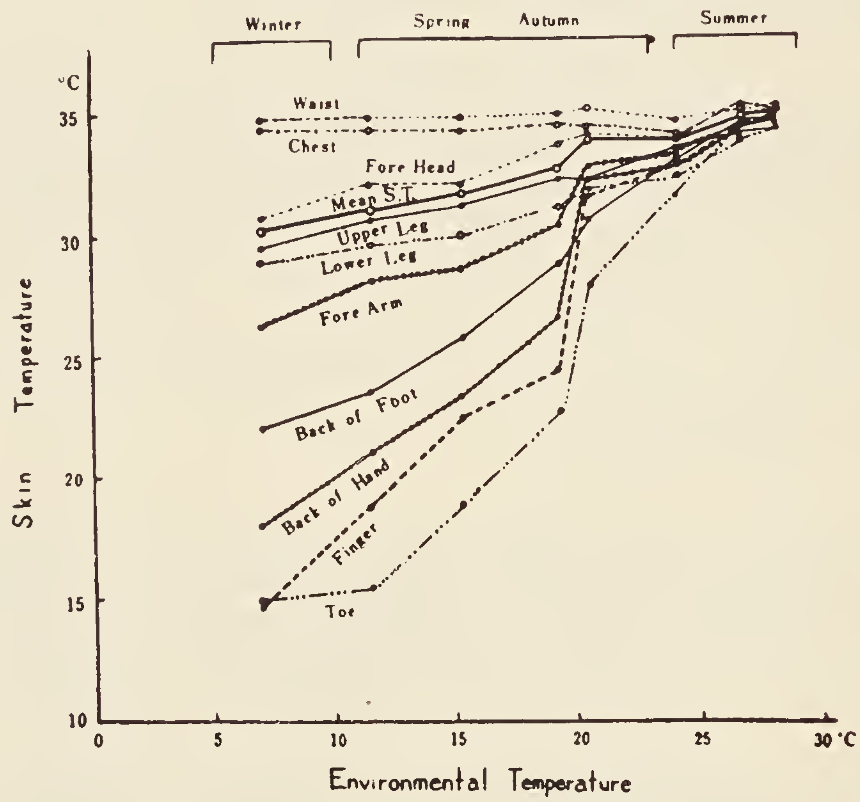

Figure V.1 - Seasonal variation of skin temperature

Sweating. The ability to perspire increases in summer, while it decreases in winter (Kuno, 1934). The sweat secretion not only appears promptly with slight heat stimulation, but also is large in amount. This short latency of reflex sweating in summer has been attributed to an enhanced excitability of the sweating centre in summer (Kuno, 1934). The increased rate of sweating in summer is due to an increase of the activity of sweat glands brought about by training to heat.

Immigrants in the tropical zone, especially newcomers, are always bathed in sweat, while natives may remain comparatively dry. Kuno (1956) measured the rate of the onset of sweating simultaneously among Japanese and tropical natives exposed to the same heat stress. Sweating developed rapidly in the Japanese but not in the natives, while the Japanese born in the tropics reacted similarly to the natives. Once sweating had started, however, the rate of sweating was higher in the natives than in the Japanese. The higher sweating rate among tropical natives is probably due to a large number of active sweat glands (Kuno, 1956).

On this basis, one can distinguish a temporary adaptation of sweat apparatus to heat from its acclimatization to a tropical climate by permanent residence (Kuno, 1956). Seasonal variation of sweating is a temporary adaptation to seasonal changes of weather. The difference in sweating between natives and temporary tropical immigrants may be in permanent acclimatization to heat.

Heat production or metabolism. When the subject is exposed to cold, cutaneous vascular reactions occur which attempt to conserve metabolic heat. When body cooling proceeds beyond a certain limit, shivering is initiated to augment bodily heat production. The initiation of shivering and the rise of metabolism are more retarded in winter than in summer even under the same cold stress (Yoshimura, 1960). The maximum rise of metabolism under the same cold stress, however, does not differ appreciably between the two seasons. Thus the rectal temperature is necessarily maintained somewhat higher in winter than in summer under the same cold stress. The retardation of shivering in the winter in the cold is presumably an effect of acclimatization to cold just as is the lowering of the skin temperature.

Another effect of acclimatization on metabolism is the seasonal variation of basal metabolism. While most American authors (e.g. Du Bois, 1936; and others) support the view that the basal metabolism is almost constant throughout the year, Japanese investigators (Suzuki, 1960; Sasaki, 1954; and others) agree it varies seasonally. Osiba (1957) measured each month the basal metabolism of four male subjects, aged 19 to 28 years, under the same

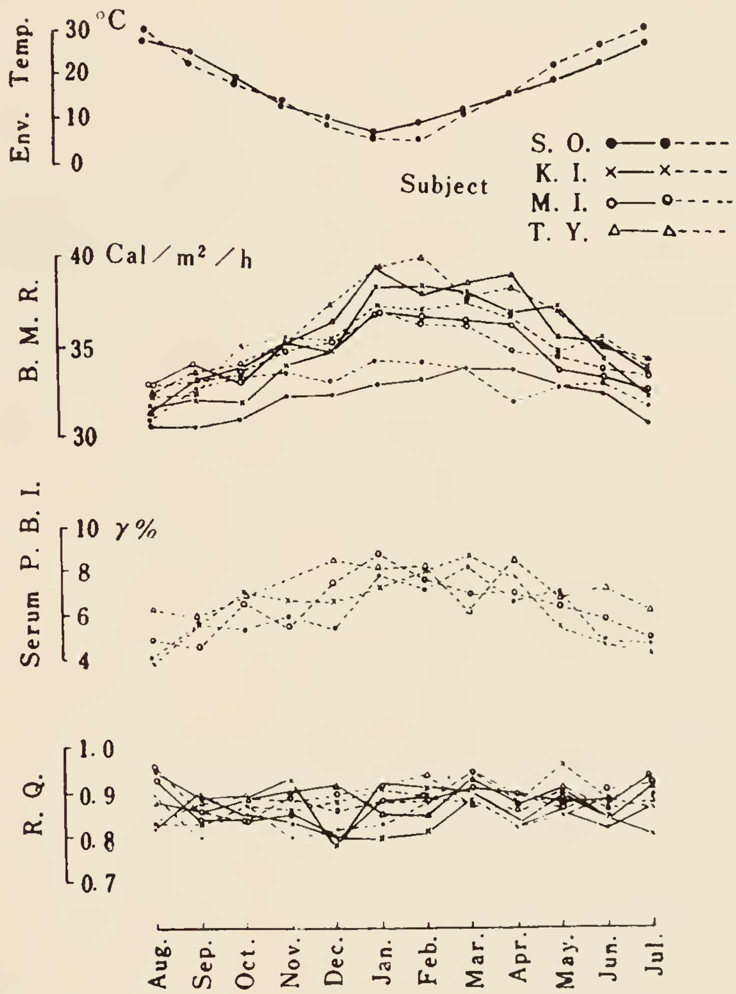

Figure V.2 - Seasonal variation of BMR and serum PBI

standard conditions over a two-year period. In the first year a standard diet was fed for a week prior to each test and the measurements were made after an overnight rest in a regulated comfortable room. In the second year, the subjects were studied under natural conditions. Similar seasonal variations of the basal metabolisms were observed (Figure V.2). Thus seasonal alterations in the metabolic rate are independent of diet and environmental temperature; presumably they represent physiological adaptation to heat and cold.

To elucidate the mechanism of this seasonal variation, Osiba (1957) measured the concentration of serum protein bound iodine (PBI) concurrently with the measurement of basal metabolism under natural conditions. The results are illustrated by dotted lines in Figure V.2. Each subject had a distinct seasonal variation : an increase in winter and a decrease in summer. When the monthly values of PBI were correlated with the basal metabolism, a highly significant correlation coefficient of 0.77 ± 0.08 (probable error) was obtained. These seasonal variations in basal metabolism and PBI concentration can be reproduced experimentally by exposing winter-acclimatized subjects to summer heat. When such subjects enter a hot room regulated at 30°C, dry-bulb temperature, and 25°C, wet-bulb temperature, the basal metabolism begins to fall gradually; a minimum value is attained after seven to ten days. The decrease may amount to 12 per cent of the control. The concentration of PBI likewise decreases. It is concluded that the thyroid activity undergoes adaptative changes to seasonal alterations of environmental temperature. The seasonal variation in basal metabolism should contribute to changing the level of total metabolism and thus allow man to endure exposure to heat and cold with less discomfort (Koga, 1959).

Seasonal variations in compositions of body fluid

Sodium, potassium and chloride. It is well known that changes of blood properties accompany thermoregulatory function. In sailing from England to Peru, Barcroft (1922) found that the blood water content increased when he passed the equator, and attributed its cause to the increase of blood volume. Kuroda (1943) reported that blood water increased in summer and decreased in winter. Yoshimura (1958) confirmed his findings and conducted experiments to clarify how and why the seasonal change of weather can influence the water and salt composition of blood. He demonstrated (Figure V.3) that the total circulating serum volume increased in summer, while the serum protein concentration decreased. The total blood volume paralleled the serum volume and the haematocrit was reduced in summer and increased in winter.

Concentrations of Na, Cl and K in serum increase in winter and decrease in summer (Figure V.4). As these are the main salts in serum, the variations result in similar changes in the serum osmotic pressure (freezing point depression). Because the total serum protein content of circulating serum is constant throughout the year (Table V.1), it may be concluded that the seasonal changes in serum volume are due to variations in the water content of serum.

The volume of total body water (TBW), of extracellular fluid (ECF) and of intracellular fluid (ICF) were determined monthly (Table V.1). The body fluid compartments, especially ECF, undergo seasonal variations similar to those of serum. Consequently variations in serum volume seem to be a partial outcome of changes in the volume of body fluid. From the ECF volume, the salt concentration in serum water, and the correction factor for Donnan equilibrium (distribution of sodium, potassium and chloride ions on either side of cellular membrane as influenced by non-diffusable charged protein molecule), the total salt content of ECF was calculated (Table V.1). Na and Cl increased in summer and decreased in winter. The change of K, though small, was just the opposite. Thus the ratio of Na/K in ECF increased in summer and decreased in winter. These facts cannot be explained only by changes in distribution of water and salts in body fluid compartments; they strongly suggest the presence of seasonally adaptative alterations in water and salt metabolism. The latter interpretation is supported by the fact that secretion of antidiuretic hormone and the salt-retaining adrenal hormone, aldosterone (cf. Chapter III and Chapter IV, Section 3), increases in summer and decreases in winter (Yoshimura, 1958, 1960).

These seasonal changes in body fluid seem to have important physiological meanings. As sweating increases considerably in hot seasons, the body fluid compartments are always threatened with dehydration and salt loss. The hydration and the increase of NaCl content in body fluid maintained by adaptation in summer may be regarded as a preparatory counteraction to these threats.

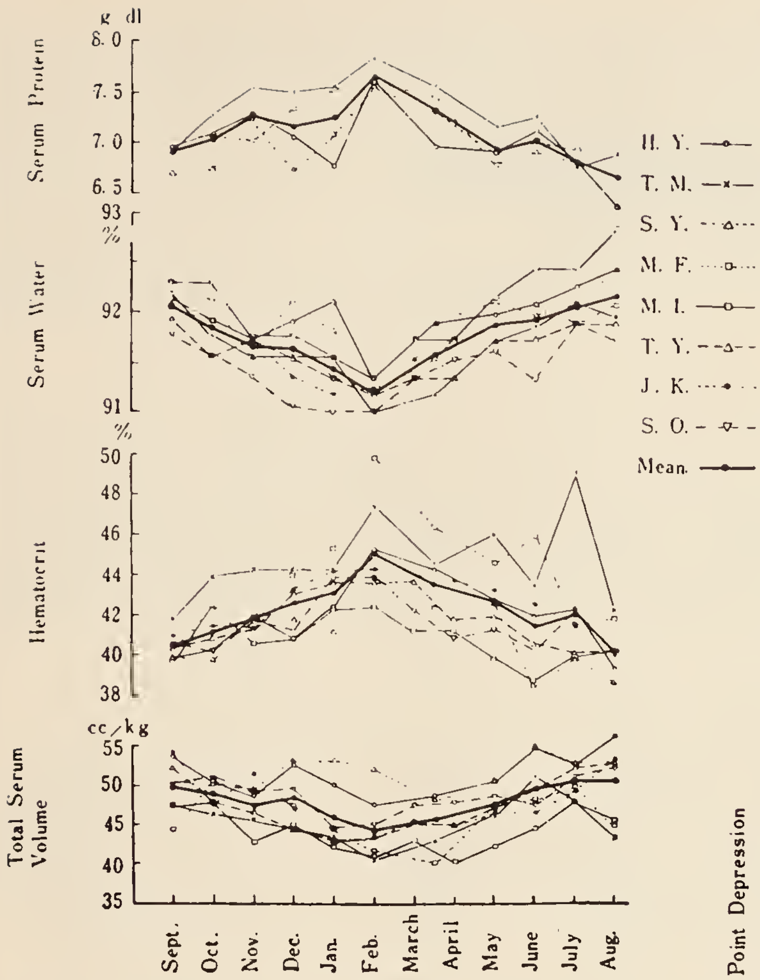

Figure V.3

Seasonal variation of blood concentration

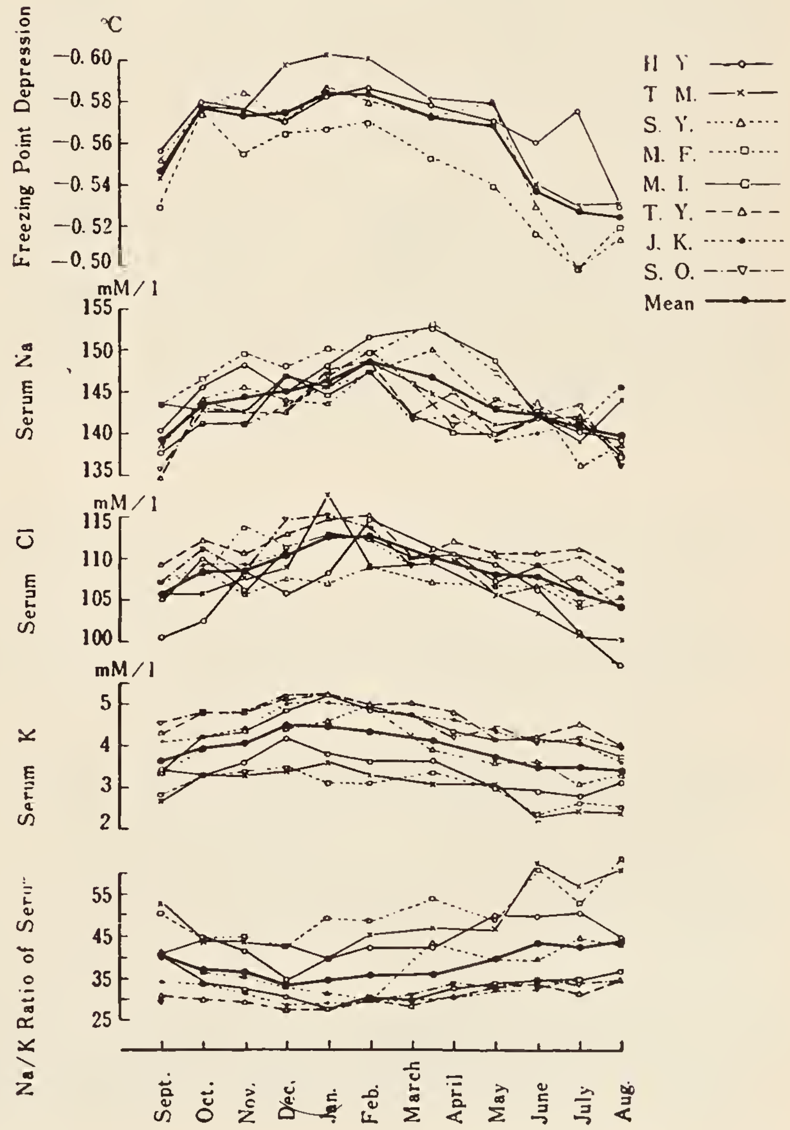

Figure V.4

Seasonal variation of serum salt concentrations

TABLE V.1

SEASONAL VARIATIONS OF BODY FLUID DISTRIBUTION
AND SALT CONTENT OF EXTRACELLULAR FLUID

(After Yoshimura, 1960)

	No. of subjects	Annual mean	Summer	Winter	Difference (%)
Atmospheric temperature (°C)		15.5	25.7	6.0	+ 19.7
Body weight (kg)	4	52.04	52.50	51.89	+ 0.61 (1.2 %)
Total circulating serum Volume/B.W. (cc/kg)	8	48.0	50.2	46.1	+ 4.1** (8.59 %)
Total serum protein/B.W.(g/kg)	4	3.46	3.50	3.51	- 0.01 (- 0.25 %)
Total body water/B.W. (%)	4	60.4	63.3	56.8	+ 6.5**(10.8 %)
Extracellular fluid/B.W. (%)	4	22.4	23.7	20.6	+ 3.1**(13.8 %)
Intracellular fluid/B.W. (%)	4	38.0	39.7	36.2	+ 3.5**(9.2 %)
Total Na in ECF/B.W.(mM/kg)	4	29.5	30.8	27.9	+ 2.9**(9.8 %)
Total Cl in ECF/B.W.(mM/kg)	4	24.9	25.9	23.0	+ 2.9 (11.6 %)
Total K in ECF/B.W. (mM/kg)	4	0.94	0.90	0.97	- 0.07(*)(-7.5 %)

1) The value in summer represents the mean value of June, July and August, while that in winter is the mean value of December, January and February.

2) ECF is the abbreviation of the extracellular fluid volume and ICF the intracellular fluid volume. B.W. means the body weight in kg.

3) The difference is expressed as positive when the value in summer is higher than that in winter. The percentage difference from the annual mean is given in parenthesis.

4) The seasonal difference is subjected to analysis of variance and the statistical significance is indicated by asterisk, i.e. * is significant at 5 % level and ** at 1 % level. (*) means higher than but very close to 5 % level.

Calcium and phosphorus. Calcium and phosphate have different physiological meanings from sodium, potassium and chloride. The former are the main materials for bone growth. Their metabolism is always interrelated and it is regulated by the activity of the parathyroid gland. Yoshimura and his colleagues (1959) have demonstrated that the metabolism of calcium and phosphate varies seasonally. From nine male adults specimens of blood were taken twice in each month for a year. The conditions for the week prior to venipuncture were carefully standardized. Among these subjects (Figure V.5) the serum inorganic phosphate increased in summer and decreased in winter, while the total calcium changed in the opposite direction. The main cause for the heightened serum concentration of inorganic phosphate in the summer was a reduced urinary excretion of this substance.

These summer to winter changes of phosphate and calcium could be reproduced by the experiment in which a subject already acclimatized to winter cold changed his residence to a hot room of 30°C illuminated with an ordinary Matsuda lamp which is somewhat deficient in ultra-violet radiation and stayed there for about two weeks or more. On this basis it was deduced that the seasonal changes in serum phosphate and calcium were mainly provoked by seasonal changes of atmospheric temperature. This conclusion disagreed with the widely maintained view that seasonal variations of calcium and phosphorus metabolism were primarily due to the action of solar ultra-violet radiation (Sargent, 1951).

Since phosphate and calcium metabolism are mainly regulated by the parathyroid gland, seasonal variations in its activity were investigated by measuring the ratio of phosphate re-absorbed by renal tubule to that filtered through the glomerulus according to the technique of Crawford, Osborne, Talbot, Terry and Morill (1950). These workers verified that the ratio of reabsorbed to filtered phosphate was an index of parathyroid activity. The measurements were made on the same four adult males in summer as well as winter. The observations were consistent with the view that parathyroid activity was greater in the winter than summer.

Since the parathyroid hormone can decrease the phosphate level in serum,the increased activity of parathyroid may be one of the most important factors producing a decrease in serum phosphate in winter. The seasonal variation of serum calcium seems to result either from the inverse relationship with serum inorganic phosphate (Peters and Eiderson, 1925) or from an effect of seasonal variation of serum volume, or from both. The reason why the parathyroid activity undergoes such marked seasonal variation is obscure. Since the author has demonstrated a change in phosphate metabolism as a result of adaptation to heat and cold, it is suggested that alterations in the activity of the parathyroid may also be produced by some temperature adaptive mechanism.

With respect to the physiological significance of the seasonal variation of calcium and phosphorus little is known except their effects on the growth of bone which undergoes seasonal changes in childhood (de Rudder, 1952). Bodily growth is increased from spring to summer and decreased in winter; it is accompanied by variation of bone growth. The interrelation between variation in serum phosphate and calcium and that in bone growth, however, is not yet well established. There is great need for systematic studies.

Inorganic phosphate has an intimate bearing on metabolism of carbohydrate. Kravitz and Guarino (1958) demonstrated that the concentration of inorganic phosphate in a tissue culture of tumour cells influenced the manner of glucose breakdown. Alternative chemical reactions may take place depending upon the concentration of phosphate in the medium. According to Cori and Cori (1927) the rat exhibits a seasonal variation in the capacity to oxidize glucose which is associated with a seasonal variation in susceptibility to ketosis. They demonstrated that ketone body formation after fasting was increased in summer, while glucose oxidation and glucose tolerance were decreased. On the other hand, Sargent and Weinman (1963) insisted that fasting ketosis was greater in the human body in winter than in summer and attributed this greater tendency to nutritional ketosis in winter to an influence of lowered environmental temperature. If the seasonal variations of serum inorganic phosphate are

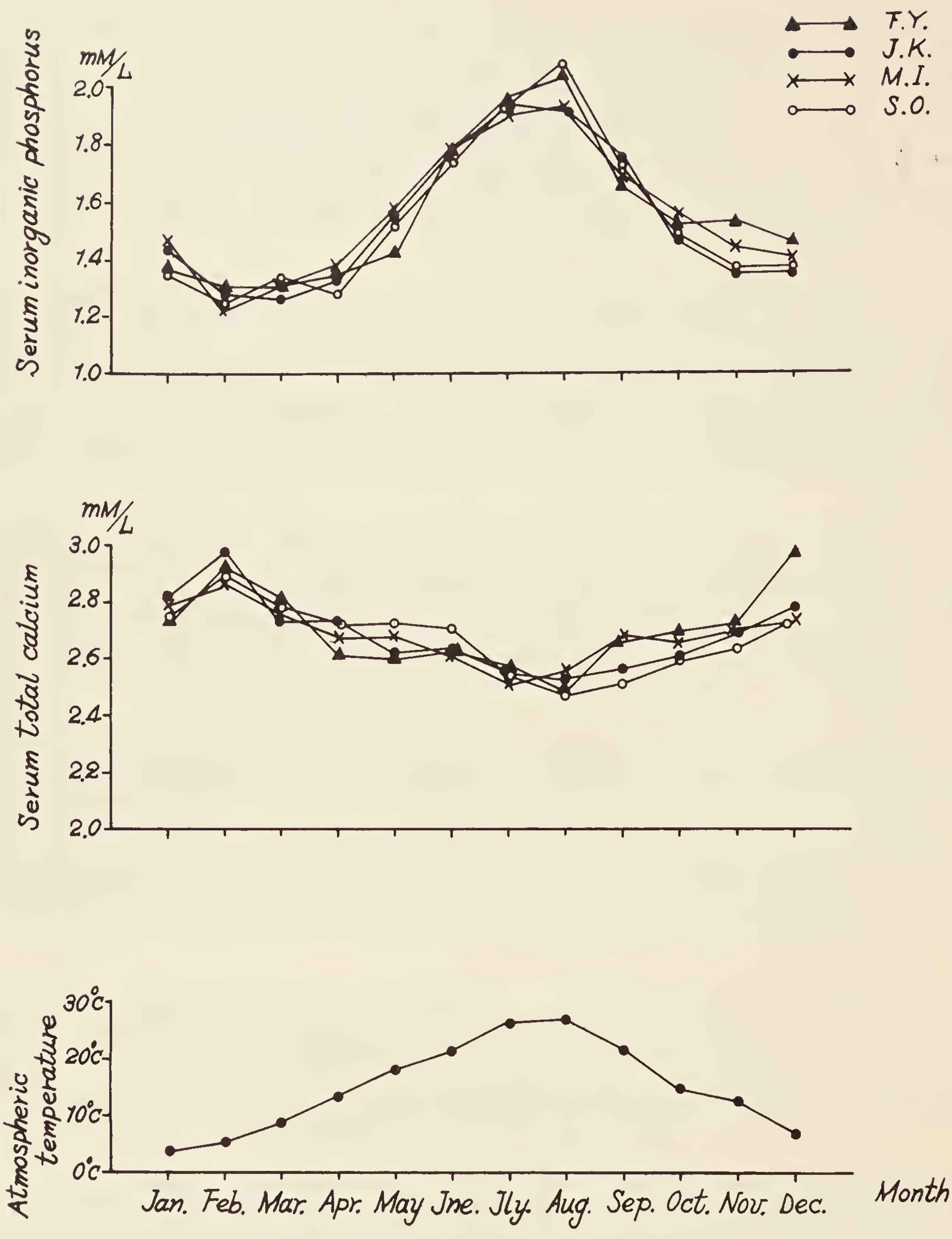

Figure V.5

Seasonal variations in serum inorganic phosphate and calcium related to that of the capacity of glucose breakdown, the data presented above may well conform to those of Sargent (1962). In view of the conflicting reports, it is difficult now to draw a definite conclusion on the role of seasonal variation of serum phosphate in the control of glucose metabolism.

Comments on mechanism of acclimatization

The author has outlined studies on acclimatization of the healthy human body which were mainly conducted by Japanese investigators. He concluded that physiological acclimatization was attained by adaptative mechanisms of nervous functions as well as by metabolic adaptations subject to hormonal control. Since both nervous and endocrine processes are integrative (cf. Chapter III), acclimatization to heat and cold is accomplished efficiently.

It is generally recognized that the chronic hyperactivity of a certain organ may be accompanied by hypertrophy and hyperfunction, and may result in an increase of its metabolism. Increased activities of endocrine glands after acclimatization may be explained by this general principle. A raised activity of vasoconstrictor centre of the cold-adapted person and an elevated excitability of the sweating centre of a heat-adapted individual may similarly be explained.

On the other hand, Glaser (1957) insisted that evidences of acclimatization can best be explained by lessened responses to heat and cold stimuli, namely by habituation of the central nervous function, and that the physiological processes which bring about habituation may be "plastic" changes in the functioning of the central nervous system. Thus the delayed onset of shivering of the cold-adapted person and the reduced sweating of natives of the tropics may be examples of habituation.

Thus, there are two general mechanisms of physiological acclimatization which appear to be contradictory. In the author's opinion, which of the two processes may be active depends upon the degree of acclimatization. Habituation seems to account for the long-term alterations of physiological function; hypertrophy and hyperactivity of organs for the short-term changes.

2. THE INFLUENCE OF WEATHER AND CLIMATE ON HUMAN DISEASES

Since William F. Petersen (1938), formerly Professor of Pathology at the University of Illinois, published his famous four-volume monograph "The patient and the weather" and over 60 papers on the influence of meteorological factors on various human diseases, several hundred research studies have been published on the influence of weather and climate on human diseases. Most of these studies have had an empirical character. Usually only statistical correlations have been described but in a few instances the investigator has elucidated the deeper physiological mechanisms involved. In a still smaller number of cases it has been possible, on the basis of statistically significant correlations, to make predictions on the frequency of meteorotropic diseases (i.e. illnesses triggered by meteorological factors). Such predictions have tended to support the assumption that the observed statistical correlation described a causal relationship. In cases where the meteorotropism could be reproduced under controlled conditions in climatic chambers, further support for this assumption was provided.

Problems in studying the influence of daily weather

It may seem rather surprising that, whereas long-period biological phenomena related to seasonal or other changes in weather and climate are fairly well known in human biometeorology, the daily influence of weather changes on the physiology and pathology of man is extremely difficult to demonstrate in a way which complies with modern scientific standards. Some of the reasons can be summarized as follows :

(1) A certain biological effect, as a result of specific weather conditions, often does not develop in every individual of a population at the same time and to the same degree. This is due primarily to the fact that every person has a different genetic background. Furthermore, their individual physiological "experiences", particularly during the days or hours preceding the weather action, are different. Modern physiological studies have clearly shown that preceding experiences may affect the outcome of a physiological experiment (The Law of the Initial Value of Wilder). Therefore, we can never expect all in a large group of persons to respond to a given meteorological change at the same moment and to the same degree. We can only expect a statistical correlation.

(2) Making statistical correlations between weather events and the occurrence of disease involves two fundamental assumptions.

First, it is hypothesized that variations in disease processes, the frequency of illness, or the occurrence of death are triggered by weather changes on the basis of the assumption that all other relevant exogenous or endogenous events are either controlled or are of no consequence. It can be argued that this assumption may be valid for a very large population where weather is certainly the most important circumstance that the individual members have in common. In this case, other events tend to act randomly. When, however, a small population is involved in the biometeorological study, the validity of the assumption is less certain and the investigator must convincingly demonstrate that all other things are indeed equal.

Second, it is assumed that weather observations made under standardized conditions at a central meteorological observatory precisely describe the actual atmospheric conditions to which all members of the study population have been exposed. That is, it is supposed that these observations are in fact truly representative of the atmospheric environment that the individual members have in common. For biometeorological studies involving macro- or mesometeorological events, this assumption may be valid, but for micrometeorological events it remains to be proven that correlating official data from a weather bureau and a clinical event are valid.

Granting the validity of these assumptions it is difficult to know whether a given weather event precedes or coincides with the occurrence of certain clinical phenomena. The change in rate of illness may appear only after days or weeks. One may propose various time-lags between a triggering weather phenomenon and a certain clinical event (e.g. heart attack or accentuation of asthma), and then test each supposition by standard statistical procedures. A high degree of statistical association usually identifies the most appropriate lag-time. Nevertheless biometeorological relationships are difficult to find because of the very complex nature of meteorotropic phenomena.

(3) Each biometeorological analysis of clinical data on an empirical basis requires two groups of observations : accurate meteorological data, compiled in specially devised biometeorological logs (Tromp 1963, p. 163) and clinical data. Despite all the necessary precautions taken, there are various reasons why clinical records

should always be accepted with some reserve :

(a) Errors in diagnosis. Although a point is made of using quite large groups of cases of a particular condition (as otherwise differences in opinion between physicians may more easily arise), it should nevertheless be realized that many diseases, e.g. schizophrenia and asthma, are far from homogeneous. Many varieties of each disease are known and there is no reason to assume that each variety would react in the same way to the same meteorological factors.

(b) Errors in recording. Physicians and nurses, being fallible like all human beings, are liable to make errors in their daily recordings, partly on account of personal momentary inattention, distraction or preoccupation and partly on account of day-to-day differences in accuracy. The lack of homogeneity in the clinical material and the various methods of recording used by different physicians in the many clinics may well add to these errors. However, the use of data from different institutes has in its favour the fact that the total number of patients is considerably larger and recording errors made by one individual will have little effect on the total body of clinical data.

(c) Errors due to medical treatment. As many patients are under constant medical treatment, their reactions to meteorological factors are usually suppressed. For instance, the reactions of mental patients will be less pronounced as the result of treatment with tranquillizing drugs.

Statistical methods applied in human biometeorology can be found in various texbooks (e.g. De Rudder, 1952, pp. 32-43; Tromp, 1963, pp. 169-178). The reader is referred to these sources for a more detailed consideration of the problems of studying the influence of daily weather.

Summary of meteorotropisms

In Table V.2 a summary is given of the reported meteorotropic phenomena, both short-period weather effects and long-period (seasonal and pseudoseasonal) ones. The interested reader is referred for details to Assmann (1963), De Rudder (1952), Petersen (1938) and Tromp (1963). As often the primary or secondary cause of disease (i.e. the appearance of certain symptoms in the human body) is a serious disturbance of the functioning of the body, not only are the direct effects of weather and season on various diseases given, but also the effects on a number of basic physiological processes in the healthy body.

It is beyond the scope of this account to discuss in detail the deeper mechanisms involved in each of the phenomena described in Table.V.2. However, in Table V.3 a brief summary is presented of the principal centres in the human body which respond to meteorological stimuli and of the possible reactions which follow. The mechanisms involved in various diseases are a combination of these basic reactions and therefore they are considerably more complex than may appear from this table. Three examples of the extreme complexity of this problem will be briefly discussed : the possible mechanisms involved in the influence of weather on (1) bronchial asthma, (2) some rheumatic diseases and (3) heart diseases.

Influence of weather on asthma

The word asthma was used originally as a synonym for breathlessness (dyspnea) or gasping. At present it is used to indicate recurrent paroxysmal breathlessness accompanied

TABLE V.2

REPORTED EFFECTS
of the
INFLUENCE OF WEATHER AND CLIMATE ON DISEASES *)

Effect on basic physiological mechanisms

SHORT-PERIODICAL EFFECTS	LONG-PERIODICAL EFFECTS (seasonal or pseudo-seasonal)
BLOOD	
LEUCOCYTES : Increasing after steep barometric fall, accompanied by atm. cooling	High in winter, max. around December, min. in August (in W. Europe).
EOSINOPHILS : ---	High from Nov.- April (max. March), low from May-Sept. (min. July-Aug.) (in W.Europe).
TOTAL SERUM PROTEIN : ---	Usually higher in winter than in summer.
ALBUMIN : Usually higher during cold periods	Usually higher in winter than summer.
γ-GLOBULIN : Usually lower during cold periods	Usually higher in summer than winter.
HAEMOGLOBIN : Usually higher during cold periods.	Highest in winter, usually min. around June (in W. Europe).
PROTHROMBIN : ---	In adults min. in winter and spring.
CALCIUM LEVEL (SERUM) : ---	Min. in winter, max. in summer.
MAGNESIUM LEVEL : Strong cooling lowers magnesium level in cows.	" " " " " "
PHOSPHATE LEVEL : ---	" " " " " "
IODINE LEVEL : ---	Min. in winter, max. in summer.
VIT. C CONTENT : ---	Low in winter, high in summer.
LIVER ENZYMES : Transaminases usually increase after cold stress.	---
FIBRINOLYTIC PROPERTIES : Increased fibrinolysis after cold front passage.	---
BLOOD VOLUME : Decreases after cold stress.	Lower in winter than in summer.

*) For authors and references see S.W. Tromp : "Medical biometeorology" (1963); Elsevier Publ. Co., Amsterdam; pp. 374 - 378 and 575 - 584.

OXYGEN CAPACITY : ---	In children (< 6 y.) increasing from Jan. - May, in older children (in Sweden) from Feb.-Aug.
SEDIMENTATION RATE : Usually higher percentage of 1-2 mm/1st hr during cold periods.	Higher percentage of 1-2 mm/1st hr in winter than in summer.
BLOOD COAGULATION : Coagulation time in rabbits shortens particularly before cold front passage.	---
BLEEDING AFTER TREATMENTS WITH ANTICOAGULANTS : ---	Max. in Jan. - Feb., min. in July (in the Netherlands).
URINE	
URINARY VOLUME : Increases after cold stress.	Average values usually smaller in spring and early summer, high amplitudes in autumn.
17-KETOSTEROIDS : Increase after cold stress; after previous period of serious stress, cold stress causes fall in output of 17-Ketosteroids and 17-hydroxycorticosteroids.	Highest average daily values in winter.
CHLORIDES : Decrease after cold stress.	Lowest average daily values in autumn.
pH : Increase after cold stress.	---
SODIUM : Decreases after cold stress.	Lowest values in autumn and early winter.
POTASSIUM : Usually decreases after cold stress.	---
UREA : Decreases after cold stress.	Highest daily values in summer during cold stress.
HEXOSAMINES : Decrease after cold stress.	Highest average daily excretion in summer.
METABOLISM	
---	General metabolism in children high in summer, max. during autumn; sharply decreasing during winter.
DUCTLESS GLANDS	
THYROID GLAND : Cold stress causes hyperthyroidism and increased activity : intense congestion of intra-alveolar capillaries and disappearance of colloid from alveoli. Ultra-violet deficiency or darkness causes hyperplasia and colloid loss.	Increased activity in winter.
ADRENAL GLAND : Cold stress causes hypertrophy and increased hormonal production.	Increased activity in winter.
PITUITARY : Cold stress increases production of thyrotrophin and adrenotrophin.	Increased production of gonadotrophic hormones in spring and early summer.
BLOOD PRESSURE (diastolic)	
Increasing after a period of strong atmospheric cooling.	Highest in autumn and winter, lowest in summer (in W. Europe).

CAPILLARY RESISTANCE AND MEMBRANE PERMEABILITY	
Resistance increases after atmospheric cooling; permeability decreases.	---
CEREBRAL HAEMORRHAGE AND CAPILLARY FRAGILITY	
---	Highest in winter and spring.
BIRTHWEIGHT	
---	Greatest in June - July, smaller Dec. - March.
BIRTH FREQUENCY	
---	Highest number of conceptions in June (legitimate children) or May (illegitimate); stillborn : max. in January.
ONSET OF PARTURITION	
---	According to certain authors length of period of pregnancy increases during warm summers.
SEX	
According to Petersen conceptions during cold periods cause a statistical predominance of males, during warm periods predominance of females.	---
FERTILITY	
In animals usually increasing with increasing sunlight.	Lower in winter than in summer (at least in animals).

Effect on diseases

SHORT-PERIODICAL EFFECTS	LONG-PERIODICAL EFFECTS (seasonal or pseudo-seasonal)
LUNG DISEASES	
TUBERCULOSIS : Haemoptysis suddenly increases in clinics after oppressive warm weather before thunderstorms, after Föhn, humid cold foggy weather or sudden heat-waves.	Increased sensitivity to tuberculin test in March and April; low during autumn.
ASTHMA (bronchial) : Increases with sudden cooling (particularly if accompanied by falling barometric pressure and rising wind speed); during high barometric pressure and fog (in W. Europe) very low asthma frequency.	Low in winter, suddenly increasing after June, max. in late autumn (W. Europe).
BRONCHITIS : Increasing complaints during fog (particularly in air-polluted areas) and specially if accompanied by atmospheric cooling.	High in winter, low in summer (in W. Europe).
HAYFEVER (and various forms of rhinitis) : Allergic reactions often increase during atmospheric cooling.	Hayfever is related to flowering season of certain plants or grasses, different for different countries. In W. Europe usually max. complaints in May - June.
CANCER	
SKIN CANCER : More common with increasing number of sunhours and increased exposure of the skin to the sun.	---
EYE DISEASES	
GLAUCOMA (acute) : Most attacks during very cold days in winter or very warm days in summer.	High incidence in winter (max. in Nov. in W. Europe); low in summer.
RETINAL DETACHMENTS : ?	Max. in June (Netherlands) or March - May (Switzerland); min. in winter.
CONJUNCTIVITIS (acute) : During sunny weather.	Common in May and September (in W. Europe).
RHEUMATIC DISEASES	
Most forms of arthritis react on strong cooling (falling temp.; strong wind). Humidity seems to have no direct effect, only indirect through cooling.	Arthritic complaints particularly common in autumn and early winter (in W. Europe).
HEART DISEASES	
CORONARY THROMBOSIS, MYOCARDIAL INFARCTION and ANGINA PECTORIS occur more frequently shortly after a period of strong cooling.	Highest mortality in Jan.-Feb. (in W. Europe and N. U.S.A.), lowest July - Aug. In hot countries (e.g. southern U.S.A.) highest mortality in summer, lowest in winter.

INFECTIOUS DISEASES	
COMMON COLD : Weather changes affecting thermoregulation mechanism, membrane permeability and growth and transmission of common cold virus seem to initiate the diseases (e.g. very cold period followed by sudden warming up).	Max. in Feb. - March; increasing from Sept.-March (in W. Europe).
INFLUENZA : Rel. humidity below 50 % and low windspeeds seem to favour the development and transmission of influenza virus.	Max. in Dec. - Feb. ; increasing from Sept. March.
POLIOMYELITIS : Warm humid air seems to favour development and spread of polio virus.	Max. in Aug. - Sept.; increasing from May - Sept. (N. hemisphere).
MENTAL DISEASES	
SCHIZOPHRENIA : Increasing unrest and increased diuresis with influx of warm air masses.	Max. unrest in Nov. - Jan. (in W. Europe). Highest birth frequency in Jan. - March (W. Europe and N. U.S.A.).
EPILEPSY : Increasing number of attacks after sudden atmospheric cooling (cold fronts, polar air masses etc.). On very sunny days driving along closely spaced high trees, rapid changes in light intensity triggers epileptic attacks.	Max. around Nov. - Dec., min. in summer.
APOPLEXY : Increases during periods of strong cooling.	Highest mortality in Jan. - Feb.; lowest in July - Aug. (in W. Europe).
MENTAL DEFICIENCY : ?	Highest birth frequency in Jan. - March.
COLICS (hepatic, urinary and renal)	
According to some authors particularly common after influx of cold humid air masses.	?
DENTAL CARIES	
According to some authors inverse relationship between amount of sunshine (ultraviolet, Vit. D. serum PO_4 level) and caries.	According to some authors in U.S.A. max. in late winter and early spring, min. in summer.
DIABETES	
---	Conditions often deteriorating in late autumn and winter (more need for insulin).
GOITRE	
Extreme cold and excess of U.V. may cause increased hyperthyroidism in goitre patients.	Simple goitre : max. in winter; Exophthalmic goitre (Basedow's disease) max. in May; min. in summer.
SKIN DISEASES	
Affected by weather conditions changing sweating rate and acid coating of skin; sunlight may cause "light-dermatoses".	High eczema incidence in spring; higher incidents of furuncles in July - Aug.

ULCERS

GASTROACIDITY secretion decreases with altitude and heat stress.	Hyperacidity increases in winter; anacidity increases in summer.
PEPTIC ULCER : Ulcer perforations are common during drastic changes in air masses.	In Germany most common in Dec. - Feb. In U.S.A. max. in May and Sept.
DUODENAL ULCER : ---	Max. in May and November (in Germany).

GENERAL MORTALITY

Mortality from arteriosclerotic heart diseases increases after sudden strong cold or heat stress.	In W. Europe max. in Dec. - Jan.; min. in July.

Table V.3 - Principal Centres* of the Human Body Registering Meteorological Stimuli

Compiled by: S.W. Tromp

I Skin	II Lungs and throat (Respiratory tract)	III Nose	IV Eyes	V Direct effects on the nervous system
1 **Thermal effects** through conduction, convection or infrared radiation recorded by thermoreceptors in skin and hypothalamus, effects counter-balanced by vasodilatation or constriction or sweating. Effects on: (a) **Hormonal functions** of pituitary (anti-diuretic, thyrotraphin and gonadotrophic hormones), thyroid and adrenal gland (17-ketosteroids) and pancreas (insulin production and blood sugar level). (b) **Blood**: changes in albumin and globulin levels and blood cells composition. (c) **Electrolyte balance** Cold stress decreases excretion in urine of chloride, sodium, urea, hexosamines, rise in pH. (d) **Liver function** (transaminoses and hepatic metobolism) (e) Other physiological processes affected by (a)-(d) 2 **U.V. radiation effects:** (a) Melanin oxidation (b) Increased vit. D and histamines. (c) Increased gastric acid secretion. (d) Blood: increased haemoglobin, Ca, Mg, and phosphate level (e) Protein metabolism (increase) (f) Hormones: thyroid (hyper-thyroidism) and adrenal gland, gonadotrophic functions (g) Direct lethal effects on bacteria. (indirect effect on man) 3 **Changes in acidity of the skin** (Marchionini) (a) by aerosols (b) by factors affecting sweat production and evaporation	1 **Temperature and Humidity**: Affecting mucous membrane **Dry air** (a) drying and decreased elasticity of mucous membranes (leading to micro-fissures) and decreased ciliary activity (inefficient removal of dust) (b) decreased mucous (and anti-body) production (c) decreased bloodflow and warming up of inhaled air **Cooling** (a) decreased permeability of membrane (b) constriction of blood capillaries. Affecting survival of bacteria and viruses 2 **Ionisation**: Surplus of negative ions causes (acc. to Krueger): (a) Increased ciliary activity (from 1100-1700/min.) (b) Increased mucous production. 3 **Acidity of the air** (a) pH > 8.0: increased permeability, inflation of mucous membrane cells, decreased ciliary activity (b) pH < 7.0: shrinkage of cells (c) pH < 5.0: bronchitis complaints. 4 **Decreased partial oxygen pressure** (a) increased lung ventilation (b) increased adrenal activity (c) increased heart and pulserate (d) changes in composition of blood cells (e) increased peripheral blood-circulation (f) increased thermoregulation efficiency. 5 **Increased partial oxygen pressure** Treatment of gas gangrene and phlegmone 6 **Trace elements** (a) **Ozone**: In low concentration killing bacteria, in high concentration irritating mucous membranes and increasing infections (b) **Salt** (NaCl) Fine aerosols with 1/4-1/2 % hypotonic salt solution (< 0.9 % NaCl) cause swelling of mucous membranes. Hypertonic solutions cause shrinkage	1 See effects on lungs and throat 2 Direct stimulation of olfactory brain (rhinencephalon), affecting mood, cardio-vasomotoric, visceral and endocrinal activities Col. II cont. 7 **Airpollution** (a) **Gases**: (SO_2, CO_2, benz-pyrene etc.) (b) **Particles**: (1) organic (pollen, spores) causing allergic reactions (2) inorganic: mineral dust (silicosis etc.) (c) **Aerosols**: Strong increase of physico-chemical action due to increased action surface.	1 Direct overstimulation of the eye causing inflammation 2 Light-flickering of certain frequences activating epileptic attacks 3 Benoit-effect on pituitary (gonadotrophic effects) 4 Complete darkness causes changes in carbohydrate metabolism, urine volume, blood sugar level, reduction in size of pituitary, affecting thyroid and adrenal gland (see also U.V. effects on skin)	1 Electrostatic (pulsating) and electromagnetic fields: affecting bees (Schua, Becker, Haine and König), golden hamsters (Schua), nerves (Gengerelli, Thompson), reaction speed (Reiter), etc. 2 Microseismic effects (ampl. 1-20 μ and freq. 6-8/sec) on eel (Deelder) 3 Direct stimulation of olfactory brain (see sub III) * Note: Recent studies by F.H.J. Figge (1947), J. Eugster (1951), S.G. Ong (1961) and others suggest direct biological effects at cellular level due to **cosmic rays**

by a wheezing cough and a sense of constriction. Asthma can be caused by heart diseases (cardiac asthma), renal diseases (renal asthma), or allergy of the bronchi (allergic asthma).

In most countries, at least in the northern hemisphere where the majority of the detailed studies have been made, the frequency of asthma, as observed in large groups of adults or children, increases rapidly after a sudden increase in general turbulence of the atmosphere. The increase is most striking if preceded by a quiet period. This change in turbulence is characterized by a sudden rise or fall in atmospheric pressure. Periods of steep barometric fall, due to rapidly approaching low pressure areas, have a particularly marked asthma-increasing effect when the following meteorological sequence obtains :an active cold front preceding a sudden invasion of cold polar or continental air followed by one or more secondary cold fronts. During periods of slight atmospheric turbulence, a sharp decrease in asthma frequency is observed. A rapid succession of cold and warm air masses, or cold and warm fronts, may create rapid alternations in the frequency of asthma. Each episode of asthma then has only a relatively small maximum amplitude. If the succession is too rapid (e.g. within a few hours), often no effect at all is observed.

It is striking that in most of the long-term studies on asthma in Europe, Japan and U.S.A. no consistent relationship between the observed number of pollen or spores and asthma frequency has been established. As the number of pollen and spores greatly depends on the degree of air turbulence, an apparent correlation between the number of spores and asthma may be observed under certain atmospheric circumstances but it is not a consistent relationship.

Another interesting meteorotropic observation is that patients suffering from bronchial asthma have very few complaints during foggy weather (at least in western Europe). In contrast are patients with bronchitis; they suffer badly under these circumstances.

<u>An hypothesis for the meteorotropism of asthma.</u> The great sensitivity of asthmatic patients to atmospheric cooling can be explained in different ways, but Tromp (1963) is inclined to believe that the principal reason must be sought in a functional disturbance of the thermoregulatory centre of the brain (cf. Chapter III; Chapter IV, Section 3). That these patients do in fact have decreased ability to regulate their temperature has been demonstrated by a newly developed "thermoregulation water bath test". In the light of this hypothesis, the physiological mechanism for the contraction of the bronchi after atmospheric cooling may be somewhat as follows :

The calibre of the bronchi is controlled reflexly by the autonomic nervous system (cf. Chapter III). The integrative centre for this system is located in the hypothalamus, the same region of the brain wherein is located the temperature regulating centre. There are two divisions of this system : the sympathetic and the parasympathetic. In so far as the bronchi are concerned, the sympathetic neurons cause reflex dilatation and the parasympathetic neurons cause reflex constriction. The usual calibre of the bronchi is maintained by a balanced action of the two divisions of the autonomic nervous system. The balance in the healthy individual reveals a dominance of the sympathetic division, for the bronchi are somewhat dilated. In the asthmatic patient the balance shifts. The parasympathetic dominates or easily becomes relatively over-active. Constriction of the bronchi and then dyspnea develop readily. Other evidence for the dominance of the parasympathetic among asthmatic patients derives from observations on blood pressure, activity of the adrenal gland, and gastro-intestinal complaints.

A period of strong environmental cooling causes, first, a considerable stimulation of the portion of the hypothalamus subserving the sympathetic division of the autonomic nervous system. Continued stimulation may then lead gradually to decreased activity of this part of the hypothalamus and finally to a reversed situation in which the more reactive system is the parasympathetic. The process by which this reversal may come about is habituation. It is known from neurophysiology that a long-lasting stimulus or a repetition of short stimuli changes the response of the nervous system and may lead to an opposite reaction. This phenomenon of habituation has been explained by Eccles, Konorski and Young in terms of changes in the size of nerve cells.

In the asthmatic patient with his relatively over-active parasympathetic system, the process of reversal might be facilitated. The consequence would be an accentuation of the bronchial action of the parasympathetic leading to constriction and dyspnea. Thus, by this means the reaction of patients with asthma to cold weather may in part be accounted for.

However, other processes controlled by weather change seem to be involved. For instance, in asthmatic patients the production of adrenal hormones is depressed. An artificial supply of these hormones may help to suppress an attack of asthma. Biometeorological studies (Zimmermann, 1957; Tromp, 1958-62)* have shown that after sudden environmental cooling the urinary output of derivatives of adrenal hormones sharply increases until a maximum is reached, which is often 100 per cent or more above the initial value. A steep decline then follows. During this period of declining output of adrenal hormones the complaints of asthmatic patients tend to increase. If a period of mental stress precedes the cold stress, the urinary output of adrenal hormones may decrease instead of increasing.

These and other similar meteorotropic mechanisms, of which only part is known at present, seem to be responsible for the asthma-weather relationship, a relationship which is not only based on statistically significant correlations between weather and asthma frequency, but also on the observation that is possible, at least in the Netherlands, to predict the degree of asthma which can be expected in a group of asthma patients under certain weather conditions.

Influence of weather on rheumatic diseases

Many studies have been devoted to the effect of weather and climate on rheumatic diseases. While these diseases are difficult to define sharply, they may, for present purposes, be described as a group of processes affecting the connective tissues, marked by pain or stiffness in the joints, muscles and related structures. The pain and stiffness are usually recurrent and symptomatic episodes are frequently related to acute or chronic exposure. Rheumatic diseases are more common among females than males. The incidence of this group of diseases varies considerably in different parts of the world and also in the same country.

In Assmann (1963), De Rudder (1952), and Tromp (1963) reviews are given of a number of studies indicating highly significant statistical correlations between certain weather types and certain forms of rheumatic diseases, in particular the arthritic forms which are due to inflammation of the joints or tissues, as a result of bacterial or virus infection, or injuries. Both extreme heat and cold stress seem to evoke rheumatic complaints. Some patients suffer from both forms of stress, others are only sensitive to one, usually cold stress.

It is beyond the scope of this publication to discuss in detail the various reported weather correlations. Only a few of the possible physiological mechanisms will be briefly reviewed.

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* Starred references are fully cited in Tromp (1963).

Disturbance of the temperature regulatory mechanism. Experimental studies by Tichy, Mierisch and Warmbt (1960)* in Germany and Tromp (1963) in the Netherlands strongly suggest that most rheumatics have a poorly functioning thermoregulatory mechanism. Their sensitivity to cooling and the high incidence of this disease (at least in Western Europe) amongst people living in cold humid houses (especially houses along the course of rivers or houses built above former watercourses, etc.) support this assumption.

Disturbances of enzyme activity. Various metabolic processes in the muscles and connective tissues are controlled to a considerable extent by different enzymes. These substances are biological catalysts, for they facilitate chemical reactions vital to proper functioning of living organisms. A disturbance in the metabolic processes may lead to the accumulation of waste products and give rise to complaints from rheumatic patients. An important enzyme in providing energy for the contraction of skeletal muscle is adenosine triphosphatase. Racker (1960)* demonstrated that the activity of this enzyme decreased rapidly at 4°C. Similar thermal effects on other enzymes have been described. Although the body temperature - or even the muscle temperature - does not fall to 4°C, it does seem possible that strong local cooling of the extremities might alter enzymatic activity in the organ by a change in the peripheral blood flow.

Disturbances of mucoprotein metabolism. Mucoproteins are important constituents of connective tissues and of mucin. Mucin is found, among other places, in the fluid that lubricates the joints, the synovial fluid. The viscosity of this fluid is related to its content of mucin. Derivatives of mucoprotein serve to indicate the metabolic state of these tissues and fluids. Hexosamine is a derivative of mucoprotein.

It has been reported (Tromp, 1959-63)* that the amount of hexosamine excreted in the urine is low during periods of atmospheric cooling and high during warming. These observations suggest that the metabolism of mucoprotein may be altered by weather change. Whether cooling causes an accumulation of hexosamine in the tissues or a slowing of the breakdown of mucoprotein to hexosamine cannot be decided from the data in hand. Presumably mucin increases, for Hunter (1951)* reported that during cooling the viscosity of synovial fluid increased and the resistance of joints to movement was greater. Furthermore, he found that during cooling the greatest fall in temperature took place in the joints, followed by muscle and the skin. After heating, the joints exhibit prolonged recovery. The poorer the functioning of the temperature regulating system, the slower will be the recovery. Presumably a disturbed control of blood flow in rheumatic patients contributes to the pain they experience even during slow cooling.

These few examples suggest the extreme complexity of the processes involved in the meteorotropic phenomena in rheumatic patients. Many of these problems require considerably more research, but the key factors responsible for weather induced rheumatic complaints are probably related to the processes just described.

Influence of weather on heart diseases

The study of the possible influence of weather and climate on various heart diseases is very important, because in many countries a considerable percentage of the total mortality arises from heart diseases such as coronary thrombosis (formation of a blood clot in one of the coronary arteries of the heart), myocardial infarction (development of an acute local deficiency of blood supply in the cardiac muscles, usually due to a blood clot, followed by injury of the cells and usually involving the left ventricle of the heart), angina pectoris (paroxysmal thoracic pain, usually radiating to neck and left arm and due to spasms of the heart muscles and temporarily insufficient blood supply), or death through heart failure.

Studies by Bartels (1925),* Beljajen (1949),* Kisch (1908),* Kolisko (1913)* and others strongly suggest a meteorotropic relationship between the passage of weather fronts or the sudden influx of polar air masses, and the increased occurrence of heart diseases. The studies of Amelung et al.(1951),* Fladung (1952)* and Ströder et al.(1951)* in Germany, in particular, have given considerable statistical support to these observations. A review of these studies in Europe and the U.S.A. can be found in Assmann (1963) and Tromp (1963).

Various investigations (see Tromp, 1963, pp. 507 ff.) indicate a clearly seasonal incidence of both morbidity and mortality from the above-mentioned arteriosclerotic heart diseases. The same seasonal incidence was found for apoplexy. The highest mortality from these diseases is found in winter (in northern countries usually in January - February), the lowest in summer (usually July - August). In countries with very hot and humid summers (e.g. southern part of the U.S.A.) the highest mortality was found in summer, the lowest in winter (Heyer et al., 1953).* Studies by Tromp in the Netherlands have shown an almost perfect inverse relationship for all months of the years 1935-1958, between the curves representing the average monthly temperature and the mortality from arteriosclerotic heart diseases.

The influence of heat stress on cardiac output has been studied by several authors, but particularly the work of Burch (1959)* should be mentioned. This worker followed up the earlier estimate of Scott et al. (1940)* that cardiac output increases on exposure to heat. He measured the work of the human heart in New Orleans during the summer at 35°C with high humidity and found an increase in heart rate, in cardiac output (by about 40 per cent), and in work performed by the myocardium. Dry heat, at 37°C, on the other hand, seemed to have little effect on the work of the heart other than to reduce it when the subjects were adapted. This latter observation supports the work of Sancetta et al. (1958).* Which physiological mechanisms could be responsible for these various findings ? The following may be involved :

Changes in elasticity and peripheral resistance of the blood-vessels. The blood pressure varies as the product of the cardiac output and the peripheral resistance. A change in peripheral resistance will affect the functioning of the heart. The frictional resistance encountered by blood passing through the arterioles and blood capillaries depends on the blood viscosity (considerably affected by the haematocrit content of the blood), the diameter of the tubes, and the velocity of flow. The diameter of the arteries and arterioles (i.e. the tone of contraction) is under continuous control of the vasomotor centre, the cells of which are located in a special part of the medulla oblongata, not very far from the centre in the brain which controls respiratory activity. A slight increase in carbon dioxide in blood stimulates the vasomotor centre chemically and increases the vasoconstrictor discharges, resulting in a rise of blood pressure. Due to these various factors which are affected, directly or indirectly, by meteorological changes (usually through the intermediary of the hypothalamic thermoregulation system), environmental cooling usually increases the peripheral resistance of the arteries. This could be one of the reasons that in a healthy, rather constant, group of blood donors the average diastolic blood pressure increases during the winter and decreases during the summer (Tromp, 1963).

Changes in the autonomic nervous system. During cold periods the activity of the sympathetic system is increased. As a consequence the heart rate is accelerated and the force of the beat is increased. Studies by Wood, Bass, Burch, and others (see Tromp, 1963) suggest that the higher resting heart rates during heat stress have their origin in afferent impulses from skin, carotid sinus, and right atrium, with reflex outflow passing down the sympathetic nerves to the heart. Due to these mechanisms the perfusion pressure in the larger vascular beds in the body can be maintained.

Changes in the physico-chemical state of the blood. Various studies have shown that stress conditions (and also weather stress) could increase the blood viscosity

(Levine et al., 1954).* The blood clotting time (at least in rabbits) shortens considerably shortly before the passage of cold fronts (Caroli and Pichotka, 1952).* The fibrinogen content of blood changes during and after weather fronts (Halse and Losnitzer, 1949; Caroli, 1950);* the blood sedimentation rate is lower in winter and shortly after a period of cold weather conditions (Tromp, 1963).

Changes in capillary fragility. Kerpel-Fronius (1948)* and others observed a seasonal variation in the haemorrhagic tendency and capillary fragility in the new-born, the incidence being highest in January-February and lowest in August (at least in Hungary). It has been related to a vitamin P deficiency in winter. This mechanism combined with the others, mentioned above, may be responsible for the high apoplexy incidence during winter.

Further studies may reveal which combination of these four mechanisms, or other still unknown factors, are responsible for each of the mentioned heart diseases and apoplexy. It is evident that the meteorotropic effects described will only lead to a pathological development if a dysfunction of the heart muscles and of the nervous stimulation of the heart exists apart from arteriosclerotic changes of the blood-vessels. The meteorological factors act only as a trigger on an existing unstable cardiac mechanism.

Summation

The various physiological mechanisms involved in these different meteorotropic diseases are only partly known. However, the data in Table V.3 give a résumé of our present knowledge of the principal mechanisms which may be involved in each of these meteorotropic diseases.

3. THE INFLUENCE OF CLIMATE ON DRUG ACTION IN MAN

Introduction

The actions of drugs are much influenced by temperature changes. For example, weather by its effect on body temperature may influence drug activity within the organism. However, the human body is generally able to maintain a fairly constant internal temperature in environments from below 0°C to above 40°C depending on humidity, clothing, etc. Consequently, it is only when climatic stress is severe enough to overcome the body's temperature regulating mechanisms that drug actions are likely to be affected to any appreciable degree. Nevertheless, if the regulatory mechanisms are rendered inadequate by disease, undue physical activity, anaesthesia, etc., a much smaller degree of climatic stress will be able to affect body temperature. Physicians practising in either hot or cold climates do not as a rule find it necessary to vary drug doses because of climatic factors alone. Standard pharmacological doses are generally prescribed, and with few exceptions the results are similar to those obtained by the same drugs and doses administered in temperate climates. Despite this, recent conquests of extreme climates, and the increasing use of artificial hypothermic microclimates in modern surgery, have made investigation into the effects of environment on drug action a matter of great practical importance. There are many inherent difficulties in doing well-controlled pharmacological studies in human subjects involving stress and possible harmful drug effects. This has made it necessary to rely to a large extent on animal experiments and to interpret the results in terms of human reactions. Information derived in this manner is not always accurate, and may be misleading because of unsuspected species differences.

A fairly extensive literature exists on the effects of temperature on the actions of a large variety of drugs. Most of the studies reported are related specifically to body temperature changes rather than directly to climatic variations. The subject has been reviewed by Fuhrman and others (Euler, 1961; Fuhrman, 1946; Fuhrman and Fuhrman, 1961; Shemano and Nickerson, 1958).

General considerations

The rate of action of drugs administered to intact animals is determined in part by the time required for the drug to be absorbed and reach its site of action in sufficient concentration to produce an effect. This is influenced by the physiological effect of temperature on the blood circulation time. During general hypothermia the circulation time may be prolonged two to three times that at normal body temperature. Following subcutaneous or intramuscular injections the rate of absorption is dependent upon the blood flow in the region of the injection. Local cooling reduces blood flow and so delays absorption and vice versa.

The interaction of drugs and the tissues is considered to be chemical in many instances and it is to be expected that the reactions will be temperature sensitive and similar to most chemical reactions. The rate of action at a given temperature will be about two to three times the rate at a temperature 10°C lower. This has in fact been found to be the case by experiment with several groups of drugs (Sollman, 1957). However, it must be appreciated that, besides affecting the chemical reactions, temperature also affects the reactivity of the tissues themselves, altering rates of nervous conduction, metabolism, viscosity, etc., so that in spite of such temperature coefficients, one may in many instances doubt whether the processes are truly chemical.

The intensity and duration of drug actions are dependent upon the concentration of the drug at the site of action and upon physiological factors which may alter the response of the tissues acted upon. These include the processes of absorption, excretion and detoxification or breakdown of the drug. This last factor is in many instances enzyme dependent. Enzyme activity and the other physiological processes mentioned are all affected by variations in temperature.

Changes in lethal doses with variations in temperature may result from a greater effect of temperature on the organism itself, rather than from any effect on the rates of absorption and elimination of the drug. For example the summated depressant effect of cold on the nervous system, and of anaesthetics may lead to respiratory failure with lower doses of anaesthetics than are lethal at normal body temperature (Setnikar and Temelcou, 1962).

Pharmacological effects of temperature

The nature and type of temperature effects on drug action that may be encountered, are illustrated by the following examples.

With increasing temperature there is an increase in the action and toxicity of cardiac glycosides (McGuigan, 1938). Although slowing of the heart may be produced by digitalis, this in turn may be obscured by the increased heart rate resulting from a rise in temperature. Under such conditions larger doses of digitalis cannot be tolerated since for each 1°C rise in temperature the toxicity of digitalis is increased 10 to 15 per cent. Caution is always necessary when using large doses of digitalis if the body temperature is raised.

The toxicity of analeptics or central nervous system stimulants is generally increased in hypothermic animals (Fuhrman, 1946). Strychnine is more active and toxic to mammals in a cold environment, probably as a result of the increased excitability and reflex activity induced by cold rather than of a different type of action of strychnine at lower temperatures.

The lower toxicity of caffeine at higher temperatures is said to be due to the more rapid detoxification (demethylation) of the drug with increase in temperature.

Temperature affects the anaesthetic activity and the toxicity of the various barbiturates differently, depending on the mode of elimination or detoxification in the body (Fuhrman, 1947; Raventos, 1938; Setnikar and Temelcou, 1962). Thus those barbiturates that are metabolized in the body such as pentobarbital, allylbarbituric acid and thiopental, all have a shorter sleeping time or narcotic action at higher room temperatures. Fuhrman (1947) suggested that lowering of room temperature, and hence the body temperature, slows down the catabolism of the barbiturates, which can thus perform their anaesthetic activity for a longer time. Barbital, on the other hand, which is not metabolized, and is excreted unchanged in the urine, is affected little by temperature changes. The action of phenobarbital is actually shortened by low room temperatures. Temperature influences the toxicity of some barbiturates in the opposite direction to the effect on sleeping time. For instance, the toxicity of thiopental and pentobarbital decreases with lowering of room temperature and that of phenobarbital increases in this condition (Setnikar and Temelcou, 1962).

A fall in body temperature increases the toxicity and mortality due to morphine, and similar effects have been noted with paraldehyde (Fuhrman, 1946).

Alcohol metabolism is increased slightly with increased body temperature. Despite this there is a decreased general tolerance to alcohol in a hot climate due to its effect on the circulation and state of acclimatization.

Acetanalide, histamine, atropine and epinephrine all show greater action in the hypothermic state probably due to slower enzymatic detoxification at lower temperatures.

Dicumarol and related drugs have a greater activity at higher body temperatures, indicating the enzyme dependence of their action on the prothrombin time (Richards, 1943).

Shemano and Nickerson (1962) have pointed out the importance of the environmental temperature on drug induced effects on thermoregulation. They have suggested the use of the "critical ambient temperature", i.e. the temperature above which hyperthermia, and below which hypothermia is produced, as a measure of the effect of drugs on temperature regulation. Chlorpromazine, for instance, was found to elevate this critical ambient temperature to 36°C. Dinitrophenol greatly increases metabolic rate when administered at ambient temperatures above 20°C, but depresses metabolism below 16°C (Euler, 1961). This may be attributable in part to the fact that the narcotic effect of the drug inhibits shivering. Histamine decreases body temperature of rats and mice at a room temperature of 20°C. At ambient temperatures above 30°C histamine in similar doses causes hyperthermia and increased oxygen consumption (4).

Salicylates and other antipyretics such as acetanilid, acetophenitidin, antipyrine and amidopyrine have little or no effect when the body temperature is within normal range (Euler, 1961). In fever they change the heat balance mainly by increasing heat dissipation due to sweating and vasodilatation. Sympatho-mimetic agents such as ephedrine, amphetamine, methylene blue and cocaine have pyretic effects which are attributed at least partly to vasoconstriction and which occur mainly in a warm environment (Sollman, 1957).

The anhidrotic action of atropine which blocks sweating at comparatively small doses in man, does not affect the body temperature of a subject at a comfortable ambient temperature.

In a hot environment, however, hyperthermia may develop in response to moderate doses of atropine, in spite of simultaneously occurring vasodilatation. This has been known to lead to heat-stroke (Horne, 1954).

In homeotherms insulin causes a prolonged hypoglycemia at low temperatures. This may be due to decreased glyconeogenesis, or to a prolongation of insulin action. However, there is an increased survival and inhibition of convulsions in animals cooled to 25° - 30°C and receiving insulin. This is probably due to the decreased demand for substrates by the vital centres of the brain (Tyler 1940).

The toxic action of oxygen is enhanced by an increase in environmental temperature (Bean, 1954). The new-born of most mammals are more resistant to the effects of anoxia than are adults of the species (Fazekas, Alexander, and Himwich, 1941). This is due to the fact that the new-born is poikilothermic and a fall in body temperature aids survival. Warming the body decreases the survival time with anoxia.

Narcosis was induced in rats and dogs by breathing an 11 per cent carbon dioxide gas mixture in an environment of 5°C (Barbour and Seevers, 1943). At warmer room temperatures this same concentration of carbon dioxide failed to induce narcosis.

Conclusion

From the above brief outline it can be appreciated that different drugs may react quite differently to climatic variations and that the patterns are not always predictable without prior experiment. The reactions observed are not only dependent on the drug's physical and chemical properties, but to a large extent on the physiological status of the body at the time. Generally, altered drug actions due to climatic variations are less marked in acclimatized persons. This in itself does not necessarily imply an altered reactivity on the part of the tissues concerned, but that the climate has less effect on the internal body temperature due to improved temperature regulation.

To date most studies in the literature have been concerned with the acute or short-term effects on drug action. Little appears to be known about long-term effects : particularly the effects of climate on the actions of the large group of drugs related to endocrine and nutritional functions, and which might possibly influence the growth, development and function of persons taking these drugs.

4. THE INFLUENCE OF WEATHER ON REACTION SPEED, WORKING EFFICIENCY AND ACCIDENTS

Weather types and phases

Short-term aperiodic weather changes act as stimuli on the human body. If a person is unable to adjust to these stimuli their effect is disturbing. He may at first be affected by subjective disorders - general complaints, depression, over-excitability, insomnia, headaches, palpitation of the heart, etc. If his regulating capacity becomes lowered still further, he may become really ill. The decisive factor is the individual's proneness to disturbance or illness. The effects will be accelerated in biologically unfavourable weather and retarded in biologically favourable weather.

A meteorological classification scheme is therefore needed for use in research on the relationships between weather and the reactions of the human body. This scheme must contain a classification of all possible varieties of weather into a number of groups - weather types or phases. These may be divided into two main groups, "biologically favourable" and "biologically unfavourable" which, as medical-meteorological research has shown, differ sharply in respect of the numbers of human disturbances with which they are associated.

The results of these researches, summarized below, have been presented (Brezowsky, 1960) in the form of diagrams of the meteorological scheme, simplified for the purpose and prepared at the Medical-Meteorological Centre of the German Weather Service at Bad Toelz. Apart from the two main groups (biologically favourable and unfavourable weather), it classifies further the biologically unfavourable weather types, e.g. appearance of warm air at the front part or of cold air at the rear of a depression. Biologically favourable weather types are exclusively linked with high pressure areas or anticyclones. The disturbing effects of the weather begin in the transitional zone between high and low pressure. As it is not yet possible to provide an accurate classification of the individual weather elements associated with these effects, the term "accord effects" is used. However, numerous organic reactions to temperature and humidity changes in the atmosphere are known in considerable detail; there are definite relationships between a combination of these two meteorological elements and the observed biological reactions. The temperature/moisture environment corresponding to each weather type is indicated in Brezowsky's diagrams, which are summarized in Table V.4.

TABLE V.4

RELATIONSHIP BETWEEN REACTION TIME, WORKING EFFICIENCY AND WORK AND TRAFFIC ACCIDENTS, AND BIOLOGICALLY FAVOURABLE AND UNFAVOURABLE WEATHER PHASES

Weather phase	Anticyclone	Passage of depression	Front part of depression	Rear part of depression
Temperature/humidity environment	Cool-mild/ dry	Warm/ very dry	Warm/ humid	cold
Reaction time (m/sec)	239	256	254	254
Working efficiency*				
(a) Reifferscheid (1954)	- 5.0	2.0	1.6	1.4
(b) Brezowsky and Weisser (1961)	-35	16	19	-1
Accidents (per cent, difference from average)				
(a) Brezowsky and Weisser (1961)	-15	7	4	4
(b) Daubert (1956)	- 8	2	6	6
(c) Spann (1956)	-18	6	8	3

* Mean number of complaints (a) and mean number of cases (b) per day, difference from average.

Reaction time

Reaction time is one of the physiological processes that is influenced by disturbance of the human body provoked by weather stimuli. This time is shortened in biologically favourable weather and lengthened in biologically unfavourable weather. Reiter and Ungeheuer (Reiter, 1960) studied the dependence on weather of reaction time to a light signal. The data comprised 118,000 individual readings contributed by visitors to the International Communications Exhibition held at Munich in 1953. The reaction times were compared for the several weather phases. The latter included the influx of cold air at the rear of a depression and the cold front environment, where electromagnetic high-frequency radiations (atmospherics or sferics) are usually found (c.f. Chapter IV, Section 6). The sferic readings were, on this occasion, used as the sole index for this weather situation. The reaction time is prolonged at the transition zone from biologically favourable to unfavourable weather and is shortened again only when the alien air masses cease to appear. This prolongation of reaction time is shown in all types of biologically unfavourable weather, not merely in the cold front environment.

This result is of special importance because it demonstrates that even healthy persons react to the weather, the 118,000 visitors tested being a representative cross-section of people in all degrees of health, not, as it were, a selection of persons with disturbed health. Further proof was provided by Daubert and Aichinger (1962) who measured the seasonal changes in reaction time in healthy human subjects. Their reaction times were low in summer and autumn but increased from winter to late spring.

Rheinstein (1960) reported on the relationship between reaction time and the presence of electrically charged air molecules (ions). The effects of ions on biological processes have long been studied but results have frequently been contradictory (cf. Chapter IV, Section 5). Rheinstein showed that there was certainly some relationship between artificially produced atmospheric ions and reaction time. He also found reaction time was shortened and prolonged in the presence of both negative and positive ions. The results were thus inconclusive.

Working efficiency

Since numerous experiments suggested that general complaints and reaction time depend on the weather, it was inferred that working efficiency was similarly affected. Reifferscheid (1954) studied health disturbances among piece-workers in various industrial plants in Munich. He found that general complaints were more frequent in biologically unfavourable weather than in favourable (Table V.4). When the experiment was repeated, but with the administration of a medicament which increased the working efficiency of the human body, the complaints fell by an average of 45 per cent and the differences in the effects of biologically favourable and unfavourable weather disappeared. Mücher (1956) measured the performance, in a three-hour period of concentration, of persons who had already worked for six hours. Some of the workers received a medicament which assists the circulation, the others a placebo. The performance of the latter group fell in biologically unfavourable weather phases while that of the former remained steady.

Brezowsky and Weisser (1961) studied the records of the medical officer of a plant in Munich. The results (Table V.4) revealed that the number of aids to performance administered in biologically unfavourable weather was appreciably greater than in favourable weather. If the weather had been biologically favourable on all working days, there would have been only 3,162 general complaints compared to the actual number of 5,429 who visited the medical officer, i.e. 42 per cent more than expected.

Accidents

The survey of Brezowsky and Weisser (1961) also included accidents at work. Their relationship is shown in Table V.4. If there had been biologically favourable weather on all working days, only 3,570 accidents would have occurred compared with the actual number of 6,501, an increase of 45 per cent. Daubert (1956) studied the influence of weather on accidents at work in South Germany. His findings support those of Brezowsky and Weisser.

Reiter (1960) established a connexion between sferics and 360,000 accidents in South Germany. His results confirmed the adverse effects of cold front weather with accidents showing a 21 per cent increase in this weather type. There was also a greater number of accidents associated with the appearance of warm air in advance of low pressure areas.

The dependence of traffic accidents on weather can similarly be demonstrated. In this case the disturbance caused by weather stimuli may be especially dangerous because, even without any perceptible general symptoms, a driver's efficiency may be reduced through a reduction in his power of concentration and a lengthening of his reaction time, these latter changes generally being unnoticed.

The relationship between traffic accidents and weather has been carefully studied in Germany on many occasions. Spann (1956) found an increase of 15 to 20 per cent (Table V.4) among 43,000 accidents in Munich in biologically unfavourable weather. A study of the accidents involving intoxicated drivers showed an even greater increase on warm air days alone, and on Sundays and holidays, moreover,that is on hot and sultry days when the penchant for alcohol is greater.

Similar observations were reported from Stuttgart by King (1961) where some 30,000 traffic accidents showed a dependence on weather. Reaction times were longer when the number of accidents was higher. On the other hand, King found that sferics had only a relatively small effect. In contrast Reiter (1960) reported a 32 per cent rise in traffic accidents in the vicinity of cold fronts in a study of 106,000 traffic accidents in South Germany.

Specially interesting results were provided by Kohn (1956), who, in an analysis of 67,000 traffic accidents in Hamburg, showed that 85 to 90 per cent took place in biologically unfavourable weather. He later (Kohn, 1958) evaluated the accident figures of 50 major European cities, tracing the progress of low pressure areas and the increase in traffic accidents occurring in the cities that were affected by the biologically unfavourable weather associated with them. He showed that the biological reaction along with its cause, the weather stimulus, followed the path of the low pressure area over wide regions.

It is most noteworthy that all researchers have been able to show that the so-called trivial weather dangers to traffic - fog, slippery roads, glazed frost, etc - played an appreciably smaller part in causing the accidents than the simultaneous disturbance to the human body, caused by the direct onset of the weather stimulus. In Hamburg days of glazed frost showed an increase of only 6.4 per cent in the accident rate and fog 5.2 per cent. During the same period, the number of traffic accidents rose by about 40 per cent as a result of disturbances to the human body caused by the direct onset of the weather stimulus.

All these results have been statistically checked and coincidence is out of the question. The observations of the various researchers were made quite independently at different times and places. The results are mainly based on medical-meteorological procedures developed in Germany by various workers over the past 15 years. By these methods the observed biological phenomena can be evaluated in a satisfactory and accurate way. The individual phases of biologically unfavourable weather provoked prolonged reaction time,decreased working efficiency and power of concentration, increased numbers of work and traffic accidents and of general complaints, the opposite being the case in favourable weather.

The maximum effects of biologically unfavourable weather occurred in the warm air in the front parts of areas of low pressure; peak unfavourable effects also occurred in the vicinity of cold air masses at the rear of areas of low pressure. The Föhn, occasionally found in the northern Alpine foothills, e.g. in Munich, did indeed have disturbing effects, but, as work elsewhere has shown, this wind cannot be regarded as a particularly strong or unique disturbing factor. The total effect to be ascribed to weather in respect of the production of the biological phenomena described, is, on average, between 20 and 40 per cent. This fact is evidence of the major medical and economic significance of biologically unfavourable weather.

CHAPTER VI

URBAN BIOMETEOROLOGY

The Effects of Town Planning and Architectural Design on the Microclimatic Environment of Man

1. GENERAL PRINCIPLES

The basic aim of urban biometeorology should be so to engineer the microclimatic environment of man that the climate of his habitat is made optimal as far as economic resources will permit. Unfortunately the economic forces opposing this aim can be very great. The urban microclimate can be subdivided into external microclimate and internal microclimate. It should be one of the chief aims of town planning to provide an optimal external climate, and of building design, an optimal internal climate. Clearly, however, the internal and external climates are interrelated and cannot be considered as independent variables. In the case of interiors, suitable artificial climates may be maintained by technological means. The problem is not usually so much one of the engineering feasibility of providing particular indoor climates, but of the economic feasibility of doing so. Crude but economic methods of environmental control are often to be preferred to refined but over-expensive systems. What is considered over-expensive must depend on the economy of the region, and the resources of the owner.

All studies of urban biometeorology should start with a balanced consideration of the nature of the stresses imposed on man by the unmodified climate so that the directions of most profitable climatic modification can be clearly identified. The nature of these biometeorological stresses often varies from season to season, and from one time of day to another. For example, in Northern India, one can identify three seasons of thermal stress; the winter period when the maximum stress is likely to occur at night due to cold when there is considerable outgoing radiation and the air temperatures are low; the hot dry season when the maximum stress is likely to occur in the middle of the day when the sun is fiercest and the air temperatures highest; and finally the monsoon season when the maximum stress is likely to occur in the early evening because evaporation of sweat becomes difficult due to the high prevailing humidities and low wind speeds. The best possible thermal design in this context requires that these three facets of the problem should receive balanced attention.

Among the factors which require attention in urban design, one may mention as particularly important, freedom from excessive respiratory strain due to dirt and pollution, freedom from excessive thermal stress, and adequate light for vision. The noise climates of cities are also very important, and these are tending to become more adverse as the use of mechanical transport becomes increasingly widespread. In particular, serious disturbance of sleep is becoming more commonplace (Comm. on Noise, 1963).

Unfortunately from the viewpoint of design, many of the basic environmental requirements considered separately produce conflicting design aims; for example, the provision of adequate air movement to reduce thermal stress in hot humid climates implies a very open type of building designed to make full use of natural wind forces. This type of building, however, will have adverse noise characteristics, and may also allow free entry of insect vectors transmitting diseases, e.g. mosquitoes carrying malaria. There is another important conflict between the requirements of the eye for sufficient light to see well and of the body for thermal comfort in hot weather which makes it essential to avoid large short-wave radiational gains to the body surfaces. One may reduce the radiational load but then one must decrease the light intensity simultaneously. The problem, therefore, becomes one of rational design, and the various factors involved must be arranged into some sort of order of priority which will vary from place to place and from building to building. Only when the basic biological aims have been clearly settled, does it become feasible to look sensibly at meteorological possibilities.

In considering the broad meteorological possibilities, one must start with the important consideration that building design, meteorologically speaking, is dominated by microclimatic effects on vertical surfaces rather than horizontal surfaces. In other words, the faces of the buildings have extreme slope climates. Consequently, variations due to orientation may swamp variations due to other microclimatological factors such as siting in relation to topography and so on. The detailed study of the climate must, therefore, take proper account of the directional characteristics of the various weather elements. Hence, the majority of the variables involved cannot be treated in biometeorological terms as scalar quantities, possessing only magnitude; they must be treated as vector quantities. For example, it not only matters whether there is a hot wind or not, but it also matters from which direction this wind comes for without this information sensible design measures cannot be devised to attempt to solve the problems presented.

Frequently it is possible to achieve a reasonably optimal internal climate by taking advantage of the directional characteristics of the external climate. For example, the traditional "north-light" factory roof (facing the pole for the hemisphere in question) can provide a high level of daylight in all types of weather while avoiding excessive amounts of direct sunshine which would make the interior unpleasantly hot on sunny days. It is important in design to be able to identify such climatically rational solutions and to know to what degree the achievement of an optimal milieu depends on orientation.

It is the job of the meteorologist to provide the basic data for solving the problems of design. Normally the designer will be interested in two types of problems; circumstances where an extreme situation provides the critical design condition, e.g. extremes of hot weather; and design situations where typical weather types are of concern, e.g. wind direction and strength in the design of natural ventilation systems. The data required for design purposes often involve several variables and it is important that they should be selected on a well-considered statistical basis, especially where extreme values are involved. Different approaches have been adopted in different countries towards different weather elements. For many purposes a simple presentation of the essential facts is more useful than very complicated tables, the significance of which may be difficult to grasp in relation to the complex process of building design.

Simplified presentations along the lines chosen by Reidat (1957) for Hamburg may enable effective decisions to be made. A fundamental problem is that the majority of meteorological stations are not sited in towns. Even if they were so sited, it is by no means easy to decide whether they are representative of the climate of the town as a whole. The presentation of a standard design data derived from conventional meteorological records can often be very misleading, and the microclimate of any particular site must be investigated with care.

2. THE CLIMATE OF TOWNS

The climate of a town can be considered as a statistical assembly of a wide range of separate microclimates. It is not possible, therefore, to make any simple statement about the climate at any particular point. There are, however, a number of important characteristics of urban climates, which differentiate them from their surrounding country areas (Kratzer, 1937). The temperature and wind fields in particular are very different.

The temperature régime of towns tends to be bioclimatologically somewhat less favourable in times of high heat stress than that of the countryside, though in cold weather in winter, the situation is reversed. The higher city temperatures linked with the reduced wind speeds that normally prevail at street level then make the city climate thermally the less severe. However, from the bioclimatic point of view, this advantage is often offset by the more adverse pollution which tends to prevail during the heating season.

Temperature of towns

The temperature régime in the centre of the town differs from that of the surrounding country for four principal reasons :

(1) There is an appreciable generation of heat from stoves, fires etc., particularly in winter, and from cars and machinery at all seasons.

(2) The thermal capacity of the buildings is high. The heat of day tends to be stored in the masonry and then released in the evening. This means that the town centre heats and cools more slowly than the surrounding countryside.

(3) The absence of grass and other vegetative cover, except in parks and other open spaces, reduces cooling by evapotransporation.

(4) The presence of smoke pollution tends to reduce the intensity of the incoming short-wave radiation. This if offset by the lower net rate of exchange of long-wave radiation. Partly because of the pollution and partly because of the interaction of the buildings, radiation losses to the sky at night are not so rapid as a rule in the city as in the surrounding countryside.

The significance of these factors depends on the size of the town, as, for example, the study by Duckworth and Sandberg (1954) shows. The values given in Table VI.1 refer to the evening period, the time of greatest temperature differential. As is well known the centres of cities tend to be particularly unpleasant during the early evening during heat waves. The same factors that tend to make the town warmer during the evening tend to make it cooler than the surrounding countryside during the early part of the day. The heavy masonry only heats slowly. Town climates are, therefore, much more pleasant in the morning in summer than in the afternoon and evening when the advantages lie with the countryside. The temperature régime of a town can be mitigated by providing suitable parks and open spaces (provided there is sufficient water available to support vegetation). Not only do these spaces produce a direct cooling effect by evapotranspiration, but they also provide places where people may relax during the heat of the early evening away from the hot buildings.

Wind circulation in towns

The wind circulation in towns is so complex that it is very difficult to provide any precise description of it. In general, the mean wind velocities are much lower at street level. In London, for example, the wind speed at street level was found to be, on average, one third of that of a site of normal exposure. Local accentuations of flow may occur due to sideways deflections of the free air stream, or the downward displacements of air which occur in the turbulent layer when the stream flows past tall buildings. Each street tends to have its own prevailing wind direction depending on orientation topography, obstructions, etc. However, the most stagnant conditions are normally found in high density areas of uniform building height. In such situations the problem of pollution from motor vehicles can become very serious. A greater circulation of air is normally found in the suburban areas, but even here the flow tends to be somewhat slower and more turbulent than over the surrounding countryside. The turbulent boundary layer tends to grow deeper as the wind stream flows across a city. The disturbed boundary layer tends to extend to heights at least twice as great as the average roof-top height and to become deeper as the air crosses the city. Furthermore, the wind shadows behind buildings can be very long indeed, extending horizontally and down-wind up to twenty times or more the height of the building. Reverse flow often occurs in the sheltered regions, and even with expert knowledge it becomes very difficult to predict what wind effects are likely to obtain in any particular situation. Wind speed, however, tends to increase fairly rapidly with height.

TABLE VI.1

HORIZONTAL TEMPERATURE PATTERN CHARACTERISTICS OF THREE AMERICAN CITIES

After Duckworth and Sandberg (1954)

	San Francisco	San Jose	Palo Alto
Population	784,000	101,000	33,000
Incorporated land area : sq. miles	45.1	14.8	8.6
Population density : persons/sq. mile	17,383	6,824	3,837
Representative urban differential between city centre & countryside during evening (2000 - 2400 hrs)*	10-12°F	7-9°F	4-6°F
Representative size of area at least 4°F hotter than surrounding country-side : sq. mile	4.0-6.0	1.5-2.0	0.1-0.3
Max. observed urban differential between city centre and countryside	20°F	14°F	13°F

* Time of maximum difference

The significance of wind speed from the biometeorological point of view is fourfold :

(1) Adequate air movement helps to remove pollution and disperse contaminants.

(2) Cooling breezes can contribute to summer comfort, both by helping to keep the micro-climatic temperature field more favourable and also by providing cooling directly to the human body.

(3) High winds can cause severe damage and loss of life.

(4) In cold weather, air movement produces additional chilling.

In view of the growing menace of air pollution and the increasing tendency to higher buildings, the study of diffusion in towns is becoming of ever-increasing importance and implies a study of vertical wind profiles as well as the more customary measurements of wind made near ground level.

Sunshine in towns

Pollution of the atmosphere reduces the sunshine in towns appreciably, especially in winter. For example, the sunshine recorded at Kingsway in the centre of London may be compared with the sunshine at Kew in the outer suburbs of London. Neither atmosphere is very clean, but the sunshine recorded in January at Kingsway was only 77 per cent of that at Kew for the years 1954-1963, while in June the corresponding figure was 93 per cent.

The pollution is, of course, reflected in the lower radiation and illumination intensities recorded at the centre of cities. As is well known, the UV intensity may be very low in the centre of cities, especially in winter. This was thought to have considerable biological significance in the 1920's and 1930's. The improved diet of the present day town dweller and the availability of supplementary vitamins make it a little dubious whether UV light is any longer of such dominating importance. Atmospheric pollution is probably the greatest urban menace to health today.

Atmospheric pollution in towns

In most areas of the world, the problems of atmospheric pollution are becoming increasingly serious, and city air is tending to become more and more contaminated (Landsberg, 1962). Three important factors are contributing to this trend :

(1) Population pressure which is tending to lead to a significant increase in urban densities, especially in areas where building land is in short supply.

(2) Vastly increased reliance on the internal combustion engine as the prime means of transport.

(3) Growth of industry in areas where industry was previously conducted on a relatively modest scale.

From the medical point of view, the urban atmosphere is far from satisfactory. Two factors are of particular importance :

(1) The trend towards higher SO_2 contents of urban atmospheres that has resulted from the increased use of fuels of a high sulphur content.

(2) The amounts of toxic and irritating products caused by large concentrations of motor vehicles.

Control of these problems must depend on regulation either of the rate of emission of contaminants or of the rate of their dispersal. Control of the rate of emission lies outside the scope of this discussion. However, regulation of the rate of dispersal is very much a meteorological problem. The principal factors that need consideration are vertical temperature gradients, diffusion in both the horizontal and vertical directions and topographical effects. The pattern of contemporary urban pollution usually shows a strong correlation with urban density, and the highest concentrations are normally found in the densest areas of cities. Increased wind flow normally reduces the levels of concentration significantly, but does not appreciably displace the region of highest pollution from the region of greatest density. Most serious conditions normally result from a combination of low wind speed, vertical temperature inversion, combined with a high rate of production of pollutants. Air drainage due to topographical effects may accentuate the problems.

Control of air pollution cannot be treated entirely as a local problem, for the air from one city passes on to the next. The problems must be reviewed in a regional context.

On a microclimatic scale, the basic problem is to retain sufficient diffusion of air to prevent adverse accumulations of pollutants. Open types of planning, which enable the wind to circulate freely at street levels, are desirable under modern urban traffic conditions. This requirement for traffic, however, may be in conflict with the microclimatic requirements of pedestrians, who may as a consequence of the openness be more exposed to strong sunshine, and adverse weather such as wind and driving rain. Segregation of traffic and pedestrians may be desirable to secure optimal environments for both.

While considerable effort is going into making scientific studies of the various problems involved, the economic conditions of city life do not make it easy to enforce practical decisions of a progressive kind especially where these are in conflict with the profit motives of individuals. However, if mankind is to continue to live at increasingly high densities, with an ever-increasing rate of production of pollutants, active steps will have to be taken to restrain the activities of offending individuals in spite of the economic losses they may encounter.

In spite of all that has been said, the exact connexions between health and pollution are still poorly understood, and much medical work remains to be done. (See also Chapter IV, Section 8).

3. THE MICROCLIMATE OF BUILDINGS

The exterior microclimate of buildings

The microclimate of a building can be considered in two parts, the microclimate of the exterior spaces formed around the building, and the microclimate of the interior spaces, which is often artificially adjusted to make it more suitable biologically than it would be otherwise. The degree to which people can make effective use of outdoor spaces will depend very much on the basic climate. An appropriate analysis of design objectives must be made before attempting to engineer the outside microclimate in detail. In cool regions, optimal orientation with respect to the sun and protection against excessive air movement are desirable. In hot dry regions provision of shade is essential and in hot humid regions provision of ample air movement around buildings is vital. These requirements are expressed often in the basic building forms adopted, the courtyard type house being very common in desert areas, and almost unknown traditionally in hot humid areas. In the latter the linear type of open house with surrounding verandahs usually provides the commonest type of house plan. The courtyard will have its own microclimate depending on the depth/width ratio and the amount of insolation received. This microclimate may be much more favourable than the surrounding climate, especially if fountains are used and vegetation is grown to provide cooling by evaporation. The air movement in courtyards is slight and is often dominated by convection currents set up by the sun shining on particular walls. In the humid regions an understanding of the principles of fluid flow can be very useful in deciding how to make best use of the wind, both in and around dwellings. By taking advantage of the pressure differences which may be set up by different building arrangements, it is possible to deflect the breeze through 90° or more and so secure air movement for unfavourable locations.

The interior microclimate of buildings

The microclimate inside buildings tends to differ very significantly from the microclimate outside buildings, even in the case of buildings where no mechanical or other equipment is provided for the purpose of modifying the indoor environment. In design, priority often tends to be given to temperature but other factors such as daylight, ventilation, air movement and noise, also require proper attention.

The thermal microclimate in cold weather

Thermal comfort can only be achieved in really cold weather by using artificial sources of heat to raise the level of environmental warmth. There are a large number of ways of achieving this end. On the one hand, there are devices which are primarily radiative devices which promote comfort by producing a radiant beam falling directly onto people. On the other hand, there are devices which are purely convective, which promote comfort by raising the air temperature. The basic problem is to balance body heat production with body heat loss, and the comfort of an environment is dependent on the level of physical activity of an individual in that environment. It is not only essential to achieve a satisfactory overall thermal balance for the body, but also to achieve suitable thermal balance for the extremities. Hot floors can cause considerable discomfort for the feet, excessive radiation onto the head is not acceptable, and so on. An important factor affecting comfort in cold weather is the radiation exchange between people and the surrounding surfaces. For example, the outgoing radiation to a cold sheet of glass may be considerable. Thermal insulation not only reduces the building heat losses, but also raises the surrounding wall surface temperatures making the radiative environment more favourable. Microclimatic factors like down-draughts from cold surfaces can exert a considerable influence on comfort. One of the basic objectives in design is to avoid excessive air movements which will be experienced as draughts.

The interiors of buildings must certainly not be thought of as constant temperature enclosures. The vertical variations of temperature are usually very much more significant than the horizontal variations, and thermal stratification is quite common with many systems of heating. The smallest temperature gradients are normally encountered with floor heating systems, while the largest normally occur with air heating systems, especially where the outlets are positioned high in the room and the rate of discharge is too low to produce adequate vertical mixing.

Many systems of heating are of an intermittent type, and the thermal response characteristics of the building can exert a significant influence on the rate of build-up of temperature. Buildings of high thermal capacity tend to heat slowly and cool slowly while buildings of low thermal capacity change their temperature more rapidly and by greater amounts for a given heat input or heat loss. In areas where the inhabitants can only afford intermittent heating, e.g. where the fire is let out at night, there is much to be said for using heavyweight construction, for the stored heat protects the occupants against the full effects of the considerable fall of outside air temperature which usually occurs during the night.

Thermal conditions in buildings in hot weather

As cooling buildings is normally a much more expensive process than heating them, the use of cooling plant is not nearly so widespread as is the use of heating plant. In the majority of countries, the summer indoor climate has to be made optimal by ingenuity of design. In this situation it is essential to have a clear grasp of the precise nature of the thermal stress encountered in biometeorological terms so that any corrective measures taken relate to the problem. In hot dry climates the peak stress occurs in the middle of the day. Thus the basic aim is to keep indoor air temperature down in the middle of the day and to protect people from direct sunshine. Advantage can be taken of the big swing in outdoor air temperature in such regions to pre-cool the house at night using the principle of night-time ventilation. If the walls are thick and have a high thermal capacity, they will require a large amount of heat to raise their temperature appreciably. Therefore, if all openings are adequately shaded from the sun, thick walls pre-cooled at night can help to stabilize the indoor air temperature, thus keeping the house much cooler than the surrounding air, provided day-time ventilation is restricted to minimal requirements.

In hot humid regions thermal stress usually arises from the difficulty in achieving an adequate rate of evaporation of sweat. In such climates good air movement is essential. Unfortunately the wind which can provide such air movement indoors, usually drops in the evening, and the time of maximum physiological strain indoors usually lies between 1800 hours and 2400 hours. It is necessary, therefore, to design buildings to make full use of the evening breeze, and also to ensure that the indoor temperature is as low as possible in the early evening. This implies the use of a structure that will cool quickly. The traditional lightweight materials such as the bamboo, used in humid tropical regions, are ideal. In contrast, heavyweight buildings are quite unsuitable for sleeping quarters in these climates.

Another problem which requires attention in design is control of indoor humidity. Many human activities, e.g. breathing, sweating, cooking, bathing, laundering, etc., add considerable amounts of moisture to the air. The indoor vapour pressure often tends to rise as a consequence, making the interior sultry and unpleasant. Adequate ventilation is essential in hot humid climates to prevent accumulation of moisture. This is especially true of places of public assembly where the number of people per unit floor area can become very high. Indoor humidity is also important from the point of view of risk of biological growth such as fungi, algae, etc., on room surfaces. Such growths may sometimes give rise to allergic reactions in the occupants.

Natural ventilation

Ventilation is important not only for comfort but also because it provides the usual way of removing pollutants generated internally from the indoor air. The pollutants may be of a very varied nature, but pathogenic organisms, toxic chemicals of one sort or another, and tobacco smoke are obviously important pollutants from the health point of view. The basic aim in design should be to remove pollutants as near as possible to their sources. Local extraction is always very much safer than general dilution. The exchange of air between the inside and outside may be brought about by mechanical or by natural means. In the latter case, two main forces are at work :

(1) Wind forces which produce pressure differences across the building;

(2) Buoyancy or stack forces which exist because of temperature differences between inside and outside air.

Buoyancy forces dominate at low wind velocities in low buildings and in tall buildings at somewhat higher wind velocities. The actual rate of air change achieved will depend on the type of windows provided and the way the occupants use them. It should be an aim in design in hot climates to site the inlets so as to face the prevailing winds. However, the location of outlets is not so crucial as negative forces producing outward suction are normally found over the remaining three faces of a rectangular building. Care should be taken to avoid as far as possible bringing highly polluted air into the building. With mechanical ventilation it may be possible to avoid an excessive intake of traffic fumes, etc. Furthermore, it is possible in this way to provide filtration and washing. Air conditioning, however, is an expensive method of defense against atmospheric pollution and so can only rarely be justified on grounds of medical need. Window design should always be carefully considered so that adequate ventilation may be achieved without excessive draughts in cool weather and so that good air movement can be achieved at living levels in hot weather.

Sunshine in buildings

Architectural design is still very much under the influence of the sun-worshipping phase that came about as a result of studies of the role of sunlight in health earlier in this century. A balanced contemporary approach tends to show that the importance of sunshine in buildings has been very much exaggerated, and the sun control is really a far more vital problem. Better designs would emerge were windows more often regarded as avenues for solar radiation that could be opened when there is a deficiency of radiation, e.g. in winter, and closed when there is an excess, e.g. in summer. Traditional window design was often based on this assumption. Favourable orientation can help too. Contrary to popular opinion, in latitudes between 50°N and 50°S, westerly and easterly exposures are usually less favourable in summer than exposures facing the equator. Furthermore, summer sun protection is much more difficult on the east and west sides of buildings.

The noise microclimate

The high noise levels characteristic of modern city life are producing increasingly serious problems. Disturbance of sleep due to noise is becoming very commonplace. Furthermore in many central urban areas the traffic noise levels have become so high that it is not easy to carry on conversations in buildings overlooking major thoroughfares, when the windows are open. Aircraft noise is also becoming increasingly unbearable, as aircraft speeds rise and traffic increases. Very formidable noise control problems are likely to arise from the use of supersonic aircraft. Such problems tend to be given little advance publicity prominance by aircraft operators for obvious reasons.

The two ways open for improving the internal noise climate are either to site buildings so that they stand in a favourable external noise climate in the first place, or alternatively, to seal them against noise by using effective barriers such as sealed double windows, etc., combined with full air-conditioning. This latter alternative is usually too expensive for most organizations and individuals. The occupants of buildings on noisy sites are often left with the choice of shutting the windows to keep out the noise and accepting the unbearable thermal climate that arises due to lack of ventilation in hot weather or improving the thermal microclimate by opening the windows and accepting the adverse noise microclimate. Noise can, therefore, contribute indirectly to thermal stress.

The daylighting of buildings

The amount of daylight available in a building depends on the levels of illumination out-of-doors and on the precise design of the room and its windows. Illumination levels at the back of typical rooms are of the order of 0.5 to 2.0 per cent of those obtaining outside, while close to the windows the levels may rise to 10 to 20 per cent depending on fenestration. The illumination climate varies very much from season to season. In higher latitudes it is normal to base design on typical overcast sky conditions for the winter half of the year. Nearer the equator in desert regions design may be based on clear sky conditions and some account may be taken of reflected sunshine. In hot countries a balance has to be struck between internal daylight and risk of excessive radiational gains. Glare is another factor requiring careful attention. Glare is particularly serious in hot humid climates where skies of very high brightness occur often. It is also encountered in higher latitudes especially on sunny days in summer with scattered cumulus cloud. In desert regions ground glare due to reflected sunlight can be most unpleasant. Window design, therefore, has to be related to the different visual strains imposed by various climates, and daylighting design has become a complex science in its own right (Hopkinson, 1963).

4. CONCLUSION

This review has covered a vast field of human endeavour, and it has only been possible to present a few fundamental factors. It should be clear, however, that modern urban life is being conducted under increasingly adverse biometeorological conditions, and considerable thought needs to be given to improving the general urban environment. In the case of individual buildings, a great deal can be done by intelligent design to improve the internal microclimate and so reduce stress. Unfortunately since the majority of architects are not aware of the biometeorological principles underlying design their designs often fall far short of the standard possible were existing knowledge properly applied.

CHAPTER VII

THE INFLUENCE OF WEATHER AND CLIMATE ON FARM ANIMALS AND ON INSECTS AFFECTING THE HEALTH OF MAN

FARM ANIMALS

General

Weather and climate can influence farm animals in two ways. The meteorological elements can affect the animal either directly, or indirectly through their effects on intermediate factors such as soil, water, plants or micro-organisms. Under field conditions, where a multitude of factors may be operating simultaneously, it is often difficult to dissociate direct from indirect meteorological effects. It may be difficult for instance to decide to what extent the low milk yield of a cow grazing in a tropical environment is due to direct heat stress, to poor quality pasture, to scarcity of water, or to pathogenic micro-organisms. This difficulty can be overcome by conducting experiments under standardized conditions in the controlled atmosphere of a climatic room, where one factor at a time may be varied. Studies in climatic rooms, however, also have their limitations in that the conditions are unnatural and some of the meteorological elements, e.g. solar radiation, are difficult to reproduce. Both field observations and climatic room experiments are therefore necessary to elucidate fully the physiological effects of weather and climate on animals.

Among the various meteorological elements temperature, humidity, air movement and solar radiation are of primary importance since they affect the thermal balance of farm animals. Of these elements, temperature is usually taken as the principal factor whose effect on the organism may be modified by one or several of the other elements.

Optimum thermal environments

When an animal does not have to use its thermal defence mechanisms - constriction of skin blood-vessels, erection of hairs and increase of heat production by shivering and other means against cold; dilatation of skin blood-vessels, panting, sweating, and possibly decrease in heat production against heat - it may be said by analogy to man to be in thermal comfort. Thus, in this zone body temperature is maintained with a minimum expenditure of energy, leaving a maximum of energy for productive processes.

When the environment becomes colder, the defence mechanisms against cold come into play, first the physical ones, then the chemical ones. The environmental temperature at which heat production begins to increase as a defence against cold is termed the lower critical temperature. Once all these compensations have reached their limits, homeothermy breaks down and the animal eventually dies from cold.

When the environment becomes warmer, the heat defence mechanisms are activated. If their action does not cool the animal sufficiently, homeothermy again breaks down. Heat production then rises mainly as a result of the increasing body temperature, eventually leading to a fatal vicious cycle. The environmental temperature at which this rise in heat production begins is termed the upper critical temperature. The range between the lower and the upper critical temperature is known as the zone of thermoneutrality. For adult European type cattle the zone of thermoneutrality extends from about 4° to about 15°C (Kibler and Brody, 1949). Thus, a thermal environment which is cool by human standards, is optimal for cattle.

Within the zone of thermoneutrality, and particularly within the slightly narrower zone of comfort, there is no biometeorological problem for the organism. Below and above it, however, animal well-being and production become impaired. The effects of extreme weather and climate can be mitigated in two ways : (1) By adapting the climate to the animal, i.e. by keeping the animals within houses or shelters which eliminate climatic extremes. This is a technical problem. (2) By adapting the animal to the climate through breeding and acclimatization. This is a biological problem. It involves the selection of animals that can survive climatic extremes with a minimum economic loss. Since selection must be based on physiological criteria, a knowledge of the various responses of animals to cold and heat is of importance.

Reactions to cold

With falling environmental temperature heat production increases. The onset and the magnitude of this increase depends on a variety of modifying factors which will be discussed later.

Cold stimulates appetite which leads to an increase in feed intake. Hay consumption of Holstein cows in Canada rose from 9.5 kg at 8°C to 12.3 kg at -18°C (MacDonald and Bell, 1958 b). Since the water requirements in a cold environment (where there is no need for water to cool the body) are mainly determined by the amount of the dry matter intake, an increase in feed consumption in the cold is accompanied by an increase in water consumption (Ragsdale, Worstell, Thompson and Brody, 1949; MacDonald and Bell, 1958 a). Hence the necessity to supply cattle even in a cold environment with plenty of water.

Cold depresses milk yield, but the temperature at which the depression begins varies considerably. MacDonald and Bell (1958 c) found a slight fall in milk yield of Holstein cows from 4°C to - 12°C, but a substantial one from -12°C to -21°C. These workers considered an air temperature of -12°C as critical for milk production. Similar results are reported by Yeck and Stewart (1959) who also showed that the smaller and less cold-tolerant Jersey cows at -12°C suffered a 20 per cent reduction in milk yield. In a hot environment, on the other hand, the Jerseys could maintain their milk yield longer than the Holsteins (Figure VII.1). Within a breed the response of milk yield to cold (and also to heat) appears to depend on the level of production, high yielders being more affected than low yielders.

Animals, particularly pigs, and to a lesser extent sheep and cattle, combat cold by social temperature regulation. By huddling together they decrease their total area of heat-dissipating body surface which results in an economy of heat.

Reactions to heat

Farm animals, in particular those of high productivity tend to be heat intolerant because they generate much heat which, in a hot environment, is difficult to dissipate.

Heat dissipation in a hot environment occurs mainly, and under extreme conditions exclusively, by the evaporation of moisture from the respiratory tract by panting or from the skin by sweating or by both. The chicken, the pig and the dog cool themselves by panting, the horse by sweating. The ox, the goat and the sheep use both ways of cooling in various proportions. Cooling by means of a high respiratory activity in the panting species may lead to a disturbance of the acid-base status of the body owing to the elimination of an excessive amount of carbon dioxide from the lungs (Bianca, 1955; Bianca and Findlay, 1962). Profuse sweating, on the other hand, affects the water balance of the body, so that ultimately heat tolerance may be limited by the availability of water (Adolph, 1947).

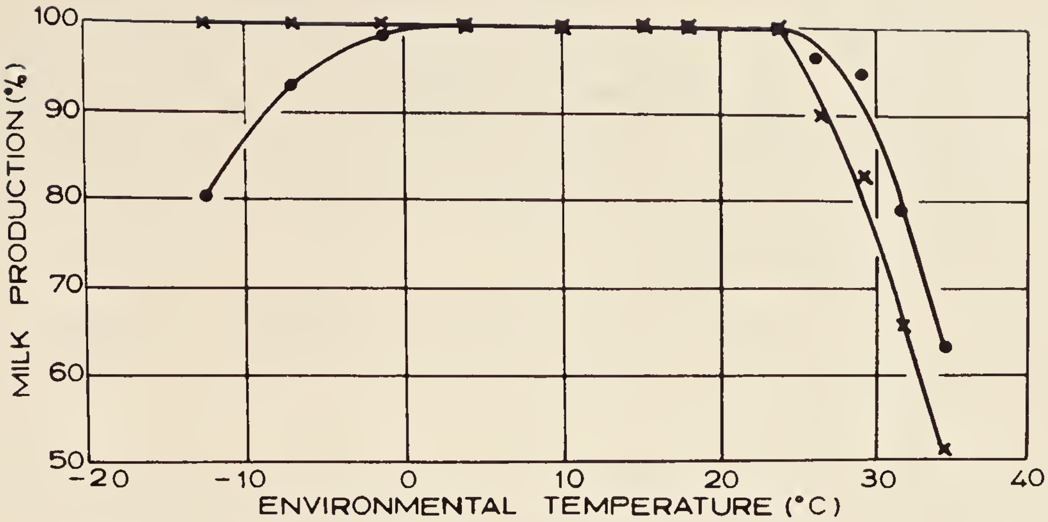

Figure VII.1

Milk production as a per cent of normal at various environmental temperatures. X = Holstein cows, ● = Jersey cows (redrawn from Yeck and Stewart, 1959)

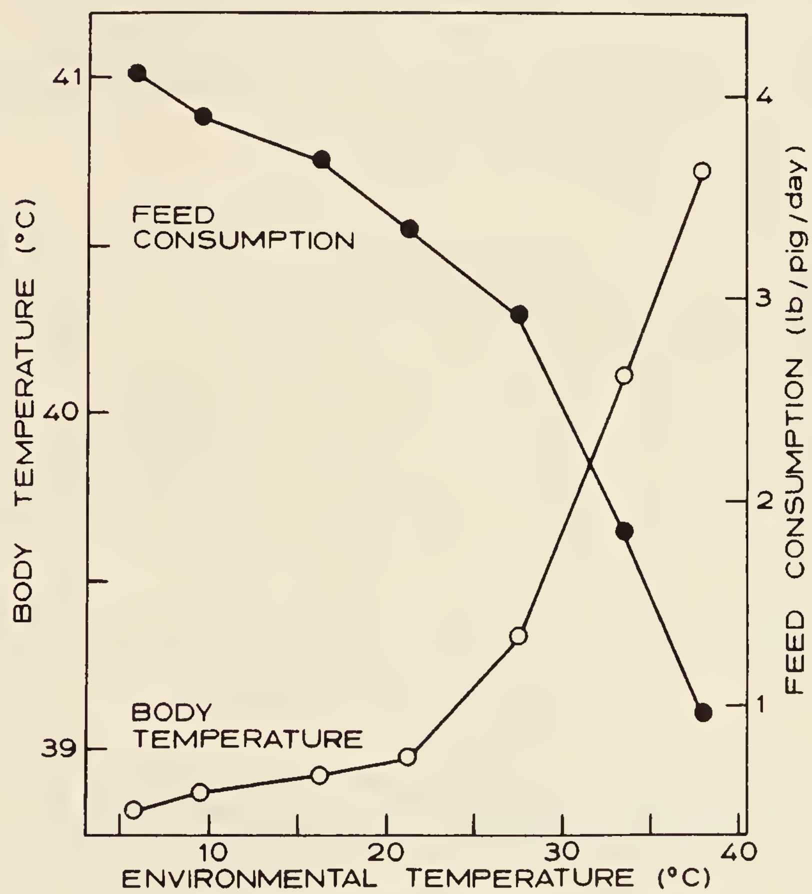

Figure VII.2

Effect of environmental temperature on rectal (body) temperature (○) and on feed consumption (●) of pigs weighing 75-118 kg (modified from Heitman, Jr. and Hughes, 1949)

With rising environmental temperature appetite is lost, food intake is reduced and eventually it is completely suppressed. The inverse relationship between body temperature and voluntary food intake that occurs with rising ambient temperature is illustrated in Figure VII.2 for the pig. Since the animal by reducing its food intake generates less heat, which improves its thermal balance in a hot environment, food intake may be said to act as a temperature regulating mechanism, as suggested by Brobeck (1948). Climatic room studies by Wortsell and Brody (1953) have shown that cows may begin to decrease their feed intake at an ambient temperature of 21° to 24°C. At 41°C the intake of digestive nutrients was only 20 to 28 per cent of that at 10°C.

Although the reduced feed intake lowers the requirements for water, the water consumption of heat-stressed animals may rise to several times the normal level to provide the water necessary for evaporation.

Milk yield reacts very sensitively to heat. The decline may begin at temperatures as low as 17°C (Oosterlee, 1959). It is certainly pronounced beyond 24°C as is also evident from Figure VII.1. Such air temperatures are not infrequently found within cow houses.

Growth, although not as sensitive to environmental stress as milk secretion, is depressed by heat. Cattle kept at a constant temperature of 27°C performed poorly (Worstell and Brody, 1953; Ragsdale, Chu Shan Cheng and Johnson, 1957). Solar radiation reduces performance under such conditions still more (Ittner, Bond and Kelly, 1958). Figure VII.3 illustrates the depressing effect of high ambient temperature on growth rate of pigs. It may be seen that the depressing effect becomes more pronounced the heavier the pig. Low temperatures down to 4°C affected growth rate comparatively slightly.

Finally there is evidence to show that a hot environment adversely affects reproduction in both sexes of farm animals. Various aspects of infertility induced by heat stress have been reviewed by Ulberg (1958) and by Hafez (1959).

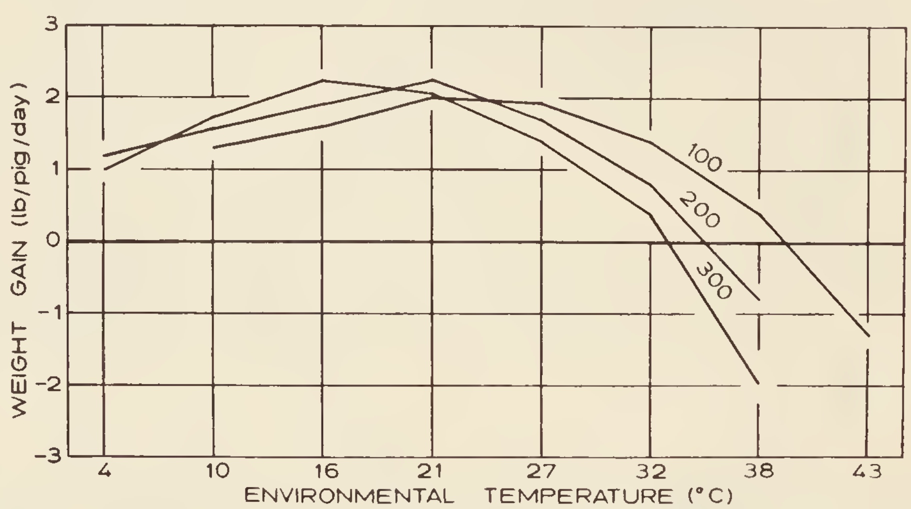

Figure VII.3

Effect of environmental temperature on weight gain of pigs in the live weight classes 100, 200 and 300 lb (modified from Heitman, Jr., Kelly and Bond, 1958)

Factors that modify reactions to cold and heat

The responses of animals to cold and heat vary considerably in their intensity depending on a multitude of factors. If quantitative relationships are to be established between the animal and its climatic environment, these factors have to be taken into consideration.

Age. The new-born animal is very sensitive to cold. It may take several days after birth until the temperature regulating mechanisms are fully functional. But even then the demands of the young for warmth are high. The minimum ambient temperature which the animal can tolerate without increasing its heat production, i.e. the lower critical temperature, has been calculated to be 35°, 29°, 19° and -12°C for pigs weighing 1.5, 4, 10 and 200 kg (Bianca and Blaxter, 1961). The new-born lamb has also a relatively high critical temperature (29°C) but it has a remarkable capacity for combating cold. By increasing its heat production two to three times and, to a lesser degree by reducing heat loss from the extremities by constriction of the skin blood-vessels, it is able to maintain its body temperature normal in an ambient temperature as low as -5°C (Alexander, 1961). The high heat production, however, burns up very quickly the relatively small energy reserves, so that adequate feeding of the cold-stressed new-born lamb is of vital importance (Alexander, 1962).

In spite of its great demands for warmth, the young animal cannot tolerate heat as well as the adult animal. This has been demonstrated for cattle by Bonsma (1949) in South Africa.

Species, type, breed. The various species, types and breeds of farm animals represent an enormous variation in form and function and consequently also in response to climatic stress. Tolerance to cold is normally associated with intolerance to heat, i.e. cold tolerance and heat tolerance tend to be mutually exclusive. The pig and European-type cattle (*Bos taurus*) are comparatively cold-tolerant whereas the goat and the Zebu (*Bos indicus*) are comparatively heat-tolerant. Within one species large differences may exist as is evident from a comparison of the cold-tolerant Shetland pony with the heat-tolerant Arabic horse, or of cold-tolerant British sheep with heat-tolerant Australian Merino sheep. Even within one breed there may be considerable individual genetic variation with respect to tolerance to climatic stress, a fact that may successfully be exploited by breeders.

Among the various structures and functions of the animal body which are responsible for such differences, the hair coat plays a major role. A heavy hair coat, by virtue of the layer of entrapped air, insulates the body against a cold environment. An extreme example is the Arctic fox which can tolerate an ambient temperature as low as -40°C without having to increase its heat production to maintain normal body temperature (Scholander, Hock, Walters and Irving, 1950). Heat lost by a Blackface sheep to an environment of 8°C was found to be 2,343, 1,300, 1,122 and 1,059 kcal/m^2/day when the fleece length was 4, 22, 40 and 56 mm (Armstrong, Blaxter, Clapperton, Graham and Wainman, 1960). Thus, clipping makes sheep very susceptible to cold. Fully fleeced sheep are able to tolerate temperatures down to freezing point without increasing their heat production; when clipped, they require an environment of almost 30°C to prevent extra heat being produced (Blaxter, 1961).

The fleece also protects against heat gain from intense solar radiation. Merino sheep in tropical Australia responded to shearing by an increase in skin temperature and a doubling of their respiratory rate (Macfarlane, 1958).

Two other modifying factors, which are interrelated, are the level of feeding and the level of production. A high producing cow generates so much heat - it may be double that of a non-lactating cow - that heat dissipation becomes a problem even at relatively low ambient temperatures. On the other hand, the extra heat generated facilitates the maintenance of body temperature in a cold environment.

Acclimatization. Finally, the magnitude of response to climate depends on whether the animal has had the opportunity of 'practising' defence against cold and heat, i.e. on acclimatization. In contrast to man where acclimatization to heat and to a minor degree also to cold has been established, there is relatively little known about thermal acclimatization in farm animals. It has, however, been demonstrated that calves in response to repeated short exposures to a hot atmosphere show progressive reductions in rectal temperature, skin temperature and heart rate (Bianca, 1959 a, b). Furthermore, rearing calves in a warm environment (27°C) improved their performance in a hot environment, and rearing them in a cool environment (10°C) improved their performance in a cold environment (Kamal, Johnson and Ragsdale, 1962).

Altitude

In some areas, farm animals may also be subjected to the stress of high altitude. The partial pressure of oxygen which decreases with increasing altitude necessitates adjustments of the body to secure an adequate supply of oxygen to the body tissues. As in man these adjustments in the first place involve the circulatory and the respiratory systems. At very high altitudes - the actual level varying greatly with species, breed and individual - compensation becomes insufficient and body functions suffer. In cattle there is evidence of chronic mountain sickness. In some areas of the western United States this is reported to affect as many as 10 per cent of the range animals (Alexander and Jensen, 1959). Systematic research into the effects of high altitude on farm animals has only recently begun and is certain to expand in the future, since there is an increasing need to utilize high altitude pastures for producing more food for human consumption.

REFERENCES

In addition to the specific citations the reader is directed to the following general reviews : Bianca (1961); Bonsma (1949); Brody (1956); Findlay (1950); Hess and Bailey (1961); Ittner, Bond and Kelly (1958); Krüger and Stephan (1960); Lee and Phillips (1948); McDowell (1958); Yeck and Stewart (1959).

2. INSECTS AFFECTING THE HEALTH OF MAN

Introduction

The influence of weather and climate on animals is related to ability to regulate the internal environment under the stress of external change. In insects, as compared with other animals, abundance and variety are measures of success in meeting or compensating for this requirement. Unlike mammals which have developed a high degree of thermoregulation, insects, perhaps as a result of their small size, depend largely on highly developed sensory systems with which they are successful in seeking out and inhabiting favourable environments. From an evolutionary point of view, morphological and physiological organization in insects is capable of a variety of modifications. This capacity has been exploited by evolving a large number of different species and subspecies, each adapted to a relatively narrow range of environmental conditions, and each with patterns of behaviour that compensate for limited physico-chemical regulation in meeting variations in climate. As in most other phyla of animals, however, there is no comparable alternative for the need to regulate water and ionic concentration and this ability is well developed in some insects. On the other hand, most insects studied so far seem to be more tolerant of osmotic and ionic changes than mammals, and in some arthropods such as ixodid ticks, osmotic tolerance within limits appears to take the place of regulation.

Physiological relationships between the insect and its external environment emphasize the implications of weather and climate in determining the development, survival, and abundance of arthropods as man's chief group of competitors. Insects exert an important influence on man's environment through destruction of crops, transmission of disease, parasitism, and long-term changes in such natural resources as forests. Man's concept of the effects of insects on the economy and welfare of communities has a long history of development, mainly through experience with plagues and epidemics. Some of the accumulated evidence supports the view that insect populations normally tend to be controlled by density-dependent factors that confine fluctuations within certain limits. This concept does not account for major fluctuations or epidemics and a substantial amount of literature indicates that mass outbreaks of insects occur when weather and climate provide a release for certain types of activity and reproduction. For this reason, interpretations of conditions that influence the development,activity, reproduction, and abundance of insects are incomplete unless the effects of meteorological factors are fully considered.

Insect response to meteorological factors

Response to meteorological and climatic environment varies widely among morphologically different groups of species with specialized adaptations to environment. A comparative study of temperature and water relations in insects reveals diverse capabilities for meeting particular conditions (Wigglesworth, 1950). For this reason, temperature and humidity, the most important factors influencing the physiology of insects, should always be considered together.

Temperature. In the resting insect at moderate temperatures heat production through metabolism balances heat loss. Loss of heat is primarily due to evaporation while gain of heat is largely the result of metabolism, particularly during muscular contraction. Even more so than in larger animals, radiant energy from the sun is an important source of heat in many insects and in some environments accounts for greater elevations of body temperature above the surroundings than any other factor. Body temperature fluctuates widely and is subject to slight degrees of regulation, if any, in most insects. Hymenopterous insects achieve more definite regulation mainly through social behaviour, e.g. by closing the entrance to a nest according to temperature, or through activity, e.g. by fanning the wings to cool the nest when temperature is excessive.

Resistance of insects to high temperature depends on interaction of other factors. Some species may exist in environments far above the lethal temperature by resting in sites cooled by evaporation. Humidity has a great effect on resistance to temperature as demonstrated by the cockroach Periplaneta which dies at 38°C in moist air but can survive for a time at 48°C by cooling through evaporation from its own body. Resistance to high temperature in dry air depends on the ratio of volume to surface area, and therefore favours the larger insects for survival during short periods of supralethal temperatures.

Metabolism in insects is stimulated by an increase in temperature. For this reason, such measurements as 'preferred temperature' and 'thermal death points' are frequently used to indicate thermal tolerance. However, these indices may bear little relation to the natural type of environment in which the insects occur. Exhaustion of food reserves may be the real cause of death at high temperature in some insects. In other insects lethal upsets in the balance of some metabolic process may lead to accumulation of some product more rapidly than it can be removed. Blow-fly larvae at lethal high temperatures show an increase in lipoid phosphorus, inorganic phosphorus, and adenyl pyrophosphate in the haemolymph. Although body temperature normally follows closely that of the environment, insects are orientated by temperature and this response is indicated by the 'preferred temperature'. Adaptation plays a large part in the significance of 'thermopreferenda' and may take many forms. The activity level of Ptinus tectus at a given temperature depends on the rearing temperature during previous weeks. Temperatures for immobilization and 'chill coma' are similarly affected by adaptation. The effect of atmospheric humidity on preferred temperature has been difficult to test because a gradient of temperatures is impossible to arrange without also creating a gradient of relative humidity in the same enclosed space.

Resistance to low temperature varies widely among species. Some insects die at temperatures well above the freezing point, most are killed as soon as their tissues freeze, but a few can withstand complete freezing and die from unknown causes when the temperature is lowered still further. 'Cold hardiness' in insects is chiefly an ability to prevent freezing of tissues. When the temperature is lowered in some insects, the body water becomes supercooled and ice does not form until the temperature has fallen far below the true freezing point. In this case the temperature of the insect follows that of the air until it reaches the 'critical point' or 'under-cooling temperature' (as low as -15°C) and then increases suddenly to just below freezing (approximately -1 or -2°C). Following the rebound of temperature which occurs through liberation of latent heat, the body proceeds to cool once more. The 'critical point' where freezing begins varies in different species and is significant in measuring cold hardiness, an important factor in the winter hibernation of some species.

Unlike warm-blooded animals in which metabolism is depressed by rising external temperature, metabolism of cold-blooded animals such as insects is increased. Increased activity exhibited by the insect with rising temperature accounts for most of the increase. Response of resting or narcotized animals to rising temperature suggests that the extra energy may be expended in augmented movements of the internal organs. In the developmental stages the extra energy is expended on growth which is correspondingly accelerated.

Each species has a wide range of temperature between cold stupor and heat stupor within which it performs normal physiological functions. Certain functions such as growth or reproduction may be adversely affected towards the limits of a favourable range of temperature and some point within this range is often described as the optimum temperature. This point is usually difficult to define and is influenced by other factors such as humidity. Curves for the relation between temperature and the development of insects represent a number of chemical and physical reactions, many of which are affected differently by changes in temperature. In spite of this, a great deal of work has been devoted to the development of simple formulae that might have predictive value for insects. Although certain equations are found to fit particular cases and have descriptive value, none have sufficient general application to demonstrate a basic principle. Descriptive formulae have taken the form of at least six mathematical relationships for growth and development : (1) that the velocity is proportional to the temperature (thermal summation theory), (2) that the logarithm of the velocity is proportional to temperature, (3) that the logarithm of the velocity is proportional to the reciprocal of the absolute temperature, (4) that the logarithm of the velocity is proportional to the logarithm of the temperature, (5) that the destructive action of temperature at the upper limit of the temperature range also follows the van't Hoff rule, and (6) that the relation between temperature and the rate of biological processes is best described by a logistic curve.

Humidity. Humidity of the external environment is important in considering the water relations in insects. The quantity of water in different species ranges from less than 50 to 90 per cent of total body weight and high variation within species may be common even when reared under identical conditions. The percentage tends to be low in insects in which a heavy protective cuticle contributes a large proportion of the body weight and high in thin-skinned larvae that are in the feeding stages. There is a tendency in over-wintering insects to lose water before entering either hibernation or a state of suspended development known as diapause. Ability to withstand reduction in water content varies considerably and diminution in the water content usually depresses metabolism and retards development. Sometimes rate of development is retarded at very high humidities in the external environment.

Most insects require a favourable balance in water relations between external environment and body tissues.

Water is lost by insects chiefly through evaporation. Dalton's physical law is applicable to the rate of water loss; but there are many exceptions and the physiology of evaporation has been appreciated most by an analysis of departures from the rule. These departures involve both physical and physiological factors : (1) rate of diffusion increases as temperature rises, (2) high temperature increases the permeability of the cuticle to water in some insects, (3) much of the evaporation takes place through the spiracles of some insects and is dependent on respiration rate, (4) activity may determine the opening of spiracles and in this case influences the loss of water through the tracheal system as metabolism increases, (5) a falling off of the rate of water loss in some insects in a very low humidity indicates the operation of internal factors, and (6) water vapour is absorbed from the air by a few species in humidities as low as 45 per cent, e.g. in the pupating larva of the flea Xenopsylla.

The chief problem for insects, like all terrestrial animals, is retention of water. When normal water balance is upset, it is usually in the direction of desiccation which is a serious factor in survival. Upsetting the water balance in the opposite direction, or short-term fluctuations in water balance, also influences the behaviour of insects, especially mosquitoes, and accounts largely for movements of populations in alternating their habitats.

Water in insects has a significant relation to body temperature and thermal resistance. For this reason physical concepts of the exchange of water between the insect and its external environment have received critical consideration. Attempts to reduce the mass of ecological observations to some order and to predict fluctuations in insect numbers led to a simple relation expressed in the 'saturation deficit law'. 'Saturation deficit', the amount by which the water vapour present in a sample of air falls short of the saturation value at the same temperature, represents the drying power of air fairly closely and is a means of expressing the combined effects of temperature and humidity in desiccation of insects. The validity of the 'saturation deficit law' in referring to loss of water has not been established conclusively and some objections are raised on the grounds that movement of air has to be considered. Ramsay (1935) investigated the physics of evaporation in relation to biological systems and has pointed out complicating physical factors that make the 'saturation deficit' law theoretically unsound. Some experimental results with insects in air containing vapour of heavy water imply a continuous exchange between body water and external water because the proportion of heavy water in tissues stabilizes at the same level as in the external air. It is possible therefore that both active and passive transfer are involved in exchange of water between the insect and its external environment.

Wind. Wind is an important factor in the relations between insects and external environment for both temperature and humidity. It also exerts a direct influence on the abundance and activities of flying insects. Some populations of migratory insects are either carried or orientated by winds for hundreds of miles. At low wind speeds, strong flyers orientate into the wind so that steady dispersal and migration under certain weather conditions depend on the direction and speed of prevailing winds. Orientation in some insects such as mosquitoes also depends on a visual component. Flight is maintained only when a visual pattern moves beneath the animal from front to rear. This accounts for the reversal of flight direction at critical wind speeds. An insect flies into the wind if it can maintain a forward motion in relation to the ground pattern. At wind speeds above the critical point it must turn and fly with the wind to maintain the correct motion in its visual pattern or else settle to the ground. Wind speed and wind direction together account for the progressive seasonal invasion of crops and communities by some pest insects.

Radiation. As mentioned earlier, radiation from the sun and from terrestrial objects is an important factor in heating the insect body. Some insects have highly developed visual systems and are acutely sensitive to radiation wavelengths associated with changing light conditions. Variations in wavelength discrimination among species have received detailed study in some species, particularly bees, as a means of explaining remarkable behaviour patterns in relation to their surroundings. Insects as a group are characterized by their sensitivity to the shorter wavelengths in the spectrum. The 'circadian' rhythms in many insects depend on certain light conditions as cues for the initiation of mass activity in populations. The light reactions peculiar to species have to be considered in interpreting the relation between insect activities and weather. The physiological basis of behaviour and the relation of various insect reflexes to light have been described fully by Wigglesworth (1950). Photoperiodism influences development in many insects and, with temperature, is a factor in the induction of diapause, a form of arrested development which facilitates survival of the species in certain stages of metamorphosis during unfavourable seasons.

Atmospheric pressure. Many studies on insects have shown that activity is related to changes in atmospheric pressure. Differences in static levels of pressure are not important apparently since some insects survive periods in an evacuated chamber. However, experiments show that activity increases during certain changes of pressure. Irritability of laboratory colonies of several insect species has been observed during the passing of a hurricane when temperature and humidity were controlled at a constant level. Although both males and females of some insects are known to possess 'companiform sensilla' which perceive mechanical stimuli in the antennae, no experiments so far have established a direct connexion with response to changing atmospheric pressure as a mechanical stress. For this reason and because atmospheric pressure changes involve variations in the atmospheric constituents as well, no definite physiological conclusions are possible. On the other hand, extensive correlations on the activities of insects in the field continue to show striking relationships with cyclonic and anticyclonic pressure systems.

Other meteorological factors. Some factors such as electric state of the atmosphere and ionization of the air, electromagnetic fields, and sun-spot activity have been the subject of considerable speculation among entomologists. Recently these factors have been considered in some experimental work. Increased rate of moulting in laboratory populations of aphids appears to be related to fluctuations in the ratio of positively charged to negatively charged ions in the air. The orientation and dispersal of mosquitoes along valleys was associated in one set of experiments with certain variations in the electromagnetic field measured above ground level. Long-term correlations of the abundance of pest species of insects with sun-spot intensity have been initiated at a few locations, but there is insufficient data so far for an adequate analysis.

Relation of insects to weather and climate

The physiological relations between insects and meteorological factors, especially temperature and humidity, emphasize the dependence of species on climate for development, reproduction, and survival. The significance of these relationships has been recognized chiefly by ecologists interested in the prediction and prevention of insect outbreaks. Uvarov (1931) comprehensively summarized all of the early literature on the relations between insects and climate. This review has been supplemented by Messenger (1959) for the more recent studies. Graham (1956) has described the role of biometeorology in the ecology of forest insects. Wellington (1957) has considered the synoptic approach in studying the relation between climate and the abundance of forest insects with reference to insect outbreaks. Vertical distribution in the lower air is an important factor in the effect of weather conditions on flying insects and has been reviewed by Johnson (1954) in relation to dispersal and migration of aphids. An account of the reactions of insects to their meteorological environment (Haufe, 1963) emphasizes the importance of insects as vectors of disease in man's relation to his physical environment. For the reader interested in deeper concepts, these reviews together provide a more complete account of insect climatology as related to the climatology of man.

In conclusion, one must consider the insect to be a very successful competitor of man in meeting the same meteorological environment. Most significant is the fact that the insect achieves its survival in basically different ways. The arthropod depends on adaptative modifications among numerous species. Adjustment to variations in the climate of habitats is enhanced by a high reproductive potential and rapid rate of development, features that permit populations to survive with periodically high rates of mortality. The insect has an additional advantage in highly developed and specialized neurosensory systems. Numerous special receptors provide the ability not only to detect small gradients in the external environment but also to orient the insect to favourable habitats. A full understanding of the physiological relations between insect reactions and meteorological factors and the correlation of behaviour patterns with weather systems have important applications in the border science of biometeorology. It would appear that many unique physiological features in the insect provide the basis for practical studies on the influence of weather and climate on the living organism.

CHAPTER VIII

CLIMATIC THERAPY

The utilization of various climates for treatment of diseases is based on three principles :

(1) The elimination of those climatic factors which are injurious to the patient assists the healing process. This principle may be called "climatic treatment".

(2) The effect of individual climatic factors on the human body is used as an aid in the training of certain organs. This principle may be designated "climatic charging", given in prescribed doses for specific purposes.

(3) Individual climatic factors have specific effects on the organism. This may be described as "specific climatic therapy".

1. Climatic treatment

The patient can, by means of a suitable change of climate, be protected from the following three injurious factors :

(1) Intense heat, particularly damp heat, makes great demands on the circulation, on the perspiratory mechanism, and thence on the water and mineral balance. The removal of patients to cooler and drier regions is of special significance in the tropics and is also to be recommended in damp, hot river valleys in moderate latitudes in high summer.

(2) Protection from impurities in the air is of major importance in diseases of the respiratory system. Asthma, chronic bronchitis, emphysematous bronchitis and pulmonary tuberculosis cannot be properly treated in fog-bound industrial regions. In winter-time, the temperature inversions within areas of high pressure hinder the removal of industrial waste gases, smoke and aero-allergens; consequently, toxic aerosols are concentrated in those air layers which are near the ground. Localities on slopes (300 to 600 metres above the valley bottom) and sea-coasts provide the most effective protection against air impurities.

(3) Certain types of weather (e.g. biotropic) have unfavourable effects on certain patients. Consequently, patients with severe regulatory disturbances should be transferred to areas where, for example, stormy polar air currents or up-slope movements in the frontal regions of areas of low pressure occur rarely, e.g. the lee side of high mountains or areas of high pressure in subtropical regions if they are not too hot.

"Climatic treatment" always depends on the individual case. There is no such thing as a universally favourable climate; the climatic treatment depends on the particular climate to which the patient is accustomed. Although there is no need for acclimatization, re-acclimatization can be a problem when the patient returns home.

2. Climatic charging

The human body, from the very day of birth, is equipped for the struggle with its home climate; if these defence mechanisms do not operate, the result is "softening", "domestication", and ultimately, functional disturbances in the circulation, respiratory system, skin, etc. These disturbances can be cured through "climatic charging". Two examples can be adduced :

The heat regulatory system can be improved through judicious doses of cold weather on the sea-coasts of moderate latitudes or in high mountains. As a primary consequence, the flow of blood through the skin is developed. As a secondary consequence, the overall circulation, respiratory system and metabolism are improved.

The removal of the patient to altitudes above 1,500 m leads, through the fall in the oxygen partial pressure, to stimulation of the processes of blood formation, deeper breathing and improved blood flow in the lungs.

So far as is currently known, hot climates in the tropics are not suitable for climatic charging; short doses of heat such as are provided by saunas or steam baths are more effective.

A characteristic of this type of treatment is the latency occurring until the cure begins to take effect. In each case a process of adjustment and acclimatization is necessary before the therapeutic value can be determined. This process lasts at least three weeks.

3. Specific climatic therapy

In heliotherapy ultra-violet rays are, *inter alia*, used for their effects on skin cell metabolism, formation of substances such as Vitamin D, and detoxification processes. The prerequisites are ultra-violet rays applied in sufficient quantities over as long a period as possible during the day, hence little cloud in relatively cool air temperatures.

Some aerosols have specific effects on the human body. The sea spray found in the air on beaches has a particularly beneficial effect on the mucous membrane of the respiratory system; in this connexion, coasts with abundant and strong sea winds are to be preferred.

In addition, some springs enrich the air with substances which have specific effects, e.g. iodine, sulphur, radon, and others, all of which can be reabsorbed by the lungs.

In practice, all three principles are, generally speaking, applied. For serious cases, climatic treatment is the only one of importance. All over the globe there are latitudes, mountains, forests and sea-coasts of manifold climatic variety; it is one of the tasks of medical-meteorological research to utilize these climates in the treatment of disease.

4. An application of therapeutic principles

The physiological effects observed in healthy subjects who spend a considerable time at high altitude (cf. Chapter IV, Section 4), have been applied in Germany and the Netherlands (at Leiden) and in the therapeutic treatment of asthma and other diseases, such as whooping cough. Particularly asthmatics, known for their poor thermoregulation, can be considerably improved after a series of treatments in a climatic low-pressure chamber at simulated altitudes of 2,000 - 2,5000 m, three to five times per week, each time for one or two hours. The improvement seems to be related to the following processes; increased pulmonary ventilation, increased peripheral blood flow, stimulation of the hormone production of the adrenal gland, and improvement of the thermoregulatory efficiency. Although the method is still new and in an experimental stage, it may prove to be an important clinical tool for several diseases.

For a more detailed discussion of climatic therapy the reader is referred to Czeck (1954); Krieger (1953); Nückel and Lincke (1960, 1962), and Tromp (1963).

CHAPTER IX

CLIMATE OF HEALTH RESORTS AND CLIMATIC CONDITIONS SUITABLE FOR SANATORIA

1. Climatic zones

The physical complex of our atmosphere, especially that of the troposphere, varies in different parts of the globe. Four major climatic zones can be distinguished, in the light of their biometeorological effects and of current knowledge.

Tropical. Around 40 per cent of the earth's surface can be identified as tropical. Tropical regions have high temperatures, considerable moisture and pronounced and extensive instability. The diurnal and annual variations of these factors are relatively small. An effective seasonal rhythm is found only in precipitation, due to fluctuations in the equatorial zone of instability, in accordance with the sun's declination.

Subtropical. This climate zone lies approximately between 20° and 40° latitude north and south. A major feature is the slow downward motion of the air in the troposphere resulting in a low degree of cloudiness and hence strong insolation by day and outgoing radiation by night. Air temperatures are high by day and low by night. Precipitation is sometimes significant only in the poleward parts in winter-time; the result in continental areas is a desert climate.

Temperate. The temperate zone lies between about 45° and 70° latitude and is sometimes called the "west-weather" zone. Its weather is characterized by relatively short and aperiodic variations and the zone may be likened to a battlefield between the warm air masses from the subtropical zones and the cold air masses from polar latitudes. Travelling depressions and anticyclones give rise to continual weather instability, which in Europe, for example, takes up 45 per cent of all observational times.

Polar. This zone, lying between about 70° and 90° latitude, is characterized by strong radiation towards outer space and by the resulting coldness of the air. Temperatures rise above freezing point for only short periods at the height of summer. Although the absolute moisture content of the air is low, relative humidities are high. A pronounced feature is the wide annual range of insolation between polar night and polar summer and the concomitant temperature and moisture variations.

2. Characteristics of therapeutically favourable climates

These climatic zones can serve as a basis for defining special therapeutic climates, in which the patient is so affected by the geophysical environment that his recovery may be expected to follow as a matter of course. Each climatic zone may be subdivided into areas in which the climatic factors vary substantially according to the particular orographic or geographic features. These areas can thus be used for particular therapeutic purposes. Foremost among them are mountains and sea-coasts. As altitude increases, air temperature, pressure, density, moisture and oxygen content decreases, but radiation from sun and sky (particularly in the biologically effective ultra-violet region), evaporation, air purity and wind speed all increase. Since these altitudinal changes follow established physical laws, the most important bioclimatic values can, in most climatic zones, be calculated with sufficient accuracy for practical use. In making such calculations distinction must be made between windward and leeward sides of mountains. In coastal areas the unequal heating and cooling of the land and sea surfaces give rise to circulation systems in the biosphere, which appear as monsoons between maritime and continental regions and as land-sea winds on other coasts. The prerequisites for favourable therapeutic climates, in the light of present knowledge, are as follows :

Temperature and moisture conditions are such that the heat regulatory system of the human body is not appreciably disturbed. On the one hand, the cooling power must not exceed about 40 millicalories/cm^2/sec, and, on the other hand, sultriness must not be long lasting. Sultriness provokes a characteristic strain in the temperature regulatory system of man when the equivalent temperature of the air (approximately given by dry-bulb temperature in degrees Celsius plus twice the vapour pressure in mm Hg) exceeds 38° at a time when the radiant energy from long-wave atmospheric reflected radiation (6-60 μ) exceeds 9 mcal/cm^2/sec and the cooling power simultaneously falls below the value of 9 mcal/cm^2/sec.

Air purity is so high that breathing becomes pleasant and refreshing; for this the particle count for solid, liquid and gaseous aerosols must not exceed 10,000 to 20,000 per cubic metre or 0.1 mg/m^3 of air.

Radiation from sun and sky is so abundant and intense that the patient can, with benefit, go for walks or lie in the open.

The weather is, both absolutely and relatively, very quiet. This is especially so when the influence of high pressure predominates for long periods. Relatively quiet weather also obtains on the lee slopes of mountains, where the descent of the air masses gives rise to dryness and purity of the air and to increased sunshine.

The prerequisites for unfavourable therapeutic climates are :

Temperature and moisture conditions predominantly hot/damp or cold/damp, particularly when there is much fog.

Air impurity is such that excessive demands are made on the defence mechanism of the respiratory system. A dust load of 0.22 mg/m^3 will disturb the system, 0.3 mg/m^3 or more will be still more dangerous. If the dust load lasts for a lengthy period, as in smog, it will be detrimental to health.

Radiation of sun and sky decreases (due to heavy clouds, fog formation or low altitude of the sun) to such an extent that the lack of light (in particular the lack of ultra-violet rays) leads to physico-psychical disturbances (avitaminosis).

The weather is so stormy (as, for example, in the aperiodic disturbances of the "west-weather" zone) that disturbing or even detrimental influences may manifest themselves in the vegetative nervous system, as a consequence of marked air mass changes (fronts) and of biotropic weather movements (upward glide movements, extensive instability, etc.).

3. Therapeutic climates

The Polar Zone can be eliminated as a therapeutic climatic area. It contains almost all the unfavourable factors, being predominantly cold/damp with high cooling power and low radiation. The weather is frequently cyclonic and the atmosphere generally disturbed. The only favourable aspect is the purity of the air, sources of dust being absent.

The Temperate Zone contains therapeutic climatic areas in numerous gradations. In the northern hemisphere, the region of maximum weather fluctuations lies between 50° and 65° latitude; south of 45° latitude, the weather is much less disturbed, for this is a region transitional to the high pressure belt of the subtropical zone.

In addition, therapeutic-climatic requirements must be subdivided according to the seasons. The following therapeutic climates can be distinguished in the "west-weather" zone of the northern hemisphere :

(i) Maritime - in coastal areas of oceans and inland seas. Favourable therapeutic conditions obtain only in the summer half-year (May - October). Noteworthy features include moderate cooling power, little sultriness, moderate stimuli from radiation and weather and favourable aerosol ratios.

(ii) Mountain ranges of medium height - generally in conjunction with a pure forest climate. These regions are suitable for therapeutic purposes in summer and autumn and, in addition, in winter and spring at heights exceeding 300 m above the surrounding lowlands. A distinction must be made between the windy and strong-stimulus windward side and the protected and mild-stimulus lee side. In the winter half-year, localities above the lowland inversion can be used for mild-stimulus recuperative and curative purposes. Slopes of medium height, with pronounced mountain/valley wind systems are especially favourable.

(iii) High mountain chains - with sharp differentiation of therapeutic climates. Normally the recuperative areas extend up to 2,000 m. Above that level adverse factors such as lack of oxygen and strong cooling come into play. The windward side of high mountain ranges is somewhat more stimulating than in ranges of medium height; the lee side is often characterized by an only moderately stimulating and sheltered biological climate. Cloudiness and dry radiation weather can be exaggerated here; in the European Alps this is termed "Föhn". Föhn air is a downward gliding airstream on the lee side of a mountain chain, which may have a prejudicial effect on the patient if it leads to a strong temperature inversion above the therapeutic locality. In the Alps this type of Föhn is particularly effective in all longitudinal valleys running from south to north which debouch into a narrow or transverse valley, for the warm and dry Föhn air meets and overlies a small mass of stagnant cold air lying in the valleys. In high mountain chains, heights exceeding 1,000 m are especially favourable for therapeutic purposes in winter and spring on account of the purity of the air, the moderate cooling power above the inversions and the frequent radiation weather.

In the northern part of the Subtropical Zone, the weather of the transitional seasons, spring and autumn, can be regarded as favourable for therapeutic purposes, while in lowland and coastal areas in winter unfavourable bioclimatic factors predominate on account of the generally unsettled weather. In summer the therapeutic conditions are favourable only to a limited extent because of the intense solar radiation and the hot and dry, or sultry, climate. However, more favourable climatic conditions can be found in places above 500 m in altitude in the hot seasons.

The southern part of the Subtropical Zone can be considered only to a very limited extent for therapeutic purposes. The large diurnal variations in temperature over the continents call for considerable adaptability in the heat-regulating system of the human body. However, considerable climatic protection is afforded in all seasons in the island areas of this zone, provided that doses of solar and sky radiation are limited to meet therapeutic requirements. Dry heat, without prejudicial sultriness, and high radiation (including high illumination and ultra-violet intensity) are the therapeutic characteristics of this zone.

The Tropical Zone as a whole is almost as unfavourable for the patient as the Polar Zone. The continual damp and heat with the high instability (up to 18 km) and the almost perpetual electrical discharges, make very heavy demands on the human system. Therapeutic treatment, and that with several reservations, is conceivable only in the 1,000 - 2,000 m zone, since tolerable humidity and wind conditions are to be found there.

4. Sites for sanatoria

The above observations can serve as a sound basis for selecting suitable sites for sanatoria. However, the climatic stimuli and therapeutic climates required vary according to the disease. The difference between the indoor and the outdoor climate is also an important factor to be taken into account. The following are the prerequisites for sanatoria in a given region :

(i) A cooling power which fluctuates between moderate and protective;

(ii) Freedom, as far as possible, from prejudicial sultriness;

(iii) Extensive doses of radiation from sun and sky;

(iv) Freedom from dust, smoke and fog;

(v) Protection, in the main, against cold squally winds;

(vi) Adequate and agreeable ventilation.

These favourable biometeorological and therapeutic features are mainly to be found in the subtropical and moderate climatic zones, for instance, islands, coasts, wooded mountain ranges of moderate height and in the lower and middle parts of high mountain chains. The windward and leeward sides of mountain chains determine the stimulating effects of numerous bioclimatic factors in the mountainous therapeutic areas. Table IX.1 illustrates how these general concepts of the therapeutic classification of climates have been applied in Germany.

For detailed discussions of the ideas dealt with in Chapter IX, the reader is referred to the following references cited in the bibliography. Amelung (1941); Amelung, Becker and Ströder (1962); Becker (1962 a); Becker (1962 b); Daubert and Aichinger (1962); Knoch (1962); Vogt and Amelung (1962).

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TABLE IX.1

BIOCLIMATIC STIMULUS VALUES IN GERMANY

<table>
<tr><th colspan="2">Stimulus / Relief</th><th colspan="2">Cooling power</th><th>Sultri-ness</th><th>UV</th><th>Radiation global</th><th>Radio-activity*</th><th>Aerosol</th><th colspan="2">Weather</th><th>Mean</th><th>Stimu-lus range</th></tr>
<tr><td colspan="2">N. German coastal area</td><td colspan="2">2-3</td><td>0-1</td><td>1-2</td><td>2</td><td>0</td><td>0</td><td colspan="2">2-3</td><td>1.4</td><td>0-3</td></tr>
<tr><td colspan="2">N. German plain</td><td colspan="2">2</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0-1</td><td colspan="2">2</td><td>1.2</td><td>0-2</td></tr>
<tr><td rowspan="6">Mountain chains of medium height</td><td>River valleys</td><td colspan="2">1</td><td>2</td><td>0-1</td><td>1</td><td>1</td><td>2</td><td colspan="2">1-2</td><td>1.3</td><td>0-2</td></tr>
<tr><td>Narrow valleys</td><td colspan="2">0-1</td><td>2-3</td><td>0-1</td><td>1-2</td><td>1-2</td><td>2-3</td><td colspan="2">0-1</td><td>1.4</td><td>0-3</td></tr>
<tr><td>Windward side (luff)</td><td colspan="2">1-2</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1-2</td><td colspan="2">1-2</td><td>1.2</td><td>1-2</td></tr>
<tr><td>Leeward side (Föhn)</td><td colspan="2">0-1</td><td>1-2</td><td>1-2</td><td>2</td><td>1</td><td>0-1</td><td colspan="2">0-1</td><td>1.1</td><td>0-2</td></tr>
<tr><td>Slopes</td><td colspan="2">1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td colspan="2">1</td><td>1.0</td><td>1</td></tr>
<tr><td>Peaks</td><td colspan="2">2</td><td>0-1</td><td>1-2</td><td>2</td><td>1</td><td>0-1</td><td colspan="2">2-3</td><td>1.4</td><td>0-3</td></tr>
<tr><td rowspan="3">High mountain chains</td><td>up to 1000 m</td><td>Luff
1</td><td>Lee
0</td><td>0-1</td><td>2</td><td>2</td><td>2-3</td><td>0-1</td><td>Luff
1-2</td><td>Lee
1-3</td><td>1.3</td><td>0-3</td></tr>
<tr><td>up to 2000 m</td><td>2</td><td>1</td><td>0</td><td>3</td><td>3</td><td>2</td><td>0</td><td>2-3</td><td>2-3</td><td>1.5</td><td>0-3</td></tr>
<tr><td>up to 3000 m</td><td>3</td><td>2</td><td>0</td><td>3</td><td>3</td><td>2</td><td>0</td><td>3</td><td>3</td><td>2.1</td><td>0-3</td></tr>
</table>

Key :

0 = none or protective
1 = weak
2 = moderate
3 = strong

* ionizing rays of natural radioactivity

REFERENCES

Adolph, E.F. - Physiology of man in the desert. Interscience, N.Y., 1947.

Alexander, A.F. and Jensen, R. - Gross cardiac changes in cattle with high mountain (Brisket) disease and in experimental cattle maintained at high altitudes. Amer. J. Vet. Res., 20, pp. 680-689. 1959.

Alexander, G. - Temperature regulation in the newborn lamb. III. Effect of environmental temperature on metabolic rate, body temperatures and respiratory quotient. Aug. J. Agric. Res., 12, pp. 1152-1174. 1961.

Alexander, G. - Temperature regulation in the newborn lamb. IV. The effect of wind and evaporation of water from the coat on metabolic rate and body temperature. Aust. J. Agric. Res., 13, pp. 82-99. 1962.

Amdur, M.O. - The effect of aerosols on the response to irritant gases, inhaled particles and vapours. Pergamon, Oxford, p. 281. 1961.

Amelung, W. - Klimatische Behandlung innerer Krankheiten. Springer, Berlin, 1941.

Amelung, W., Becker, F and Ströder, U. - Wetter Klima und Mensch, 1962.

Anonymous - Air over cities. Symposium at Robert A. Taft Sanitary Engineering Center, 6-7 Nov. 1961, SEC Tech. Rept. A62-5, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 1962.

Anonymous - Air pollution, WHO Monograph, World Health Organization, Geneva, 1961.

Armstrong, D.G., Blaxter, K.L., Clapperton, J.L., Graham, N.McC. and Wainman, F.W. - Heat production and heat emission of two breeds of sheep. J. Agric. Sci., 55, pp. 395-401. 1960.

Aronin, J.E. - Climate and architecture. Reinhold, N.Y., 1953.

Assmann, D. - Die Wetterfühligkeit des Menschen. Ursachen und Pathogenese der biologischen Wetterwirkung. 2nd edition, Fischer, Jena, 1963.

Baker, P.T. - The biological adaptations of man to hot deserts. Am. Nat., 92, pp. 337-357. 1958.

Baker, P.T. - Climate, culture and evolution. Human Biol., 32, pp. 3-15. 1960.

Barbour, J.H. and Seevers, M.H. - Narcosis induced by carbon dioxide at low environmental temperatures. J. Pharmacol. and Exper. Therap., 78, pp. 296-303. 1943.

Barcroft, J. et al. - On the relation of the external temperature to blood volume. Phil. Trans. Roy. Soc., London B., 211, p. 455. 1922.

Barnicott, N.A. - Climatic factors in the evolution of human populations. Cold Spring Harbor Symposia on Quant. Biol., 24, pp. 115-129. 1959.

Bean, J.W. - Effects of oxygen at increased pressure. Physiol. Rev., 25, pp. 1-147. 1945.

Becker, F. - Bioklimatische Reizgrössen und Landschaft. Arch. Phys. Therapie, 14, pp. 177-181. 1962 a.

Becker, F. - Meteorologische Grundlage der Klimaheilkunde. Handbuch der Bäder- und Klimaheilkunde. F.K. Schattauer, Stuttgart, p. 501. 1962 b.

Becker, L. - Untersuchung über das Heimfindevermögen der Bienen. Z. Vergl. Physiol., 41, p. 1. 1958.

Bianca, W. - The effect of thermal stress on the acid base balance of the Ayrshire calf. J. Agric. Sci., 45, pp. 428-430. 1955.

Bianca, W. - Acclimatisation of calves to a hot environment. J. Agric. Sci., 52, pp. 296-304. 1959 a.

Bianca, W. - Acclimatisation of calves to a hot humid environment. J. Agric. Sci., 52, pp. 305-312. 1959 b.

Bianca, W. - Heat tolerance in cattle - its concept, measurement and dependence on modifying factors. Intern. J. Biometeor., 5, pp. 5-30. 1961.

Bianca, W. and Blaxter, K.L. - The influence of the environment on animal production and health under housing conditions. VIII Int. Congr. Anim. Prod. Hamburg, Gen. Rep. III, pp. 113-145. 1961.

Bianca, W. and Findlay, J.D. - The effect of thermally induced hyperpnea on the acid-base status of the blood of calves. Res. Vet. Sci., 3, pp. 38-49. 1962.

Blaxter, K.L. - The nutritional physiology of livestock under natural conditions. J. Royal Soc. Arts, Vol. CIX (5062), pp. 764-781. 1961.

Blum, H.F. - Sunburn. Ultraviolet radiation and cancer. Chs. 13 and 14, Radiation Biology, Vol. II (Ed. Alexander Hollaender), McGraw-Hill, N.Y., 1955.

Blum, H.F. - On the origin and evolution of human culture. Am. Sci., 51, pp. 32-47. 1963.

Bonsma, J.C. - Breeding cattle for increased adaptability to tropical and subtropical environments. J. Agric. Sci., 39, pp. 204-221. 1949.

Bradtke, F. and Liese, W. - Hilfsbuch für raum- und aussenklimatische Messungen. 2nd ed. Springer, Berlin, 108 pp. 1952.

Brezina, E. and Schmidt, W. - Das künstliche Klima in der Umgebung des Menschen. Enke, Stuttgart, 212 pp. 1937.

Brezowsky, H. - Uber die pathogene Belastung durch Wettervorgänge. Med. Klinik, 50, pp. 2235-2240. 1960.

Brezowsky, H. and Weisser, P. - Der Einfluss der Wettervorgänge auf Betriebsunfälle und Befindensstörungen in einem grossen Industriewerk. Zentralbl. f. Arbeitsmed. u. Arbeitsschutz, 11, pp. 81-84. 1961.

Brobeck, J.R. - Food intake as a mechanism of temperature regulation. Yale J. Biol. Med., 20, pp. 545-552. 1948.

Brody, S. - Climatic physiology of cattle. J. Dairy Sci., 39, pp. 715-725. 1956.

Buchanan, A.R., Heim, H.C. and Stilson, D.W. - Biomedical effects of exposure to electromagnetic radiation, Part I. Wright Air Development Division, Tech. Rept. 60-376. Wright-Patterson Air Force Base, Ohio, 1960.

Buettner, K. - Physikalische Bioklimatologie. Probleme der Kosmischen Physik, Vol. XVIII (Ed. Christian Jensen), Akademische Verlagsgesellschaft, Leipzig, 1938.

Buettner, K. and Pfleiderer, H. - Bioklimatologie. Lehrbuch der Bader- und Klimaheilkunde (Ed. H. Vogt), Springer, Berlin, 1940.

Burch, G.E., and DePasquale, N.P. - Hot climates, man and his heart. C.C. Thomas,Springfield, 1962.

Burton, A.C. and Edholm, O.G. - Man in a cold environment. Arnold, London, 1955.

Carlson, L.D., Burns, H.L., Holmes, T.H. and Webb, P.P. - Adaptive changes during exposure to cold. J. Appl. Physiol., 5, pp. 672-676. 1953.

Carter, C.O. - Human heredity. (Pelican Book A523), Penguin Books, Inc., Middlesex, 1962.

Cauer, H. - Schwankungen der Jodmenge der Luft in Mitteleuropa. Beihefte Zschr. d. Vereins dtsch. Chemiker, No. 34. 1939.

Chiles, W.D., Cleveland, J.M. and Fox, R.E. - A study of the effects of ionized air on behavior. Wright Air Development Division, Tech. Rept. 60-598. Wright-Patterson Air Force Base, Ohio, 1960.

Committee on Atmospheric Sciences - The atmospheric sciences, 1961-1971. National Academy of Sciences - National Research Council, Publication 946, Vol. II, pp. 55-65. 1962.

Committee on the Problem of Noise - Noise. Final Report. H.M.S.O., London, 1963.

Cori, G.J. and Cori, C.F. - Seasonal occurrence of ketonuria in fasting rats accompanied by changes in carbohydrate metabolism. J. Biol. Chem., 72, pp. 615-625. 1927.

Crawford, J.D., Osborne, M.M., Talbot, N.B., Terry, M.L. and Moffill, M.F. - The parathyroid gland and phosphorus homeostasis. J. Clin. Invest., 29, pp. 1448-1461. 1950.

Curry, M. - Bioklimatik. Riederau, 1946.

Czeck, W. - Klimakammerbehandlung des Asthma bronchiale. Med. Mschr., 11, pp. 732-735. 1954.

Daubert, K. - Betriebsunfälle der Bundesbahn in Württemberg und Wettergeschehen. Med. - Meteorologische Hefte, 11, pp. 149-151. 1956.

Daubert, K., and Aichinger, F. - Wetter- Klima- Haut. Dermatologie und Venerologie, Band I, Teil 2. G. Thieme, Stuttgart, pp. 905-954. 1962.

Davis; T.R.A. and Joy, R.T.J. - Natural and artificial cold acclimatization in man. Biometeorology (Ed. S.W. Tromp), Pergamon, Oxford, pp. 286-303. 1962.

Dobzhansky, T. - Mankind evolving. The evolution of the human species. Yale U. Press, New Haven, 1962.

Du Bois, E.F. - Basal metabolism in health and disease. Lea and Febiger, Philadelphia, pp. 145-200. 1936.

Dubos, R. - Mirage of health. (Anchor Book A258), Doubleday, N.Y., 1961.

Duckworth, F.S. and Sandberg, J.S. - The effect of the cities upon horizontal and vertical temperature gradients. Bull. Amer. Meteorol. Soc., 35, pp. 198-207. 1954.

Edney, E.B. - The water relations of terrestrial arthropods. Cambridge Univ. Press,Cambridge, England, pp. 1-93. 1957.

Edwards, D.K. - Effects of experimentally altered unipolar air-ion density upon the amount of activity of the blowfly, Calliphora vicina. R.D. Canad. J. Zool., 38, pp. 1079-1091. 1960.

Erban, L. - A study of biochemical and haematological changes under the application of ionized air. Intern. J. Biometeorol., III, Part IV, pp. 1-4. 1959.

Euler, C. von - Physiology and pharmacology of temperature regulation. Pharmacol. Rev., 13, pp. 361-398. 1961.

Fabinyi-Szebehely, M., and Szebehely, J. - The influence of antihistamines on the effect of histamine upon body temperature and oxygen consumption in mice and rats. Acta Physiol. Scand., 27, pp. 1-9. 1953.

Fazekas, J.F., Alexander, F.A.D. and Himwich, H.E. - Tolerance of newborn to anoxia. Amer. J. Physiol., 134, pp. 281-287. 1941.

Findlay, J.D. - The effects of temperature, humidity, air movement and solar radiation on the behaviour and physiology of cattle and other farm animals. The Hannah Dairy Research Institute, Bull. No. 9. 1950.

Freebairn, H.T. - The toxicity of ozone. J. Appl. Nutrition, 12, No. 1. 1959.

Frey, A.H. - Behavior and atmospheric ions. G.E. Advance Electronic Center, Cornell Univ., Ithica, N.Y., 1959.

Fuerst, R. - Annual Report, M.D. Anderson Hospital and Tumor Inst., Univ. of Texas, 1955.

Fuhrman, F.A. - The effect of body temperature on drug action. Physiol. Rev., 26, pp. 247-274. 1946.

Fuhrman, F.A. - The effect of body temperature on the duration of barbiturate anaesthesia in mice. Science, 105, pp. 387-388. 1947.

Fuhrman, G.H. and Fuhrman, F.A. - Effects of temperature on the action of drugs. Ann. Rev. Pharmacol., 1, pp. 65-78. 1961.

Garn, S.M. - Human races. C.C. Thomas, Springfield, 1961.

Glaser, E.M. - The part played by the central nervous system in acclimatization. First Bioclimatological Congress of the International Society of Bioclimatology and Biometeorology (Human bioclimatology), 1957.

Glaser, E.M., Hall, M.S., and Whittow, G.C. - Habituation to heating and cooling of the same hand. J. Physiol., 146, pp. 152-164. 1959.

Givoni, B. and Belding, H.S. - The cooling efficiency of sweat evaporation. Biometeorology (Ed. S.W. Tromp), Pergamon, Oxford, pp. 304-314. 1962.

Graham, S.A. - Ecology of forest insects. Ann. Rev. Entomol., 1, pp. 261-280. 1956.

Green, H.L. and Lane, W.R. - Particulate clouds : dusts, smokes, and mists. Spon, London, 1957.

Griffith, F.R. Jr., Pucher, G.W., Brownell, K.A., Klein, J.D. and Carmer, M.E. - Studies in human physiology, IV. Vital capacity, respiratory rate and volume, and composition of the expired air. Am. J. Physiol., 89, pp. 555-583. 1929.

Hafez, E.S.E. - Reproductive capacity of farm animals in relation to climate and nutrition. J. Amer. Vet. Med. Assoc., 135, pp. 606-614. 1959.

Haine, E. and König, H. - Uber die Behandlung von Blattläusen mit elektrischen Feldern. Z. Angew. Entomologie, 47. 1960.

Hardy, J.D. - The pain threshold and the nature of pain sensation. In "The assessment of pain in man and animals" (Edited by C.A. Keele and R. Smith). UFAW, London; Livingstone, Edinburgh, pp. 170-201. 1962.

Hardy, J.D. - Temperature. Its measurement in science and industry. Vol. 3, Pt. 3, Biology and Medicine. Rheinhold, N.Y., 1963.

Hardy, J.D. and Muschenheim, C. - The radiation of heat from the human body, IV. The emission, reflection and transmission of infra-red radiation by the human skin. J. Clin. Invest., 13, pp. 817-831. 1934.

Haufe, W.O. - Insects as vectors of disease. In "Medical biometeorology, Weather climate and the living organism" (Edited by S.W. Tromp). Elsevier, Amsterdam, pp. 688-703. 1963.

Heer, R.R. - The absorption of human skin between 420 and 1010 mμ for black body radiation at various colour temperatures. Science, 115, pp. 15-18. 1952.

Heitman, H. Jr. and Hughes, E.H. - The effects of air temperature and relative humidity on the physiological well-being of swine. J. Anim. Sci., 8, pp. 171-181. 1949.

Heitman, H. Jr., Kelly, C.F. and Bond, T.E. - Ambient air temperature and weight gain in swine. J. Anim. Sci., 17, pp. 62-67. 1958.

Hensel, H., Iggo, A. and Witt, I. - A quantitative study of sensitive cutaneous thermoreceptors with C afferent fibres. J. Physiol., 153, pp. 113-126. 1960.

Hermann, R. and Heine, E. - Die Beeinflussung der K- und Ca-Konzentrationen im Serum durch künstliche Ozonierung der Raumluft. Strahlentherapie, 87, p. 473. 1952.

Hess, E.A. and Bailey, C.B.M. - Comparative physiological effects of cold on farm and laboratory animals. Anim. Breed. Abs., 29, pp. 379-392. 1961.

Hollander, J.L. and Yeostros, S.J. - The effect of simultaneous variations of humidity and barometric pressure on arthritis. AIBS, Bull., 13, pp. 24-28. 1963.

Hopkinson, R.G. - Lighting. H.M.S.O., London, 1963.

Horne, G.O. - Sensitivity to atropine in anhydrotic heat exhaustion. Trans. R. Soc. Trop. Med. and Hyg., 48, pp. 153-155. 1954.

Houssay, B.A. - Human physiology, 2nd edition. McGraw-Hill, N.Y., 1955.

Howell, J.B. - The sunlight factor in aging and skin cancer. Arch. Dermatol., 82,pp. 865-869. 1960.

Ittner, N.R., Bond, T.E. and Kelly, C.F. - Methods of increasing beef production in hot climates. California Agric. Expt. Sta. Bull., No. 761. 1958.

Iwanami, M.S., Oshiba, Y. Yamada and Yoshimura, H. - Seasonal variations in serum inorganic phosphate and calcium with special reference to parathyroid activity. J. Physiol., 149, pp. 23-33. 1959.

Johnson, C.G. - Aphid migration in relation to weather. Biol. Rev., 29, pp. 87-118. 1954.

Kamal, T.H., Johnson, H.D. and Ragsdale, A.C. - Metabolic reactions during thermal stress (35° to 95° F) in dairy animals acclimated at 50° and 80° F. Res. Bull. Mo. Agric. Expt. Sta. No. 785. 1962.

Kibler, H.H. and Brody, S. - Influence of temperature 50° to 5° F and 50° to 95° F on heat production and cardiorespiratory activities of dairy cattle. Res. Bull. Mo. Agric. Exp. Sta. No. 450. 1949.

King, E. - Die Wetterabhängigkeit von Verkehrsunfällen. Zschr. f. Verkehrssicherheit, 7, pp. 19-40. 1961.

Kingdon, K.H. - Interaction of atmospheric ions with biological material. Physics.Med. Biol., 5, pp. 1-14. 1960.

Knoch, K. - Problematik und Probleme der Kurortklimaforschung als Grundlage der Klimatherapie. Mitteilungen des Deutschen Wetterdienstes, No. 30. 1962.

Koga, Y. - Studies on individual variation of complaint during cold exposure test. Bull. Res. Inst. Diath. Med., Kumamoto Univ., Japan, 10, pp. 180-191, (Japanese.) 1959.

Köhn, W. - Hamburger Verkehrsunfälle und Wetter. Med. -meteorologische Hefte, 11, pp. 137-147. 1956.

Köhn, W. - Verkehrsunfälle in biosynoptischer Sicht. Med. -meteorologische Hefte, 13, pp. 88-93. 1958.

König, H. and Krampl-Lamprecht, L. - Uber die Einwirkung niederfrequenter elektrischer Felder auf das Wachstum pflanzlicher Organismen. Arch. f. Mikrobiologie, 34, p. 204.1959.

König, H. and Ankermüller, F. - Uber den Einfluss besonders niederfrequenter elektrischer Vorgänge in der Atmosphäre auf den Menschen. Naturwiss, 47, p. 486. 1960.

Kornblueh, I.H., Piersol, G.M. and Speicher, F.P. - Relief from pollinosis in negatively ionized rooms. Amer. J. Phys. Med., 37, pp. 18-27. 1958.

Kozak, W., Macfarlane, W.V. and Westerman, R. - Long-lasting and reversible changes in the reflex responses of chronic spinal cats to touch,heat and cold. Nature, 193, pp. 171-173. 1962.

Kratzer, A. - Das Stadtklima. Braunschweig, 1937.

Kravitz, E.A. and Guarino, A.J. - On the effect of inorganic phosphate on hexose phosphate metabolism. Science, 128, pp. 1139-1140. 1958.

Krieger, K. - Uber die Erfolge der Keuchhusten-Behandlung in der Klimakammer. Münch. Med. Wschr., 95, pp. 148-150. 1953.

Krueger, A.P., Andriese, P.C. and Kotaka, S. - The biological mechanism of air ion action : The effect of CO_2^+ in inhaled air on the blood level of 5-hydroxytryptamine in mice. Intern. J. Biometeorol., 7, pp. 3-17. 1963.

Krueger, A.P., Kotaka, S. and Andriese, P.C - Studies on the effects of gaseous ions on plant growth. I. The influence of positive and negative air-ions on the growth of Avena sativa. J. Gen. Physiol., 45, pp. 879-895. 1962.

Krueger, A.P. and Smith, R.F. - The biological mechanisms of air-ion action. I. 5-hydroxytryptamine as the endogenous mediator of positive air-ion effects on the mammal trachea. J. Gen. Physiol., 43, pp. 533-540. 1960.

Krueger, A.P., Smith, R.F. and Go, I.G. - The action of air ions on bacteria. I. Protective and lethal effects on suspensions of staphylococci in droplets. J. Gen. Physiol., 41, pp. 359-381. 1957.

Krüger, L. and Stephan, E. - Grundzüge der Bioklimatologie der Haustiere. Z. Tierzücht. Zücht. Biol., 74, pp. 361-392. 1960.

Kuno, Y. - The physiology of human perspiration. Churchill, London, p. 186. 1934.

Kuno, Y. - Human perspiration. C.C. Thomas, Springfield, pp. 318-335. 1956.

Kuroda, K. - Seasonal variation of blood water. Medicine and Biology, 12, pp. 12-15. (Japanese.) 1943.

Landsberg, H. - Bioclimatology of housing. In "Recent studies in bioclimatology". Meteorol. Mongr., 2, pp. 81-98. 1954.

Landsberg, H.E. - City air - better or worse. In "Air over cities". U.S. Public Health Service, Taft Sanitary Engineering Center Technical Report A 62-5, pp. 1-22. 1962.

Lawther, P.J., Martin, A.E. and Wilkins, E.T. - Epidemiology of air pollution : Report on a symposium. WHO Public Health Papers No. 15. World Health Organization, Geneva, 1962.

Lee, D.H.K. and Phillips, R.W. - Assessment of the adaptability of livestock to climatic stress. J. Anim. Sci., 7, pp. 391-425. 1948.

MacDonald, M.A. and Bell, J.M. - Effects of low fluctuating temperatures on farm animals. II. Influence of ambient air temperature on water intake of lactating Holstein-Friesian cows. Canad. J. Anim. Sci., 38, pp. 23-32. 1958 a.

MacDonald, M.A. and Bell, J.M. - Effects of low fluctuating temperatures on farm animals. III. Influence of ambient air temperature on feed intake of lactating Holstein-Friesian cows. Canad. J. Anim. Sci., 38, pp. 148-159. 1958 b.

MacDonald, M.A. and Bell, J.M. - Effects of low fluctuating temperatures on farm animals. IV. Influence of temperature on milk yield and milk composition. Canad. J. Anim. Sci., 38, pp. 160-170. 1958 c.

Macfarlane, W.V. - Experimental approaches to the functions of tropical livestock. UNESCO Arid Zone Research. XI. Fifth Session : Microclimate of man and domestic animals. Proc. Canberra Symposium, pp. 227-234. 1958.

Macfarlane, W.V. - Endocrine functions in hot environments. Arid Zone Research. XXII. Physiology and psychology of arid zones. UNESCO, Paris, pp. 153-222. 1963.

Macpherson, R.K. - Physiological responses to hot environments : An account of work done in Singapore, 1948-1953, at the Royal Naval Tropical Research Unit, with an appendix on preliminary work done at the National Hospital for Nervous Diseases, London. Medical Research Council Special Report No. 298. 1961.

Magill, P.L., Holden, F.R. and Ackley, C. (Eds.) - Air pollution handbook. McGraw-Hill, N.Y., 1956.

McDowell, R.E. - Physiological approaches to animal climatology. J. Hered, XLIX, pp. 52-61. 1958.

McGuigan, R.A. - Effect of temperature on digitalis action. J. Lab. and Clin. Med., 23, pp. 999-1006. 1938.

Medawar, P.B. - The uniqueness of the individual. Methuen and Co., Ltd., London, 1957.

Messenger, P.S. - Bioclimatic studies with insects. Ann. Rev. Entomol., 4, pp. 183-206. 1959.

Meyer, A.E.H. and Seitz, E.O. - Ultraviolette Strahlen. Walter de Gruyter and Co., Berlin, 1942.

Minehart, J.R., David, T.A. and Kornblueh, I.H. - Artificial ionization and the burned patient. Medical Science, 25 March 1958.

Mücher, H. - Uber einen experimentellen Ansatz zur Analyse wetterbedingter physiologisch - psychologischer Wechselwirkung. Med. -meteorologische Hefte, 11, pp. 86-88. 1956.

Newburgh, L.H. (Ed.) - Physiology of heat regulation and the science of clothing. Saunders, Philadelphia, 1949.

Newman, M.T. - Biological adaptation of man to his environment : heat, cold, altitude and nutrition. Ann. N. Y. Acad. Sci., 91, pp. 617-633. 1961.

Nückel, H. and Lincke, G. - Klimakammertherapie. Intern. J. Bioclim. Biometeor., IV, Part 4, Section C 6 h. 1960.

Nückel, H. and Lincke, G. - Climatic chamber treatment. In "Medical biometeorology" (Edited by S.W. Tromp). Elsevier, Amsterdam, pp. 631-642. 1962.

Ogata, K. - Kanrei to Taion-chosetu (Thermal regulation in cold). Najo, Tokyo, Japan, p. 103. (Japanese.) 1949.

Oosterlee, C.C. - The influence of climatic factors on the heat balance and milk yield of the cow in relation to the design of farm buildings in the Netherlands. Intern. J. Bioclim. Biometeor., III, Part 3, Section C. 1959.

Osiba, S. - The seasonal variation of basal metabolism and activity of thyroid gland in man. Jap. J. Physiol., 7, pp. 355-365. 1957.

Peters, J.P. and Eiderson, L. - The influence of protein and inorganic phosphorus on serum calcium. J. Biol. Chem., 84, pp. 155-166. 1925.

Petersen, W.F. - The patient and the weather. 4 vols. Edward Brothers Inc., Ann Arbor, Michigan, 1938.

Pratt, R. and Barnard, R.W. - Some effects of ionized air on penicillium notatum. Amer. Pharm. Assn., Scient. Ed., 49, pp. 643-646. 1960.

Pucher, G.W., Griffith, F.R. Jr., Brownell, K.A., Klein, J.D. and Carmer, M.E. - Studies in human physiology. V. Urine chemistry; composition of 24-hour and short-period basal excretion; correlations between urine constituents and menstrual and seasonal variation. J. Nutrition, 7, pp. 131-167. 1934 a.

Pucher, G.W., Griffith, F.R. Jr., Brownell, K.A., Klein, J.D. and Cramer, M.E. - Studies in human physiology. VI. Variations in blood chemistry over long periods of time, including those characteristics of menstruation. J. Nutrition, 7, pp. 169-193. 1934 b.

Ragsdale, A.C., Chu Shan Cheng and Johnson, H.D. - Effects of constant environmental temperatures of 50°F and 80°F on the growth responses of Brahman, Santa Gertrudis and Shorthorn calves. Res. Bull. Mo. Agric. Expt. Sta., No. 642. 1957.

Ragsdale, A.C., Worstell, D.M., Thompson, H.J. and Brody, S. - Influence of temperature, 50° to 0°F and 50° to 95°F, on milk production, feed and water consumption and body weight in Jersey and Holstein cows. Res. Bull. Mo. Agric. Exp. Sta., No. 449. 1949.

Ramsay, J.A. - Methods of measuring the evaporation of water from animals. J. Exp. Biol., 12, pp. 355-372. 1935.

Raventos, J. - Influence of room temperature on action of barbiturates. J. Pharmacol. and Exp. Therap., 64, pp. 355-363. 1938.

Reidat, R. - Wetterdaten für das Bauwessen No. 1, Hamburg (Weather data for the building industry), Hamburg, Deutscher Wetterdienst, Seewetteramt, 1957.

Reifferscheid, H. - Uber den Einfluss des Wetters auf Leistung und Befinden bei Akkordarbeiten. Zentralbl. f. Arbeitsmed. u. Arbeitsschutz, 4, pp. 112-116. 1954.

Reiter, R. - Die Bedeutung extrem langwelliger elektromagnetischer Strahlungen in der Bioklimatologie. Strahlentherap., 89, p. 628. 1953.

Reiter, R. - Gibt es einen direkten Kausalzusammenhang zwischen raschen elektrischen und elektromagnetischen Feldänderungen und biometeorologischen Reaktionen ? Med. Meteor. Hefte, 9, p. 35. 1954 a.

Reiter, R. - Nachweis der biologischen Wirksamkeit elektrischer Wechselfelder niedriger Frequenz. Naturwiss, 41, p. 22. 1954 b.

Reiter, R. - Meteorobiologie und Elektrizität der Atmosphäre. Leipzig, 1960.

Reiter, R. - Welche atmosphärisch-elektrischen Elemente können auf den Organismus einwirken? Z. angew. Bäder- u. Klimaheilkunde, 10, p. 161. (Vortrag auf der Tagung für Medizin-Meteorologie in Timmendorfer Strand (1962).) 1963.

Reiter, R. - Atmospheric electricity and natural radioactivity. Physical Medicine Library, Vol. VII, Climate, Health and Disease (Ed. Sidney Licht), New Haven, Conn. (In press.) 1963 a.

Reiter, R. - Felder, Ströme und Aerosole in der unteren Troposphäre. Steinkopff, Darmstadt, 1963 b.

Renbourn, E.T. - The spine pad : A discarded item of tropical clothing. J. Roy. Army Med. Corps, 103, pp. 217-233. 1956.

Renbourn, E.T. - Life and death of the solar topi. A chapter in the history of sunstroke. J. Trop. Med. and Hyg., 65, pp. 203-218. 1962.

Rheinstein, J. - Der Einfluss von künstlich erzeugten atmosphärischen Ionen auf die einfache Reaktionszeit und auf den optischen Moment. Dissertation, Techn. Hochsch, München, 1960.

Richards, R.K. - Influence of fever upon action of 3,3' -methylene-bis- (4-hydroxycoumarin) (dicumarol). Science, 97, p. 313. 1943.

Ronge, H.E. - Ultraviolet irradiation with artificial illumination. University of Uppsala, Sweden, 1948.

Rudder, B.De. - Grundriss einer Meteorobiologie des Menschen. Springer, Berlin, 1952.

Sargent, F. II. - A critique of homeostasis : season and metabolism. Arch. Meteorol., Geophys. u. Bioklimatol., Serie B, 3, pp. 389-396. 1951.

Sargent, F. II. - The nature and nurture of biometeorology. AIBS Bull., 13, pp. 20-23. 1963 a.

Sargent, F. II - Environment and human health. Proc. Symp. on Environmental physiology and psychology of man in arid conditions. Lucknow, India, 7-14 Dec. 1962. UNESCO, Paris. (In press.) 1963 b.

Sargent, F. II and Weinman, K.P. - Variabilité physiologique chez l'homme jeune. Biotypologie, 23, pp. 137-171. 1962.

Sargent, F. II and Weinman, K.P. - Effectiveness of physiological regulation. Nisshin Igaku (Japan), 50, pp. 327-339. Biotypologie (France), 1964. (In press.) 1963.

Sargent, F. II and Zaharko, D.S. - Medical-meteorological forecasting - an application of fundamental bioclimatological concepts. In "Biometeorology" (Edited by S.W. Tromp). Pergamon Press, London, pp. 174-193. 1962.

Sasaki, T. - Seasonal variation in basal metabolism and resting metabolism with particular reference to a climatic element of temperature. Bull. Res. Inst. Diath. Med., Kumamoto Univ., 4, pp. 439-452. (Japanese.) 1954.

Scholander, P.F. - Evolution of climatic adaptation in homeotherms. Evolution, 9, pp.15-26. 1955.

Scholander, P.F., Hock, R., Walters, V., Johnson, F. and Irving, L. - Heat regulation in some arctic and tropical mammals and birds. Biol. Bull., 99, pp. 237-258. 1950.

Schuà, L. - Der Einfluss des Wetters auf das Verhalten der Honigbiene. Verh. Dt. Zoologen, Marburg (1950), Leipzig, p. 183. 1951.

Schuà, L. - Die Fluchtreaktion von Goldhamstern aus elektrischen Feldern. Naturwiss., 40, p. 514. 1953.

Schuà, L.- Die Wirkung von luftelektrischen Feldern auf Tiere. Verh. Dt. Zoologen Tübingen, p. 435. 1954 a.

Schuà, L. - Wirken luftelektrischer Felder auf Lebewesen ? Umschau, 54, p. 468. 1954 b.

Schulz, L. - Meteorologische Grundlagen der Klimatherapie im Gebrige. Arch. Phys. Therapie, 14, pp. 145-154. 1962.

Schumann, W.O. and König, H. - Uber die Beobachtung von atmospherics bei geringsten Frequenzen. Naturwiss., 41, p. 183. 1954 c.

Setnikar, I. and Temelcou, O. - Effect of temperature on toxicity and distribution of pentobarbital and barbital in rats. J. Pharmacol. Exp. Ther., 135, pp. 213-222. 1962.

Shemano, I. and Nickerson, M. - Effect of ambient temperature on thermal responses to drugs. Canad. J. Biochem. Physiol., 36, pp. 1243-1249. 1958.

Slote, L., Knoll, M. and Rheinstein, J. - See individual papers in Proceedings of Internat. Conf. on Ionization of the Air sponsored by Amer. Inst. of Medical Climatology, Franklin Inst., Philadelphia, Pa. Published and edited by Amer. Inst. of Medical Climatology. 2 vols., 1962.

Sollman, T. - The influence of conditions on drug actions. In "A manual of pharmacology". Saunders, Philadelphia. 8th edition, pp. 37-41. 1957.

Spann, W. - Verkehrsunfälle und Wetter. Med. -meteorologischen Hefte, 11, p. 152. 1956.

Stern, A.C. - Air pollution, 2 vols. Academic Press, N.Y., 1962.

Stetter, G. - Die Kohlensäurekerne. Acta Physica Austriaca, 13, p. 185. 1960.

Sundermann, H. - Uber die Möglichkeit eines Biotropismus luftelektrischer Erscheinungen. Arch. Meteor. Geophys. Biocklim., B5, p. 258. 1954.

Suzuki, S. - Basal metabolism in the Japanese population. World Review of Nutrition and Dietetics, 1, p. 107. 1960.

Tchijevsky, A.L. - Aeroinifikatsiya v Narodonom Khozyaystve (Aerionization, its role in the national economy). Gosplanizdat (Publishing House of the State Planning Commission of the USSR), Moscow, 1960.

Tromp, S.W. - Medical biometeorology. Weather, climate and the living organism. Elsevier, Amsterdam, 1963.

Tromp, S.W. - The application of simulated high altitude climate in low pressure climatic chambers, to asthmatic and bronchitic patients. (In press.) 1963 a.

Tyler, D.B. - Effects of body temperature and of pentobarbital on brain damage produced by insulin shock. Proc. Soc. Exper. Biol. and Med., 45, pp. 117-119. 1940.

Ulberg, L.C. - The influence of high temperature on reproduction. J. Hered., XLIX,pp.62-64. 1958.

Uvarov, B.P. - Insects and climate. Trans. Ent. Soc. London, 79, pp. 1-247. 1931.

Vogt, H. and Amelung, W. - Einführung in die Balneologie und Medizinische Klimatologie. Springer, Berlin-Gottingen, 1952.

Webb, H.M. and Brown, F.A. Jr. - Timing long-cycle physiological rhythms. Physiol. Rev., 39, pp. 127-161. 1959.

Weihe, W.H. (Ed.) - The physiological effects of high altitude. Pergamon Press, London,1963.

Wellington, W.G. - The synoptic approach to studies of insects and climate. Ann. Rev. Entomol., 2, pp. 143-162. 1957.

Wigglesworth, V.B. - The principles of insect physiology. Methuen, London, 1950.

Wilber, C.G. - Physiological regulations and the origin of human types. Human Biol., 29, pp. 329-336. 1957.

Williams, R.J. - Biochemical individuality. The basis of the genetotropic concept. Wiley, N.Y., 1956.

Williams, R.J. - Normal young men. Perspectives in Biol. and Med., 1, pp. 97-104. 1957.

Williams, R.J. - Chemical anthropology - an open door. Amer. Sci., 46, pp. 1-23. 1958.

Winsor, T. and Beckett, J.C. - Biological effects of ionized air in man. Amer. J. Phys. Med., 37, pp. 83-89. 1958.

Worden, J.L. - Proliferation of mammalian cells in ion-controlled environments. J. Nat. Cancer Inst., 26, pp. 801-811. 1961.

Worstell, D.M. and Brody, S. - Comparative physiological reactions of European and Indian cattle to changing temperature. Res. Bull. Mo. Agric. Expt. Sta. No. 515. 1953.

Yeck, R.G. and Stewart, R.E. - A ten year summary of the psychroenergetic laboratory dairy cattle research at the University of Missouri. Transactions of the American Society of Agricultural Engineers, Saint Joseph, Michigan, 2, pp. 71-77. 1959.

Yoshimura, H. - Seasonal changes in human body fluids. Jap. J. Physiol., 8, pp. 165-179. 1958.

Yoshimura, H. - Essential problems in climatic physiology (Edited by H. Yoshimura et al.), Nankodo, Kyoto, pp. 61-106. 1960.

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