0014-4754/93/090733-08$1.50 + 0.20

Multi-author Reviews

Human biometeorology, Part I

The Editors wish to thank Dr Gerd Jendritzky for coordinating this review.

The atmospheric environment – an introduction

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Abstract. The atmosphere is part of the environment with which the human organism is permanently confronted. Epidemiological research investigates the occurrence of effects on morbidity and mortality due to heat, cold, air pollution and changes in the weather. Concentrating on aspects of the environment relevant for medical questions, three major complexes of effects can be discriminated: the complex conditions of heat exchange, the direct biological effects of solar radiation, and air pollution. Biometeorological knowledge can serve to assess the atmospheric environment, and can also be of help in the field of preventive planning, to conserve and develop the climate as a natural resource with regard to man's health, well-being and performance.
Key words. Human biometeorology; complexes of effects; environmentally applied medical sciences; preventive planning; bioclimatic impact; bioclimatic assessment; medical meteorology.

Introduction

Atmosphere is part of the environment with which the human organism is perpetually faced in maintaining the balance of its life's functions[76]. Reactions of the organism can be comprehended as an answer to changes in the physical and chemical state of the atmosphere[66].
Meteorological information on its own has not yet acquired a biological-medical meaning. Regarding the effects of the atmospheric conditions on man's health, well-being, and performance it is necessary to transform the 'primary' information so that it becomes biologically relevant[37]. It is not only air temperature that is important for the human heat budget, but the complex conditions of heat exchange, which can only be completely described if information about wind, humidity and short- and long-wave radiation fluxes is simultaneously available. It is not generally solar radiation but a certain spectral wave-length (here: UV-B) that is responsible for the buildup of erythema. It is not the total dust, but a certain size fraction, that goes down into the lungs, and among these particles, only those of certain origins possess a carcinogenic potency. The biological relevance determines whether a meteorological parameter will become a biometeorological one.
Apart from direct effects of atmospheric conditions on man's health and well-being there are numerous indirect effects[83]. The influence of food production on nutrition, the availability of drinking water, occurrence of communicable diseases and vector-borne diseases, floods connected with hurricanes and similar catastrophes have to be mentioned. But these indirect factors are not objects of study in human biometeorology in a strict sense and, consequently, they are not dealt with in the following discussion.
Human biometeorology is part of environmental meteorology[38]. It covers a series of questions relevant to environmentally applied medical science. In investigating complexes of effects it uses almost the same epidemiological methodology to ascertain damaging potentials, to give information about limits of exposures which may affect human health, to discover the relationship between atmospheric conditions, diseases, and indisposition, and to define the importance of atmospheric environmental factors for the transition between health and disease[19]. Complexity is inherent in research into these effects. There are many confounding variables such as smoking, socioeconomic factors, individual health behaviour, living conditions, etc., which are often dominant. In epidemiological studies individual risks are often found to be higher than environmental risks. Thus negative results cannot be taken as a proof of the absence of a relationship between health and environment[78]. Basically, there is a lack of detailed individual morbidity and mortality data.

In the field of thermoregulation, UV-effects, and the effects of oxygen decrease with increasing altitude above sea-level, at least the physiological – to be precise, the pathophysiological – effects are basically known[10,24,26,27,41,45,84]. Nevertheless, the epidemiological results are still often contradictory, partly because of a certain misunderstanding of the effects of acclimatization. The fact that epidemiological results are only 'means' for a certain group, and are not valid for the individual, points to the insoluble dilemma between generalization and individuality.

Research in human biometeorology has the task of finding out which clinical manifestations and other disturbances in human well-being are influenced by atmospheric environmental factors, and precisely which factors exert an influence on health and well-being, and to what extent[36]. Positive effects (eu-stress) have to be examined systematically in view of their therapeutic relevance for relief or cure on the basis of climatotherapy, or for convalescence. (See Schuh in Part II.)

With regard to risk factors, biometeorology has to inform and advise the public and the decision-makers in politics and administration with the aim of recognizing and averting health risks at an early stage, in the framework of preventive planning, for example by making recommendations for ambient quality standards, by evaluating site decisions, and by consultation on adapted behaviour.

Definitions

The atmospheric environment of the human being is referred to as 'weather' or 'climate'. 'Weather' means the current physical condition of the atmosphere, defined by the classical meteorological elements air pressure, air temperature, air humidity, cloudiness, precipitation, fog, etc. and their combinations. The typical period involved is between some hours and some days. The term 'climate' involves all of the meteorological conditions and processes during a relatively long but limited period. Climate is characterized by statistical figures (mean values, frequencies, duration, extreme values, threshold probabilities, etc.). Climate comes into existence within the climate system atmosphere-hydrosphere-cryosphere-land surfaces-biosphere, when mostly non-linear feed-back mechanisms of different intensity and with varying time-behaviour are combined. Climate is the long-term aspect of weather. The elements considered in climate are the same as in weather. According to the spatial scale, to which a varying measurement methodology belongs, a differentiation is made between 'macro climate' (100–10 000 km), e.g. the climate of Central Europe; 'meso climate' (1–100 km), e.g. the climate of the Upper Rhine fault; 'local climate' (100 m–1 km), e.g. the climate of a district in a town, and finally 'micro climate' (1 cm–100 m), e.g. the climate in a street canyon or beneath a tree in a park.

Climate is an inherent part of the environment. Therefore it is part of the basis for the existence of life, and its conservation and development is an important public responsibility[65].

Climatological factors

Natural climatological factors

The climate of a place or an area is characterized by natural and anthropogenic climatological factors. One of the natural factors is the latitude, on which sun altitude and consequently radiation intensity depend[64]. But climate is also affected by soil type, soil cover, and surface structure, since heat exchange is determined by their physical properties, such as specific heat, heat conductivity, albedo (reflecting ability), and soil roughness. Consequently, the distance from the sea (maritimity/continentality) plays a role because of the varying heat behaviour. Climate elements generally change with increasing altitude above sea level and orography (surface inclination and surface form, exposure) leads to the development of local peculiarities.

Anthropogenic climatological factors

Anthropogenically caused changes in land use generally lead to a change in climate, too. The changes in the physical attributes of the soil that go hand in hand with settlement, for example, have their effect on the energy budget of the atmospheric boundary layer[6,23,47]. The same occurs for the emissions of heat and air pollutants from domestic fuel, commercial enterprises, industry, power stations, and traffic. Clearance and reforestation, irrigation, drainage and cultivation, plus the expanse of water in an area also influence climate through effects on wind field, energy budget, and water budget.

Fundamental observations

The human organism is perpetually forced to come to terms with the atmosphere to remain in good health. Healthy persons can adapt to different atmospheric conditions to an extraordinary degree. How else would it be possible for human beings to live – though not always comfortably – in such extreme climates as scorching deserts, hot and humid tropics, icy cold polar regions or the high altitudes of the Andes[69]. Even the zones with temperate climates require some adaptions[74], but a healthy organism will accomplish this by means of autonomic regulation, which mostly goes unnoticed. The adaptability of sensitive, elderly and sick persons, pregnant women, and children is, however, more easily overtaxed. Particularly cardiovascular diseases and diseases of the respiratory tract may be triggered or aggravated, depending on the individual predisposition[13,70,80]. There are a lot of epidemiological studies on the impact which extreme conditions (heat, cold, air pollution, but also changes in the weather) have on morbidity and

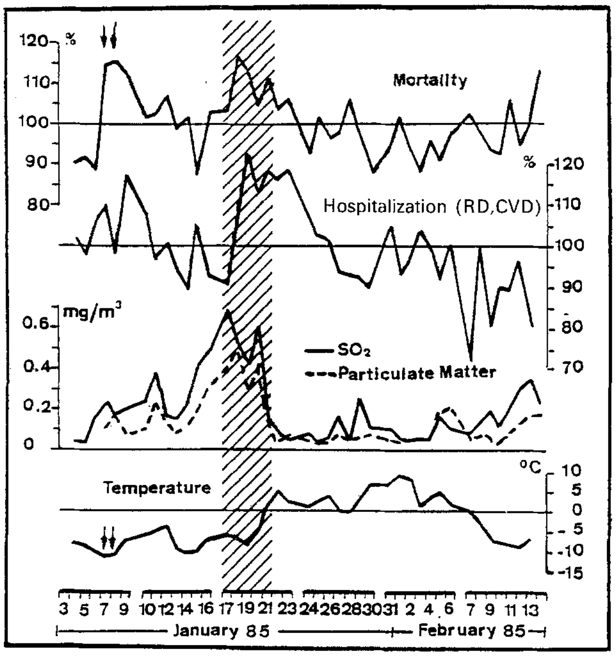

Figure 1. Daily mortality rate and hospitalization (for respiratory, RD, and cardiovascular, CVD, diseases). Data for SO_2, particulate matter, and air temperature are 24 h means. Arrows, two extremely cold days; hatched area, smog event[77].

mortality. In 1987, during a heat wave in the eastern part of the Mediterranean area, with air temperatures over 45°C, the mortality rate increased by 2,000 in Greece alone[44]. Most of the systematic studies on this topic have been carried out in the USA[42], and recently also in Canada[43] (see Kalkstein and Smoyer in Part II of this Multi-author Review).

The seasonal variation in mortality generally tends to show a maximum in winter and a minimum in summer[63] which indicates that cold conditions might be a stress to the organism[59,62].

A good example for an air pollution effect is the smog event in the Ruhr area in Germany in 1985[77] (fig. 1). The changes in the parameters 'mortality rate' and 'hospitalization due to respiratory and cardio-vascular diseases' follow the increase of the air pollution with a short time-lag. But surprisingly, the highest value in mortality occurs near the start of the time-series. It is associated with the very low air temperature of −15°C, which is a further hint that the atmospheric conditions of heat exchange play an important role in the health[2], well-being, and physical performance of a human being. The application of a complete heat budget model of the human to cerebrovascular mortality data in southwest Germany demonstrates that cold stress as well as heat-load are obviously stressors[7] (fig. 2). Similar results have been published recently[18] as a 'postulated generalized relationship' between myocardial infarct death and thermal stress, though using air temperature only instead of an adequate heat budget model of the human being. Persons from risk groups with limited adaptive capacity are not able to resist such stress factors.

Meteorotropy

It has become difficult to maintain a satisfactory overview of the many statistical correlation studies dealing with the influence of weather on topics including subjective feelings[17,54], morbidity and mortality (infectious diseases, neurological and psychiatric diseases[55,56], spastic manifestations (colics), cardiovasular diseases[8,11,49,67], respiratory tract diseases[15,21,68], rheumatism[48]), accident events[31] and physiological parameters[4] (e.g. clotting of the blood). The results of the epidemiological investigations are interpreted as meteorotropic effects connected with the term 'biotropy', which is the biological effect of the weather and its changes. Biotropy has to be considered as one of the numerous stressors which affect an organism, or cybernetically as a disturbing factor to which the organism has to react in order to maintain its equilibrium (homoeostasis).

To answer the question of causality it can be assumed that the single components of the three atmospheric complexes of effects listed in figure 3 (see next page) summarize the medically relevant elements completely (but see also Reiter reference 60 and in this issue). Medical-meteorological weather classifications[8] have proved suitable for studies of the coincidences between meteorological conditions and medical data. These classifications have the advantage of being especially suitable for the application of standard statistical methods, and are useful because they can clearly show the characteristic time-sequences of the above mentioned meteorological variables in a medically relevant manner. However, they merely present a suitable indicator. The weather situation 'Föhn' only describes the (biotropic)

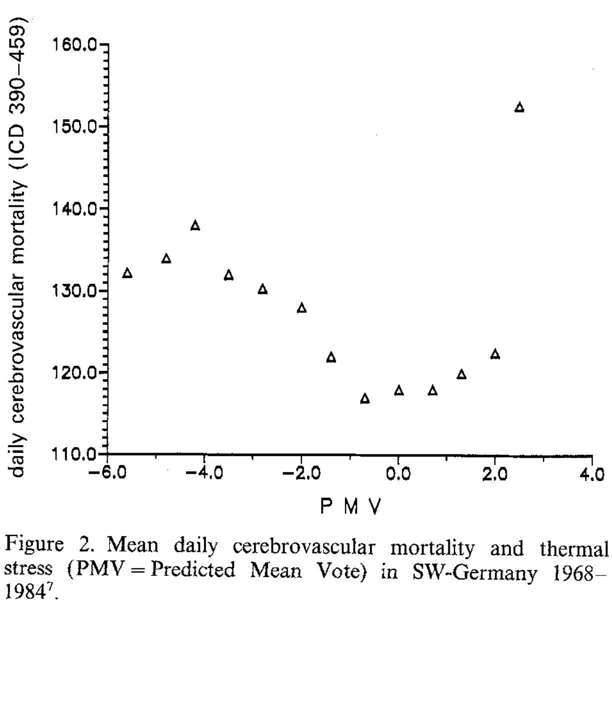

Figure 2. Mean daily cerebrovascular mortality and thermal stress (PMV = Predicted Mean Vote) in SW-Germany 1968–1984[7].

change in the weather and the corresponding changes in the atmosphere.

Meteorotropic reactions are adaptive reactions[76] to a changing atmospheric environment on any time scale (from seconds to years). In the temperate climate of Central Europe, meteorological disturbances are relatively small compared to the extreme heat waves and the onset of cold spells which occur, for example, in North America, and their effects therefore are often overshadowed by those of competing ecological factors. The cause-effect-relations[38] are accordingly difficult to describe explicitly, particularly since the variation of meteorological elements is often more significant in terms of diurnal changes, e.g. under high pressure weather conditions, than in terms of weather changes. It is possible that the deviation from a periodic diurnal course caused by the weather situation represents the stressor for the organism. Such a deviation may derive, for example, from the duration of daylight, the illumination intensity or the thermal sphere.

Doubts have been expressed about the medical relevance of the results, but the order of the statistically significant variance shows that biotropy plays a role as a risk factor[25,32,39]. The problem is discussed in detail by Bucher and Haase in this issue.

Complexes of effects

Health-related effects of the atmosphere never originate from an isolated meteorological element, but the atmosphere always works as a whole[37,38]. Nevertheless we are able to distinguish three main areas: the complex conditions of heat exchange of the human being in order to maintain thermal equilibrium, the radiation of the sun in the UV and visible ranges, and air pollution (fig. 3).

In the actinic complex of effects, direct biological effects of solar radiation in the visible and UV wave lengths are discussed, which reach beyond the pure heat effect (Table 1). To this chapter belongs the influence of solar radiation, for example on the endocrine system[28], the significance of the change between light and dark[58] as a zeitgeber[46,61,79], and the effects of the two UV components which reach the lower levels of the atmosphere where they can affect the skin, according to its pigmentation (erythema, vitamin D synthesis, skin cancer, etc). UV radiation is discussed in detail by Ambach and Blumthaler[3] in this issue.

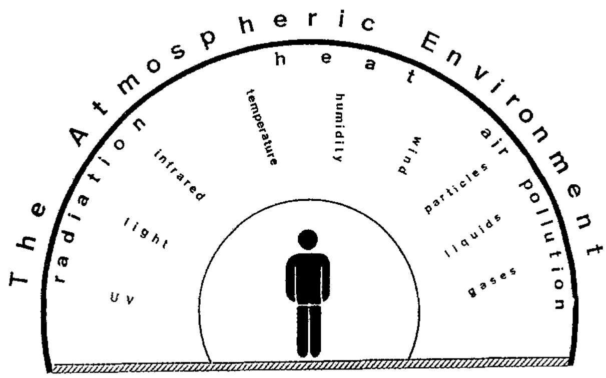

Figure 3. The atmospheric environment.

Table 1. Health effects of solar radiation

UV-C (100–280 nm)	bactericidal effect cell destruction erythema
UV-B (280–315 nm)	erythema reaction secondary pigmentation 'light callus' ageing of the skin antirachitic effect bactericidal effect skin cancer cataract keratitis immune response
UV-A (315–400 nm)	immediate pigmentation psoriasis treatment
Visible light (380–780 nm	light effect through the eye effect on hypothalamus zeitgeber effect heat effect
Infrared	heat effect erythema reducing effect

Although the investigation of air quality has developed into an independent discipline, the air-pollution complex of effects represents a 'classical' topic of human biometeorology as well. The air contains solid, liquid, and gaseous natural and anthropogenic air constituents that show effects on the health of human beings (for a more detailed discussion see Wanner in this issue, and also Leuschner, Puls and Bock, and Lecheler in Part II). In contrast to the other biometeorological complexes of effects, the importance of effects detrimental to health is widely acknowledged. Therefore many countries undertake enormous efforts to reduce air pollution.

A central role in human biometeorology is performed by the thermal complex of effects[1]. The human organism is in a permanent state of confrontation with the thermal environment[27], and must keep heat production and heat loss in an equilibrium in order to keep the body core temperature at a constant level[41].

The factors influencing body temperature are the meteorological variables air temperature, humidity, wind velocity, and short- and long-wave radiation fluxes, and, additionally, metabolic rate and the insulating properties of clothing. The complex conditions of heat exchange between humans and their environment require a complete computation of man's energy balance[35] (fig. 4) (see Höppe in this issue). This is nothing but the application of the first law of thermodynamics. The approach was found to be extraordinarily successful in the assessment of human bioclimate, because only a

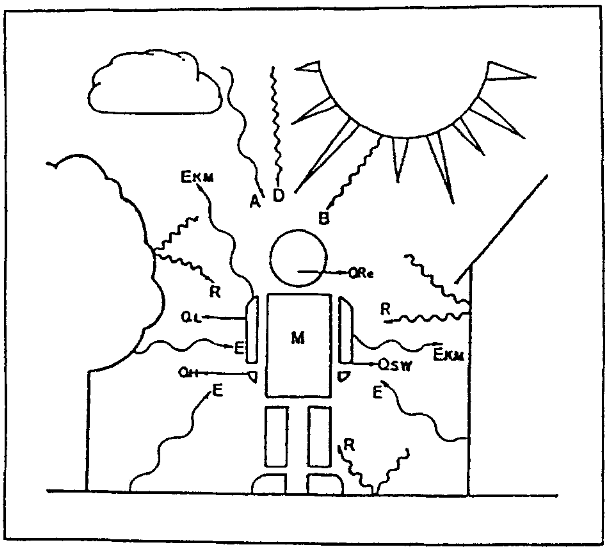

Figure 4. The thermal environment. M, metabolic rate; Q_H, turbulent flux of sensible heat; Q_{SW}, turblent flux of latent heat (sweat evaporation); Q_L, turbulent flux of latent heat (diffusion of water vapour); Q_{Re}, respiratory heat flux (sensible and latent). Components of radiation budget Q*: I, direct solar radiation; D, diffuse solar radiation; R, reflected radiation (shortwave); A, thermal radiation of the atmosphere; E, thermal radiation of surrounding surfaces; E_{KM}, thermal radiation of the human body.

procedure that considers all mechanisms of heat exchange can be universally valid.

Some models of this kind already exist; those of Fanger[14], for example, can be taken as representatives of the state-of-the-art. The 'Klima-Michel' model of the Deutscher Wetterdienst (the National Meteorological Service in Germany) consists of Fanger's comfort equation plus a radiation model[34,35,72]. It can be used as a valuable tool in bioclimate assessments. The simple thermal indices of former times, such as discomfort index, effective temperature, equivalent temperature, wet bulb globe temperature and wind chill index, should no longer be used in human biometeorology because of their obvious thermophysiological insufficiency.

Apart from natural and anthropogenic air constituents, and short- and long-wave radiation fluxes, the biometeorological complexes of effects are not emissions. They are, rather, characteristic for the state of the atmosphere. Generally, the single elements do not work in isolation but like notes in a chord. In urban and industrial conurbations[9] cold stress and air pollution often occur at the same time[15]. In summer high pressure weather conditions, heat load, UV radiation, and high levels of air pollution by photooxidants are observed. As a consequence of frequent changes in the weather (air mass changes) all values for biometeorological elements change, too.

The characteristics of the atmosphere relevant to environmental medicine[38,50,69] can be summarized under the following headings: 1) heat, 2) cold, 3) decreased oxygen partial pressure, 4) air loaded with solid, liquid, and gaseous pollutants, 5) too high or too low light intensity, 6) too high or too low UV radiation intensity, 7) changes in the weather (biotropy), and 8) changes in the climate. Frequently, the effects of stress caused by atmospheric conditions are mastered by reasonable behaviour[78], such as appropriate clothing in the thermal sphere, avoidance of exposure to solar radiation, restriction on physical activity when ozone values have reached peak values, or well-directed acclimatization (for example climatotherapy, discussed by Schuh and Lecheler in Part II).

Biometeorological assessments

The multitude of variables involved makes it clear that usually no mono-factorial cause-effect relationship can be expected between the atmospheric environment and human health. Consequently, the biological response to the effect of different parameters may range from perfect health to inconvenience, impairment, subclinical alterations and even clinically manifest damage and an increased mortality rate[78]. The basic difficulties encountered in establishing standard values for biological parameters predetermine the problems of establishing critical values and standards.

Many attempts have been made to describe the characteristics of a climate with regard to health, well-being, and human performance[35,69] using benign, stimulating and stress factors. As differences occur associated with weather and seasons, and as usually not all determinating factors belong to the same category, and, finally, as the initial situation of the oganism determines whether the current meteorological conditions will be stressful, benign or stimulating, no climate can be considered to be the benign or the stimulating climate in every detail.

The natural and anthropogenic climatological factors that were discussed above dominate the spatial development of bioclimate. For bioclimatological outline maps on a small scale, of a country, or even of a continent, the influence of different land-use is generally not important for the presentation of the spatial distribution of the single bioclimates. Thus a digital terrain model provides all the necessary information for the calculation of bioclimatic maps from meteorological measurements and observation data. For the thermal complex of effects maps have been designed e.g. for Germany (1:1,5 Mio.) and for Europe (1:5 Mio). For bioclimatic maps on a larger scale, land-use has to be taken into account in an appropriate form, according to the formulation of the question. As soon as the digital terrain model has been extended with simple land-use types, such as open field, forest, water, dense settlement, and dispersed settlement, bioclimate maps can be developed up to a scale of 1:50,000 for various planning purposes.

In a pre-set mesoclimate the conditions of heat loss of the human being are determined by the specific character of different land-use structures (within settlements building-complex structures are taken into account), by exchange effects with the corresponding neighbourhood and by topography (local climate) on a micro-scale[52,53]. When it comes down to urban planning[20,71], the biometeorological conditions near the ground, in the living-space of the human being, i.e. the urban 'canopy-layer', are of specific interest[33,34]. To study this problem the urban bioclimate model UBIKLIM[40] has been developed on the basis of a geographic information system (GIS), on a scale of 10 m grid distances. It serves for the production of bioclimate maps on a micro-scale for urban planning, which also shows the effects of planning alternatives for the thermal environment of humans (see Mayer in Part II). Thus biometeorology has already made suitable tools available for the spatial evalutation of thermal conditions.

Climate change

Model calculations that simulate the influence of the increase of greenhouse gases on the climate[12,30] predict the following for the year 2030:

- the global mean air temperature will increase by 3 °C ± 1.5 °C
- in the upper latitudes of the northern hemisphere it will increase up to 10 °C
- increase of the sea-level by 0.10–0.32 m
- extreme events such as heat waves, droughts etc. will increase and will probably be of greater importance than the increase of mean temperature
- increase of the variability of climate
- increase of UV-B radiation of 20% to 25% due to stratospheric ozone depletion.

The effects on human health cannot yet be predicted in detail, especially as the models cannot offer a satisfactory regionalization[29,51]. Most of the effects might be in the sphere of indirect effects[82]. The increase of tropospheric ozone in the northern hemisphere is expected to slightly overcompensate the stratospheric ozone depletion with respect to UV-radiation in summer[5]. The problem of heat waves is discussed in detail by Kalkstein and Smoyer in Part II. A joint publication of the World Health Organization, WHO, and the World Meteorological Organization, WMO, with the title 'The Impact of Climate on Human Health and Implications of Climate Change' is in preparation for 1994.

Conclusion

Biometeorology is an exciting interdisciplinary field with practical consequences. Events such as the WMO, WHO, UNEP-Symposium on 'Climate and Human Health' in Leningrad (St. Petersburg) in 1986 have promoted this discipline[36,81]. More than a hundred experts from 28 countries in disciplines such as climatology, public health, medical sciences, epidemiology, environmental planning and adjacent subjects took part. The main topics are summarized in Table 2. Furthermore, there is a common consensus that biometeorologists should concern themselves more intensely with the problems of 'third world' countries. There, simple survival is the dominant problem, rather than quality of life, which is rather a concern of industrialized nations. The main problems in tropical countries are the environmental conditions in rapidly growing and unsupervised agglomerations. This topic will be discussed by Jauregui in the second part of this Multi-author Review.

Table 2. Climate and Human Health: main topics for research (WMO, WHO, UNEP-Symposium 1986[81])

- bioclimatic assessments using heat balance models (comfort, discomfort, adaptive behaviour) in all scales
- impact of different climates on diseases, morbidity and mortality using epidemiological data banks
- impact of air pollution on climate with regard to human health
- aspects of comfort and health in housing, urban and regional planning
- climatotherapy
- impact of climate changes on health, well-being, and socioeconomic conditions

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