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PERSONAL PERSPECTIVES

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Aspects of human biometeorology in past, present and future

Abstract Human biometeorology is quite an old science: during the times of Hippokrates in ancient Greece the influence of weather changes on physiological processes in the human body were considered to exist. However, not until the progress in modern statistics, physics and physiology in the course of this century provided quantitative methods did human-biometeorology become an acknowledged natural science. In the first half of this century primarily the explanation of the phenomena of reactions of the body to weather changes was the general objective. In the second half of this century quantitative descriptions of thermal interchanges between the human body and the environment by means of energy balance models of the human body have gained increasing importance. The methods of modern human biometeorology increasingly are acknowledged by workers in disciplines of potential application, such as urban or regional planners or air conditioning engineers. Human biometeorology tries to assess all atmospheric influences in its entirety, including the air pollution pattern. The discipline considers itself as branch of science which is tied closely to environmental meteorology and environmental medicine.

Introduction

Human biometeorology is the science of the influences of the atmospheric environment on man. These influences may be thermal, hygric, actinic or electrical, but also caused by the composition of the ambient air (air hygienic). Human biometeorology, often synonymously called medical meteorology, considers itself a subdiscipline of meteorology and hence physics. Contrary to many other subdisciplines of meteorology, e.g. micrometeorology or synoptics, an interdisciplinary collaboration with scientists from other fields such as biology and medicine is essential in human biometeorology, especially when effects within the human body are looked at more closely. In Fig. 1 is given a traditional scheme of the assignment of human biometeorology. Due to lack of space only a few of the many subdisciplines of meteorology are given as an example.

In a short statement on the nature of human-biometeorology, Faust (1987) certainly speaks on behalf of many biometeorologists. Faust considers human biometeorology as being both a frustrating and a fascinating science. "Frustrating, because despite modern meteorological tools and powerful computing facilities the diversity of the effective parameters clearly show the limits of the things that can be achieved. Frustrating, also, because in the necessary correlation calculations the methodological problem turns up how to determine with the aid of two only approximately known quantities (atmospheric events and human organism) a third quantity (influence of the weather on man). Fascinating, however, because it has been an interdisciplinary field of interest for thousands of years, which brings together a multitude of diverging branches under a common roof …". I believe that the complexity and also the special appeal of human biometeorology cannot be described any better.

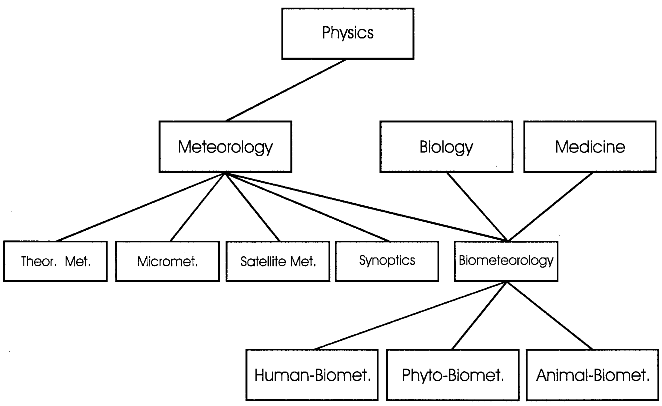

Fig. 1 Scheme showing traditional assignment of human biometeorology of other scientific fields

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The early ages of human biometeorology

Human biometeorology is a very old science. As early as 400 BC, Hippokrates in his book ‘Air, water, sites’ warned physicians of possible complications in medical surgery during weather changes. In ancient times it was common practice with Romans and Greeks to ask the weather gods prior to political decisions and war operations. These examples show that for a very long time since, an influence of the atmospheric conditions on man has been considered to exist.

In 1803 Knogler published his book ‘Meteorologie’, in which he puts the main emphasis on the investigation of the influence of weather on human health. Also Alexander v. Humboldt (1827) gives his definition of ‘climate’ as “… all changes in the atmosphere, which affect our senses …” Already in 1876, Max v. Pettenkofer discussed in a class held in Dresden ‘On the relation of air to the clothed body’ aspects of the heat balance of the human body in enclosed spaces. This early work still reflects the state of the art in human biometeorology as, for example, “The heat loss due to radiation can be quite substantial under certain conditions, and usually amounts to 50 percent of the total heat loss …”

Developments in the 20th century

From the thirties to the sixties of our century classical medical meteorology flourished, with phenomenona such as ‘Wetterfühligkeit’ (weather sensitivity) and meteorotropic illnesses being examined. This ‘classical’ medical meteorology was practised mainly in german-speaking countries. Outstanding authors in this field of human biometeorology were Sauberer (1948), de Rudder (1952), Ungeheuer (1955), Donle (1956), Flach (1957), Assmann (1963), Faust (1977) and Tromp (1980). Since no single meteorological parameter could be determined as the causal factor for the triggering of symptoms of Wetterfühligkeit, weather-type-schemes were defined, e.g. the ‘Tölzer Wetterklassenschema’ or the ‘Hamburger Dezimalklassifikation’. It was recognized that for certain weather conditions a typical pattern of symptoms of Wetterfühligkeit occurred. Hence using statistical methods correlations between the weather conditions and a reduced state of health up to the triggering or strengthening of illnesses could be validated. This kind of thinking still is the basis for the daily biometeorological weather forecasts, which play an increasingly important role in the media, at least in Europe. The difference to the traditional schemes of weather types is that the modern classifications are more objective (i.e. calculated from weather data by a computer) and more diversified.

In 1938 Büttner took up again the energetic approach of interactions between the human body and the environment. Thus is postulated in the chapter on ‘Fundamentals of the heat balance of the human body’: “If one wants to explain the effects of the climate on the human body, it is always necessary to determine the effects of not just one, but of all the components of the heat exchange – so we come to the need to set up an energy balance equation”. This statement, which is still valid today, pronounced the need for the development of energy balance models on the human body. However, their development and implementation was suspended until modern computing facilities were available. From around the early sixties, the remark of Kant relating to human biometeorology is more and more acknowledged, viz. “As much truth is in science as there is mathematics in it”. This is evident in the usage of mathematical methods for epidemiology (statistics) as well as models of interactions between the human body and the environment (physics). Up until the present day more and more pieces have been set into the energy balance puzzle. Part of this information concerns the meteorological input data as, for example, for the field of radiation given in the outstanding book ‘Das Strahlungsfeld im Lebensraum’ by Dirmhirn (1964). On the other hand also physiological processes such as heat transport from the body core to body shell (Gagge and Stolwijk 1971) or the onset and amout of sweating have to be parameterized (e.g. Sargent 1962; Wyndham et al. 1965).

In the seventies and eighties the development and usage of energy balance models of the human body and a multitude of derived indices for thermal stress and strain came within the focus of human biometeorology. One of the most prominent initiators of this trend was Fanger (1970), who with his book ‘Thermal comfort’ for the first time described a practical, easily programmable heat balance model of the human body. The comfort index PMV (predicted mean vote), calculated from Fanger’s comfort equation, became the most internationally widespread biometeorological index for description of the predicted mean thermal perception. Fanger’s model initially was confined to indoor conditions. By parameterization of the complex radiation fluxes outdoors by Jendritzky et al. (1979), Fanger’s comfort equation became a universally acceptable model, and under the name of ‘Klima-Michel-Modell’ is used today not only in German-speaking countries but also internationally. One example for results derived from the model (Fig. 2) makes clear that by characterizing thermal strain by the PMV-index for instance the relation between climatic conditions and daily mortality rate may be readily demonstrated.

Besides the models based on Fanger’s comfort equation and calculating a comfort index, many other energy balance models of the human body were developed (e.g. Baumgartner 1982; Höppe 1993). These in addition provide quantitative data on the individual heat fluxes, body temperatures, sweating rates and skin wettedness with dependence on the ambient conditions. In Fig. 3, quantitative assertions are shown on the typical indoor heat fluxes, as calculated by MEMI (**M**unich **E**nergy-balance **M**odel for **I**ndividuals; Höppe 1984).

For the evaluation of thermal effects at rapidly changing climatic conditions or activities leading to increasing

Fig. 2 Mean daily mortality rate (and 95% confidence interval) as dependence of thermal strain (predicted mean vote, PMV) in Southwest Germany (1968–1992) after Bucher (1992)

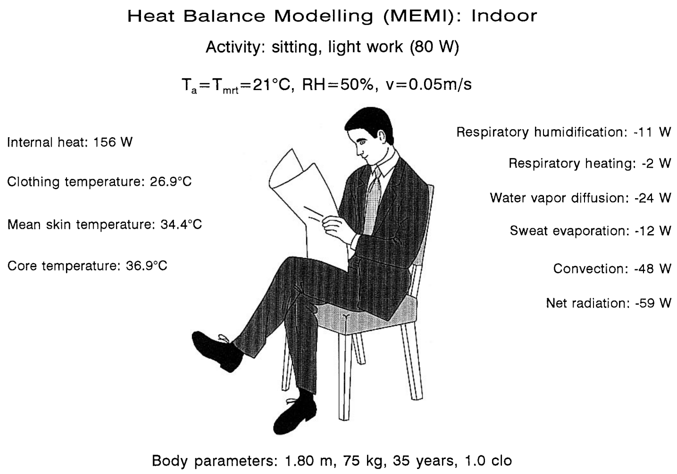

Fig. 3 Heat fluxes from the human body in indoor climate, calculated by the **M**unich **E**nergy-balance **M**odel for **I**ndividuals (MEMI; Höppe 1984)

or decreasing body temperature and hence variable heat fluxes, dynamic heat balance models were developed. Examples for these kinds of models are the two-node model of Gagge and Stolwijk (1971) or the **I**nstationary **M**unich **E**nergy-balance **M**odel (IMEM; Höppe 1989). They e.g. allow predictions of how long it takes until critical values of thermophysiological end-points like core temperature, mean skin temperature or sweating rate are reached under conditions of heat stress. An example for a calculation with the model IMEM is given in Fig. 4.

Current trends in human biometeorology

Human biometeorological research today is still done along the classical lines. Part of this forms, for instance, the refinement and expansion of prediction models for

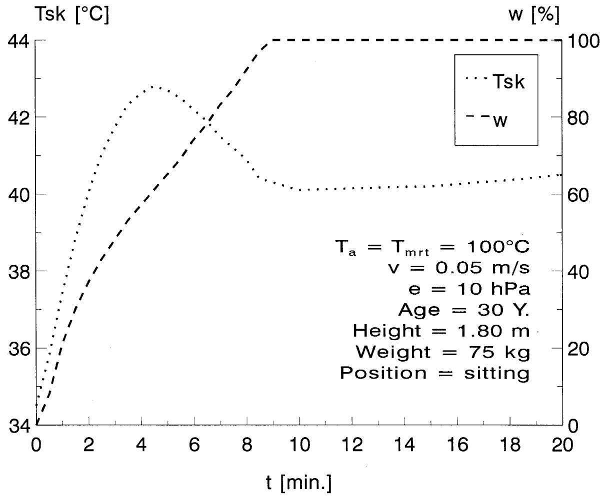

Fig. 4 Temporal course of mean skin temperature T_{sk} and skin wettedness *w* after entry into a sauna bath (calculation on the basis of **I**nstationary **M**unich **E**nergy-balance **M**odel (IMEM; Höppe 1993) (T_a = air temperature, T_{mrt} = mean radiation temperature, *v* = air velocity, *e* = water vaporpressure)

meteorotropic illnesses as an addition to the usual weather forecasts, which are developed primarily by the weather services and agencies. A very new trend is that also in North America where this aspect of human biometeorology was more smiled at than taken seriously some years ago, phenomenona of Wetterfühligkeit are investigated by several research groups. This was documented quite clearly at the 13th International Congress of Biometeorology in 1993 in Calgary by several papers from North America, e.g. on Foehn (Chinook) effects (Verhoef et al. 1993; Rose et al. 1995) or the weather pattern and periodicities and affective states in humans (Maes et al. 1993).

For evaluation of the thermal effects outdoors as well as indoors, today almost exclusively bioclimatic indices derived from heat balance models are used. Increasingly also spatial plots of thermal indices are produced, such as bioclimate maps with the frequency of exceeding or falling short of certain PMV values (e.g. Jendritzky et al. 1990). These maps now do exist on different scales – for neighbourhoods, single townships, regions, countries, Europe and even as a world map (Jendritzky, in preparation for publication).

As the most important mediator between ambient conditions and the human body, clothing has a very important function for thermal comfort. During the last few years a lot of studies have been done to investigate the effects of different types of clothing materials and ensembles on thermal perception and the thermal state of the body. Many of the studies are carried out in Japanese institutes (e.g. Li et al. 1995; Kawabata and Tokura 1993). Also the last few years, air pollution became an increasingly important topic in human-biometeorological research. To begin with, meteorological conditions influence the immission concentrations of pollutants, which can be quantified in environmental meteorology, e.g. in models calculating exchange processes and chemical reactions of air pollutants in the atmosphere. The hygienic condition of the air is one aspect of the urban or regional climate, and therefore its evaluation and assessment, as well as the thermal component of the climate, should be included in the decision making processes of planners and politicians.

Due to the expected changes in the radiation climate of the earth the 'actinic' part of the bioclimate becomes increasingly important in human biometeorology. Here especially the modelling of possible changes in UV-radiation due to stratospheric ozone depletion and the resulting effects on the human body are investigated in many studies (Ambach and Blumthaler 1993).

Supported by a trend in clinical medicine to get back to natural ways of curing diseases, in the last years the controlled use of favourable climatic conditions for the strenghening of the organism and the healing of illnesses (climatic cures in spa resorts) could be established. The scientific foundations for this, e.g. by Amelung and Evers (1962) are now expanded by means of human biometeorological studies (Schuh 1993). A recent review on the topic was given by Kevan (1993) at the Congress in Calgary.

Electro-bioclimatology as a research discipline has gained back some ground within human biometeorology in recent years. In the sixties Reiter (1960) documented correlations between atmospheric impulse radiation (atmospherics or sferics) and certain weather conditions; also currently possible effects of sferics on the human body are in the focus. As a second important electro-biometeorological factor small ions are discussed. Whether there are any effects on man at all is still discussed controversially by the scientists in the field (Reiter 1993; Baumer and Eichmeier 1981; Krueger 1985). In the case of sferics research, controlled exposures to sferics made artifically by generators will provide important information about possible causal relationships. A prototype of such a sferics generator already exists (Ruhenstroth-Bauer et al. 1994).

Weather and climate have effects on behaviour and the physiological state of humans. The investigation of these kinds of interchanges is quite a new field in modern human biometeorology. An example for a recent study in this field is the work done by Auliciems and DiBartolo (1995) on domestic violence and weather published recently in the IJB. A good overview about the state of the art in human biometeorology is given in two special issues of the journal 'Experientia' (vol 49: 9, 11; ed. G Jendritzky, 1993), in which all relevant actual lines of research are presented with review articles.

Increasingly the results of biometeorological research are taken into account in official guidelines and standards as well as in handbooks of other disciplines. Thus for example in Germany for the first time a guideline of the 'Verein Deutscher Ingenieure' (VDI, 1996) on the 'Human-biometeorological assessment of climate and air pollution for urban and regional planning' recommends the use of energy balance models of the human body,

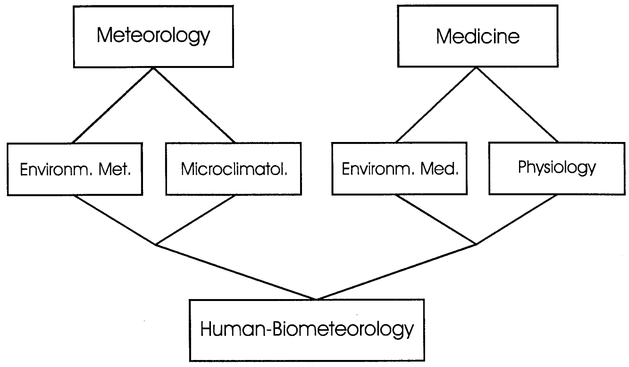

Fig. 5 Classification scheme of human biometeorology of the adjoining sciences from today's point of view

such as 'Klima-Michel', MEMI and IMEM for the evaluation of the thermal component of the bioclimate. In the 'Handbook of environmental medicine' (Wichmann et al. 1993) a chapter by G. Jendritzky is devoted to 'biometeorological parameters' as important factors in environmental medicine. This also shows how closely human biometeorology is linked to the recent fast-expanding field of environmental medicine (see also Fig. 5). An additional proof for the increasing acceptance of human-biometeorological methods is the fact that more and more in the course of planning procedures on the local and regional scale are potential biometeorological effects studied and enquired into (Mayer 1993).

A good representation of international focal research for the present and the near future may be found in the list of the Study Groups in the field of human biometeorology of the International Society of Biometeorology. The Study Groups were newly created in 1994 according to the developments of recent years:

- ☐ Urban climate and air quality
- ☐ Indoor climate and air quality
- ☐ Climate, morbidity, mortality
- ☐ Biological cycles and photoperiodicity
- ☐ Basic adaptation mechanisms
- ☐ Human adaptions to extreme environments
- ☐ Bioelectricity and biomagnetism
- ☐ Behavioral human biometeorology
- ☐ Applications and limitations of climate change scenarios
- ☐ Climate perception and decision making.

As a summation, I think it is not unrealistic to say that the role of human biometeorology will gain more importance worldwide on the verge of the new millenium. The global changes in the atmosphere, such as the greenhouse effect and stratospheric ozone depletion, will strengthen this trend further, since increasingly possible effects of these processes on humans come into focus. In Fig. 5, concludingly, a classification scheme is given of human biometeorology, similar to Fig. 1 but from a modern point of view; the modern scientific branches of environmental meteorology and environmental medicine are included as new disciplines.

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