CLIMATE, THERMAL COMFORT AND TOURISM

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ABSTRACT

Methods of human-biometeorology can be applied for the assessment of atmospheric impacts on human beings. The thermal effective complex is the most important factor for tourism among the human-biometeorological effective complexes. A procedure for the physiologically significant assessment of the thermal environment is presented. It is based on thermal indices, which are derived from the human energy balance. It is important to know the mean climatic conditions of the area of vacations and recreation for tourism climatology. As an exemplary result a bioclimate map of Greece for the summer month of August is presented which shows the pronounced spatial distribution of mean monthly values of the thermal index Physiological Equivalent Temperature (PET). Additionally, extreme conditions i.e. heat waves and its possible implications to human health were analyzed.

KEYWORDS: Tourism climate indices, thermal indices, PET, Freiburg, thermal stress

INTRODUCTION

Humans have been aware that weather and climate affect health and well being. Hippocrates, 2.500 years ago, wrote about regional differences of climate and their relationship to states of the health. Fevers vary seasonally and also mood and various psychological disturbances. Aches and pains in joints flare up in winter and summertime heat waves may debilitate and kill (WMO, 1999).

Travel to climate-stressed locations may also, result in health problems (e.g. caused by heat stress, UV-radiation, air pollution and heat strokes). Causes and effect impact relations between the atmospheric environment and human health or comfort can be analyzed by means of a human-biometeorological classification (Matzarakis and Mayer 1996, VDI, 1998) which takes into consideration:

- thermal complex (comprises the meteorological elements which have a thermophysiological effect on humans),
- air pollution complex (comprises the solid, liquid and gaseous natural and anthropogenic air pollutants which have an effect on human health) and
- actinic complex (comprises the visible and ultraviolet spectrum of solar radiation which has a direct biological effect).

In this paper, only the thermal complex is the subject of interest. It includes the meteorological factors air temperature, air humidity and wind velocity, and in addition short and long wave radiation, which affect thermo-physiologically humans in indoor and outdoor climates. This complex is relevant to human health because of a close relationship between the thermoregulatory mechanisms and the circulatory system.

The climatic indices, which are primary used for tourism climate assessments and thermal comfort studies, present a certain number of crucial points. From the point of view of human-biometeorology they do not include the effects of short and long wave radiation fluxes which are generally not available in climate records. The required, for the human erengy balance, short and long wave radiation fluxes are calculated using synoptic/climatological and astronomical data (VDI 1998, Matzarakis et al 2000). A full application of thermal indices of the energy balance of the human body gives detailed information on the effect of the thermal environment of humans (VDI, 1998). Common applications are PMV (Predicted Mean Vote), PET (Physiological Equivalent Temperature) (Matzarakis and Mayer 1997, VDI, 1998, Höppe, 1999, Matzarakis et al, 1999), SET* (Standard Effective Temperature) (Gagge et al., 1986) or Outdoor Standard Effective Temperature (Out_SET*) (Spangolo and de Dear, 2003) and Perceived Temperature (Tinz and Jendritzky, 2003). All this thermal indices are well documented and include important meteorological and thermo-physiological parameters (Matzarakis, 2001a, b). The advantage of these thermal indices is that they require the same meteorological input parameters: air temperature, air humidity, wind speed, short and long wave radiation fluxes. In Table 1, threshold values of the thermal indices Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET) are presented for different thermal perception levels and physiological stress on humans.

In order, to get answers about the interactions between tourism and the atmosphere methods of human-biometeorology can be applied. Applying methods from human-biometeorology the effects of atmospheric environment to humans can be accessed. The same methods can also be used in the construction of optimised and less climatic tourism resorts.

The objective of this article is twofold: (1) to give a brief overview of assessment methods and (2) to discuss some exemplary results.

HUMAN-BIOMETEOROLOGICAL ASSESSMENT METHODS

Thermal environment

Additional and detailed information is provided using climate indices (e.g. from applied climatology and human-biometeorology). In general, the tourism climate indices can be classified into three categories (Abegg, 1996): elementary, combined and bioclimatic indices. Elementary indices (a.e. summer index by Davies, 1968), are synthetic values without any thermo-physiological relevance. They are unproven in general. The bio-climatic and combined tourism climate indices are based on more climatological parameters, considering effects of parameter combination (Mieczkowski, 1985).

The thermal effective complex describes the influences of the thermal environment on the well-being and health of human beings. It is related to the close relationship between the human thermoregulatory mechanism and the human circulatory system. For the physiologically significant assessment of the thermal environment (Fig. 1), thermal indices are available derived from the human energy balance (Höppe, 1999, Matzarakis et al., 1999, Mayer and Matzarakis, 2003).

Since the 1960s, heat-balance models of the human body are more and more accepted in the assessment of thermal comfort. The basis for these models is the energy balance equation for the human body (1):

$$M+W+R+C+E_D+E_{Re}+E_{Sw}+S= 0 \qquad (1)$$

Where, M: the metabolic rate (internal energy production), W the physical work output, R the net radiation of the body, C the convective heat flow, E_D the latent heat flow to evaporate water diffusing through the skin (imperceptible perspiration), E_{Re} the sum of heat flows for heating and humidifying the inspired air, E_{Sw} the heat flow due to evaporation of sweat, and S the storage heat flow for heating or cooling the body mass. The individual terms in this equation have positive signs if they result in an energy gain for the body and negative signs in the case of an energy loss (M is always positive; W, E_D and E_{sw} are always negative). The unit of all heat flows is in Watt (Höppe, 1999).

The individual heat flows in Eq. 1, are controlled by the following meteorological parameters (VDI, 1998, Höppe, 1999):

- air temperature: C, E_{Re}
- air humidity: E_D, E_{Re}, E_{Sw}
- wind velocity: C, E_{Sw}
- radiant temperature: R

Thermo-physiological parameters are required in addition:

- heat resistance of clothing (clo units) and
- activity of humans (in W).

The human body does not have any selective sensors for the perception of individual climatic parameters, but can only register (by thermoreceptors) and make a thermoregulatory response to the temperature (and any changes) of the skin and blood flow passing the hypothalamus (Höppe, 1993, 1999). These temperatures, however, are influenced by the integrated effect of all climatic parameters, which are in some kind of interrelation, i.e. affect each other. In weather situations with less wind speed, for instance, the mean radiant temperature has roughly the same importance for the heat balance of the human body as the air temperature. At days with higher wind speeds, air temperature is more important than the mean radiant temperature because it dominates now the increased enhanced convective heat exchange. These interactions are only quantifiable in a realistic way by means of heat balance models (VDI, 1998, Höppe, 1999).

One of the first and still very popular heat-balance models is the comfort equation defined by Fanger (1972). Fanger introduced the thermal indices “Predicted Mean Vote” (PMV) and “Predicted Percentage Dissatisfied” (PPD), which were thought mainly to help air-conditioning engineers to create a thermally comfortable indoor climates. After the much more complex outdoor radiation conditions had been taken into account and assigned appropriate parameters by Jendritzky et al. (1979, 1990), this approach has increasingly been applied to outdoor conditions and is now also known as the “Klima Michel Model”. Since this model was designed only to estimate an integral index for the thermal component of climate and not to represent a realistic description of the thermal human body conditions, it is able to work without the consideration of fundamental thermo-physiological regulatory processes. For example, in Fanger’s approach the mean skin temperature and sweat rate are quantified as "comfort values", being only dependent on activity and not on climatic conditions (Höppe, 1999).

More universally applicable than these models, which are primarily designed for the calculation of a thermal index like PMV, are those which enable the user to predict "real values" of thermal quantities of the body, i.e. skin temperature, core temperature, sweat rate or skin wetness. For this purpose it is necessary to take into account all basic thermoregulatory processes, like the constriction or dilation of peripheral blood vessels and the physiological sweat rate (Höppe 1993, 1999). Such a thermophysiological heat-balance model is the Munich energy balance model for individuals" (MEMI) (Höppe 1984, 1993), which is the basis for the calculation of the physiological equivalent temperature, PET.

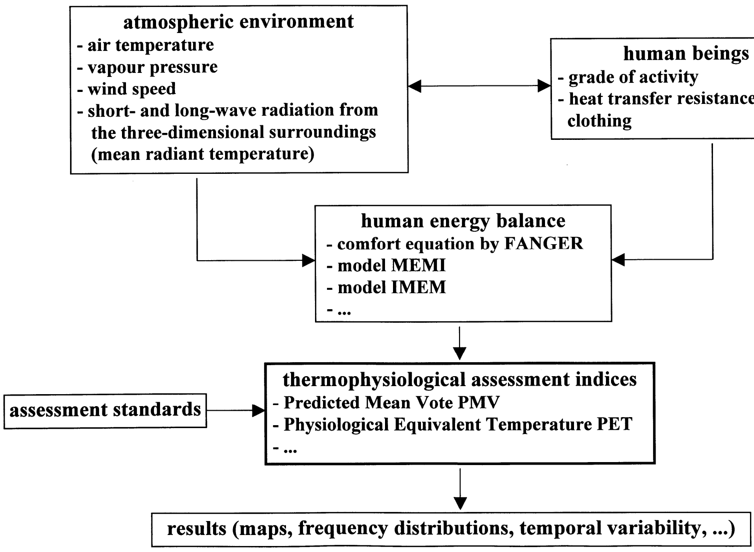

Figure 1: Flowchart of the human-biometeorological assessment of the thermal environment (Mayer and Matzarakis, 2003)

The heat-balance model MEMI is based on the energy-balance equation of the human body (Eq. 1) and some of the parameters of the Gagge two-node model (Gagge et al. 1971). In Eq. 1, some terms are dependent on the mean clothing surface temperature, the mean skin temperature or the sweat rate, all of which are affected by the ambient conditions – the physiological sweat rate (the basis for the calculation of E_{sw}) is also a function of the core temperature, which depends on both, ambient conditions and activity. Therefore, in order to solve Eq. 1, the three unknown quantities have to be evaluated first, i.e. the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c). For the quantification of these unknown quantities, two more equations are required to describe the heat flows from the body core to the skin surface and from the skin surface through the clothing layer to the clothing surface (Höppe, 1984, 1999).

Solving the human energy balance and under the inclusion of some thermo-physiological considerations (details in Höppe 1984) it is possible to estimate the resulting thermal state of the body for any given combination of climatic parameters, activity and type of clothing, characterized by the heat flows, body temperatures and sweat rate. MEMI therefore presents a basis for the thermo-physiologically relevant evaluation of the thermal component of the climate.

The most important differences to the Gagge two-node model are the procedures of calculating the physiological sweat rate (as a function of T_{sk} and T_c) and the separate calculation of heat flows from parts of the body surface, which are clothing covered or bare. For people not familiar with the fields of thermophysiology or biometeorology, the expected body temperatures or heat flows may not be very meaningful. This fact is certainly one of the reasons why Gagge et al. (1971) developed the new effective temperature (ET*), an index based on their two-node model. Using ET* the thermal effects of complex meteorological ambient conditions can be compared to the conditions in a standardized room with a mean radiant temperature not differing from the air temperature and a constant relative humidity of the air 50%.

Similar in the definition of ET* (Gagge et al., 1971), but based on the MEMI, the PET was introduced by Höppe and Mayer (Höppe and Mayer, 1987, Mayer and Höppe, 1987).

The characteristics of the methods for the determination of the human-biometeorological assessment of the thermal environment are illustrated in Figure 1.

Physiologically Equivalent Temperature

However, at the present, there are some more popular physiological thermal indices derived from the human energy balance (Höppe, 1993, Jendritzky and Tinz, 2003, Spagnolo and de Dear, 2003). One of these is the Physiological Equivalent Temperature (PET). PET is defined to be the physiological equivalent temperature at any given place (outdoors or indoors). It is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed (VDI, 1998, Höppe, 1999).

The following assumptions are made for the indoor reference climate:

- Mean radiant temperature equals air temperature (T_{mrt}=T_a).
- Air velocity (wind speed) is fixed at v = 0.1 m/s.
- Water vapour pressure is set to 12 hPa (approximately, equivalent to a relative humidity of 50% at T_a = 20°C).

The procedure for the calculation of PET contains the following steps:

- Calculation of the thermal conditions of the body with MEMI for a given combination of meteorological parameters.
- Insertion of the calculated values for mean skin temperature and core temperature into the model MEMI and solving the energy balance equation system for the air temperature T_a (with v =0.1 m/s, VP = 12 hPa and T_{mrt} = T_a).
- The resulting air temperature is equivalent to PET.

Compared to other thermal indices, which are likewise obtained from the human energy balance, e.g., the predicted mean vote PMV, PET offers the advantage of a widely known unit (degrees Celsius), which makes results more comprehensible to regional or tourism planners, who may be not so familiar with the modern human-biometeorological terminology (Matzarakis et al., 1999).

Similar to the frequently used PMV index (Fanger, 1972, Jendritzky et al., 1990), PET is one universal index to characterise the thermal bioclimate. It allows the evaluation of thermal conditions in a physiologically significant manner, too. With respect to this, Matzarakis and Mayer (1996) transferred ranges of PMV for thermal perception and grade of physiological stress on human beings (Fanger 1972, Mayer 1993) into corresponding PET ranges (Table 1). They are valid only for the assumed values of internal heat production and thermal resistance of the clothing.

It is worth mentioning that the VDI-guideline 3787 part 2 "methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning, part I: climate" (VDI, 1998) recommends the application of PET for the evaluation of the thermal component of different climates to emphasize the significance of PET more further. This guideline is edited by the German Association of Engineers ('Verein Deutscher Ingenieure' VDI).

Table 1: Ranges of the physiological equivalent temperature (*PET*) for different grades of thermal perception by human beings and physiological stress on human beings; internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (according to Matzarakis and Mayer 1996)

PET	Thermal Perception	Grade of Physiological Stress
	very cold	extreme cold stress
4 °C		
	cold	strong cold stress
8 °C		
	cool	moderate cold stress
13 °C		
	slightly cool	slight cold stress
18 °C		
	Comfortable	no thermal stress
23 °C		
	slightly warm	slight heat stress
29 °C		
	warm	moderate heat stress
35 °C		
	hot	strong heat stress
41 °C		
	very hot	extreme heat stress

In order, to calculate PET, it is necessary to determine the meteorological parameters which are important for the human energy balance at a human-biometeorologically significant height, e.g. 1.1 m above ground (average height of a standing person's gravity center in Europe). Dominant meteorological parameters influencing the human energy balance include air temperature, vapour pressure, wind velocity and mean radiant temperature of the surroundings. Depending on the objectives of the evaluation, these meteorological parameters can be measured or calculated in a grid-net by numerical models (Matzarakis et al., 1999, Matzarakis, 2001c).

RESULTS OF THE HUMAN-BIOMETEOROLOGICAL ASSESSMENT OF THE THERMAL ENVIRONMENT

The human-biometeorological radiation model RayMan was developed by Matzarakis et al. (2000) in order to calculate the mean radiant temperature. It is well suited for the application in different environments, esp. urban structures, because it is able to take into account various complex horizons. In addition, thermal indices like PMV, PET or SET* are output variables of RayMan.

Analysis of mean conditions and extreme events

Human-biometeorological analysis regarding tourism purposes can be carried out based on daily, monthly or annual conditions. Several possibilities for the assessment of climate and thermal comfort in tourism are existing. Some results of mean conditions and extreme events are presented in the following.

First, the physiologically equivalent temperature PET (Matzarakis et al., 1999), at the Urban Climate Station of the Meteorological Institute of the University of Freiburg/Germany is calculated as an example for the assessment of the thermal environment of people in a medium sized European city. The site is located at the top of a 50 m height building in the centre of Freiburg. Wind speeds have been reduced to the gravity center of humans (1.1 m). The calculations of PET were carried out by means of the radiation and thermal bioclimate Model RayMan (Matzarakis et al., 2000). Frequencies of PET in % of PET classes, according to Matzarakis and Mayer (1996), based on hourly data for the whole year, above the urban canopy layer (UCL) in Freiburg in the year of 2002 are shown in Fig. 2. In 6.4 % of all hours of the year (including winter time) we detect warm or even hot conditions, according to PET classes or conditions. This is an example for the yielding of ground information on thermal bioclimatic-tourism conditions of an area.

Extreme events, which may have negative consequences to the local populations and visitors, can be analyzed in addition. Heat waves affect human health and can result in implications e.g. deaths or heat strokes. The air temperature and PET conditions during the period May, 1 to September, 30, 2003 in Freiburg, Germany, a period with untypical summer conditions followed by extremely hot conditions is presented in Fig. 3. The wind speed is reduced to the level of the gravity center of humans (1.1 m). It is shown:

- daily maximum air temperature($T_{a,max}$),
- daily minimum ($T_{a,min}$) air temperature,
- daily maximum PET (PET_{max}),
- daily minimum PET (PET_{min})

in Freiburg for the period May, 1 to September, 30, 2003.

Additionally the frequency of days with:

- minimum air temperature ($T_{a,min} > 20$),
- maximum air temperature ($T_{a,max} > 30$),
- minimum PET ($PET_{min} > 20$),

- maximum PET (PET_{max} > 30) and
- maximum PET (PET_{max} > 35)

for the same period is shown. From Fig. 3 the extreme conditions for this specific period can be detected.

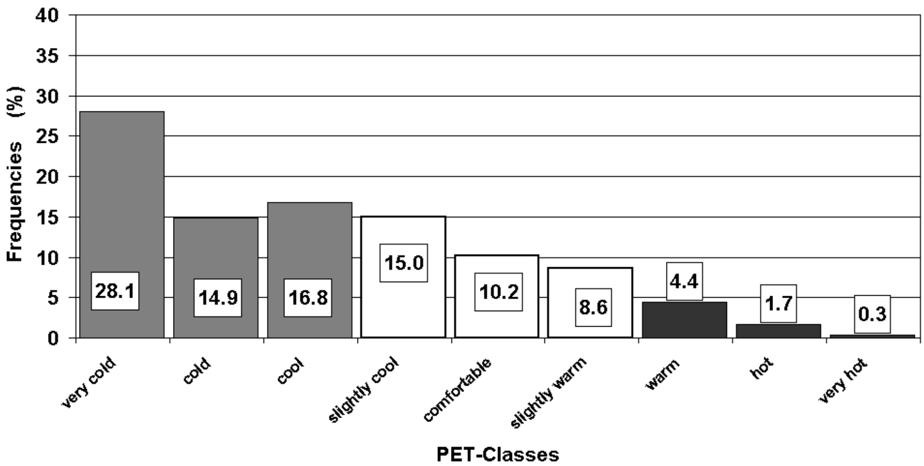

Figure 2: Hourly frequencies distribution of Physiological Equivalent Temperature (PET) in Freiburg for 2002

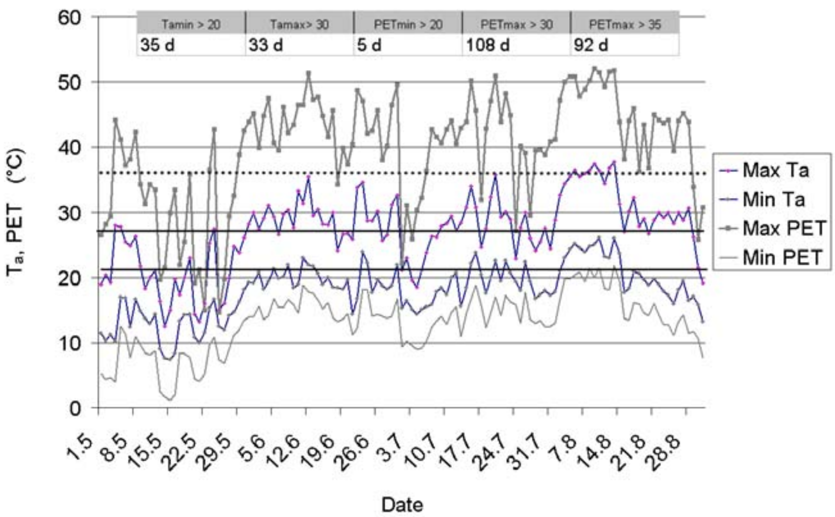

Figure 3: Daily maximum ($T_{a,max}$) (°C) and minimum ($T_{a,min}$) air temperature (°C), daily maximum (PET_{max}) (°C) and minimum (PET_{min}) Physiological Equivalent Temperature (°C) in Freiburg for the period May, 1 to September 30, 2003 and additional the frequency of days with min air temperature ($T_{a,min}$ > 20), maximum air temperature ($T_{a,max}$ > 30), minimum *PET* (PET_{min} > 20), maximum *PET* (PET_{max} > 30) and maximum *PET* (PET_{max} > 35), for the same period

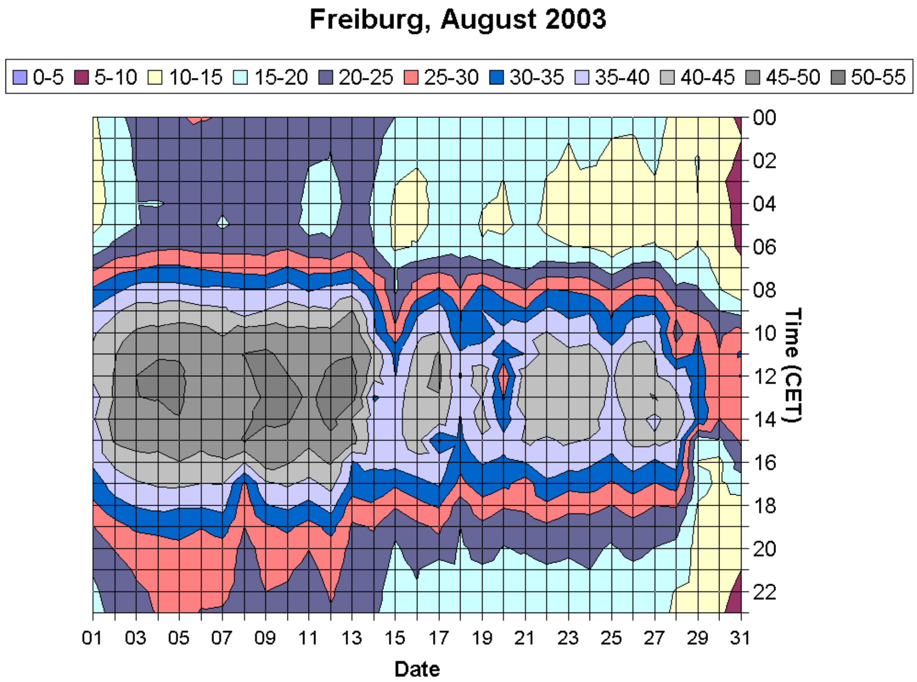

Figure 4: Pattern of hourly values of Physiological Equivalent Temperature (PET), in Freiburg for August 2003

Figure 4 presents the temporal pattern of PET values in Freiburg for August 2003. During the first 15 days of August 2003 only a few hours with thermal comfort values (PET < 20 °C) occurred. The second part of August was characterised by conditions, which are typical for Freiburg. During the first 15 days of August 2003, less little neutral thermal conditions for humans, especially during the nighttime have been observed in the vicinity of Freiburg. Results in high temporal and spatial resolution are helpful for risk assessments espc. to avoid negative implication on humans.

Mapping

In the meantime, some investigations which use thermal indices like PMV or PET for the human-biometeorological assessment of the thermal environment in different scales were performed. Results from a case study (Matzarakis et al., 1999) enables a process analyses, e.g. in the form of regressions between PET as thermal index and meteorological input parameters like single radiative fluxes, mean radiant temperature, air temperature, or vapour pressure. Maps can be drawn using geo-statistical methods converting point results to spatial distributions (Matzarakis and Mayer, 1997).

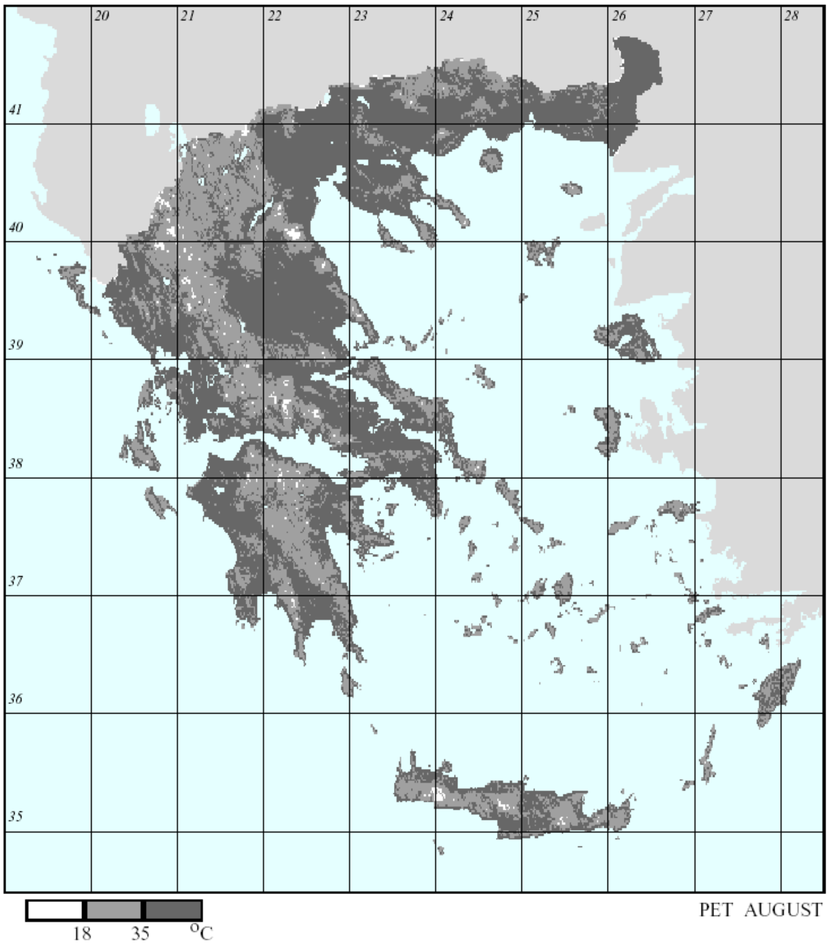

Figure 5: Spatial distribution of mean daily values of Physiological Equivalent Temperature (PET) in Greece at 12 UTC for August

As an example for bioclimate maps, the spatial distribution of mean daily *PET* values in Greece at 12 UTC in August (Figure 5) shows the influences of different site factors (site elevation or distance to the coast) which are coming out well pronounced. The month of August in Greece is one of the summer months with the highest heat stress conditions for the population. For example, all regions below 600 m a.s.l. show high heat stress. Nevertheless, there are comparatively large spatial differences between the areas with high heat stress. On the islands of the Aegean and Ionian Sea, the heat stress conditions are somewhat lower than those obtained in the interior land parts of the country. Extreme heat stress is observed in the lower elevated regions of Greece (e.g. in Thessaly, Macedonia, in the western part of Sterea Ellada and the southern part of Epirus). We find similar conditions in the coastal areas which are covered with land masses or protected bays. In this category most of the islands are to be found. Although, conditions with strong heat stress are lesser in relation to the continental mainland there. This is due to the influence of the Etesian winds in the Aegean Sea and a development of regional sea breeze wind systems in the Ionian Sea (Matzarakis and Mayer, 1997, Matzarakis et al., 1999).

The presented information can be helpful in the identification of stressed areas or suitable areas and in the extension or reduction of tourism period.

CONCLUSIONS

Human-biometeorology provides well-suited thermal indices on the basis of the human energy balance for the assessment of the thermal environment on human beings on a regional and local scale. This information can be implemented in planning and construction of tourism areas and facilities.

A range of climate information is required for tourism climatology. But simple meteorological or climatological parameters in the form of means (Fig. 5), extremes, frequencies (Fig. 3 and 4) and possibilities may not be useful unprocessed. Tourism climatology information has to be assessed and demands quantitative results and not only qualitative statements.

Scientific generated tourism climate indices, and in general, thermal climate indices are not tested at humans (tourists) and they don't include the climate adaptation of them.

Combined variables of atmospheric parameters like thermal comfort are of special interest. Nevertheless, they do not provide absolute integrated assessments and guidelines of atmospheric effects on humans, or assessment with the purpose of planning tourism resorts, etc. Physical factors like e.g. for instance ultraviolet radiation or air quality have to be further included in the assessments.

Finally, looking at the existing deficits and observing critical points at the thermal indices and their use in applied climatological studies, it has to be mentioned, that the efforts in developing scientific tools is advancing ahead. An international expert group, covered by the umbrella of the International Society of Biometeorology, the World Health Organisation and the World Meteorological Organisation is working in the development of one universal thermal climate index, based on the state of the art in human-biometeorology.

From an aestetical point of view, sunshine or visibility is important. Information on climate (including all its atmospheric and physical terms) requires well-prepared, well-presented and accessible information in order to be broadly used in tourism climatology (de Freitas, 1990, 2001, 2003). In addition, other interactions between the different facets, including recreational behaviour and socio-economic factors have to be also considered.

Many of the above mentioned questions are part of the work of the Commission Climate, Tourism and Recreation of the International Society of Biometeorology (http://www.mif.uni-freiburg.de/isb).

REFERENCES

Abegg, B. (1996) Klimaänderung und Tourismus. Schlussbericht NFP 31. vdf Hochschulverlag AG an der ETH. Zürich.

Davies, N.E. (1968) An optimum summer weather index. Weather **23**: 305-317.

de Freitas, C.R. (1990) Recreation climate assessment. Int. J. Climatol. **10**: 89-103.

de Freitas, C.R. (2001) Theory, concepts and methods in climate tourism research. Proceedings of the first international workshop on climate, tourism and recreation. (Ed.) A. Matzarakis and C. R. de Freitas. International Society of Biometeorology, Commission on Climate Tourism and Recreation. 3-20.

de Freitas, C.R. (2003) Tourism climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. Int. J. Biometeorol. **48**: 45-54.

Fanger, P.O. (172) Thermal comfort. McGraw-Hill, New York.

Gagge, A.P., Stolwijk, J.A.J., Nishi, Y. (1971) An effective temperature scale based on a simple model of human physiological regulatory response, ASHRAE Trans **77**: 247–257.

Gagge, A. P., Fobelets, A. P., Berglund, L. G. (1986) A standard predictive index of human response to the thermal environment. ASHRAE Trans **92**: 709-731.

Höppe, P. (1984) Die Energiebilanz des Menschen, Wiss Mitt Meteorol Inst Univ München No. 49.

Höppe, P. (1993) Heat balance modelling, Experientia **49**: 741–746.

Höppe, P. (1999) The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment, Int J Biometeorol. **4**3: 71–75.

Höppe, P., Mayer, H. (1986) Planungsrelevante Bewertung der thermischen Komponente des Stadtklimas, Landschaft + Stadt **19**: 22–29.

Jendritzky, G., Sönning, W., Swantes, H.J. (1979) Ein objektives Bewertungsverfahren zur Beschreibung des thermischen Milieus in der Stadt- und Landschaftsplanung (Klima-Michel-Modell), Beiträge der Akademie für Raumforschung und Landesplanung, 28. Hermann Schroedel, Hannover.

Jendritzky, G., Menz, G., Schmidt-Kessen, W., Schirmer, H. (1990) Methodik zur räumlichen Bewertung der thermischen Komponente im Bioklima des Menschen, Akademie für Raumforschung und Landesplanung, Hannover.

Mayer, H. (1993) Urban bioclimatology, Experientia **49**: 957-963

Matzarakis, A., Mayer, H. (1996) Another Kind of Environmental Stress: Thermal Stress. WHO Colloborating Centre for Air Quality Management and Air Pollution Control. NEWSLETTERS **18**: 7-10.

Matzarakis, A. and Mayer, H. (1997) Heat stress in Greece, Int. J. Biometeorol. **41**: 34-39.

Matzarakis, A., Mayer, H., and Iziomon, M.G. (1999) Applications of a universal thermal index: physiological equivalent temperature, Int. J. Biometeorol. **43**: 76-84.

Matzarakis, A., Rutz, F., and Mayer, H. (2000) Estimation and calculation of the mean radiant temperature within urban structures, WCASP-50, WMO/TD No. 1026, 273-278.

Matzarakis, A. (2001a) Assessing climate for tourism purposes: Existing methods and tools for the thermal complex. Proceedings of the first international workshop on climate, tourism and recreation, ed. by A. Matzarakis and C. R. de Freitas. International Society of Biometeorology, Commission on Climate Tourism and Recreation. 101-112.

Matzarakis, A. (2001b) Climate and bioclimate information for tourism in Greece. Proceedings of the first international workshop on climate, tourism and recreation, ed. by A. Matzarakis and C. R. de Freitas. International Society of Biometeorology, Commission on Climate Tourism and Recreation. 171-183.

Matzarakis, A. (2001c) Die thermische Komponente des Stadtklimas, Wiss. Ber. Meteorol. Inst. Universität Freiburg No. 6.

Mayer, H., Höppe, P. (1987) Thermal comfort of man in different urban environments, Theor. Appl. Clim. **38**: 43–49.

Mayer, H., Matzarakis, A. (2003) Zukunftsperspektiven der Umweltmeteorologie. Promet **30**: 61-70.

Mieczkowski, Z. (1985) The tourism climate index: A method for evaluating world climates for tourism. The Canadian Geographer 29: 220-233.

Spagnolo, J. and de Dear, R. A (2003) field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia, Building and Environment **38**: 721-738.

Tinz, B., Jendritzky, G. (2003) Europa- und Weltkarten der gefühlten Temperatur, In: Chmielewski, F.-M., Foken, Th. (Ed.) Beiträge zur Klima- und Meeresforschung, Berlin und Bayreuth. 111-123.

VDI (1998) Methods for the human-biometerological assessment of climate and air hygiene for urban and regional planning. Part I: Climate, VDI guideline 3787. Part 2. Beuth, Berlin.

WMO (1999) Climate and human health, World climate News **14**: 3-5.