

MAPPING THE THERMAL BIOCLIMATE OF AUSTRIA FOR HEALTH AND RECREATION TOURISM

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ABSTRACT

This paper analysed the thermal human bioclimate in Austria. Data covering the period of 1991 to 2000 was collected from Austria's dense network of 201 meteorological stations, and was used to compute the Physiological Equivalent Temperature (PET). Daily measurements and observations, at various times, of air temperature, relative humidity, wind velocity and mean cloud cover were the required data for the PET calculation. The results were compared with the outcome of a computation using synoptic data, not only from Austria but also from surrounding countries.

The mean radiant temperature, an important factor in the energy balance of humans, was calculated using the well established RayMan model. It was determined on the basis of the maximum possible global radiation to a certain time and place, and the existing mean cloud cover from the observations of the climatic network, as well as those computed for current conditions.

Statistical and GIS procedures were applied to the PET computation of the single climatic station in order to transfer the point into aerial values. The results give fundamental information often demanded by health, recreation, and tourism authorities.

KEYWORDS: *Physiological Equivalent Temperature, Recreation, Austria*

INTRODUCTION

The thermal bioclimate is of high interest for decision makers in the public health and recreation tourism sectors, as well as for the general public. The first and only existing description of the thermal human bioclimate, the "bioclimatic map of Austria", had its origin in the 1983 work of Rudel et al. (1). This description was based on the combination of equivalent temperature (representing the thermal load) and cooling power (measuring cooling stress using both 'simple' and 'complex' parameters). Annual mean values of different so called "Reizstufen" (Reizstufe can be translated as phases of stimulation of thermal stress) were also presented.

Current investigation into the thermal complex of human bioclimate uses more scientific methods. A large disadvantage of the older 'simple'/'complex' indices is that they disregarded the extensive interactions of all meteorological parameters affecting the thermophysiology of humans. The human organism is influenced by radiant fluxes, air temperature, water vapour pressure, wind velocity, physiological parameters (weight, size, and activity) and clothing, all of which are part of the human energy balance equation. Human beings react to the environment by adjusting both skin temperature and sweat rate, to keep core temperature constant (stationary condition). Thus, one of the new thermal indices, the Physiologically Equivalent Temperature (PET), in contrast to older indices (e.g. the Predicted Mean Vote (PMV)), is applicable to the more complex context of outdoor conditions.

Transferring this human adaptation for outdoor conditions into indoor conditions (with a clothing insulation of 0.9 clo, metabolic rate of 80 W, water vapour pressure of 12 hPa, wind velocity of 0.1 m/s and provided that the indoor air temperature corresponds to the mean radiant temperature) results in a PET value that is equivalent to the respective air temperature (degrees Celsius), which fulfills the energy balance equation in the outdoor conditions. This is useful because using the Celsius scale, instead of PMV or similar indices, makes the results much more understandable. In this paper the calculation of PET, and of bioclimatic maps based on PET, are applied for Austria.

INVESTIGATION AREA

Geographically situated between 46.5° and 49° northern latitude, and 9.5° and 17° eastern longitude, Austria covers 83855 km². Distributed throughout this area are an extensive series of 201 meteorological stations, making Austria a perfect country for bioclimate investigations and case studies. Not only does Austria collect much climatic data, but is also has an extremely differentiated climate for its relatively small size. This diversity of climatic zones is caused by various orographic characteristics, and by the interaction of atlantic and continental climatic influences (1). Also, its central geographical location in Europe increases the attractiveness of the country for a broad population spectrum, so that numerous groups have a high need for a bioclimatic zoning of Austria.

METHODS

The well being and health of humans depends on the close linkage between thermal regulation and circulation (2). The thermal bioclimatic complex comprises the meteorological variables that affect human beings in a thermo-physiologically manner: air temperature, air humidity, and wind speed, as well as short and long-wave radiation from the surrounding area. In order to consider the thermal environment of humans in a relevant way it is necessary to use evaluation methods that

- deal with the atmospheric environment as a whole and not with single meteorological components, as humans do not have receptors for such singular components
- have a thermo-physiologically relevance

Thus ‘simple’/‘complex’ indices that were often used in older publications (e.g. effective temperature or the equivalent temperature) do not fulfil the above criteria (3,4).

The VDI-guideline 3787, part 2 (2) recommends methods for the assessment of the thermal component of the human climate, which takes into account the complexity of this inquiry. The human energy balance equation (5,6,7) is the basis of these recommended methods, one of them being the thermal index PET, derived from the model MEMI.

Much analysis has been carried out with synoptic data (8,9,10,11). For the current investigation a modified method was chosen, using data from the Austrian climatic network (Figure 1), as well as the synoptic observations for the greater area. The number of climatic stations is much higher than the synoptic ones, and therefore has an excellent aerial coverage. Climatic observations were carried out at 7, 14 and 19 CET, and synoptic observations at 6, 12 and 18 UTC. The meteorological elements air temperature (T_a), relative air humidity (RH), wind velocity (v) and mean cloud cover (c) are the necessary inputs for the calculation of PET. Mean radiant temperature can be calculated by applying the radiation and bioclimate model RayMan (2) to the theoretical maximum global radiation in combination with the mean cloud cover.

A statistical model was used for the generation of spatially detailed bioclimatic data. This multiple regression model has demonstrated its suitability in former investigations (9,13). PET is the dependent variable, and the independent predictors are latitude, longitude, height above mean sea level, exposure and land use.

The multiple regression model (1) has the following form:

$$Y = f(X_1, X_2, \dots, X_5) = a_0 + a_1 * X_1 + \dots + a_6 * X_6 \quad (1)$$

where:

- Y = mean monthly PET (°C) or amount of days
- a_i = regression coefficients ($i = 0, \dots, 6$)
- X_1 = latitude (degrees, minutes)
- X_2 = longitude (degrees, minutes)
- X_3 = elevation above mean sea level (meters)
- X_4 = slope angle (°)
- X_5 = orientation (°)
- X_6 = land use

RESULTS

Figure 1 shows all of the stations used for the PET calculations. A bioclimate diagram based on the PET-classes (14) for the period 1.1.1991 to 31.12.2000 was developed in order to quantify the bioclimate of recreation areas and health spas.

Figure 2 gives an example for Vienna; it contains additional average values of PET classes (14) for 14 CET, extreme values, as well as mean frequencies of days with excesses of PET threshold values. In detail, the following values are to be found in this figure:

- annual average value of PET for the examined period (PETa)
- absolute maximum of PET for the examined period (PETmax)
- absolute minimum of PET for the examined period (PETmin)
- mean amount of days with $PET < -10,0\text{ °C}$ for 7 CET (PETd < -10)
- mean amount of days with $PET < 0,0\text{ °C}$ for 7 CET (PETd < 0)
- mean amount of days with $PET < 5,0\text{ °C}$ for 7 CET (PETd < 5)
- mean amount of days with $PET > 30,0\text{ °C}$ for 14 CET (PETd > 30)
- mean amount of days with $PET > 35\text{ °C}$ for 14 CET (PETd > 35)

PET mapping is presented in the form of:

- mean monthly and daily average values for the climatic dates 7, 14, 19 CET
- absolute monthly maximums and minimums
- annual frequencies of PET classes for climatic observations 7, 14, 19 CET
- mean monthly frequencies on the daily basis of PET classes

The linear regression model calculated the corresponding PET value for each grid point of the digital terrain model and, applying an interpolation method, allowed the plotting of maps for monthly mean PET-values at 7, 14, and 19 CET, as well as maps with number of PET days above or below a certain threshold. An additional analysis using synoptic data for 6, 12 and 18 UTC from a bigger area (not shown here) was also carried out. The comparison of the synoptic and climatic-based maps showed that the differences were small and explainable.

In figure 3 the geographical distribution of the PET values for July at 14 CET is shown. Areas with high heat load can be identified in the outer alpine regions and in the big valley systems of the Alps during summer conditions.

Figure 4 gives the distribution of the amount of days with PET values exceeding 35 °C , thus providing information on frequencies of heat waves and heat stress areas.

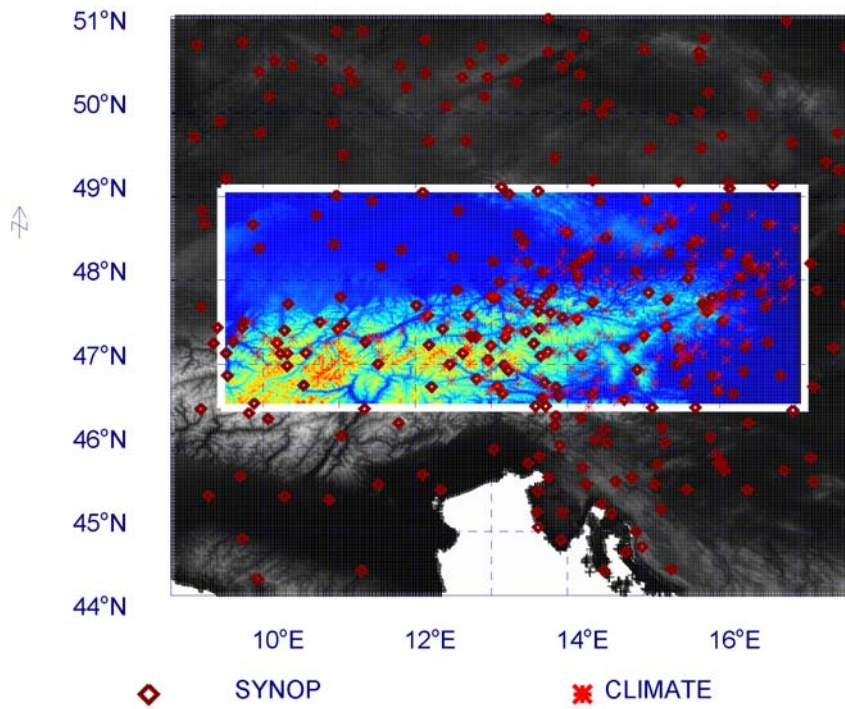


Figure 1: Digital terrain model and distribution of synoptical and climatic stations used for the PET calculations

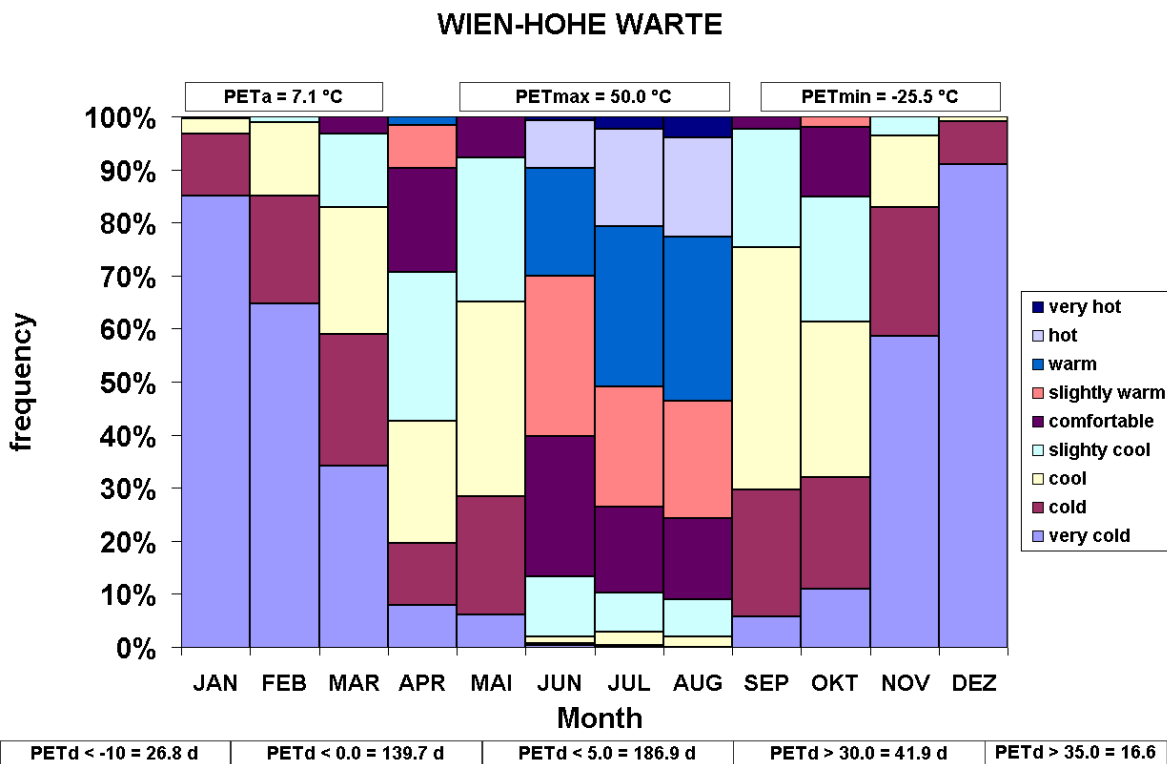


Figure 2: Thermal bioclimate diagram for Vienna, period 1991-2000

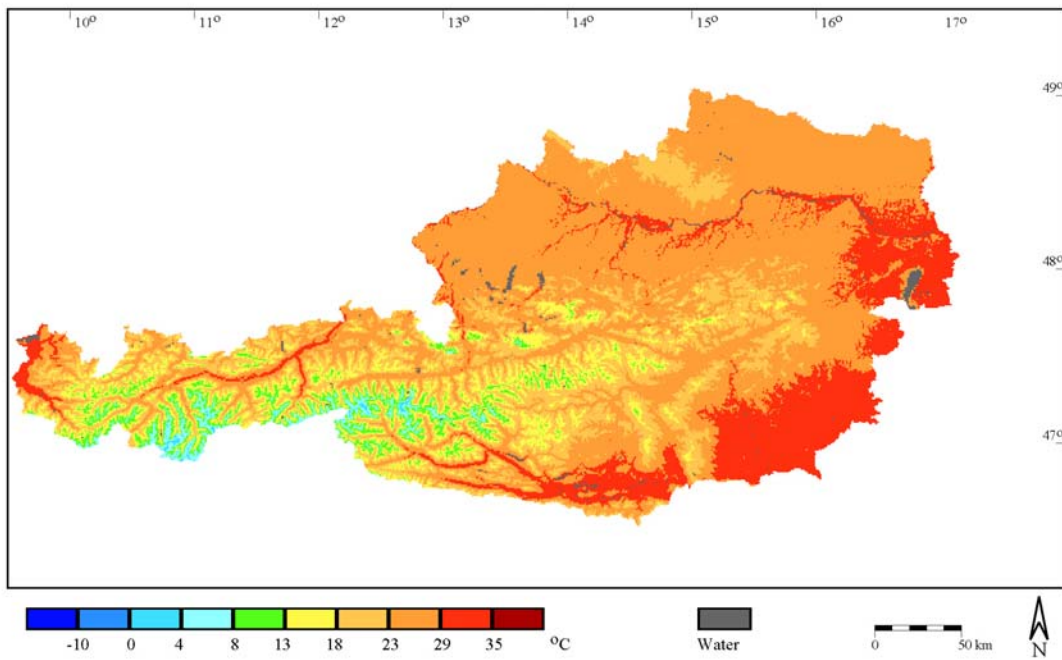


Figure 3: Geographical distribution of PET for Austria, July, at 14 CET, period 1991-2000

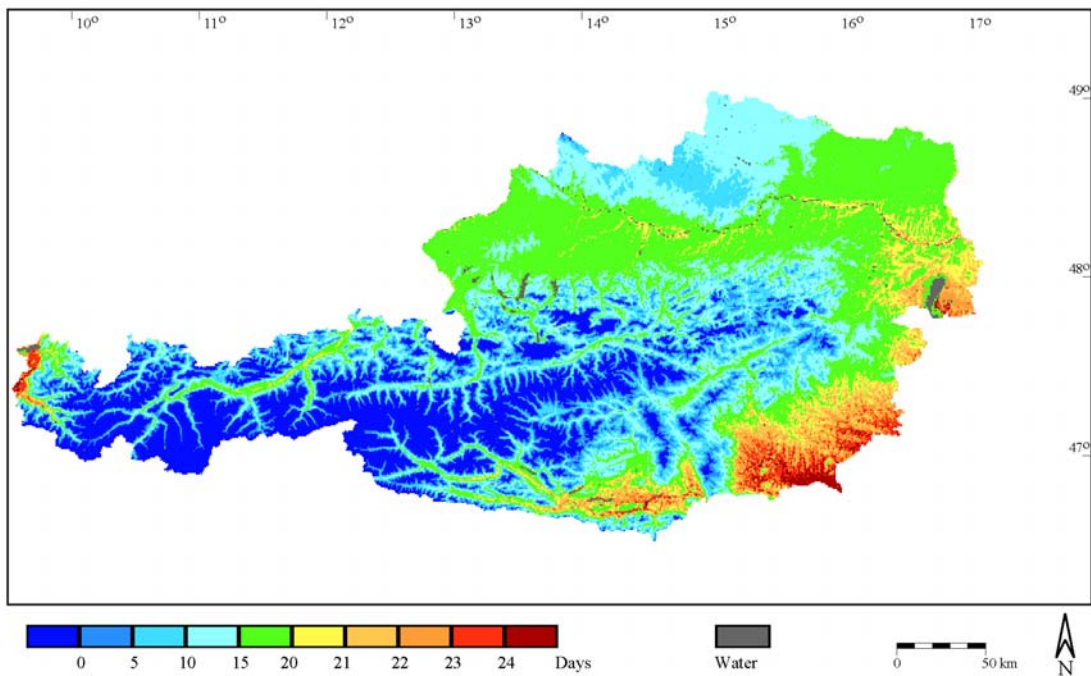


Figure 4: Geographical distribution of the amount of days with PET > 35.0 °C for Austria for 14 CET, period 1991-2000

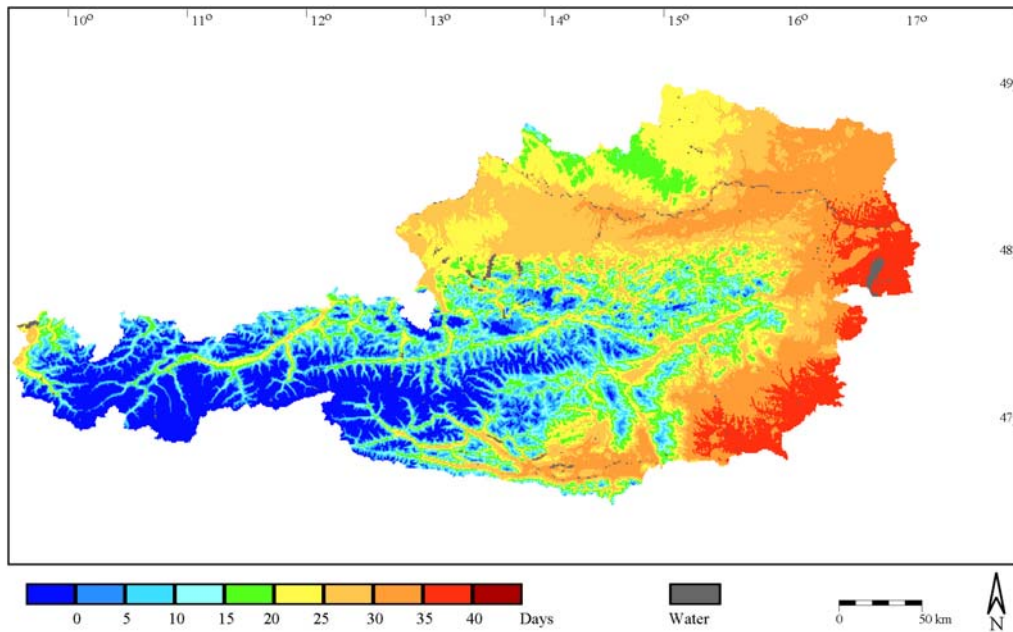


Figure 5: Geographical distribution of the amount of days with PET > 21.0 °C for Austria for 7 CET, period 1991-2000

Furthermore, figure 5 offers more detailed information about the thermal bioclimate, especially for recovery conditions during the night; it shows the number of days with a PET > 21 °C at 7 CET, which can be taken as an indicator of heat stress conditions.

DISCUSSION

The method used of analyzing the thermal bioclimatic conditions with specific bioclimate diagrams, including relevant information for tourism and recreation, presents an excellent way of transferring complex scientific information into a form that can be easily understood by decision makers and the general public. The Physiological Equivalent Temperature (PET), using the well known Celsius scale, can be easily applied and interpreted by anyone who is acquainted with this temperature scale. The method for regionalization of the PET-values, with its high statistical regression coefficients, allows the construction of bioclimate maps.

The mapping of modern bioclimatic indices, based on the human energy balance, presents an adequate method for the quantification of the human thermal bioclimate that can be applied for different uses and requirements. The need for bioclimatic information for health tourism and for tourism and recreation in general is very high. The results of our investigation are strongly demanded by decision makers because of the preparation of new legal regulations for Austrian

health resorts, where the assessment of the human bioclimate plays only one, but nevertheless an important, role.

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REFERENCES

1. Rudel, E., et al. 1983. Eine Bioklimakarte von Österreich. Mitteilungen der Österreichischen Geographischen Gesellschaft. Band 125, 1983.
2. VDI, 1998. Methoden zur human-biometeorologischen Bewertung von Klima und Lufthygiene für die Stadt- und Regionalplanung, Teil I: Klima. VDI-Richtlinie 3787 Blatt 2.
3. Hammer, N., Koch, E., and Rudel, E., 1986. Die thermisch hygrische Behaglichkeit in der Großstadt, beurteilt nach einem menschlichen Energiebilanzmodell, der Schwüle und der Abkühlungsgröße. Archiv für Meteorologie und Geophysik. Teil B. 343-355.
4. Matzarakis, A., 2001. Die thermische Komponente des Stadtklimas. Ber. Meteor. Inst. Univ. Freiburg Nr. 6.
5. Höpfe, P., 1984. Die Energiebilanz des Menschen. Wiss. Mitt. Meteor. Inst. Univ. München Nr. 49.
6. Höpfe, P.R., 1993. Heat balance modelling. Experientia. 49:741-746.
7. Höpfe, P., 1999. The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. Int. J. Biometeorol. 43:71-75.
8. Jendritzky, G., et al. 1990. Methodik zur raumbezogenen Bewertung der thermischen Komponente im Bioklima des Menschen (Fortgeschriebenes Klima-Michel-Modell). Beitr. Akad. Raumforsch. Landesplan. Nr. 114.
9. Matzarakis, A., 1995. Humanbiometeorological assessment of the climate of Greece. Dissertation, Aristotelian University of Thessaloniki. (in greek).
10. Matzarakis, A. and Mayer, H., 1997. Heat stress in Greece. Int. J. Biometeorol. 41:34-39.
11. Matzarakis, A., Mayer, H. and Iziomon, M., 1999. Applications of a universal thermal index: physiological equivalent temperature. Int. J. Biometeorol. 43:76-84.
12. Matzarakis, A., Rutz, F. and Mayer, H., 2000. Estimation and calculation of the mean radiant temperature within urban structures. Biometeorology and Urban Climatology at the Turn of the Millenium, edited by R.J. de Dear, et al. Selected Papers from the Conference ICB-ICUC'99, Sydney. WCASP-50, WMO/TD No. 1026, 273-278.

13. Matzarakis, A., Balafoutis, Ch. and Mayer, H., 1998. Construction of Bioclimate and Climate maps of Greece (in greek). Proc. 4th Panhellenic Congress Meteorology-Climatology-Physics of the Atmosphere. Athens September 1998, Volume 3, 477-482.
14. Matzarakis, A. and Mayer, H., 1996. Another kind of environmental stress: Thermal stress. WHO Newsletter No. 18:7-10.