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9B.6 INVESTIGATIONS OF URBAN CLIMATE'S THERMAL COMPONENT IN FREIBURG, GERMANY

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1. INTRODUCTION

Freiburg is a city - with about 200.000 inhabitants located in the southwest of Germany where thermal level is the highest within the country. Therefore, urban climate plays a dominant role in urban planning in Freiburg. Due to its location in the river Rhine's valley, urban climate in Freiburg is influenced by a regional wind system ('Hoellentaeler") caused by the near black forest (Gross 1989). It is responsible for fresh air breezing to Freiburg during the night and a decrease in the thermal loads on people living in the city.

The objective of this paper is to present results of experimental investigations on the thermal component of different urban microclimates in Freiburg with emphasis on a human-biometeorological assessment.

2. ASSESSMENT INDEX PET

Assessing the urban climate in a physiologically significant manner requires the use of methods of modern human-biometeorology which deals with the effects of weather, climate and air quality on human organism (Mayer, 1993).

Human-biometeorological studies in the past concerning the assessment of urban microclimates' thermal component have been based on indices which consist of only a single meteorological parameter or a combination of factors, e.g. effective temperature, equivalent temperature or heat stress index. A major disadvantage of these indices is their lack of physiological relevance.

The currently more popular thermal indices, by contrast, do have physiological significance because they are derived from the human energy balance (Höppe 1993).

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In Germany, methods for the physiologically significant assessment of urban microclimates' thermal component are at present standardized in the VDI-guideline 3787 part 2 section 1 „m*ethods for the human-biometeorological assessment of climate and air quality for urban and regional planning, section I: climate“* (VDI 1998; Mayer 1998).

Besides Predicted Mean Vote *PMV*, Physiologically Equivalent Temperature *PET* is recommended as a suitable index for the assessment of the stationary thermal environment. PET was developed from the MEMI energy balance model for the human body (Mayer and Höppe 1987; Höppe 1993). PET provides information on thermal perceptions and stages of thermal stress (Table 1). PET can be calculated as average value for a collective of human beings or as specific value for individuals.

TABLE 1. Physiologically Equivalent temperature *PET* as indicator for thermal perception and stage of thermal stress (for a metabolic rate of 80 W and a heat transfer resistance of clothing of 0.9 clo, according to Matzarakis and Mayer 1996).

PET	Thermal perception	Stage of thermal stress
	very cold	extreme cold stress
4 °C		
	cold	great 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	great heat stress
41 °C		
	very hot	extreme heat stress

PMV and PET are suitable for short-term field studies within different urban structures (e.g. Mayer 1998) and the construction of bioclimate maps for complete cities (e.g. Grätz et al. 1994).

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Up to now, PMV and PET proved to be successful in practice (e.g. Jenditzky et al. 1990; Matzarakis and Mayer 1991, 1997; Mayer and Höppe 1987, Mayer and Matzarakis 1997).

3. METHOD

The investigations were performed in the urban canopy layer of different microclimates within Freiburg because that is the space where people are living and which is, therefore, relevant for urban planning. The horizontal distance between the single measuring points in the inner city area of Freiburg was very short.

Using a special mobile measuring system, the meteorological parameters air temperature, air humidity, wind velocity and both short-wave and long-wave radiation fluxes (Mayer and Matzarakis 1997) were recorded on hot summer days in order to characterize different urban microclimates' thermal component during extreme weather situation which is responsible for human heat stress.

Taking into consideration results from analogous investigations (Mayer 1993, 1998; Mayer and Höppe 1987; Mayer and Matzarakis 1997), results obtained here are discussed with regard to their application in urban planning.

4. RESULTS

As known air temperature is not the suited meteorological parameter, if urban microclimates are to be seen from the perspective of human-biometeorology. Based on appropriate meteorological measurements on a summer day at three different built-up sites in Freiburg, the following figures will illustrate the importance of human-biometeo-rological investigations on urban climate.

The selected measuring points are located on a bridge (western sidewalk) over a small river, within a street canyon (eastern side) and within a street canyon (eastern side) below a large tree crown. The results are presented with emphasis on

** meteorological input data, especially the calculation of the mean radiation temperature T_{mrt}, wich is the most important parameter for assessing the thermal environment in summer;

** the effects of big trees in tree-lined urban street canyons;

** the influence of a regional wind system on thermal perceptions of human beings.

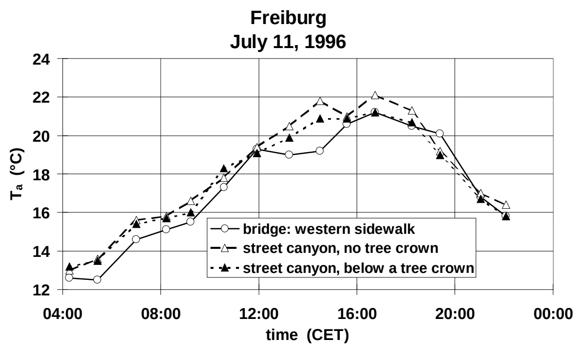

FIG. 1. Air temperature T_a in the human-biometeorologically significant height of 1.1 m above ground within different urban structures.

Fig. 1 contains the diurnal course of air temperature T_a at the three sites selected. The differences between the three measurement points are comparatively small. The tendency is obvious that T_a is highest within the non tree-lined street canyon and lowest on the bridge. Beside the lower net radiation, the higher wind speed combined with the transport of colder air masses by the regional wind system „Hoellentaeler“ from eastern directions is one reason for the lower air temperature during the morning hours and in the late evening.

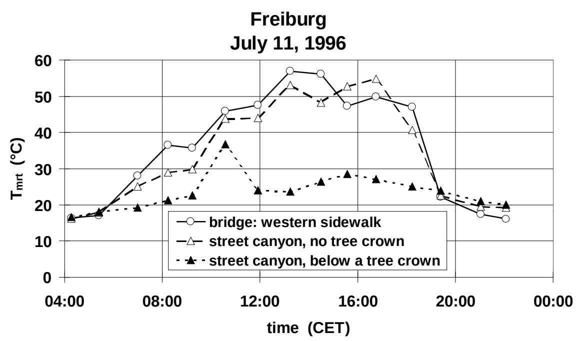

FIG. 2. Mean radiation temperature T_{mrt} in the human-biometeorologically significant height of 1.1 m above ground within different urban structures.

The mean radiation temperature T_{mrt} considers all short- and long-wave radiation fluxes and was calculated for a standing human being by using the method of Höppe (1992). The smallest values of T_{mrt} (Fig. 2) were determined at the eastern side of the urban street canyon below a tree crown because due to the shading of direct solar radiation. T_a, however, reacted only very slightly on the reduced irradiation (Fig. 1).

The mean radiation flux density S_{Str} (in

W/m^2) absorbed by the human body is calculated according to Höppe (1992):

$$S_{Str} = \sum_{i=1}^{6} W_i * (a_k * K_i + a_l * L_i) \qquad (1)$$

where K_i represents the short-wave (solar) radiation fluxes and L_i is the long-wave (terrestrial) radiation fluxes. a_k and a_l are the absorption coefficients for short-wave and long wave-radiation. W_i are weighting factors for the measured radiation fluxes from 6 directions (North, East, South, West, above, and below) for a person who is standing or walking (VDI 1998).

Having obtained S_{Str} from (1), it is possible to apply the Stefan-Boltzmann law to calculate the mean radiation temperature T_{mrt} (in °C):

$$T_{mrt} = \sqrt[4]{S_{Str} / (a_l * \sigma)} - 273.2 \qquad (2)$$

This procedure for determining T_{mrt} requires a pyranometer for measuring the short-wave radiation fluxes K_i and a pyrgeometer for measuring the long-wave radiation fluxes L_i.

In order to investigate the influence of the horizontal position of the measuring systems for radiation fluxes on T_{mrt}, additional measurements were performed with a 45 ° rotation of the measuring systems around a vertical axis.

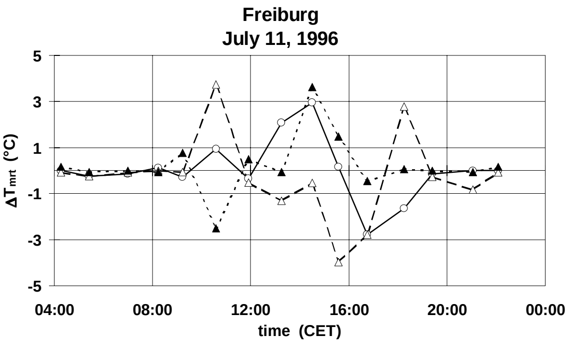

FIG. 3. Differences ΔT_{mrt} between mean radiation temperatures based on two different measurements of radiation fluxes (see text) in the human-biometeorologically significant height of 1.1 m above ground within different urban structures (signature of the sites like Fig. 2).

The results in Fig. 3 shows that, for the two kinds of measuring procedures:

- ** no differences in T_{mrt} at night under the absence of short-wave radiation,
- ** there are no significant differences during the day when short-wave radiation is present.

Therefore, it is sufficient to determine the horizontal radiation fluxes from four perpendicular directions which can be selected independent of cardinal points.

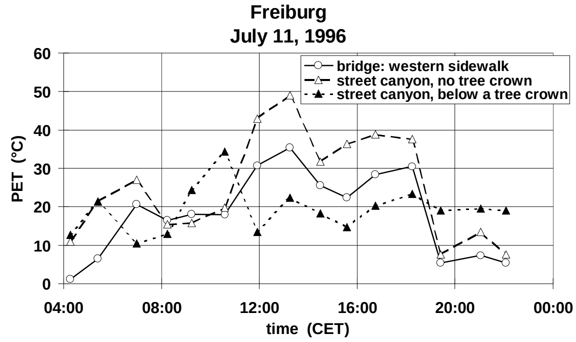

FIG. 4. Physiologically Equivalent Temperature PET in the human-biometeorologically significant height of 1.1 m above ground within different urban structures.

The diurnal courses of PET as thermophysiologically significant index (Fig. 4) are similar to the those of T_{mrt}, because there is a close relationship between PET and T_{mrt} (see example from Munich in Fig. 5) which indicates that T_{mrt} is the meteorological parameter influencing PET mostly. The importance of T_a for the calculation of PET is considerably smaller.

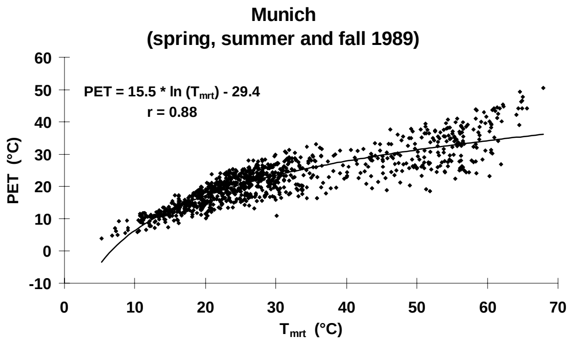

FIG. 5. Relationship between Physiologically Equivalent Temperature PET and mean radiation temperature T_{mrt} in the human-biometeorologically significant height of 1.1 m above ground, based on results from the KLIWUS project in 1989 (Mayer and Matzarakis 1997).

The results for PET (Fig. 4) show different levels of heat stress for human beings within the investigated urban microclimates which are more pronounced than for T_a. In the daytime, the shading effect of the trees reduces the heat stress level from extreme to moderate. The comparably low values of PET in the early morning are mainly caused by the value for heat transfer resistance of clothing. It related to conditions at noon and was not changed during the day, because the investigation was focused more on differences between the sites than on absolute values of PET.

5. DISCUSSION

Results from research projects in the field of urban climatology with relevance to urban planning reveal clear differences in the human-biometeorologically significant assessment of urban microclimates' thermal component. It becomes obvious that air temperature T_a which is more familiar to urban planners than PET does not represent the right indicator for the thermal environment in cities when its effects on human beings are to be considered. The reason mentioned above is that the human energy balance as basis for PET considers more meteorological parameters than only T_a.

Consequently, PET is a more suitable thermophysiological index for the assessment of the heat archipelago conditions within cities with regard to effects on human beings. Compared to T_a, the results of PET show a greater variability between the different urban mircroclimates, because the local horizon conditions influence T_{mrt} to a greater extent than T_a, which depends on the energy ba-lance of the urban surfaces and the urban air volume in a complex manner.

More detailed studies, however, are necessary on human beings' thermal perception in different climatic regions. Results presented in Table 1 are based on indoor investigations by Fanger (1972). Their validity in outdoor conditions, especially in subtropical and tropical regions needs to be examined.

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