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SHORT COMMUNICATION

Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany

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Abstract The concept of physiologically equivalent temperature (PET) has been applied to the analysis of thermal bioclimatic conditions in Freiburg, Germany, to show if days with extreme bioclimatic conditions will change and how extreme thermal conditions can be modified by changes in mean radiant temperature and wind speed. The results show that there will be an increase of days with heat stress (PET>35°C) in the order of 5% (from 9.2% for 1961–1990) and a decrease of days with cold stress (PET<0°C) from 16.4% to 3.8% per year. The conditions can be modified by measures modifying radiation and wind speed in the order of more than 10% of days per year by reducing global radiation in complex structures or urban areas.

Keywords Thermal bioclimate · REMO · Freiburg · Physiologically equivalent temperature

Introduction

Based on the IPCC scenarios, an increase in air temperature of more than 3°C is expected by the end of the twenty-first century (IPCC 2007). Air temperature is one of four meteorological parameters used in the estimation of thermal comfort or thermal stress, and on its own cannot quantify the effect of climate on humans. Some studies showed that for climate change conditions the changes based on thermal comfort indices, i.e. PET (physiologically equivalent temperature) will be much higher than air temperature changes (Matzarakis 2006; Matzarakis and Amelung 2008). For Germany, the expected changes are in the order of ΔPET≥10°C. The expected changes will affect humans more in cities because of the modified climatic conditions in urban areas. For a human biometeorological assessment of climate change conditions in urban areas or in complex environments, additional parameters have to be examined and their influence quantified. The parameters with the highest variability in urban areas are the radiation fluxes (which can be described with the mean radiant temperature) and wind speed. These two parameters can be modified to some extent by urban planning or other measures.

The physiologically equivalent temperature and its variations in Freiburg have been analysed. Freiburg presents an interesting study site for urban bioclimate research, being located at the foothills of the Black Forest. Additionally, Freiburg is one of the most important and visited cities in the Black Forest.

The objective of this paper is to show what thermal bioclimatic conditions can be expected based on regional climate model results for the area of Freiburg.

Materials and methods

To assess 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 humans (Mayer 1993).

Physiologically equivalent temperature (PET) is based on the human energy balance and describes the effects of

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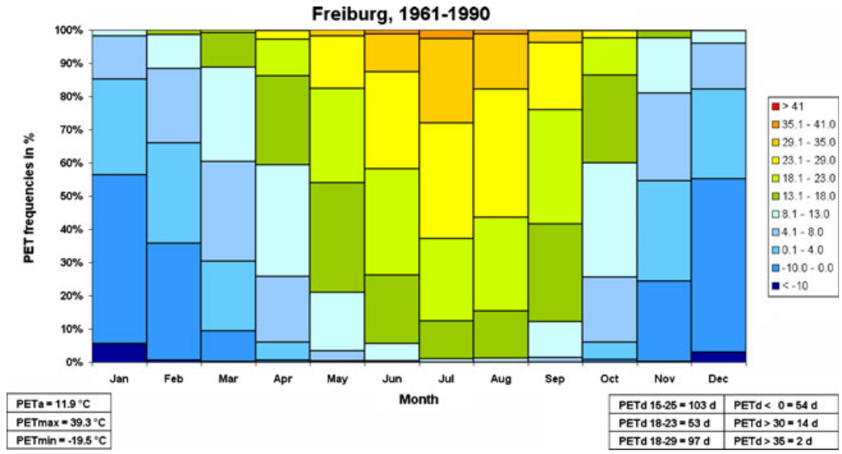
Fig. 1 PET in Freiburg for the period 1961–1990. Data: DWD



the meteorological conditions (short and long wave radiation, air temperature, air humidity, and wind speed) and thermo-physiological conditions (clothing and activity) on humans (Höppe 1999; Matzarakis et al. 1999).

For this study, the A1B and B1 scenarios carried out by REMO (Jacob 2001; Jacob et al. 2007) were initially used. The model region covers Germany and the Alps. The data have a spatial resolution of 10 km and a temporal resolution of hours.

The data are available from 1950 to 2100. Thus, the period 1961–1990 of the A1B scenario is used as reference period for future climate changes ranging from 2071 to 2100.

Furthermore, climate data (German Weather Service, DWD) for exclusive stations are available from the mid-twentieth century until now. We have chosen the time span from 1961 to 1990 for comparison. The following parameters of REMO and DWD data, respectively, are the basis for the computation of PET being the basis for thermal comfort and discomfort (Höppe 1999; Matzarakis et al. 1999):

- Date;
- Longitude, latitude, and altitude;
- Air temperature;
- Vapour pressure;
- Wind velocity;
- Cloud cover (DWD) and global radiation (REMO).

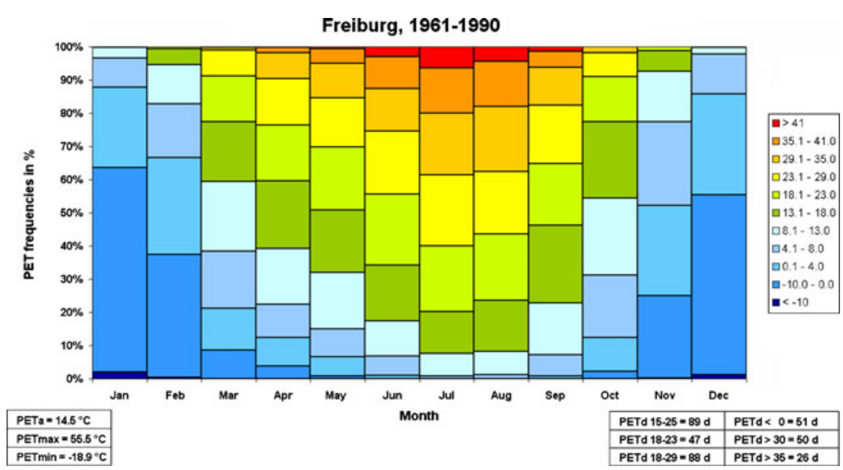
PET is computed by RayMan (Matzarakis et al. 2007).

Results

The results are presented as follows:

- Bioclimate diagrams (Matzarakis 2007; Lin and Matzarakis 2008; Zaninovic and Matzarakis 2009) have been constructed in order to compare different kinds of results and climate periods. The basic period is 1961–1990 based on measured and modelled data by DWD and the REMO model, respectively. The comparison period is 2071–2100.
- The bioclimate diagrams do not only contain mean PET values but also frequency classes of thermo-physiological stress levels for PET (according to Matzarakis and Mayer 1996).

Fig. 2 PET in Freiburg for the period 1961–1990. Data: REMO, A1B



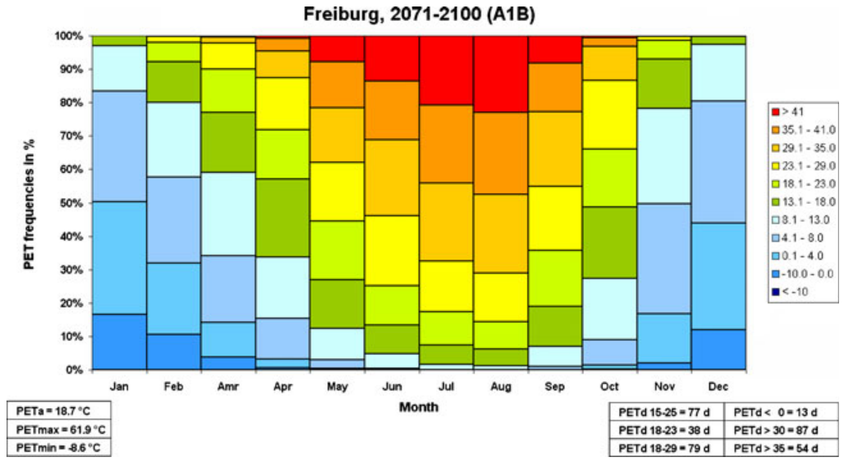


Fig. 3 PET in Freiburg for the period 2071–2100. Data: REMO, A1B

- The diagrams also include mean, max. and min. PET, as well as thresholds of days for temperate, cold and hot conditions.
- The bioclimate diagrams are based on a monthly interval (Matzarakis 2007).

Figure 1 shows the bioclimate diagram (PET) for the period 1961–1990 based on measured data of the German Weather Service (DWD) in Freiburg. Figure 2 shows the same period based on REMO simulations. Figures 3 and 4 show PET conditions based on the A1B and B1 scenarios for a future time span (2071–2100).

The analysis based on the A1B simulation shows a strong increase in heat and thermal stress compared to the B1 scenario. Heat stress shows in the “worst” case (A1B) an increase of more than 30 days to the end of the century and in the “best” case (B1) an increase of only 15 days. In general, a decrease of cold stress of more than 50% can occur. In general, changes in PET modelled by B1 are lower compared to A1B.

In addition, in order to get any information about adaptation possibilities to climate change conditions, two options have been included. Based on the assumption that, in urban structures, the parameters modified mostly are radiation fluxes (here expressed by the mean radiant temperature, Tmrt) and wind speed, several runs with modified Tmrt (effect of short and long wave radiation fluxes on the human energy balance included) and wind speed have been conducted. These two parameters are also the possibilities that can easily be modified or changed by urban planning measures.

Based on the assumption that if Tmrt =Ta (more or less shady conditions), changes in heat stress are very high. If wind speed is modified by an increase of 1 m/s then the days with heat stress decrease compared to original PET conditions.

Possible changes of heat stress days (PET>35°C) are shown for both scenarios (A1B and B1). Reducing the radiation (here Tmrt=Ta), heat stress days will only be about 10 to the end of the century for A1B. For B1, an increase of only 5 days will occur. Reducing the wind, heat stress days increase in all cases, with highest changes for A1B for the period 2071–2100 with a total of 30 days. The increase in heat stress days is similar for B1. In the case of increasing the wind speed by only 1 m/s, a decrease of days

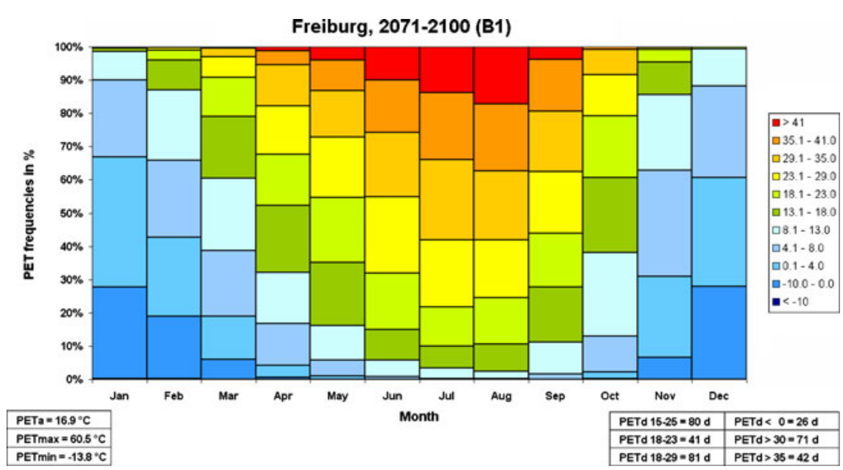


Fig. 4 PET in Freiburg for the period 2071–2100. Data: REMO, B1

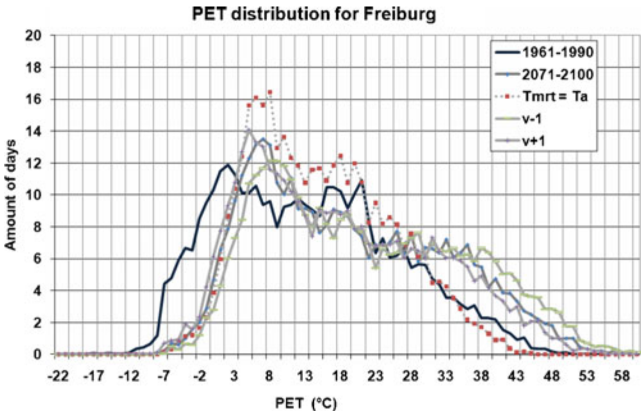


Fig. 5 Distribution of PET conditions for the period 1961–1990. PET conditions with Ta=Tmrt and modified wind conditions with wind−1 m/s and wind+1 m/s for 2071–2100. Data: REMO

with heat stress occurs. For both scenarios, the amount of days with heat stress drops by about 10 days.

For cold stress conditions (PET<0°C), the results show that there will be a decrease. Only small changes occur in cold stress days with the assumption of Tmrt=Ta. Decreasing the wind, changes in days with cold stress are less than 5 (producing better PET conditions). By increasing the wind speed by 1 m/s, the days with cold stress do not decrease as much.

In addition to the knowledge of frequencies of thermo-physiological classes of PET, the number of days with diverse thresholds are of importance. Figure 5 presents the distribution of PET standard conditions (for 1961–1990 and 2071–2100) and the applied adaptation options (Ta=Tmrt, v-1 and v+1) for 2071–2100 showing that not only the minimum and maximum conditions are shifting and changing but also that there are changes in the medium and lower thermal stress levels.

Table 1 shows the absolute values of PET and percentages of days with PET<0°C and >35°C for the period 1961–1990 and 2071–2100, and PET modified by Tmrt=Ta and wind speed conditions (±1 m/s) for the period 2071 – 2100. It can be seen that the maximum values of PET are increasing from 53°C to 60°C and the minimum from −21°C to −8°C. With the modification of wind and mean radiant temperature, the minimum values are not changing but the maximum can be reduced to about 25°C PET when Tmrt is changed. For the cold stress days (PET<0°C), the ratio is 16.4% for 1961–1990 and changes to 3.8% for 2071–2100. By modifying Tmrt, only a slight reduction occurs, but by changing the wind speed, the reduction is in the order of 1–2%. For the heat stress conditions, there is a ratio of 9.2% for 1961–1990 and an increase of 5.5% for 2071–2100. With Tmrt modification, this percentage is reduced from 14.7 to 2.6%. The slight reduction of wind increases the heat stress by about 5.2% by reducing the wind and decreases it by 2.8% when the wind is increased by +1 m/s, respectively.

In general, the distribution of the PET values shows that there is a shifting of the distribution between the periods 1961–1990 and 2071–2100 to higher values. Very cold conditions with less than 0°C PET get fewer. The frequency of PET values >35°C increases especially for the period 2071–2100. The frequency of the comfortable range (18–23°C) is also reduced. The distribution for values higher than 30°C rapidly increases for the period 2071–2100.

For the Ta=Tmrt condition, the distribution is also shifting to higher PET conditions to the end of the twenty-first century. These conditions show a general increase with a more intense shifting in the cold conditions and thermal comfort ranges.

For the PET conditions modified by changing the wind, there will be an increase in the distribution of the values with wind reduced by −1 m/s and a decrease of the distribution with wind speed increased by +1 m/s especially for the conditions with heat stress levels. The modifications by decreasing wind speed are higher than by increasing wind. The modification shown by less wind has to be seen as decreased thermal comfort levels and conditions.

Discussion and conclusion

The present analysis for Freiburg shows that, in general, the days with heat stress will increase and days with cold stress will decrease in the expected future climate conditions. In general, the results of B1 are lower compared to A1B.

The changes are much greater with the modifications in the radiation fluxes (here Ta=Tmrt), which can be achieved by planting specific and relevant vegetation types that produce shade in summer and allow short wave radiation to reach the surface or the areas where humans spend their time in winter. For the modifications by wind, the influence

Table 1 Absolute values of PET and percentages of days with PET<0°C and >35°C for the period 1961–1990, 2071–2100 and PET based on modified Tmrt (Tmrt=Ta) and wind speed (±1 m/s) conditions for the period 2071–2100

	1961–1990	2071–2100	Tmrt = Ta	v-1	v+1
Absolute minimum (°C)	−21	−8	−7	−8	−10
Absolute maximum (°C)	53	60	45	60	60
Days with PET<0°C (%)	16.4	3.8	3.2	2.3	5.2
Days with PET>35°C (%)	9.2	14.7	2.6	19.9	11.9

is not so high, but it is relevant to know that increased wind speed in complex structures can reduce hot conditions.

It is relevant to know not only about the expected air temperature changes of future climate but also about the thermal bioclimate conditions for urban dwellers. Based on the results, possibilities of reductions due to modified mean radiant temperature (at least global radiation) and wind speed have been applied in order to validate the sensitivity of these parameters on physiologically equivalent temperature and expected future climate conditions.

With smaller modifications of meteorological conditions in urban structures, i.e. increasing the shade by planting and providing big leaf trees, large modifications of the thermal bioclimate are possible. But the possibility of slight changes of wind conditions can also sustainably modify the thermal bioclimate conditions at the microscale.

Simple and less expensive adaptation strategies, especially in urban areas where humans spend their time, have not only to be seen from the point of view of climate change discussion but also generally for improved climate conditions in urban areas.

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