4.2 PHYSIOLOGICALLY EQUIVALENT TEMPERATURE AND CLIMATE CHANGE IN FREIBURG

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1. INTRODUCTION

Freiburg is a medium sized city in the south west of Germany with a population of more than 200.000 inhabitants. Based on the IPCC scenarios an increase in air temperature of more than 3 °C is expected to the end of the 21st century.

The physiologically equivalent temperature and its variations in Freiburg have been analysed. Freiburg states an interesting study site for urban bioclimate research 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.

2. METHODS

To assess the urban climate in a physiological significant manner it 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).

The physiologically equivalent temperature is based on the human energy balance and describes the effects of 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 scenario carried out by REMO (Jacob, 2001, Jacob et al., 2007) is initially used. The model region covers Germany and the Alps (Zebisch et al., 2005). The data has a spatial resolution of 10 km and a temporal resolution of hours.

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The data is available from 1950 until 2100. Thereby, the period 1961-1990 of the A1B scenario is used as reference period for future climate changes ranging from 2021 to 2050 and from 2071 to 2100.

Furthermore, climate data (DWD) for exclusive stations is available from mid 20th century till now. We have chosen the time span from 1961 till 1990 for comparison. The following parameters of REMO and DWD data, respectively, are the basis for the computation of physiologically equivalent temperature (PET) being background 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). Additionally, precipitation and snow cover are also included in the analysis. The values refer to 14 and 14:30 CET for REMO and DWD, respectively.

3. RESULTS

The results are presented as follows:

- Bioclimate diagrams (Matzarakis, 2007, Lin and Matzarakis, 2008) have been constructed in order to compare different kinds of results and climate periods. The basic period builds 1961-1990 based on measured and modeled data by DWD and the REMO model, respectively. The comparison period is 2021-2050 as well as 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).

- The diagrams include also 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).

Fig. 1 shows the bioclimate diagram (PET) for the period 1961-1990 based on measured data of the German weather service (DWD) station in Freiburg. Fig. 2 shows the same period based on REMO simulations. Fig. 3 and 4 show PET conditions based on the A1B scenario for future conditions for the periods 2021-2050 and 2071-2100.

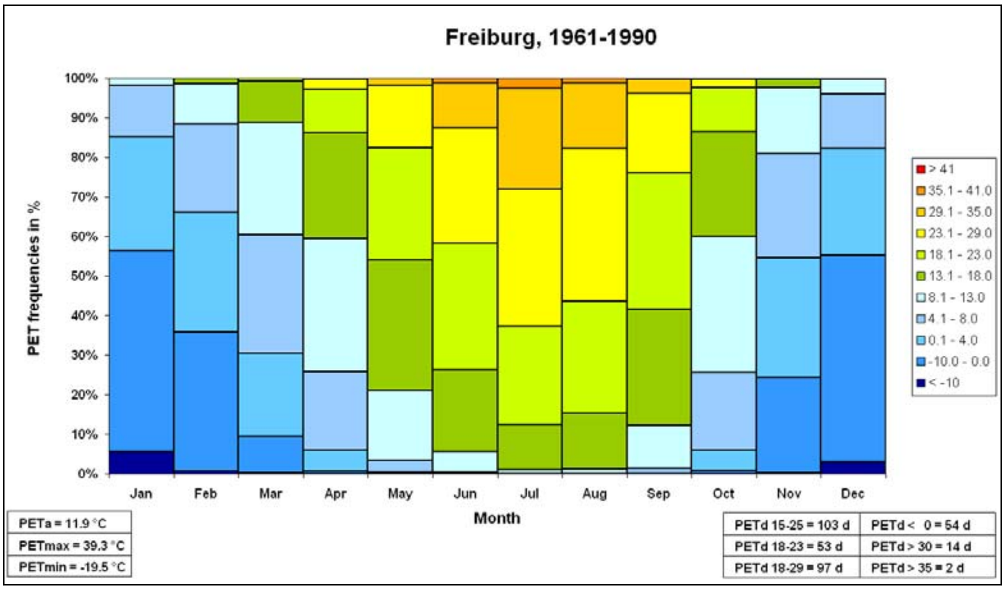

FIG. 1. PET in Freiburg for the period 1961-1990. Data: DWD.

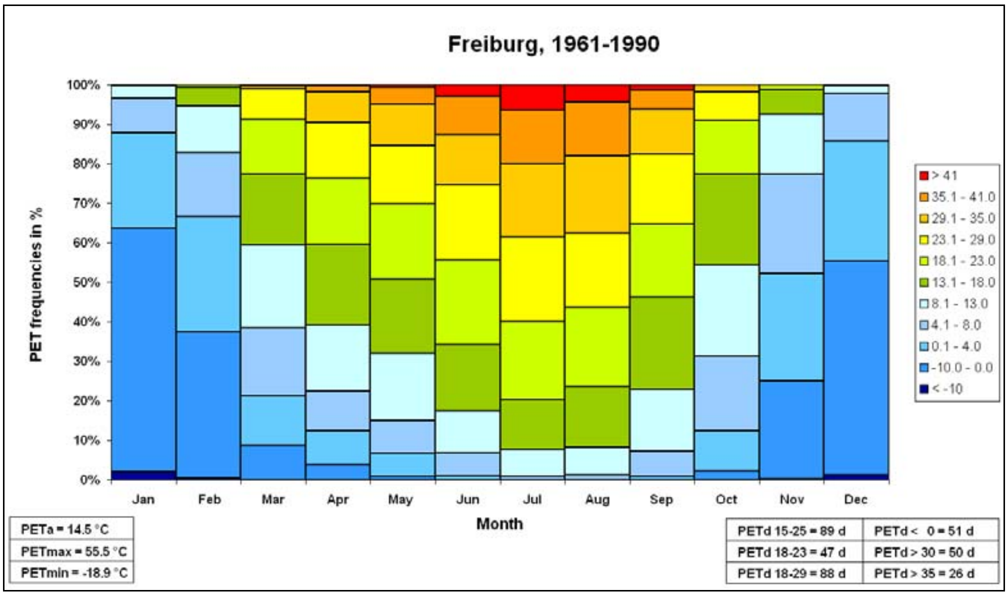

FIG. 2. PET in Freiburg for the period 1961-1990. Data: REMO A1B.

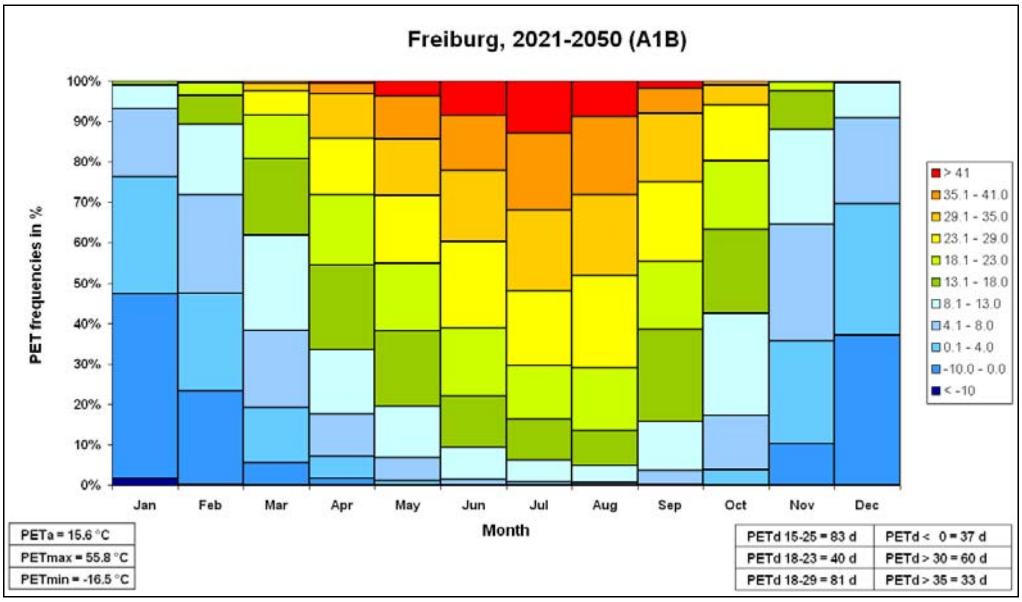

FIG. 3. PET in Freiburg for the period 2021-2050. Data: REMO A1B.

The results, based on the B1 scenario, are shown in Fig. 5 and 6, resp. for the periods 2021-2050 and 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 an increase of more than 30 days to the end of the century and in the best case only an increase of 15 days. In general, a decrease of cold stress of more than 50 % can occur. For the period 2021-2050, changes are lower and most pronounced in an increase of heat stress of about less than 10 days and for cold stress more than 10 days. In general, changes in PET modelled by B1 are lower compared to A1B.

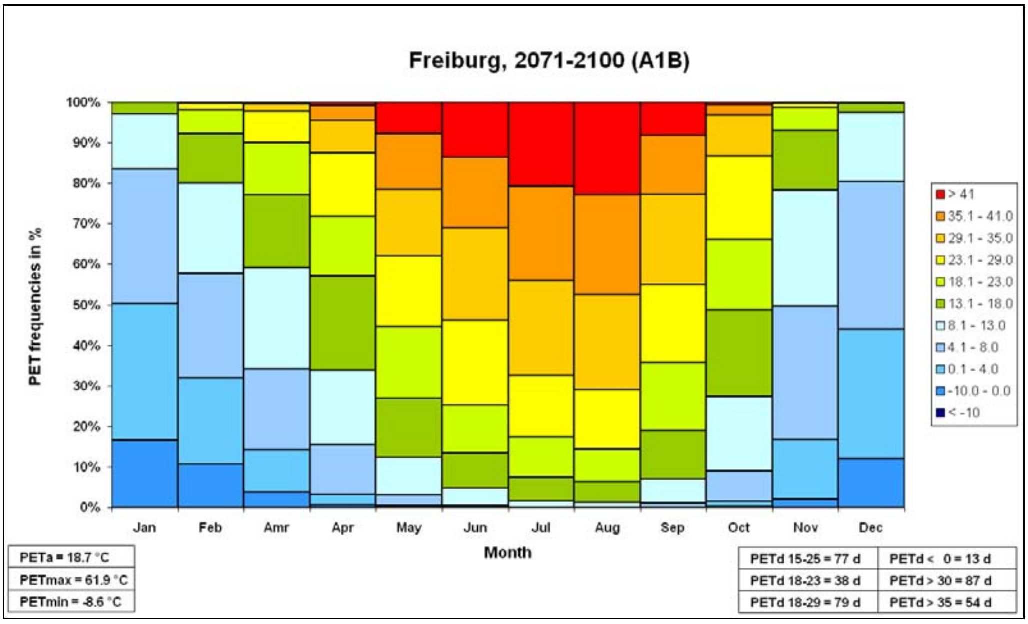

FIG. 4. PET in Freiburg for the period 2071-2100. Data: REMO A1B.

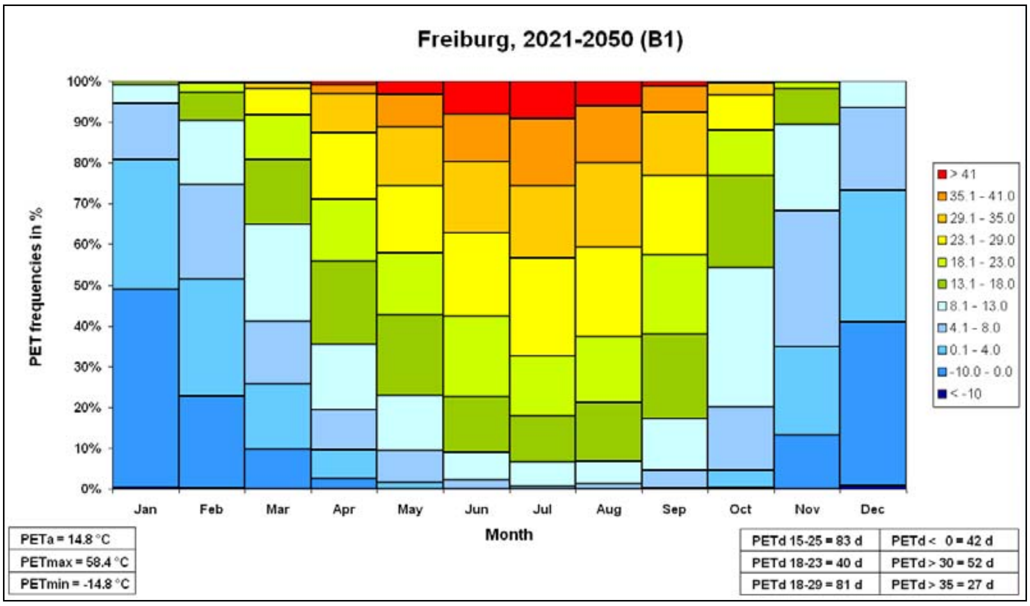

FIG. 5. PET in Freiburg for the period 2021-2050. Data: REMO B1.

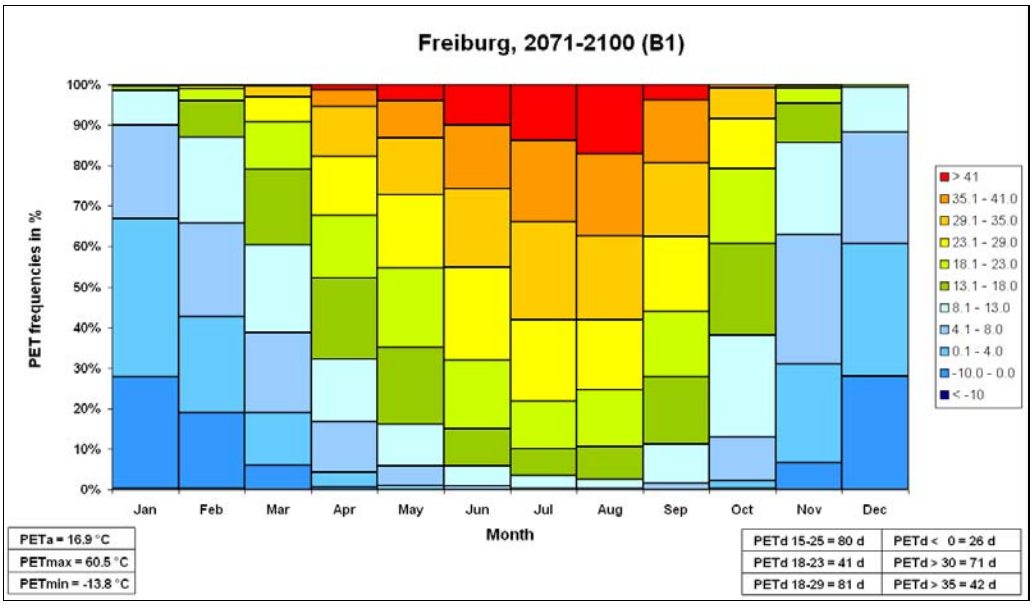

FIG. 6. PET in Freiburg for the period 2071-2100. Data: REMO B1.

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 at most are radiation fluxes (here expressed by the mean radiant temperature) and wind speed, we made several runs with modified Tmrt (mean radiant temperature, which includes the effect of short and long wave radiation fluxes on the human energy balance) and wind speed. These two parameters are also the possibilities that can 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 increasing of 1 m/s then the days with heat stress are decreasing compared to original PET conditions. In Fig. 7, possible changes of heat stress days (PET > 35 °C) are shown for both scenarios (A1B and B1). The three bars show the amount of day for the examined climate periods.

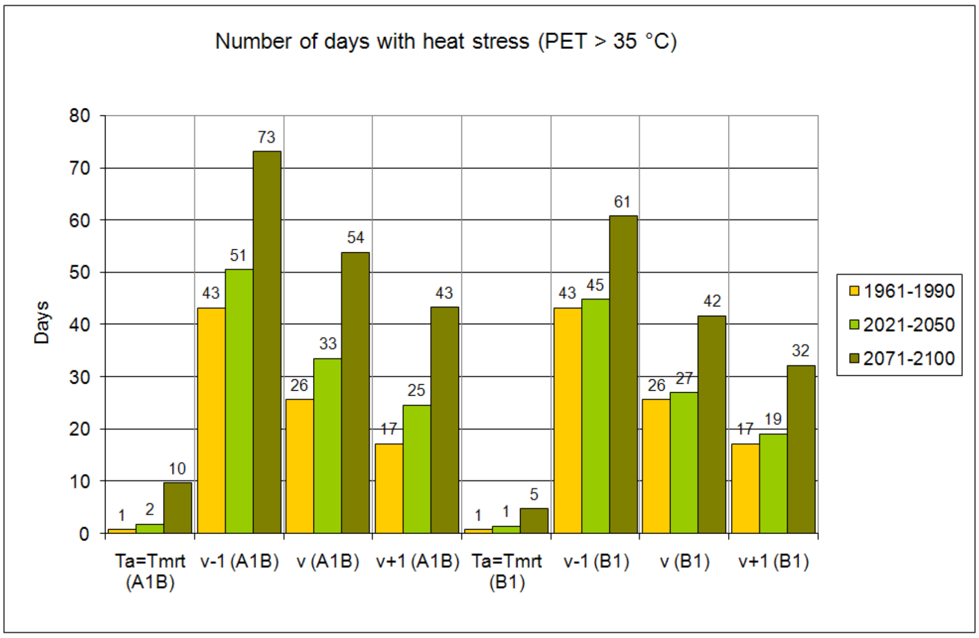

FIG. 7. Number of days with heat stress (PET > 35 °C) in Freiburg for the periods 1961-1990, 2021-2050 and 2071-2100 under following simulations: Ta=Tmrt, v-1, v, v+1. Data: REMO A1B, B1.

The first four groups of bars show the A1B scenario runs and the last four the B1 results. The bars marked with v are the original calculated conditions for PET. The Ta=Tmrt conditions show the conditions with modified Tmrt and have to be seen in comparison to the bars marked with v. The same are for v-1 and v+1, which represent the conditions with modified wind speed (v-1 and v+1).

The individual bars have to be interpreted in comparison to the original calculated conditions (v).

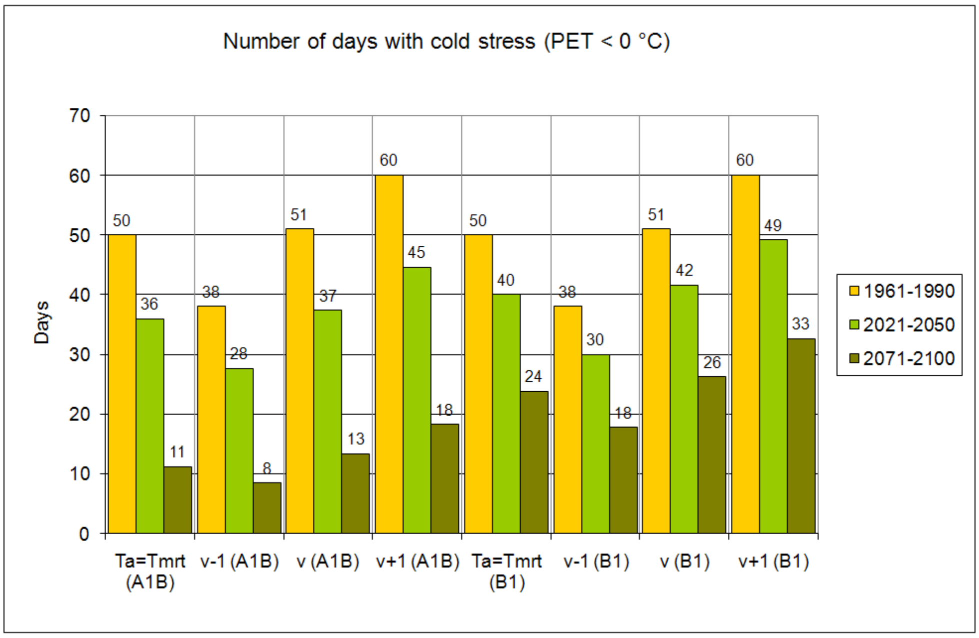

FIG. 8. Number of days with cold stress (PET < 0 °C) in Freiburg for the periods 1961-1990, 2021-2050 and 2071-2100 under following simulations: Ta=Tmrt, v-1, v, v+1. Data: REMO A1B, B1.

Reducing the radiation (here Tmrt=Ta), heat stress days will be only about 10 to the end of the century for A1B. For B1, only an increase of 5 days will occur. Reducing the wind, heat stress days increase in all cases with highest changes for A1B for the period 2071-2100 and with an amount 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 with heat stress occurs. For both scenarios, the amount of days with heat stress drops about 10 days (Fig. 7).

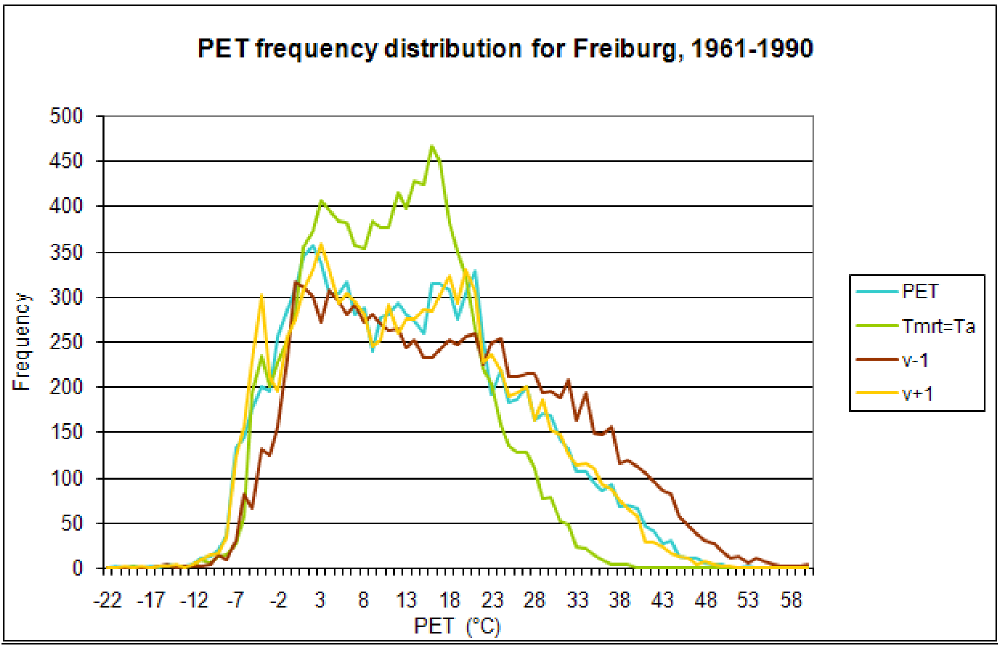

FIG. 9. Distribution of PET conditions for the period 1961-1990. Conditions with Ta=Tmrt and modified wind conditions with wind-1 m/s and wind+1 m/s. Data: REMO.

For cold stress conditions (PET < 0 °C), the results show that there will be a decrease (Fig. 8). 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 five days (producing better PET conditions). By increasing the wind speed of 1 m/s, the days with cold stress do not decrease so much.

Not only the knowledge of frequencies of thermo-physiological classes of PET and the amount of days with diverse thresholds are of importance. Fig. 9 to 11 present the distribution of PET standard conditions and the applied adaptation options (Ta=Tmrt, v-1 and v+1) and show that not only the minimum and maximum conditions are shifting and changing but also that there are changes in the medium and less thermal stress levels. The three figures show the different conditions for the periods 1961-1990 (Fig. 9), 2021-2050 (Fig. 10) and 2071-2100 (Fig. 11).

In general, the distribution of the PET values shows that there is a shifting of the distribution between the 1961-1990, 2021-2050 and 2071-2100 to higher values. Very cold conditions less than 0 °C PET are getting lower. The frequency of PET values > 35 °C is increasing esp. for the period 2071-2100. The comfortable range (18 to 23 °C) is getting lower. The distribution for values higher than 30 °C is rapidly increasing for the period 2071-2100.

For the Ta=Tmrt conditions, the distribution is shifting also to higher PET conditions for the two examined periods of the 21st century. This conditions have a general increase with a more intense shifting in the cold conditions and thermal comfort ranges. The very high conditions will increase also for PET values higher than 30 °C.

For the modified PET conditions by changing the wind there will be an increase in the distribution of the values with reduced wind of 1 m/s and a reduction of the distribution with wind speed by 1 m/s especially for the conditions with heat stress levels. The modifications by decreased wind speed are higher than the increased wind and this modification (by less wind) have to be seen as decreased thermal comfort levels and conditions.

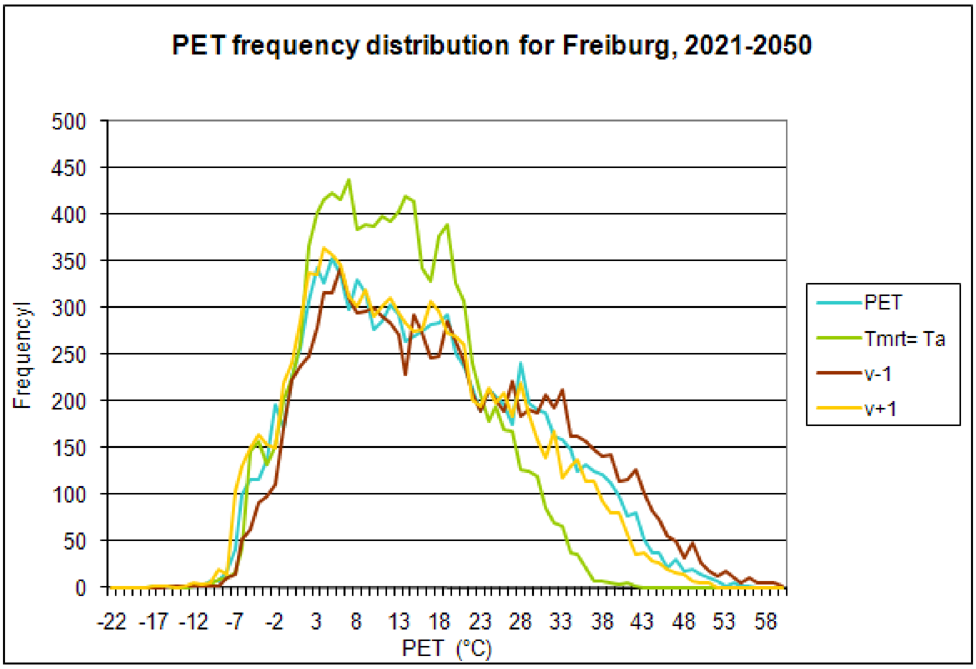

FIG. 10. Distribution of PET conditions for the period 2021-2050. Conditions with Ta=Tmrt and modified wind conditions with wind-1 m/s and wind+1 m/s. Data: REMO.

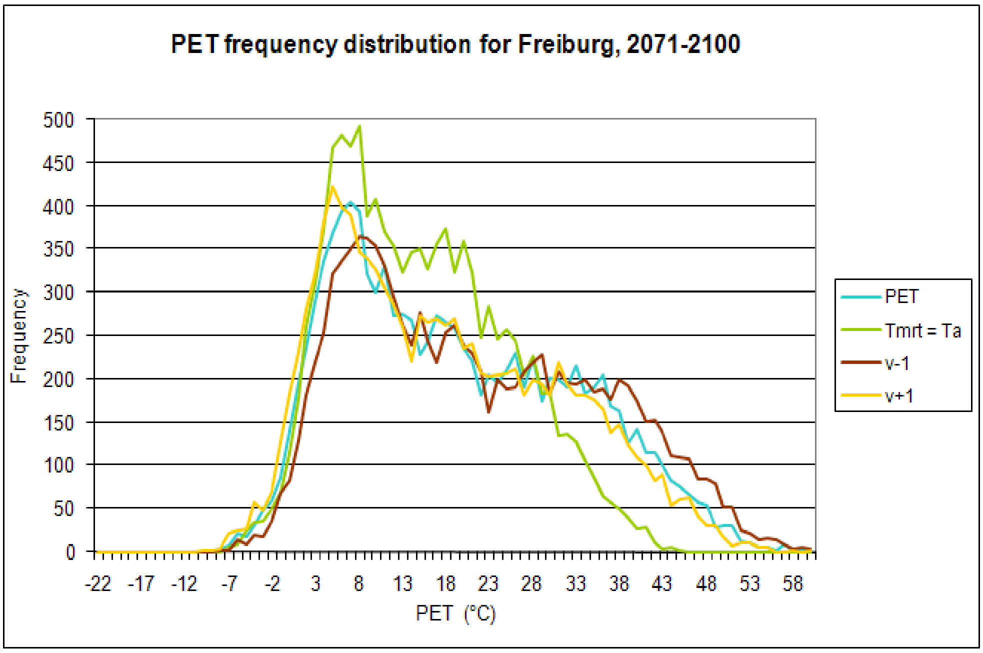

FIG. 11. Distribution of PET conditions for the period 2071-2100. Conditions with Ta=Tmrt and modified wind conditions with wind-1 m/s and wind+1 m/s. Data: REMO.

The changes are much higher with the modifications in the radiation fluxes (here Ta=Tmrt), which can be arranged by plantation of specific and relevant vegetation types, which produce shade in summer and for winter with types allowing to let short wave radiation passing the surface or the areas where human spend their time. For the modifications by wind the influence is not so high but relevant to know that increased wind speed in complex structures can reduce thermal conditions of hot conditions.

CONCLUSIONS

The present analysis shows that, in general, for Freiburg 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.

Based on the results reduction possibilities due to modified air temperature, 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. It is not relevant to know only about the expected air temperature changes of future climate but about the thermal bioclimate conditions for urban dwellers.

With less modifications of meteorological conditions in urban structures i.e. increasing the shadow by planting and providing big leaf trees, huge modification of thermal bioclimate are possible. But also possibilities of less modifications of wind conditions can sustainable modify the thermal bioclimate conditions in the micro scale.

Simple and less expensive adaptation strategies esp. in areas where humans spend their time in urban areas 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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