Influence of mean radiant temperature on thermal comfort of humans in idealized urban environments

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Abstract

Studies about thermal comfort of humans in urban areas require the meteorological parameters air temperature, air humidity, wind speed, short- and long wave fluxes. The radiation fluxes can be expressed for these studies by the mean radiant temperature, a parameter with high variability in urban area at least by the modification of the global radiation. Wind speed in urban areas is influenced by the urban obstacles and their orientation. These two factors mean radiant temperature and wind speed can be modified or changed by different height to width ratio or orientation.

1. Introduction

Aim of the study is to quantify the influence of the height to width ratio and effect of the orientation in a typical urban canyon in a western middle size European City. Usually the parameters which at most can influence thermal bioclimatic conditions in urban areas and which can also be modified by urban planning or architectural issues are the radiation fluxes (described in human-biometeorology in terms of the mean radiant temperature) and the wind speed (Lin et al., 2010). Analysing typical urban configurations with typical dimensions the influence on the two above mentioned parameters can be described. Here we analysed the effect of typical structures on the mean radiant temperature and the thermal index physiologically equivalent temperature (Höppe, 1999, Matzarakis et al,. 1999) based on over 10 year measurements of the urban climate station Freiburg (Matzarakis and Mayer, 2008) and the application of the RayMan model (Matzarakis et al., 2007).

2. Methods and data

Modern human biometeorological methods use the human energy balance of the human body (Höppe 1993) in order to extract thermal indices and describe the effects of the thermal environment on humans (Mayer, 1993, VDI, 1998). For this purpose, hourly measurements of air temperature, air humidity, wind speed and global radiation of an over ten year period (1.9.1999 to 31.12.2009) have been used in order to calculate the mean radiant temperature and the physiologically equivalent temperature. The simulations have been done by the use of the RayMan model, which is able to transfer the global radiation from an area with free horizon to urban structures. Main target is the estimation of mean radiant temperature due to atmospheric influences firstly by clouds and other meteorological compounds as vapour pressure or particles. In addition, the influences of topographical or urban morphologies in terms of obstacles modify mostly not only wind but also radiation properties in the micro scale (Lin et al., 2010).
The following configurations and setups have been used. The canyon has a length of 300 m and can be changes in his width and height. In addition the canyon can be rotated

in steps of 15 °. The height and width of the canyon starts from 5 to 40 m. As typical dimension of height and width of the urban canyon, 15 m has been chosen.

3. Exemplary results

First the data has been analysed in terms of the PET-Classes in order to quantify the background conditions at the urban climate station. Figure 1 shows the PET-Classes for the period 1.9.1999 to 31.12.2009. Figure 2 shows the mean monthly frequency distribution of PET-Classes for the same period as in Fig. 1.

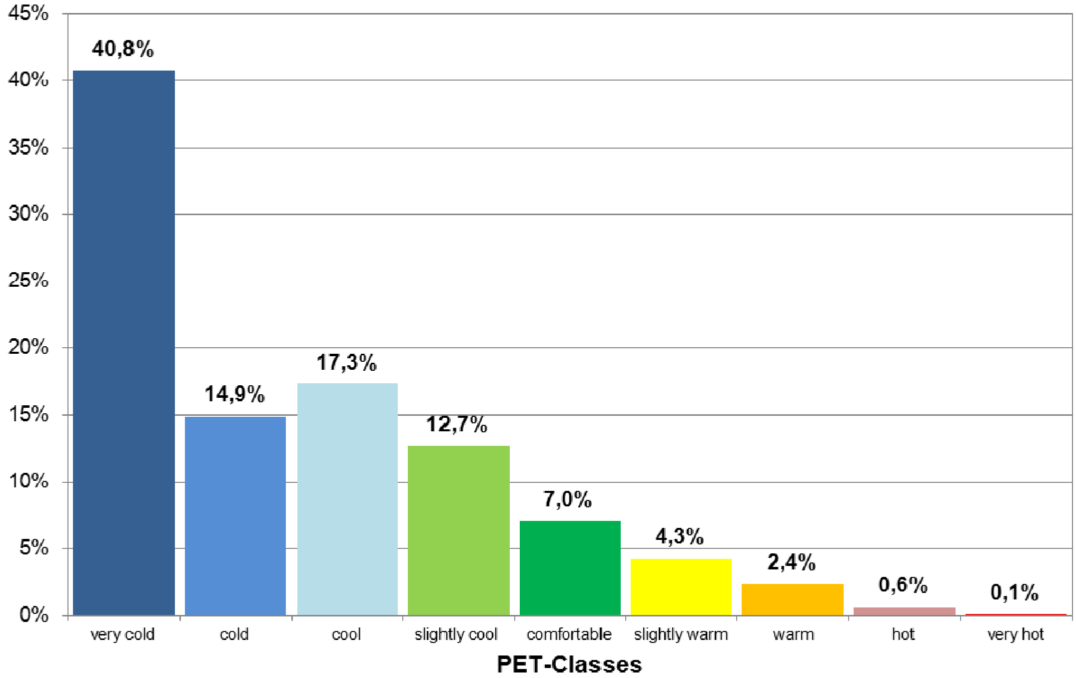

Fig. 1: PET-Classes at the urban climate station Freiburg for the period September, 1st 1999 to December 31st, 2009

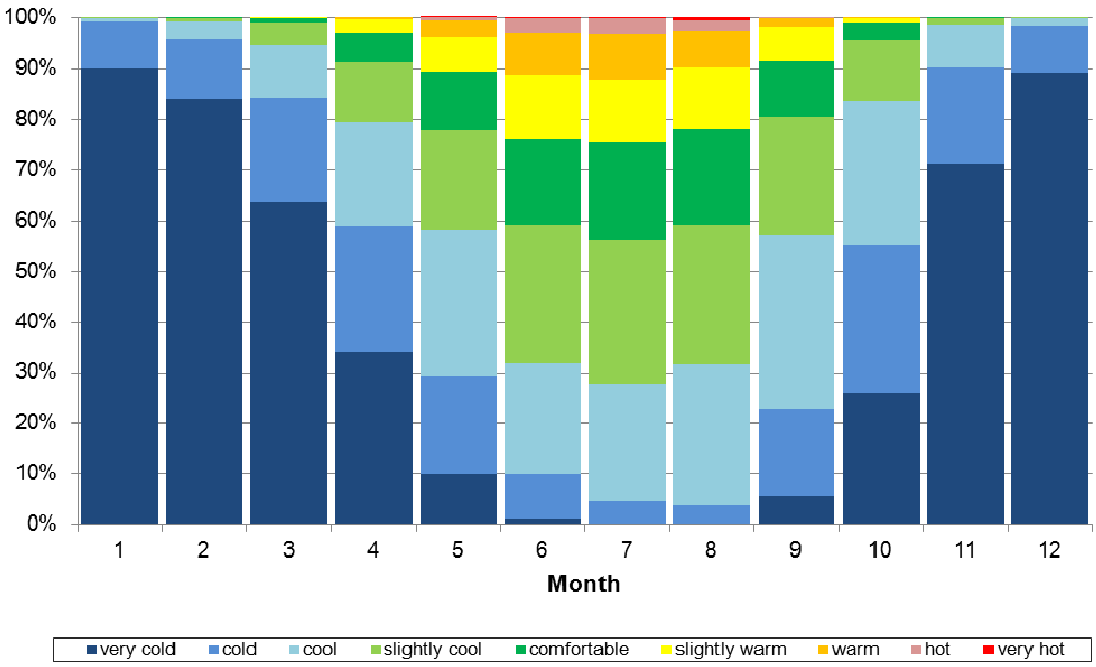

Fig. 2: Monthly Frequency distribution of PET at the urban climate station Freiburg for the period September, 1st 1999 to December 31st, 2009

Fig. 3 and 4 show respectively the diurnal course of the T_{mrt} of an idealized urban canyon in Freiburg in North-South (Fig. 3) and East-West (Fig. 4) orientation. The height of the canyon in both cases is 15 m height and the width is variable from 5 to 40 m. In addition, in the figure is the T_{mrt} at the urban climate station Freiburg included.

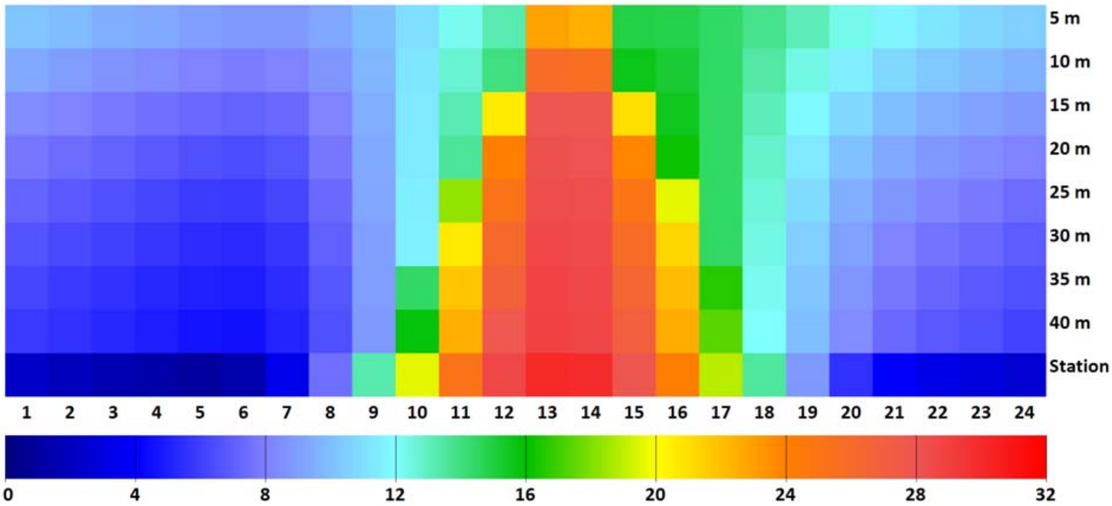

Fig. 3: Diurnal course of T_{mrt} (°C) for an urban canyon with Nord-South orientation, 15 m height and variable width (5 to 40 m) based on the data of the urban climate station and for the period September, 1st 1999 to December 31st, 2009

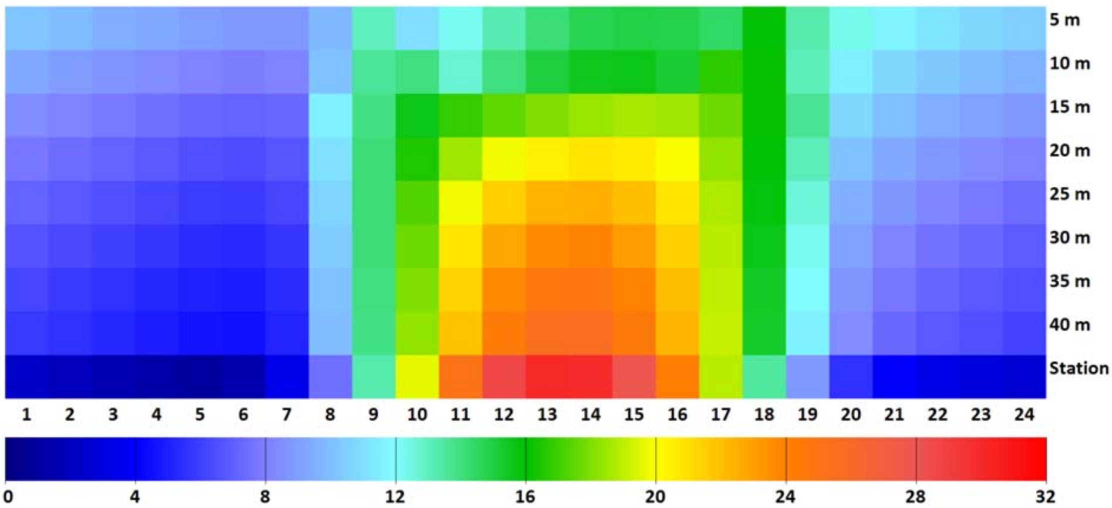

Fig. 4: Diurnal course of T_{mrt} (°C) for an urban canyon with East-West orientation, 15 m height and variable width (5 to 40 m) based on the data of the urban climate station and for the period September, 1st 1999 to December 31st, 2009

From both figures 3 and 4 is can be seen that during the night hours the conditions are similar because of the absences of the global radiation. During the day hours the picture is very clear and at highest in the North-South orientation with width > 15 m reach the highest values. For the East-West orientation (Fig. 4) the increase is lower and do not reach the high T_{mrt} values up to 40 m.

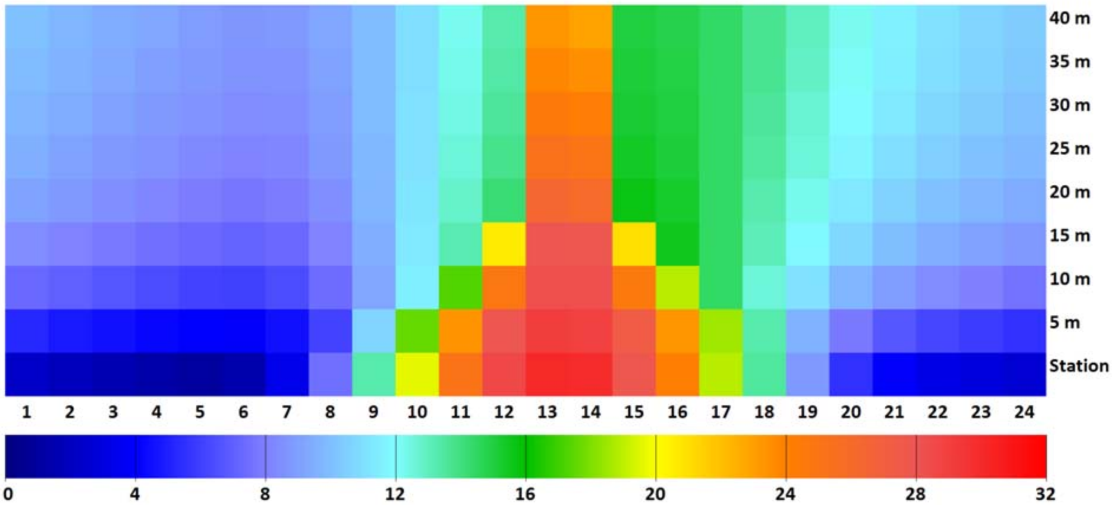

Fig. 5: Diurnal course of T_{mrt} (°C) for an urban canyon with North-South orientation, variable height (5 to 40 m) and 15 m width based on the data of the urban climate station and for the period September, 1st 1999 to December 31st, 2009

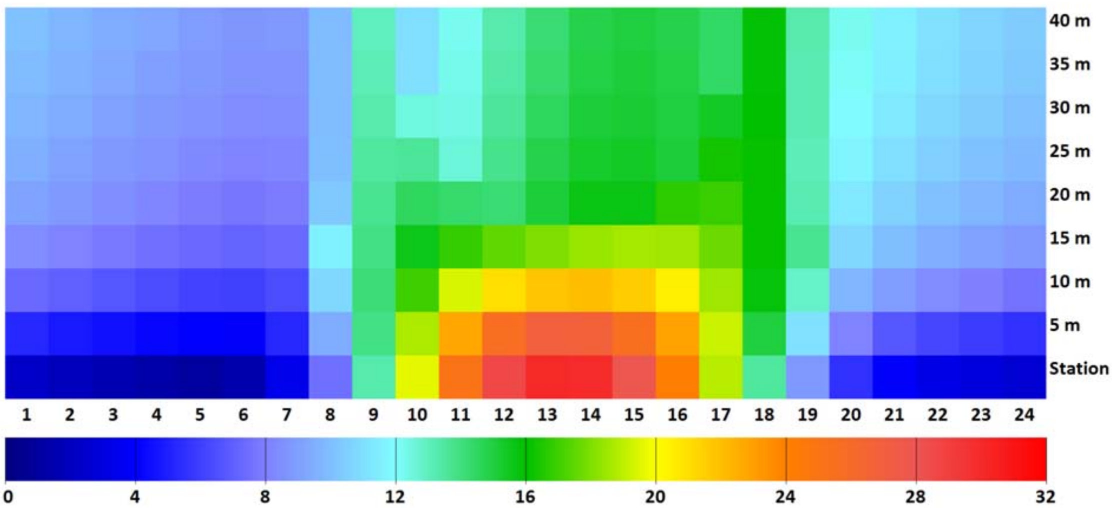

Fig. 6: Diurnal course of T_{mrt} (°C) for an urban canyon with East-West orientation, variable height (5 to 40 m) and 15 m width based on the data of the urban climate station and for the period September, 1st 1999 to December 31st, 2009

Fig. 5 and 6 show respectively the diurnal course of the T_{mrt} of an idealized urban canyon in Freiburg in North-South (Fig. 5) and East-West (Fig. 6) orientation. The width of the canyon in both cases is 15 m and the height is variable from 5 to 40 m. In addition in the figure is the T_{mrt} at the urban climate station Freiburg included. From Fig. 5 and 6 it can be seen that during the night the differences in both orientations and configurations do not differ significantly. Concerning the different orientation the conditions depend of the different height of buildings used.

Fig. 7 shows the step wise (15 °) rotation of the urban canyon with a height and width of 15 m.

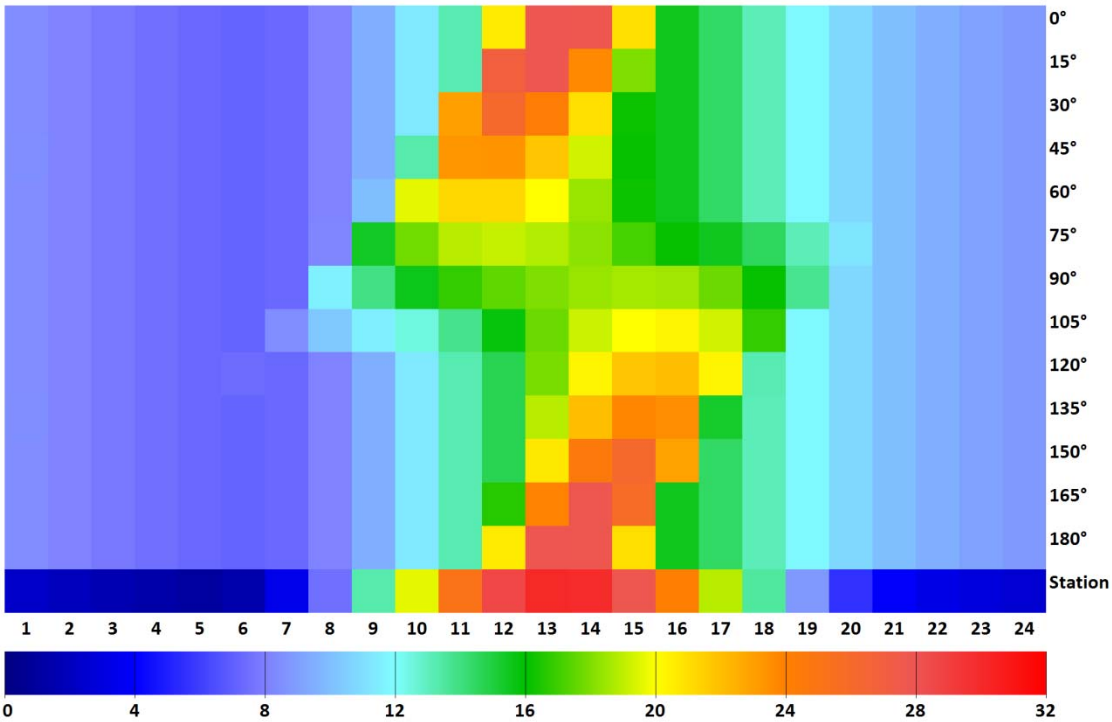

Fig. 7: Diurnal course of T_{mrt} (°C) for an urban canyon with steps of 15 ° rotation for a 15 m height and 15 m width based on the data of the urban climate station and for the period September, 1st 1999 to December 31st, 2009

The orientations 0 ° and 180 ° in Fig. 7 are identical and are marked as North-South orientation in the previous Figures. Equally, East-West is marked as 90 ° in Fig. 7. The results of these orientations can be also found in the other diurnal courses of T_{mrt} (Fig. 3, 4, 5, 6).

Fig. 7 shows that North-South and East-West orientations are the two extrema with highest values of T_{mrt} for North-South and lowest values for East-West during midday. The rotation in both directions starting at 0 ° reduces the values during midday and offset the maximum value of T_{mrt} towards the morning or the evening while the overall daytime values are decreasing. This leads to the described situation for 90 °. The conditions during the night are very similar due to the lack of global radiation, but the orientation of the canyon also affects the timing of the first increase of T_{mrt} in the morning.

4. Discussion and conclusion

The performed simulations show that the mean radiant temperature and also the thermal bioclimate conditions in urban areas can be affected strongly by the urban configuration. Width, height and orientation of an urban canyon are all very important parameters for the evaluation of specific thermal bioclimatic conditions. It is evident that based on radiation fluxes estimations and simulations results can be derived which are important not only for basic research but also for urban planning issues in order to quantify the mean thermal bioclimatic conditions of a region or location.

In this study, existing long-term data of an urban climate station were used for a micro-scale urban bioclimatic simulation. As far as specific biometeorological measurements are not an option because of effort, time, costs or conditions, it is a good alternative to obtain required thermal bioclimatic data. Especially the comparison of different street configurations with the same input data, like realized in this study, is a realistic scenario. It could be an effective way for a global comparison of different urban areas in different climate regions.

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