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SHORT COMMUNICATION

Mean radiant temperature in idealised urban canyons—examples from Freiburg, Germany

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Abstract Studies on the thermal comfort of humans in urban areas require meteorological data such as air temperature, air humidity, wind speed, and short- and long-wave fluxes. In such studies radiation fluxes can be expressed by the mean radiant temperature—a parameter with high variability in urban areas due to variability in global radiation. Wind speed in urban areas is influenced by urban obstacles and their orientation. Both mean radiant temperature and wind speed can be modified or changed by different height-to-width ratios or orientation of urban structures. Modifications to these parameters by typical urban structures (represented by the height-to-width ratio) can result in variation of mean radiant temperature over a range of more than 30°C, which can correspond to three levels of thermal stress. The results presented here provide a possible means of comparing different urban configurations in different climate regions.

Keywords Thermal bioclimate · RayMan · Freiburg · Mean radiant temperature · Physiologically equivalent temperature

Introduction

The aim of this study was to quantify the influence of the height-to-width ratio and the effect of orientation on radiation fluxes in a typical urban canyon in a medium-sized western European city. Studies on thermal comfort and urban heat islands often refer only to case studies and measurement campaigns, and are thus unable to deliver long-term information about conditions in urban areas.

The parameters that influence thermal bioclimatic conditions in urban areas most, and which can also be modified by urban planning or architectural issues, are radiation fluxes (described in human biometeorology in terms of the mean radiant temperature) and wind speed (Lin et al. 2010). By analysing typical urban configurations with typical dimensions, their influence on radiation flux and wind speed can be described. Here, we analysed the effect of typical structures on the mean radiant temperature and the thermal index physiologically equivalent temperature (PET) (Mayer and Höppe 1987; Höppe 1999; Matzarakis et al. 1999) based on over 10 years of measurements at the urban climate station in Freiburg, Germany (Matzarakis and Mayer 2008) and the application of the RayMan model (Matzarakis et al. 2007, 2010a). The RayMan model is able to calculate thermal indices (i.e. PET) and the mean radiant temperature with less data availability. The main primary input parameters for RayMan in the present study were air temperature, vapour pressure, wind speed and global radiation.

The objective of this paper was to show how thermal bioclimatic conditions can be modified in urban canyons in mid-latitude cities.

Data and methods

Modern human biometeorological methods use the energy balance of the human body (Höppe 1993) in order to extract thermal indices to 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 over a period

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of 10 years of measurement (1 September 1999 to 31 December 2009) have been used in order to calculate the mean radiant temperature and the PET. The simulations were conducted using the RayMan model (Matzarakis et al. 2007, 2010a), which is able to transfer global radiation from an area with a free horizon to urban structures. The main target is the estimation of mean radiant temperature due to atmospheric influences, primarily clouds and other meteorological compounds such as vapour pressure or particles. In addition, topographical or urban morphologies act as obstacles, modifying not only wind but also radiation properties in the micro scale (Lin et al. 2010).

The following configurations and setups were used: the model canyon was 300 m in length and its width and height can be varied in steps of 5 m between 5 and 40 m. In addition, the canyon can be rotated in steps of 15°. A typical dimension 15 m was chosen for the height and width of the urban canyon.

The results are presented using CTIS (Climate-Tourism/Transfer-Information-Scheme) software (Matzarakis et al. 2010b). CTIS was developed for the transfer of climate information for tourism purposes and can be applied here.

Results and discussion

The data were analysed in terms of PET classes (Matzarakis and Mayer 1996) in order to quantify the background conditions at the urban climate station. Figure 1 shows the PET classes for the period 1 September 1999 to 31 December 2009. In general, Freiburg belongs to a cool and moderate climate region according to PET classification (Matzarakis and Mayer 1996). Only 3.1% of the hours in the original dataset from the urban climate station in Freiburg can be found in the warm (PET>29°C), hot (PET>35°C) and very hot (PET>41°C) classes.

Figure 2 shows the mean monthly frequency distribution of PET classes for the same period as in Fig. 1. From the frequency diagram, different thermal stress levels can be extracted, with heat stress levels occurring from May to October.

Figures 3 and 4 show the diurnal course of the mean radiant temperature (T_{mrt}) of an idealised urban canyon in Freiburg in the north–south and east–west orientations, respectively. The height of the canyon in both cases is 15 m and the width varies from 5 to 40 m. In addition, T_{mrt} at the urban climate station Freiburg is included in each of Figs. 3, 4, 5, 6, 7 (figures produced using CTIS software; Matzarakis et al. 2010b).

From both Figs. 3 and 4, it can be seen that conditions are similar during the night because of the absence of global radiation. During the day, the effect is very clear and most intensive in the north–south orientated canyon with widths>15 m, where the highest values are reached. For the east–west orientation (Fig. 4), the increase is lower, reaching high T_{mrt} values only as the width approaches 40 m.

Figures 5 and 6 show the diurnal course of T_{mrt} in an idealised urban canyon in Freiburg in north–south and east–west orientation, respectively. The width of the canyon in both cases is 15 m, and the height varies from 5 to 40 m. In addition, T_{mrt} measured at the urban climate station Freiburg is included. From Figs. 5 and 6 it can be seen that the differences in both orientation and configuration do not lead to any significant differences during the night. Concerning the different orientation, the conditions depend on the different height of buildings used.

Figure 7 shows the stepwise (15 °) rotation of an urban canyon with a height and width of 15 m.

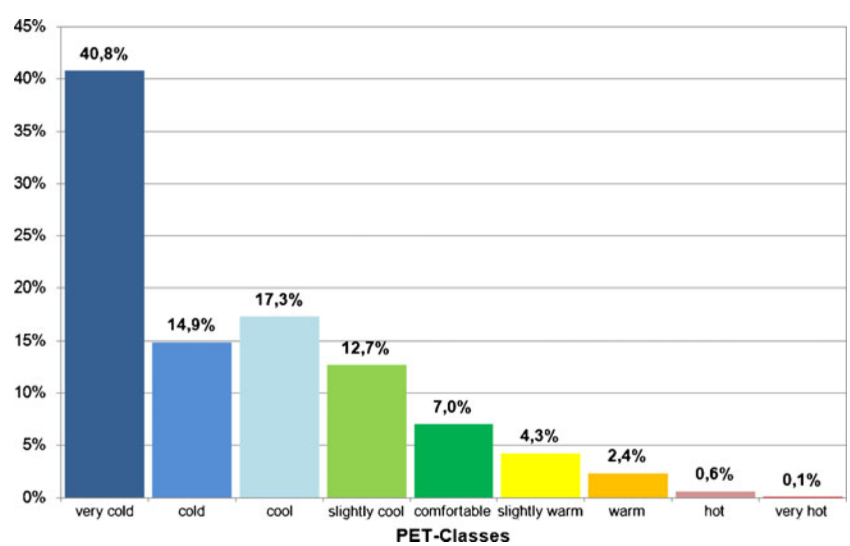


Fig. 1 Physiologically equivalent temperature (PET) classes at the urban climate station Freiburg for the period 1 September 1999 to 31 December 2009

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

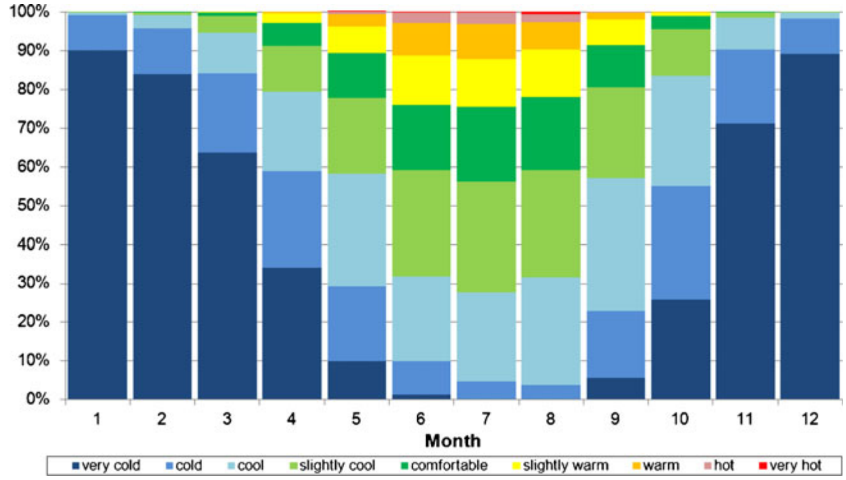


Fig. 3 Diurnal course of mean radiant temperature (T_{mrt}) (°C) for an urban canyon with north–south orientation, 15 m height and variable width (5–40 m) based on data from the urban climate station for the period 1 September 1999 to 31 December 2009

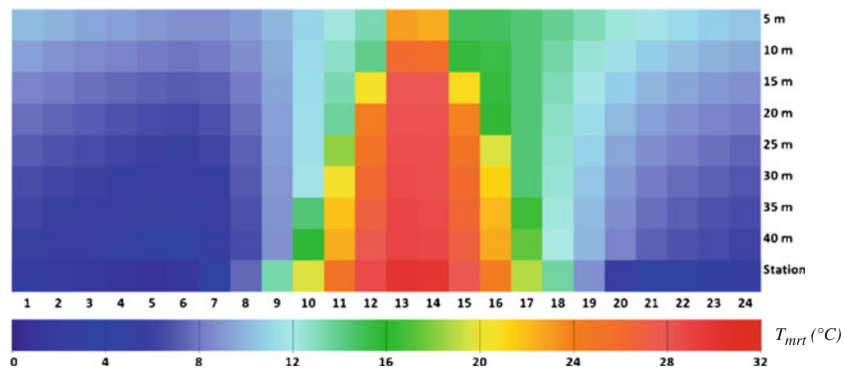


Fig. 4 Diurnal course of T_{mrt} (°C) for an urban canyon with east–west orientation, 15 m height and variable width (5–40 m) based on data from the urban climate station for the period 1 September 1999 to 31 December 2009

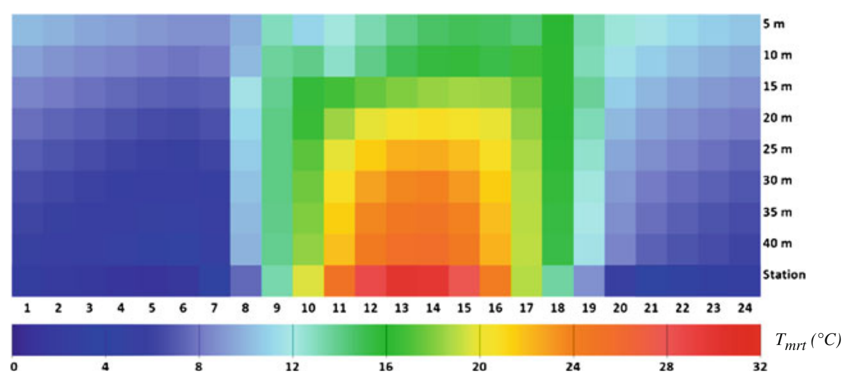
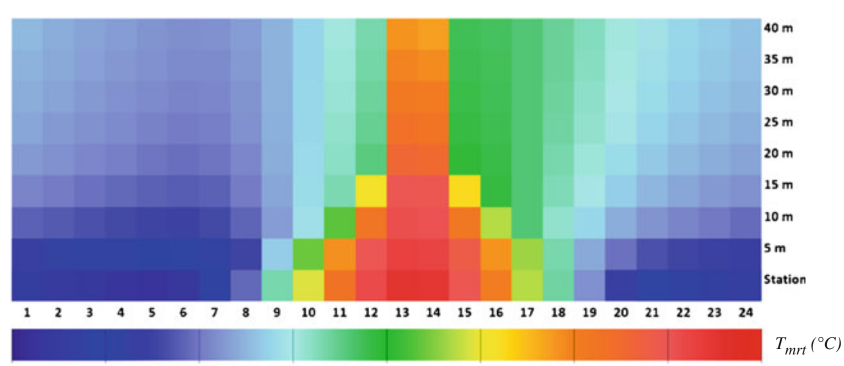


Fig. 5 Diurnal course of T_{mrt} (°C) for an urban canyon with north–south orientation, variable height (5–40 m) and 15 m width based on data from the urban climate station for the period 1 September 1999 to 31 December 2009



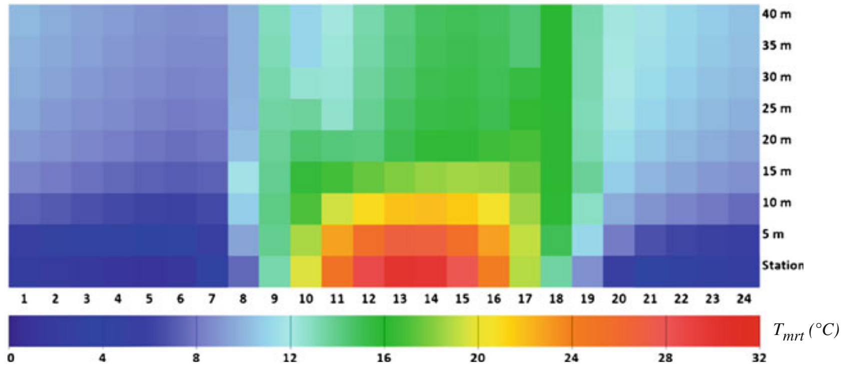


Fig. 6 Diurnal course of T_{mrt} (°C) for an urban canyon with east–west orientation, variable height (5–40 m) and 15 m width based on data from the urban climate station for the period 1 September 1999 to 31 December 2009

The orientations 0° and 180° in Fig. 7 are identical and are marked as the north–south orientation in the preceding figures; likewise, east–west is marked as 90° in Fig. 7. The results of these orientations can also be found in the other diurnal courses of T_{mrt} (Figs. 3, 4, 5, 6).

Figure 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 at midday. Rotation in both directions starting at 0° reduces the midday values and offsets the maximum value of T_{mrt} towards the morning or the evening while decreasing the overall daytime values. This leads to the described situation for 90°. Conditions at night are very similar due to the lack of global radiation, but the orientation of the canyon can affect the time of the first increase in T_{mrt} in the morning. During the day, when direct radiation occurs on specific points, no differences can be found in T_{mrt}. Finally, it has to be mentioned that the orientation and the related exposed surfaces are the main reasons for the differences in T_{mrt}, especially in the morning and afternoon.

Comparing the results for different heights of buildings and streets, and the different orientations of streets, it can be found that, even with building heights of close to 40 m, thermal stress still occurs at noon for north–south orientated streets (Fig. 5). On the other hand, thermal stress at noon is mitigated significantly at building heights >10 m in the case of east–west orientated streets (Fig. 6). In addition, rotation of street orientation reveals the daytime periods and height-to-width ratios at which T_{mrt} is most affected by global radiation at each specific location and geographical latitude.

Conclusion

The simulations performed in this study show that T_{mrt} and 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. On the basis of radiation fluxes, it is evident that estimations and simulations results can be derived that have importance not only for basic research but also for urban planning issues in quantifying the mean thermal bioclimatic conditions of a specific region or location.

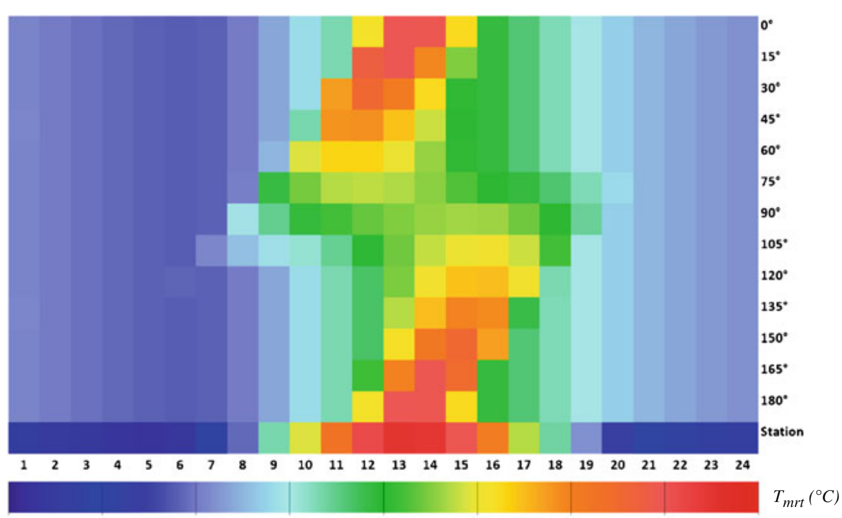


Fig. 7 Diurnal course of T_{mrt} (°C) for the stepwise (15 °) rotation of an urban canyon with a height and width of 15 m based on data from the urban climate station for the period 1 September 1999 to 31 December 2009

In this study, existing long-term data from an urban climate station were used in a micro-scale urban bioclimatic simulation. Where specific biometeorological measurements are not an option because of effort, time, costs or conditions, modeling is a good alternative to obtain the required thermal bioclimatic data. The comparison of different street configurations using the same input data, as realised in this study, is an especially realistic scenario, and could represent an effective method of global comparison of different urban areas in different climate regions and at different latitudes.

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