13.2 APPLICATION OF THE RAYMAN MODEL IN URBAN ENVIRONMENTS

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1. INTRODUCTION

Many climatic parameters and conditions are affected in their temporal and spatial behavior by the natural and artificial morphology on meso- and micro scale. These effects are significant on different levels of regional and urban planning, i.e. design of urban parks or radiation conditions in urban canyons, and a variety of other applications (Matzarakis 2001, Matzarakis et al. 2007, 2010).

For example, thermal indices that are derived from the energy balance of the human body can be of great advantage for many applications in bioclimatology and applied climatology. Standard climate data, such as air temperature, air humidity and wind speed, are needed to calculate and quantify thermal bioclimatic conditions (Höppe 1999, Matzarakis et al. 1999). One of the most important environmental parameters used to derive modern thermal indices, however, are short and long wave radiation (and the derived mean radiant temperature). These can be determined using special techniques that have been implemented in several models (Lin et al., 2010).

The RayMan model, which has been developed for urban climate studies, has a broader use in applied climatology (Matzarakis et al. 2004; Lin and Matzarakis, 2008). It also includes, outputs, such as sunshine duration and shadow, can assist in the design and planning of recreation areas and the design of urban structures.

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 model „RayMan“ estimates the radiation fluxes and the effects of clouds and solid obstacles on short wave radiation fluxes (Fig. 1).

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The model, which takes complex structures into account, is suitable for utilization and planning purposes on local and regional level (Fig. 2 left).

The final output of this model is the calculated mean radiant temperature, which is required in the energy balance model for humans. Consequently, it is also required for the assessment of urban bioclimate and thermal indices, such as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET), and Standard Effective Temperature (SET*).

The development of the model is based on the German VDI-Guidelines 3789, Part II: Environmental Meteorology, Interactions between Atmosphere and Surfaces; Calculation of the short- and long wave radiation and VDI-3787: Environmental Meteorology, Methods for the human-biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate (VDI 1994, 1998). For the calculation of thermal indices based on the human energy balance, meteorological (air temperature, wind speed, air humidity and short and long wave radiation fluxes) and thermo physiological (activity and clothing) data are required. Data on air temperature, humidity and wind speed are required to run RayMan (Matzarakis and Rutz 2005, Matzarakis et al. 2007, 2010).

When using the computer software “RayMan” (Fig. 2 left) an input window for urban structures (buildings, deciduous and coniferous trees) comes up. The opportunity of free drawing and output of the horizon (natural or artificial) are included for the estimation of sky view factors (Fig. 2 right). The implementation of fish-eye-photographs for the calculation of sky view factors is also possible. The amount of clouds covering the sky can be included by free drawing, while their impact on the radiation fluxes can be estimated (Matzarakis 2001).

For the estimation of radiation several morphological information are required and based on them additional information concerning radiation information are extracted. The most important question regarding radiation properties on the micro scale in the field of applied climatology and human-biometeorology is whether or not an object of interest is shaded.

So additional features, which can be used for the evaluation of a region's climate or the development of new urban structures are included in RayMan. These are:

a) calculation of sunshine duration with or without sky view factor (Fig. 2, right, Fig. 3, left);

b) estimation of daily mean, max or total global radiation (Fig. 2, right); and

c) determination of shaded areas are output of RayMan (Fig. 3, right).

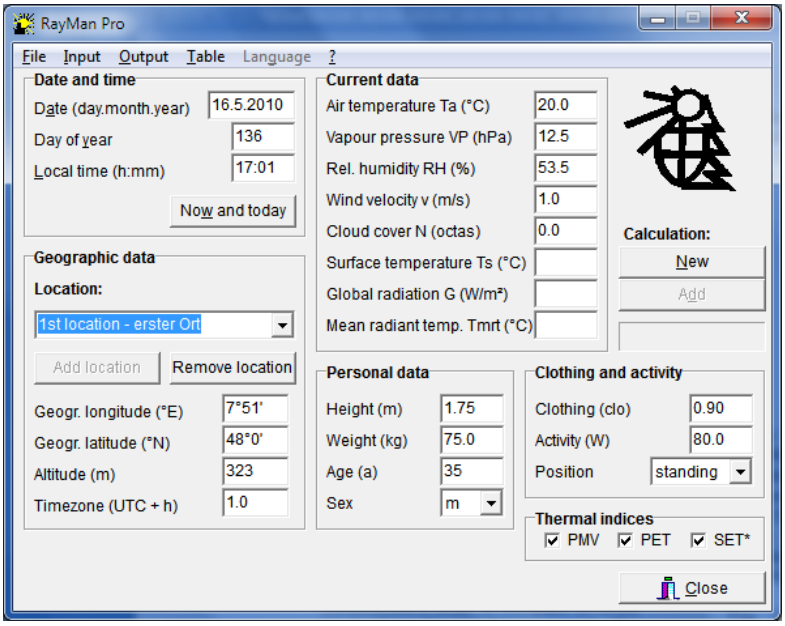

FIG 1. Main window of RayMan.

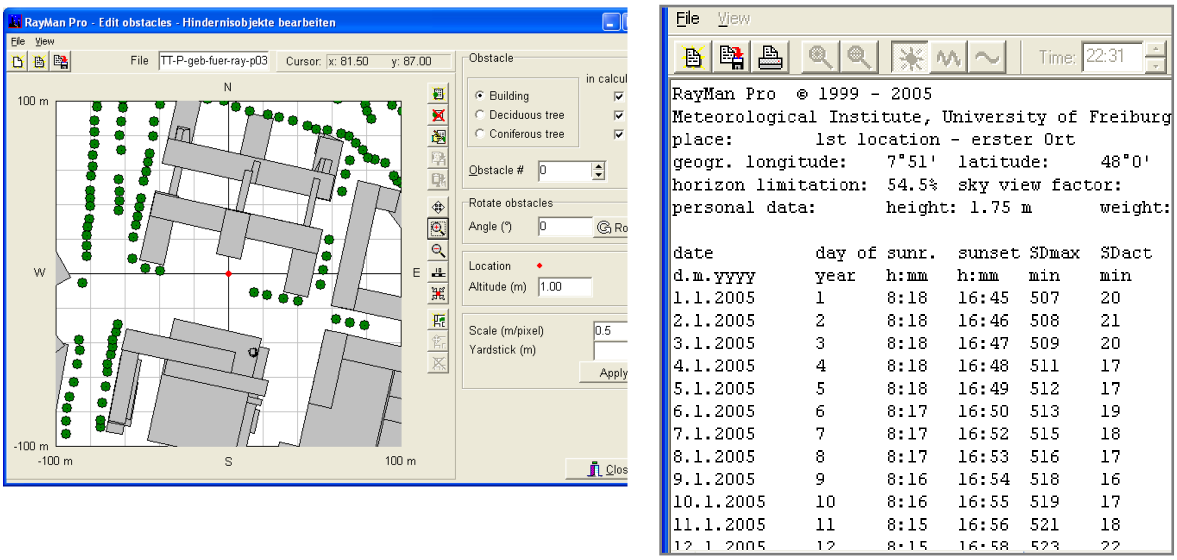

FIG 2. Window for buildings and vegetation input (left) and data output for SVF and sunshine duration in RayMan.

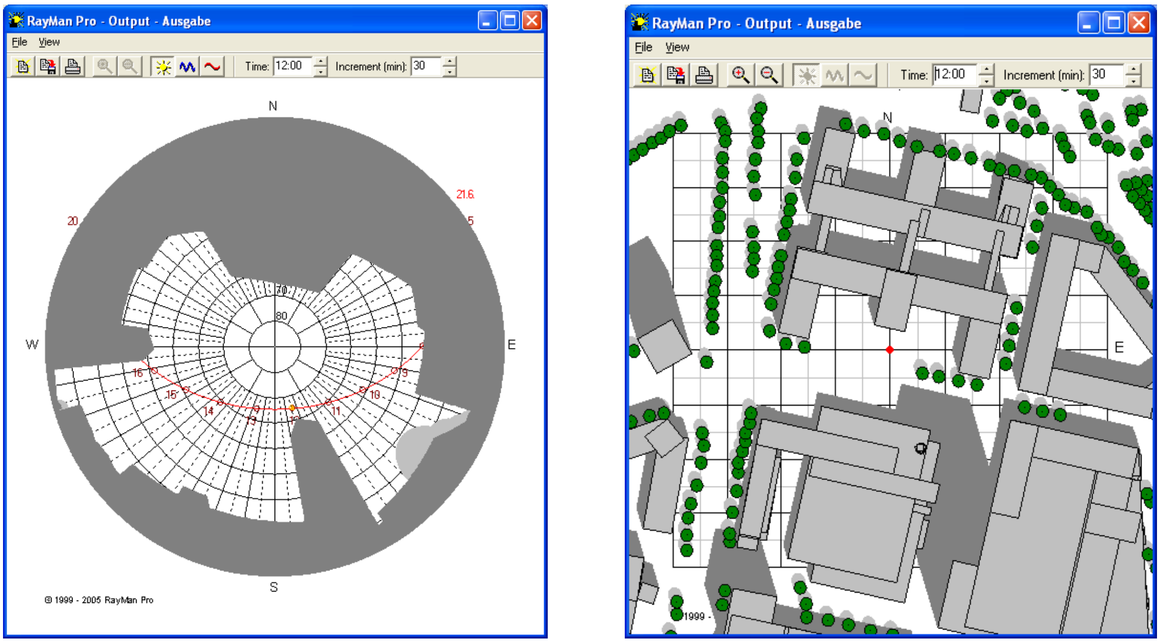

FIG 3. Example of sun path (left) and shadow (right) for June 21 for a complex environment.

Horizon information (in particular the Sky View Factor) is required to obtain sun paths (Fig. 3 left). Calculation of hourly, daily and monthly averages of sunshine duration, short wave and long wave radiation fluxes with and without topography, and obstacles in urban structures can be carried out with RayMan (Fig. 3 left). Data can be entered through manual input of meteorological data or pre-existing files. The output is given in form of graphs and text (Fig. 2 right, Fig. 3 left and right).

3. RESULTS AND EXAMPLES

The RayMan model can be applied for diverse applications. Results for radiation fluxes can even be produced without any meteorological or climatological data. Thus, it is of use for the quantification of sunshine duration at a given point with and without limited horizon (Fig. 3). Results for mean or total monthly sunshine duration can easily be presented for a variety of environments (Tab. 1 based on the building and vegetation data from Fig. 2 and 3). The calculations for a potential building and vegetation morphology presented in Table 1 have been carried out for Freiburg, Germany, in a latitude of 48 °N and for Athens, Greece (Table 2), in a latitude of 38 °N.

TABLE 1. Mean monthly daily sunshine duration without (Sdmax) and with horizon limitation (Sdmn), Sum of monthly sunshine hours without (Dsumax) and with (Dsumn) horizon limitation in h and the ratio between Dsumn and Dsumax for Freiburg, Germany, in a latitude of 48 °N . Urban morphologies (horizon limitations) are shown in Figure 2.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Sdmax (h)	8.9	10.2	11.9	13.7	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.5
Sdmn (h)	1.0	4.4	7.5	8.0	8.3	8.6	8.5	7.8	8.2	5.7	1.9	0.3
Dsumax (h)	275.5	286.4	369.0	409.8	470.5	479.3	483.6	442.6	377.9	336.5	278.9	262.1
Dsumn (h)	30.2	121.8	231.8	240.1	256.7	257.6	264.5	243.3	245.2	175.7	58.5	8.8
Ratio (%)	11.0	42.5	62.8	58.6	54.6	53.7	54.7	55.0	64.9	52.2	21.0	3.4

TABLE 2. Mean monthly daily sunshine duration without (Sdmax) and with horizon limitation (Sdmn), Sum of monthly sunshine hours without (Dsumax) and with (Dsumn) horizon limitation in h and the ratio between Dsumn and Dsumax for Athens, Greece, in a latitude of 38 °N. Urban morphologies (horizon limitations) are given in Figure 2.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Sdmax (h)	9.9	10.8	12.0	13.2	14.2	14.8	14.5	13.6	12.4	11.2	10.1	9.6
Sdmn(h)	4.3	6.1	8.4	8.2	8.1	8.2	8.1	8.2	8.3	7.1	5.1	3.3
Dsumax (h)	306.0	302.0	370.7	395.6	441.0	442.7	449.8	422.0	373.3	347.9	304.4	297.1
Dsumn (h)	134.0	171.1	260.7	244.7	251.6	245.5	252.1	254.8	249.6	219.3	153.9	103.0
Ratio (%)	43.8	56.7	70.3	61.9	57.1	55.5	56.1	60.4	66.8	63.1	50.5	34.7

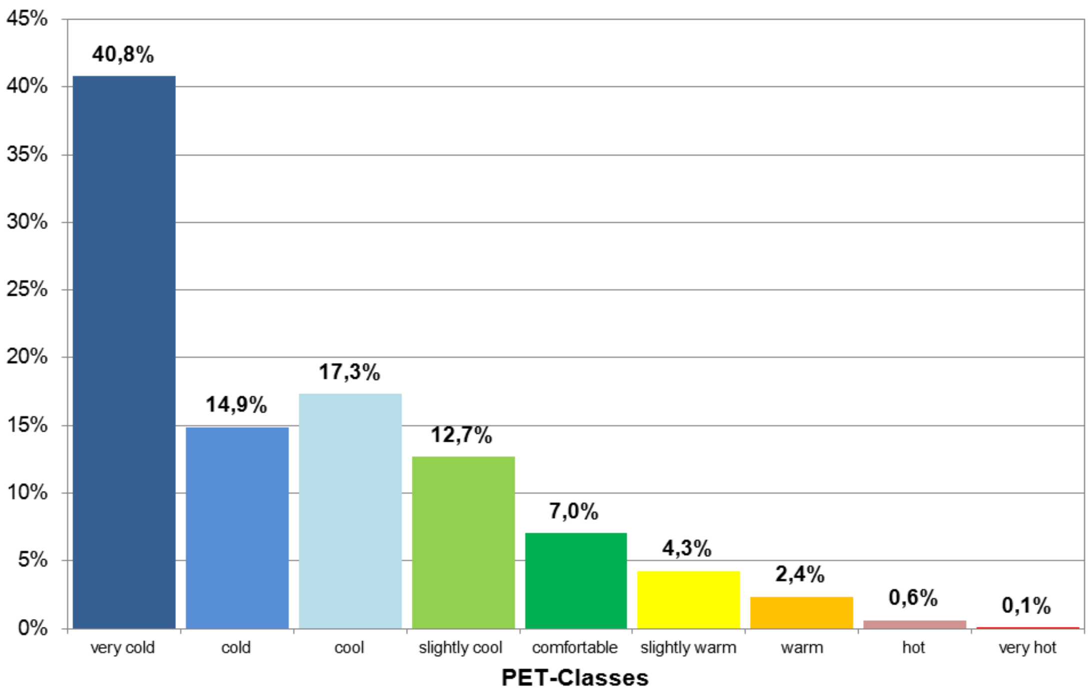

FIG. 4: PET-Classes at the urban climate station Freiburg for the period September, 1st 1999 to December 31st, 2009 (from Herrmann and Matzarakis, 2010)

Fig. 4 shows the classes of Physiologically Equivalent Temperature (PET) based on hourly data for Freiburg for the time period September, 1st 1999 to December 31st, 2009. The data are from the Urban Climate Station of the University of Freiburg (Matzarakis and Mayer, 2008). The shown classes of PET are according Matzarakis and Mayer (1996). From Fig. 4 the occurrences of thermal stress level can be extracted and quantified. It can be shown that 3.1 % of the hours of the year are lying in the heat stress classes (Herrmann and Matzarakis, 2010).

CONCLUSIONS

The presented model provides diverse opportunities in applied climatology for research and education. With available climate or meteorological data, such as air temperature, air humidity, and wind speed radiation fluxes, as well as thermal indices for simple and complex environments can be estimated. Additional information about clouds and global radiation imported in the model can be the basis for a more appropriate estimate of the radiation fluxes. Useful information in more detail can be derived in order to create climate oriented dwellings and facilities for tourism resorts and urban planning. It can also be used for the calculation of shade to be provided by specific construction in urban environments in order to create more comfortable thermal conditions with protection from direct sunlight for humans in cities.

From the human-biometeorology point of view the presented thermal indices can describe and quantify not only mean conditions but also extremes like heat waves and other climate and health issues.

In order to quantify bioclimate conditions for future scenarios, the model can produce information through the use of global and regional climate model outputs. Through the use of geostatistical techniques and tools, the data can be regionalized and provide a more detailed information on the spatial conditions of present and future climate conditions. Through the implementation of different land use and their surface properties, a more appropriate and realistic picture can be created.

When used for education purposes, the model can be applied in exercises as to how to operate these models and in what way land and urban morphology influences short and long wave radiation fluxes in simple and complex environments. Additionally, it can be used for the comparison between experimental and modelling studies in teaching.

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