Assessment possibilities of thermal comfort by micro scale models

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The quantification of thermal bioclimate assessment is based on the human energy balance and the derived thermal indices. The RayMan model can calculate mean radiant temperature and thermal indices. For the calculation of mean radiant temperature, which is one of the most influencing parameters of human thermal comfort, especially during summer many information about the radiation fluxes (short and long wave), wind speed and modifying factors (Sky View Factor, surface temperature, …) are required. This information in combination with shade, sunshine duration, wind speed and direction in simple and complex environments can be derived by the RayMan and the SkyHelios model. The models are not only able to calculate but also visualize climate and urban climate information based on grid data and vector data. They are linked together and can exchange relevant inputs and information.

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1 Introduction

Many climatic parameters and conditions are affected by the natural and artificial morphology on a meso- and micro scale in their temporal and spatial behavior (Herrmann and Matzarakis 2011). These effects are significant on different levels of regional and urban planning, i.e. design of tourism buildings, recreational facilities and urban parks (Hwang et al. 2011, Ketterer and Matzarakis 2014, Herrmann and Matzarakis 2011, Matzarakis and Endler 2010).

For urban climatological or in general for micro climatic studies and their human-biometeorological assessment detailed and precise information are required. Important and demanded parameters and factors are difficult to obtain in complex environments and mostly have to be calculated or modeled (Hwang et al. 2011, Matzarakis and Endler 2010). The required parameters start with the knowledge about and the influence of Sky View Factor (SVF), the influence of sunshine duration and modification of radiation fluxes (Matzarakis et al 2007). Other information and parameters e.g. surface temperature or different surfaces which can influence the energy exchange of different urban structures are of importance. Radiation fluxes and wind speed are the parameters which are modified mostly in urban structures and also have the highest spatial and temporal variability (Fröhlich and Matzarakis 2013).

For example, thermal indices that are derived from the energy balance of the human body, can be of great advantage for diverse application in regional/urban planning issues. Standard climate data, such as air temperature, air humidity and wind speed, are required for the calculation and quantification of human thermal bioclimatic conditions (Höppe 1999). However, one of the most important environmental parameters used to derive modern thermal indices are the short and long wave radiation fluxes (and the derived mean radiant temperature). The required parameters can be determined using micro scale models (Fröhlich and Matzarakis 2013).

2 Methods and models

2.1 Thermal comfort indices

The effect of the thermal environment on humans can be described by thermal indices, which are based on the human energy balance and are appropriate for the description of the effects of climate not only for cold but also for warm conditions (Fanger 1972). Several thermal indices such as Predicted Mean Vote (PMV) (Fanger 1972), Physiologically Equivalent Temperature (PET) (Mayer and Höppe 1987, Höppe 1999, Matzarakis et al. 1999), Standard Effective Temperature (SET*) (Gagge et al. 1986), Perceived Temperature (PT) (Staiger et al 2012) and Universal Thermal Climate Index (UTCI) (Jendritzky et al. 2012) can be calculated for the assessment of human thermal bioclimate in a physiologically relevant manner as shown in several applications (Ketterer and Matzarakis 2014, Fröhlich and Matzarakis 2013). Therefore, meteorological parameters are combined with thermo-physiological aspects of the human body, e.g., activity, height, weight, clothing and age. The values of the indices can be classified by grades of thermal perception for human beings and physiological strain (Matzarakis and Mayer 1996). The meteorological data required are air temperature, air humidity (relative humidity or vapour pressure), wind speed and the synthetically human-biometeorological quantification of the short- and long wave radiation fluxes in terms of the mean radiant temperature (Höppe 1999, Matzarakis et al. 2007).

2.2 RayMan

The „RayMan“ model is developed to calculate short wave and long wave radiation fluxes affecting the human body. ”RayMan” estimates the short and long wave radiation fluxes. The model, which takes complex building structures into account, is suitable for various planning purposes in different micro to regional scales. The final output of the model is the calculated mean radiant temperature, which is required in the human energy balance model and, thus, for the assessment of human thermal bioclimate (Matzarakis et al. 2007, 2010). The thermal indices Predicted Mean Vote, Standard Effective Temperature, Physiologically Equivalent Temperature, Universal Thermal Climate Index and Perceived Temperature can be calculated. The results can be visualized as probabilities of human thermal comfort classes (Fig. 1 right). In addition for detailed thermo-physiological approaches the energy balance fluxes of the human body and body parameters i.e. core and skin temperature can be estimated. Additional features, which can be used for the evaluation of climate in a region or for diverse other applications, are: calculation of sunshine duration with or without sky view factor, estimation of daily mean, max or sum of global radiation; calculation of shadows for existing or future complex environments (Matzarakis et al. 2007, 2010).

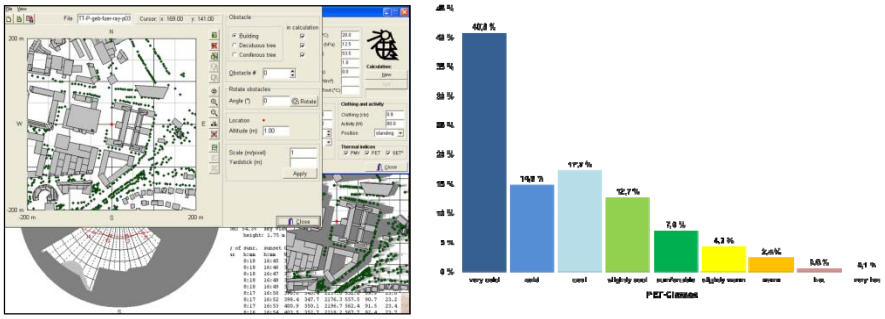

Fig. 1. Screenshots RayMan (left) and output of PET for thermal comfort assessment for Freiburg for the period 200-2010 based on hourly data (right)

When using “RayMan” an input window for urban structures (buildings, deciduous and coniferous trees) comes up (Fig. 1). The opportunity of free drawing and output of the horizon (natural or artificial) are included for the estimation of sky view factors. The usage of fish-eye-photographs for the calculation of sky view factors is also possible (Matzarakis et al 2007, 2010).

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. Hence, in the presented model, shading by artificial and natural obstacles is included. Horizon information (in particular the sky view factor) is required to obtain sun paths. 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. Data can be entered through manual input of meteorological data or pre-existing files. The output is given in form of graphs and text. Advantage of RayMan is the user friendly environment and short running time. Disadvantage is the limitation of calculation for single points.

2.3 SkyHelios

For the spatial dimension of micro climate the SkyHelios model has been developed. SkyHelios uses graphic processors which can be integrated in simulation models computing e.g. visualization of sky view factor or radiation estimation. Going a step further it is even possible to use modern graphics hardware as general-purpose array processors (Matzarakis and Matuschek 2011). These ideas and approaches use a cheap mass production technology to

solve specific problems. They can be applied for modeling climate conditions or climate-relevant parameters on the micro-scale or with respect to complex morphologies.

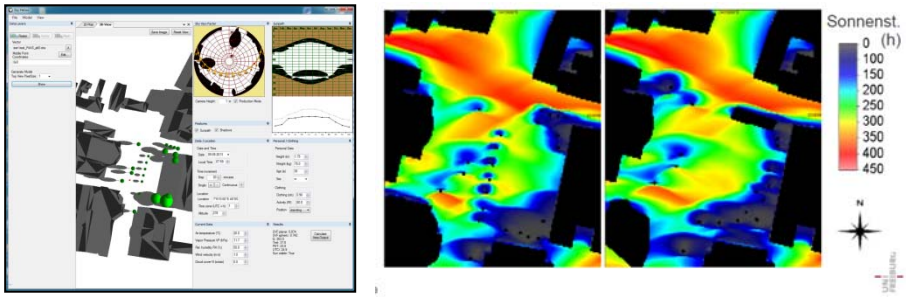

Fig. 2. Screenshot SkyHelios (left) and output of sunshine duration maps before and after a reconstruction for July (right)

To illustrate the simulation of the continuous sky view factor (Fig. 2), the calculation of the SVF for each point of a complex area is included in SkyHelios. Digital elevation models (DEM), data concerning urban obstacles (OBS) or other digital files can serve as a data base in order to quantify relevant climatic conditions such as sunshine duration (Fig. 2 right) in urban and complex areas.

The following benefits are provided by SkyHelios: (a) short computing time and (b) low costs due to the use of open source frameworks. Short computing time is reached by utilizing 3D graphics hardware to solve the complex calculations needed for 3D modeling. The main focus lies on providing a 3D model of the environment to the graphics engine, and making the engine calculate SVF.

The further development includes the integration of a diagnostic wind field driven by measurements of wind speed and wind direction and estimation of mean radiant temperature based on different approaches and also considering the procedure by RayMan. Finally the calculation of thermal indices (PET, UTCI) based on all required parameters and in some cases with the possibility of integration of results from specific measurements or output from other models.

3 Coupling of models and applications

With SkyHelios it can be shown, how the use of computer graphics hardware can improve 3D modeling in applied climatology especially for complex environments (Fig. 2 left). SkyHelios considers and implements diverse options, by not only using the graphic engine of the computer; but also running in the MS Windows environment and providing several visualization techniques. Imported data can be directly exported and viewed in the climate mapping tools (Matuschek and Matzarakis 2011). Frequently-used data formats (i.e., laser, satellite data or DTM) are supported. Direct implementation of RayMan obs files (Matzarakis et al. 2007) is a further advantage and allows for a combination of the two models. The visualization of morphological factors (especially in urban areas) helps to understand micrometeorological processes. Here are several options for the import and processing of data. Data produced in SkyHelios e.g. Fish-Eye pictures of single points can be saved and imported directly in RayMan in order to run sunshine duration, radiation fluxes and if meteorological data for the calculation of thermal indices exist, to run calculation of them.

In addition the newly developed annual sunshine duration diagrams allow for a first estimation of the influence of topography and buildings on sunshine duration both on a yearly and diurnal scale in the spatial context. In addition estimations of maximum global radiation for solar energy devices and other background information in micro-climatology are possible. The inclusion of micro scale wind field allows the quantification of micro climate conditions, which play together with the spatial variability and intensity of short and long wave radiation fluxes the highest role in pattern of thermal comfort issues in complex environments. All

produced graphs and calculated data can be saved and used for other possibilities (i.e., in RayMan or other GIS applications).

4 Conclusions

The presented models (RayMan and SkyHelios) provide diverse opportunities in applied climatology for research and education. Wind conditions, radiation fluxes and the thermal indices for simple and complex environments can be estimated. Useful information in more detail can be derived in order to create climate oriented places and green areas by urban planning and architectural measures. It can also be used for several applications in the field of tourism and recreation.

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