132: Linking urban micro scale models - The models RayMan and SkyHelios

Andreas Matzarakis

Meteorological Institute, Albert-Ludwigs-University Freiburg, Freiburg, Germany
andreas.matzarakis@meteo.uni-freiburg.de

Abstract

In order to derive complex indices for the evaluation of climate in urban and other planning levels information and data about climate and climate influencing factors are of importance. The models RayMan and SkyHelios are two free available micro-scale models for the calculation and estimation of Sky View Factor, sunshine duration, shadow and in general radiation fluxes. In addition, RayMan is able to estimate the most modern thermal indices used in human biometeorology. The two models have the possibility to correspond and link several data formats in order to produce and transfer information for further processing in urban climatological studies and issues.

Keywords: Micro scale models, RayMan, SkyHelios

1. Introduction

For urban climatological or in general for micro climatic studies and their human-biometeorological assessment detailed and precise information are required esp. in urban areas. Important parameters and factors are in complex environments difficult to obtain and mostly have to be calculated or modelled [1]. The required parameters are morphological e.g. sky view factor, which influences sunshine duration and modifies radiation fluxes. Other information and parameters e.g. surface temperature or different 3-D-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 have also the highest spatial and temporal variability.

In order to perform an human-biometeorological assessment, thermal indices which are derived from the energy balance of the human body can be of great advantage for regional/urban planning issues. Standard climate data, such as air temperature, air humidity and wind speed, are needed to calculate and quantify thermal bioclimatic conditions [2,3]. 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.

2. Models

2.1 RayMan

The „RayMan“ model is developed to calculate short wave and long wave radiation fluxes affecting the human body. ”RayMan” estimates the radiation fluxes and the effects of clouds on short and long wave radiation fluxes. The model, which takes complex building structures into account, is suitable for various planning purposes in different scales (Fig. 1). 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 thermal bioclimate [4,5]. It is also relevant for thermal indices that facilitate the human-biometeorological assessment of the thermal component of the climate. The thermal indices Predicted Mean Vote, Standard Effective Temperature, Physiologically Equivalent Temperature, Universal Thermal Climate Index and Perceived Temperature can be calculated. 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 also be calculated.

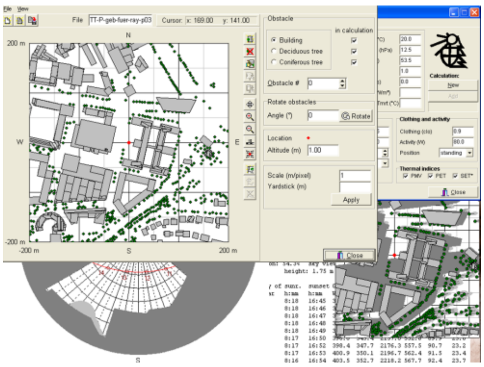

Fig 1. Sreenshots RayMan model

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 factors, estimation of daily mean, max or sum of global radiation; calculation of shadow for existing or future complex environments [4,5].

"RayMan" offers several options for the detection and inclusion of urban structures (buildings, deciduous and coniferous trees). The opportunity of free drawing and output of the horizon (natural or artificial) are included for the estimation of sky view factors). The implementation of fish-eye-photographs for the calculation of sky view factors is also possible [6].

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 (Fig. 2). 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.

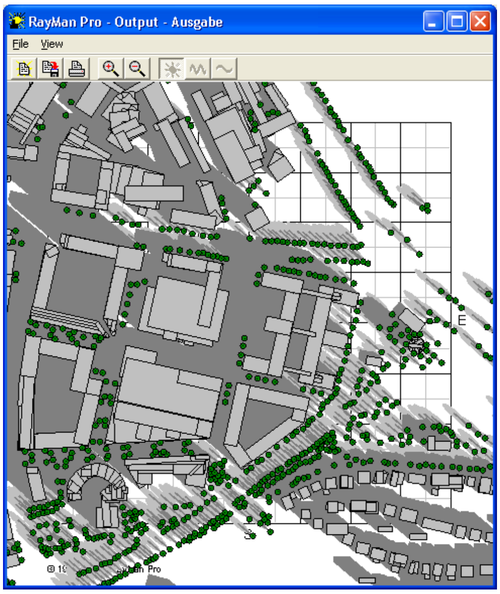

Fig 2. Output shade by RayMan model

The advantage of RayMan is his user friendly environment and the rapid calculation of the radiation fluxes, thermal indices and also visualisation. As disadvantage can be seen that the calculation has to be run for single points. This can be avoided with the adjustment by additional batch mode or macros.

2.2 SkyHelios

For the spatial dimension of micro climate the SkyHelios model has been developed. Intention was also to have the full RayMan functionality and to have a possibility of spatial calculation and visualisation of important and influencing factors of thermal bioclimate.

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. These ideas and approaches use a cheap mass production technology to solve specific problems [7].

This technology can be applied for modeling climate conditions or climate-relevant parameters on the micro-scale or with respect to urban areas. There are two major ways to utilize 3D graphics hardware in climate and meteorological research as well as an intermediary approach combining them. On the one hand, the graphics card can be used as intended by the manufacturer to visualize 3D environments. CUNTZ et al. [8] developed a Graphic Processing Unit (GPU) based framework to visualize time dependent climate flow data. Employing the particle and shadow systems of their graphics hardware, they visualize typhoon and ocean circulations. A typical indicator for this kind of use of 3D graphics hardware is that data are written to the graphics card, but results are not read from it. On the other hand, computer scientists [9] developed a framework to utilize the graphics hardware as a general purpose array processor. Utilizing the vertex programming capabilities of their graphics card, they solve typical time-consuming calculations such as matrix multiplication. THOMPSON et al. [9] further show that in many cases modern graphics hardware can outperform the CPU. First we utilize the graphics hardware to perform a rendering of a three dimensional scene and then we use the graphics hardware to calculate SVF from this rendered scene data, lastly transferring the results back to main memory for further processing.

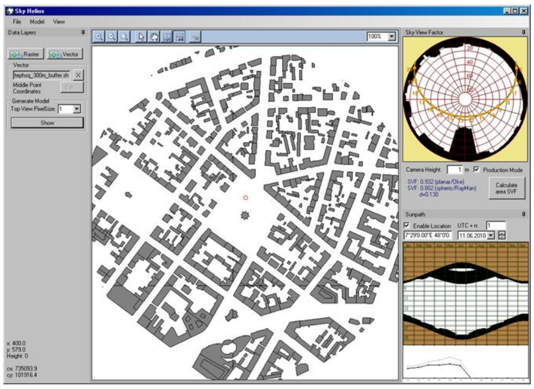

Fig 3. Sreenshot SkyHelios model

To illustrate the simulation of the continuous sky view factor (SVF), thus 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 in urban and complex areas (Fig. 3 and 4).

The following benefits are provided by SkyHelios: (a) short computing time (b) short development time and (c) 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 modelling. Short development time can be achieved since the most complex 3D algorithms have not been dealt with. The main focus lies on providing a 3D model of the environment to the graphics engine, and making the engine calculate SVF. It is not necessary to deal with low level visibility problems, face direction and other geometric algorithms, in contrast to previous approaches, e.g. [10]. Low costs have been reached by utilizing open source 3D graphics engines. These were originally developed for creating computer games. However, as is shown by this work, they can be used for scientific purposes as well.

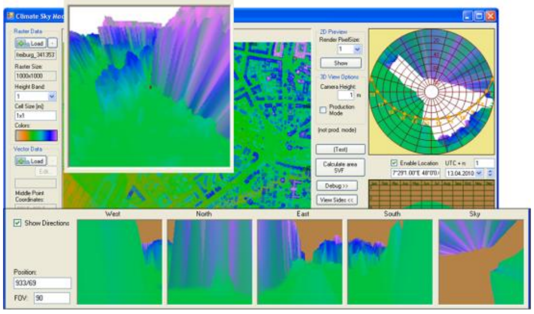

Fig 4. advanced views of SkyHelios model based on laser data

The application of the developed model will be helpful to estimate radiation fluxes and the mean radiant temperature in urban and complex situations accurately, especially in combination with an urban microclimate model, e.g. the RayMan model.

3. Examples and results

2.3 Linking of formats and models

With SkyHelios it can be shown, how the use of computer graphics hardware can improve 3D modelling in applied climatology esp. for complex environments. 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 [11]. Frequently-used data formats (i.e., laser, satellite data or DEM) are supported. Direct implementation of RayMan obs files [4,5] is a further advantage and allows a combination of the two models. Produced or calculated data from one model can be transferred to the other model for further processing. The disadvantage of the one model can be eliminated by the other model. The different data formats can be combined and visualized in order to have an integral picture of the input and output conditions.

In general, modelling cannot reproduce the full reality. Using photographs of the upper hemisphere can reproduce more details of the situation but is also more time-consuming. SkyHelios requires a potent graphics card to operate. Furthermore, on different graphic card types. SkyHelios produces slightly different results lying in the order of fractions of per mill. A SkyHelios compatibility test ensures the correct operation of the model on a specific graphics card. The visualization of morphological factors (especially in urban areas) helps to understand micrometeorological processes. Here are several options for the import and precessing 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 calculate 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. The sky view factor expresses the morphological factors for a specific site in one single value, and therefore allows for an estimation of relevant climatological information. For radiation fluxes estimation, beside the Sky View Factor, other additional features (such as shadow generation and sunshine duration) and also other morphological properties e.g. color or reflexion, heat storage capacity, etc. is required.

Finally 3D hardware is not only advantageous for visualization but can also be used for micro-scale modelling (i.e., for an estimation of maximum global radiation for solar energy devices and other background information in micro-climatology).

All produced graphs and calculated data can be saved and used for other possibilities (i.e., in RayMan or other GIS applications). In addition SkyHelios offers the possibility of running only a part of the investigation but including the effects and limitation of the whole area.

4. Discussion and conclusion

The presented model (RayMan and SkyHelios) provide diverse opportunities in applied climatology for research and education. With readily 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 urban planning [12,13]. It can also be used for the calculation of shade to be provided by special devices for recreation in urban and rural areas in order to create more comfortable thermal conditions with protection from direct sunlight for tourists and visitors.

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 but also for popular place in cities [14]. In order to quantify bioclimate conditions for future scenarios, the model can produce information through the use of global and regional climate model outputs [12]. Through the use of geo-statistical techniques and tools, the data can be regionalized and provide a more detailed information on the spatial conditions of present and future climate conditions [11]. Through the implementation of different land use and their surface properties, a more appropriate and realistic picture can be derived.

In addition that kind of models can be used for education purposes and the models can be applied in exercises as to how to operate these models and how 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. Also basic information about sunshine and shade can be helpful in gathering knowledge of basic morphological and solar access information.

The most valuable advantage of the two models is the diverse communication options in terms of common and produced data and also common graphic formats. The models can be used for different approaches in micro scale and urban climatology issues from urban climate studies an construction of new facilities and other disciplines like landscape planning and tourism.

5. Application in UHI-project

Both models will be applied and further developed in the following UHI-project. The aim of the Interreg project „Development and application of mitigation and adaptation strategies and measures for counteracting the global urban heat island (UHI) phenomenon“ is to investigate and quantify methods for prevention, adaptation and mitigation of natural and man-made risks, arising from the urban heat island.

6. Acknowledgements

The development of the models is a group work and a long term story. I would like to thank all the contributors for the valuable and interesting development work.

7. References

1. Hwang, R.L., A. Matzarakis, T.P. Lin, (2011). Seasonal effect of urban street shading on long-term outdoor thermal comfort. *Building and Environment*, 46: p. 863-870.
2. Höppe, P., (1999). The physiological equivalent temperature in an universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43: p. 71-75.
3. Matzarakis, A., H. Mayer, M.G. Iziomon, (1999). Applications of a universal thermal index: physiological equivalent temperature. *International Journal of Biometeorology*, 43: p. 76-84.
4. Matzarakis, A., F. Rutz, H. Mayer, (2007). Modelling Radiation fluxes in simple and complex environments – Application of the RayMan model. *International Journal of Biometeorology*, 51: p. 323-334.
5. Matzarakis, A., F. Rutz, H. Mayer, (2010): Modelling Radiation fluxes in simple and complex environments – Basics of the RayMan model. *International Journal of Biometeorology*, 54: p. 131-139.
6. Matzarakis, A., (2001). Die thermische Komponente des Stadtklimas. *Ber. Meteorol. Inst. Univ. Freiburg* Nr. 6. p. 267.
7. Matzarakis, A., O. Matuschek, (2011). Sky View Factor as a parameter in applied climatology – Rapid estimation by the SkyHelios Model. *Meteorologische Zeitschrift*, 20: p. 39-45.
8. Cuntz, N., A. Kolb, M. Leidl, C. Rezk-Salama, M. Böttinger, (2007). GPU-based Dynamic Flow Visualization for Climate Research Applications. In: Schulze, T., B. Preim, M. Schumann (Eds), *Simulation und Visualisierung 2007 (SimVis 2007*, 8–9 März 2007, Magdeburg: SCS Publishing House e. V., p. 371–384.
9. Thompson, C.J., S. Hahn, M. Oskin, (2002). Using modern graphics architectures for general-purpose computing: a framework and analysis. MICRO 35. *Proceedings of the 35th annual ACM/IEEE international symposium on Microarchitecture*, Los Alamitos, CA, USA, IEEE Computer Society Press, 306–317.
10. Teller, J., S. Azar, (2001). TOWNSCOPE II – A computer system to support solar access decision-making. *Solar Energy*, 70: p. 187–200.
11. Matuschek, O., A. Matzarakis, (2011). A mapping tool for climatological applications. *Meteorological Applications,* 18: p. 230-237.
12. Matzarakis, A., C. Endler, (2010). Adaptation of thermal bioclimate under climate change conditions - The example of physiologically equivalent temperature in Freiburg, Germany. *International Journal of Biometeorology*, 54: p. 479-483.
13. Herrmann, J., A. Matzarakis, (2012). Mean radiant temperature in idealized urban canyons – Examples from Freiburg, Germany. *International Journal of Biometeorology*, 56: p. 199-203.
14. Fröhlich, D., A. Matzarakis, (2011). Hitzestress und Stadtplanung - Am Beispiel des „Platz der alten Synagoge“ in Freiburg im Breisgau. *Gefahrstoffe – Reinhaltung der Luft*, 71: p. 333-338.