RayMan: A TOOL FOR RESEARCH AND EDUCATION IN APPLIED CLIMATOLOGY

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Abstract

The „RayMan" model, which is presented here, 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 micro to regional levels.

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. It is also relevant for thermal indices that facilitate the human-biometeorological assessment of the thermal component of the climate.

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.

Here, several analyses for different scenarios, i.e. urban climatology and tourism climatology, and different locations (Freiburg and Athens) are presented.

Applied climatology, biclimate, radiation, modelling

1. Introduction

Many climatic parameters and conditions are affected in their temporal and spatial behaviour by the natural and artificial morphology on a meso- and micro scale. These effects are significant on different levels of regional and urban planning, i.e. the tourism industry and also the owners of holiday homes themselves, but they are also of importance for the planning and design of tourism buildings, recreational facilities, urban parks, and a variety of other applications. With some modification, existing methods for assessing climate in human biometeorology and applied climatology can be applied a.e. to tourism climatology (Matzarakis 2001, Matzarakis et al. 2004).

For example, thermal indices that are derived from the energy balance of the human body can be of great advantage for tourism and regional/urban planning. 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. 2001). 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. The RayMan model, which has been developed for urban climate studies, has a broader use in applied climatology (Matzarakis et al. 2004). Further 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

The model „RayMan" estimates the radiation fluxes and the effects of clouds and solid obstacles on short wave radiation fluxes (Fig. 1). 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 et al. 2000, Matzarakis and Rutz 2005).
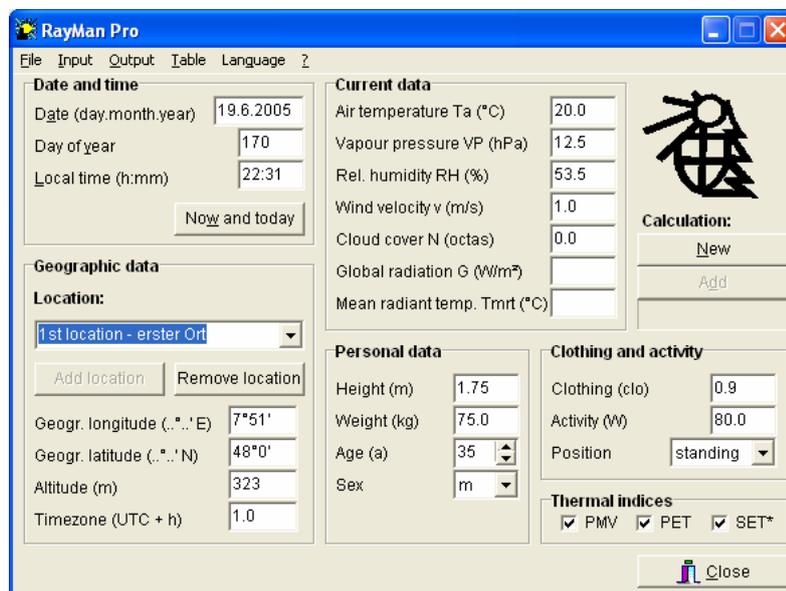

Figure 1. Main window of RayMan.

Additional features, which can be used for the evaluation of a region's climate or the development of new tourism facilities, are: a) calculation of sunshine duration with or without sky view factor; b) estimation of daily mean, max or total global radiation; and c) determination of shaded areas are output of RayMan.

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).

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 (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).
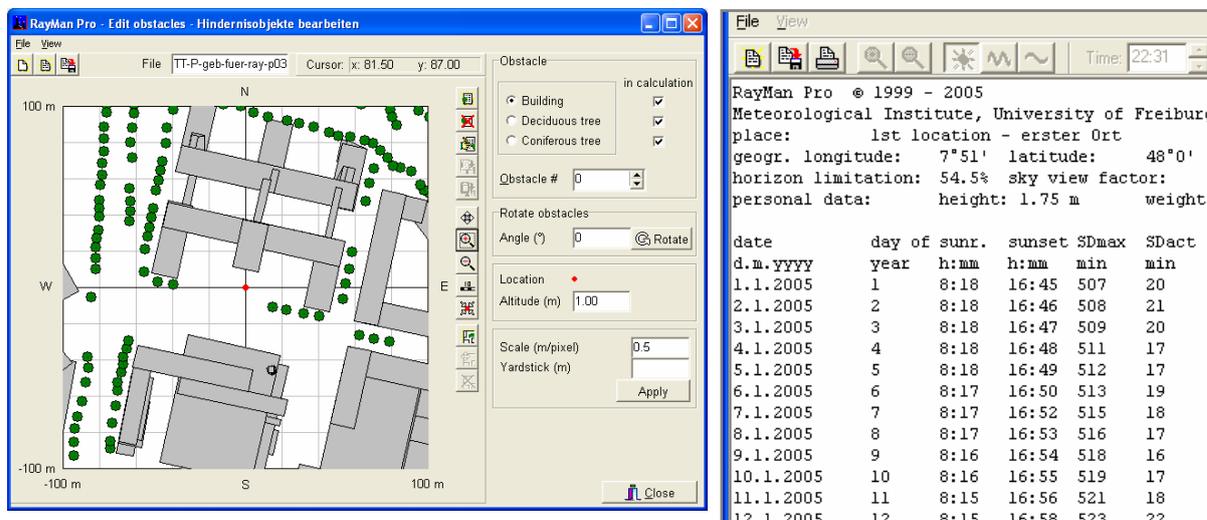

Figure 2. Window for buildings and vegetation input (left) and data output for SVF and sunshine duration in RayMan.
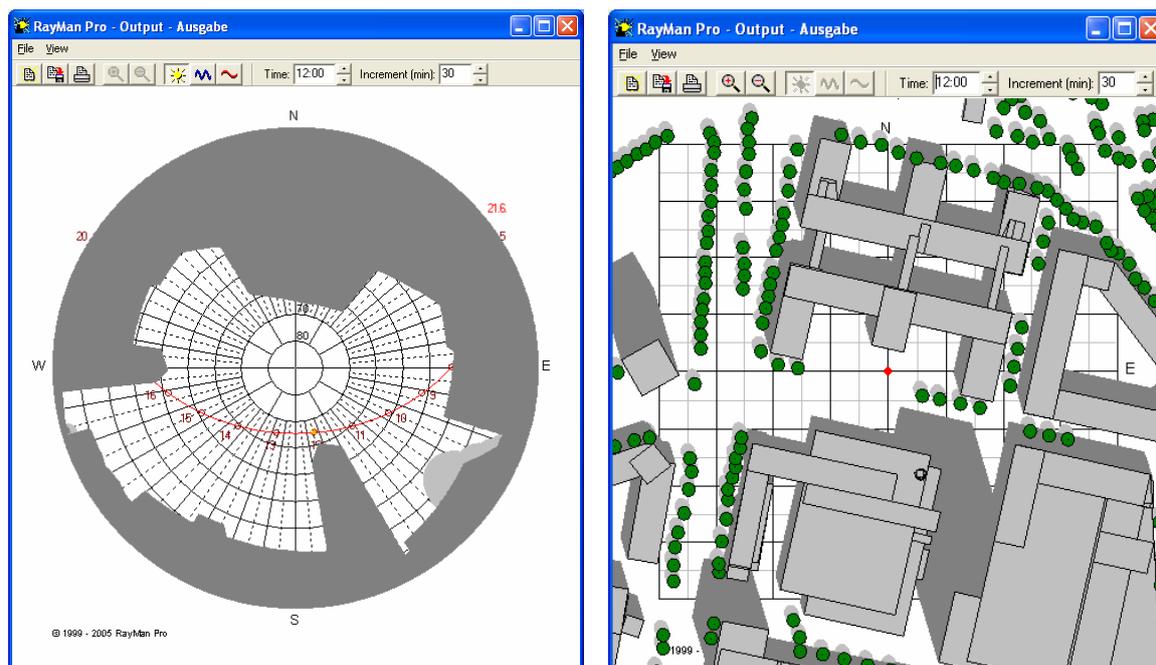

Figure 3. Example of sun path (left) and shadow (right) for June 21 for a complex environment.

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 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 shows the trend of the Physiological Equivalent Temperature (PET) based on daily data for Athens for the time period 1955 – 2001. The figure also shows calculations of PET for individual seasons, the whole year and the tourism period (April to October) based on monthly means.

Several scenarios were used to determine the meteorological parameters needed to predict PET values. Future climatic conditions cannot be predicted with any degree of certainty, as several unpredictable factors are involved. Future socio-economic and technological developments will mainly determine the amount of human-induced emissions of greenhouse gases. To get an impression of the range of possible climate conditions that may be common by the end of the century, a range of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) were used. IPCC undertook an exploration of the possible changes in socio-economic conditions and population (IPCC 2000, 2001), which resulted in a range of plausible scenarios (known as the SRES scenarios). Based on these, GHG emissions and atmospheric concentrations of greenhouse gases could be estimated, which in turn have been used to explore the response of the climate system. Among the four main SRES scenarios, the A1F and A2A represent cases of rapid climate change, while the B1A and B2A scenarios represent more moderate levels of change.
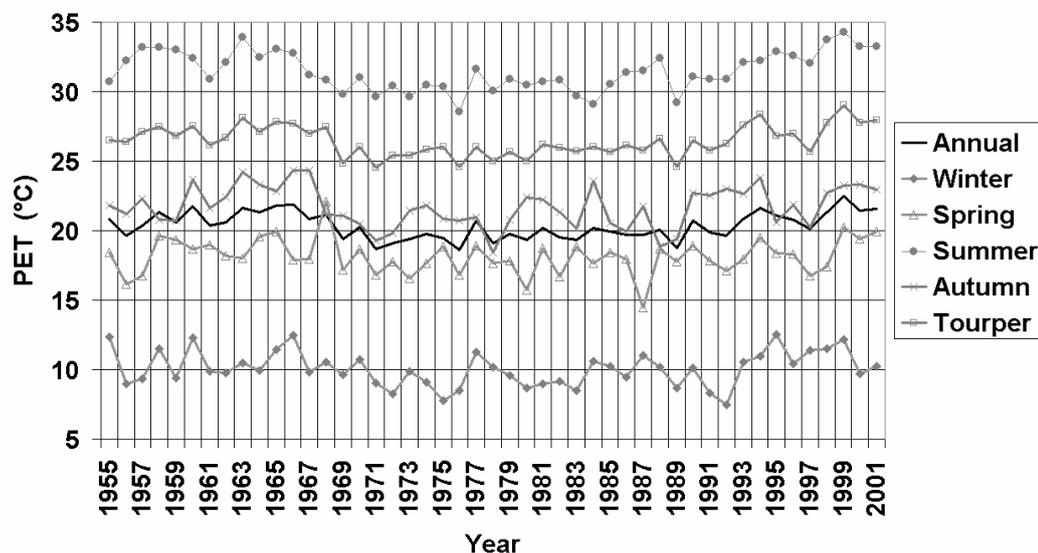
Athens, 1955 - 2001

Figure 4. Seasonal, annual and tourism period (April to October) trend of PET for Athens, Greece for the period 1955-2001.

Table 3: Mean, maximum and minimum seasonal PET values for the Base, A1F and B2A scenarios for the area of Figure 5.

		Winter	Spring	Summer	Autumn
Base	Max	12	20	32.4	23.8
	Min	-5.1	6.8	18.8	8.1
	Mean	3.9	14.2	26.8	16.7
A1F	Max	17.7	25.7	43.5	32.3
	Min	-0.7	11.4	30.8	16.1
	Mean	9.2	19.4	38.3	24.5
B2A	Max	14.8	23.5	40.3	28.7
	Min	-2.6	9.9	26.9	12.5
	Mean	6.7	17.5	34.8	21.3

The dataset of future climatic conditions was based on an integration of the Hadley Centre's HadCM3 model forced with the SRES emissions scenarios (Johns et al. 2003). The HadCM3 model produces gridded data with a spatial resolution of 2.5° latitude x 3.75° longitude, which is significantly coarser than that of the CRU 1.0 dataset. The used HadCM3 dataset consists of monthly averages for four time slices: 1961-1990, 2010-2039, 2040-2069, and 2070-2099. All variables needed for the analysis were available from the CRU 1.0 and HadCM3 datasets, or could be calculated from them. The analyses have been carried out for two seasons and two time slices (i.e. intervals). The time segments represent seasons consisting of the combined months of December, January, and February, and the combined months of June, July, and August, coinciding with the winter and summer seasons in the northern hemisphere and the southern hemisphere respectively. For the northern hemisphere spring is represented through the combined months of March, April and May and autumn is represented through September, October and November. The analysis has been carried out for the historical period 1961-1990 (CNTRL) and for the future period 2071-2100. The PET data have been recalculated

into a higher spatial resolution (1 km) through the use of geo-statistical methods (independent variables was latitude, longitude and elevation). For this purpose the digital elevation data of the GLOBE data set (Hastings et al. 1999) built the basis.
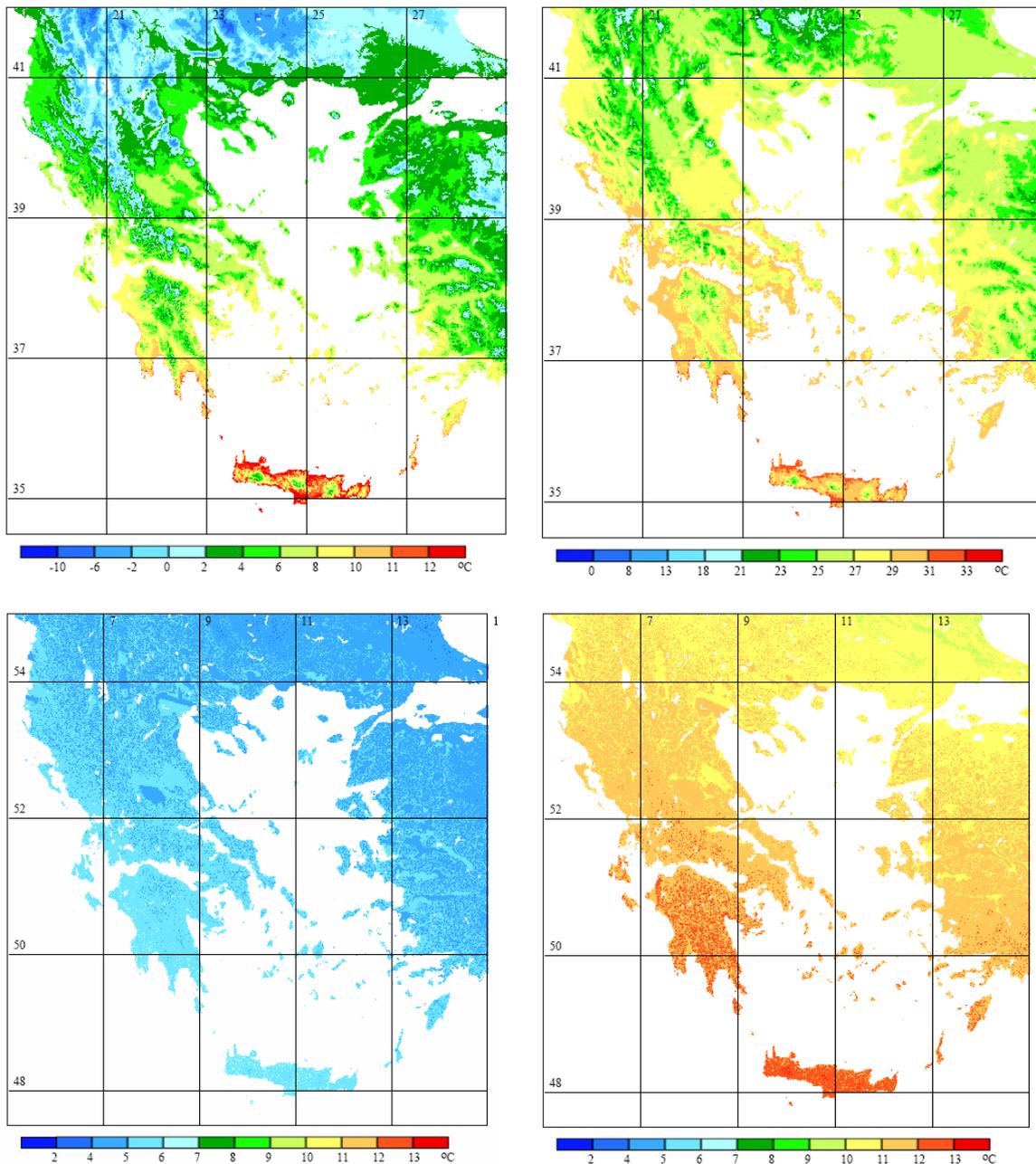
Figure 5. Seasonal maps for winter (upper left panel) and summer (upper right panel) and the differences of PET between the A1F scenario for the time slice 2070 –2100 minus control period (1961 – 1990) for winter (bottom left panel) and summer (bottom right panel).

In table 3 the maximum, mean and minimum values of PET for the seasons in the geographical area presented. The mean values for the CNTRL conditions are 6.3 °C lower for winter and for 12.5 °C lower for the summer months. For spring and autumn the differences are 5.2 °C and 7.8 °C respectively. For the B2A scenario the differences are lower and range between 3.8 °C for winter, 8.2 °C for summer, 3.3 °C for spring and 4.6 °C for autumn.

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Figure 5 shows the geographical distribution for CNTRL conditions (1961 – 1990) of PET for the area of longitude between 19° and 29° E and latitude between 34.5° and 42 °N for winter (upper left) and summer (bottom left). The upper and bottom figure on the right side of Figure 5 shows the differences of the A1F scenario minus the CNTRL conditions of the left side figures for winter and summer. From Table 4 and Figure 5 it can be extracted that the thermal bioclimatic conditions are expected to change drastically based on the A1F scenario. For summer covering changes more than three stress levels for summer in the southern part of the study area and less than two levels for the northern part of the area. For winter the expected changes are ranging between one and two stress levels in the south and one in the northern parts.

4. Conclusions

The presented model provides 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 tourism resorts and urban planning. It can also be used for the calculation of shade to be provided by special devices in tourism areas and resorts 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.

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 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. 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.

Acknowledgement

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