SOMBRERO - Shadow calculations for the use in architecture and urban planning

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ABSTRACT - Shaded areas of windows, solar thermal collectors or photovoltaic modules are of a major importance for the calculation of solar heating- and cooling-loads of buildings as well as for the determination of thermal or electrical output of corresponding solar equipment. The PC-program SOMBRERO calculates the GSC (geometrical shading coefficient), the proportion of shaded area of an arbitrarily oriented surface surrounded by shading elements as a function of time and location. Shading elements are treated as polygons located in a plane and can be combined to bodys such as buildings or trees. They may also represent overhangs and side-wings of the building under consideration. Elements, which are far away from the receiver area are treated as horizontal shading profiles. The reduction of (isotropic) diffuse radiation due to different kinds of obstacles is calculated by means of view-factors. Calculated results of the GSC are stored in ascii-format and can be used as an input for dynamic solar system simulation programs. This is demonstrated in an illustrative example showing the coupling of SOMBRERO with TRNSYS in order to calculate the effects of shading on passive cooling, respectively.

1 Introduction

Shaded areas on the radiation collecting solar aperture may be useful or detrimental for a system, depending on its type and objective. The knowledge of light and shadow finds very important applications within the solar architecture and urban planning. This is because already with the establishment of the local plan for development it is determined, how much sun a building can collect with its various facade elements [Goretzki (1989)][1]. For middle and northern latitudes shaded parts on the southern front of a building, i.e. by other houses placed directly in front of it, must be avoided during the heating period. They would reduce solar gains and with this possible energy savings. In regions further south with a higher solar irradation, however, passive cooling concepts are advantageous.

A further important factor is daylighting. Severe shading of the solar aperture prevents sufficient illumination by daylight for the inner building. On the other hand bright solar beam radiation will cause glarings, which can be avoided by certain shading measures, like overhangs.

Shadows are caused by obstacles between the source of light and the illuminated body, which may consist of several receiver planes (targets). The variety of such obstructions can be placed into three categories:

- obstacles far away, described as horizontal profiles,
- expanded objects of an average distance from the target,
- areas belonging to the illuminated body, which cause a self-shading of certain targets.

Suitable for a corresponding characterization of shading is the geometrical shading coefficient (GSC), the ratio between shaded and total receiver plane area [Yezioro and Shaviv (1994)][2]. SOMBRERO calculates the GSC for both, beam radiation and diffuse radiation [Niewienda and Heidt (1995)][3].

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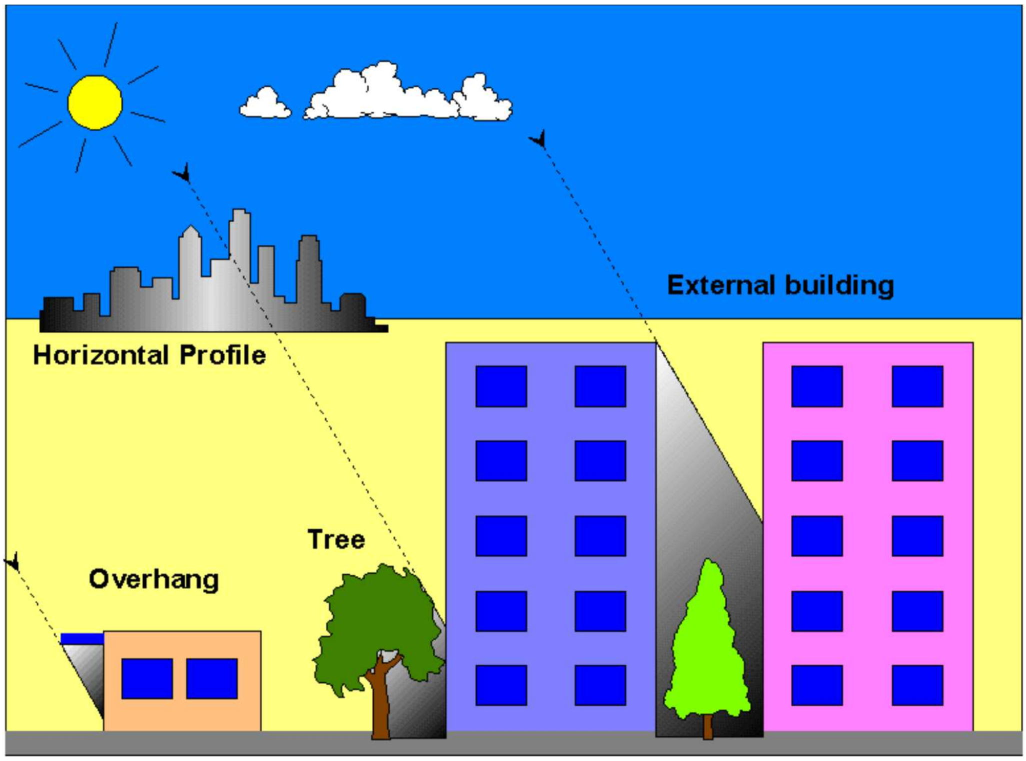


Figure 1: All types of shading shown in this picture are covered by SOMBRERO.

2 Features of SOMBRERO

SOMBRERO includes an entire user interface and runs on a standard MS-Dos PC with a VGA-graphic card. A MS-Windows version is under development. Yearly shadow simulations as well as short time studies for a day or even shorter time intervalls can be performed with a minimum expenditure in time.

The user describes an area by its azimuth, elevation and its vertex-points in the body-system (u-v-system), which is depicted in Figure 2. Because this system is 2-dimensional a description of the vertex-points is easy and can be achieved by introducing coordinates into a plan of the scenery. The origin of the u-v-system within the SOE-system can be used to position elements at their destination.

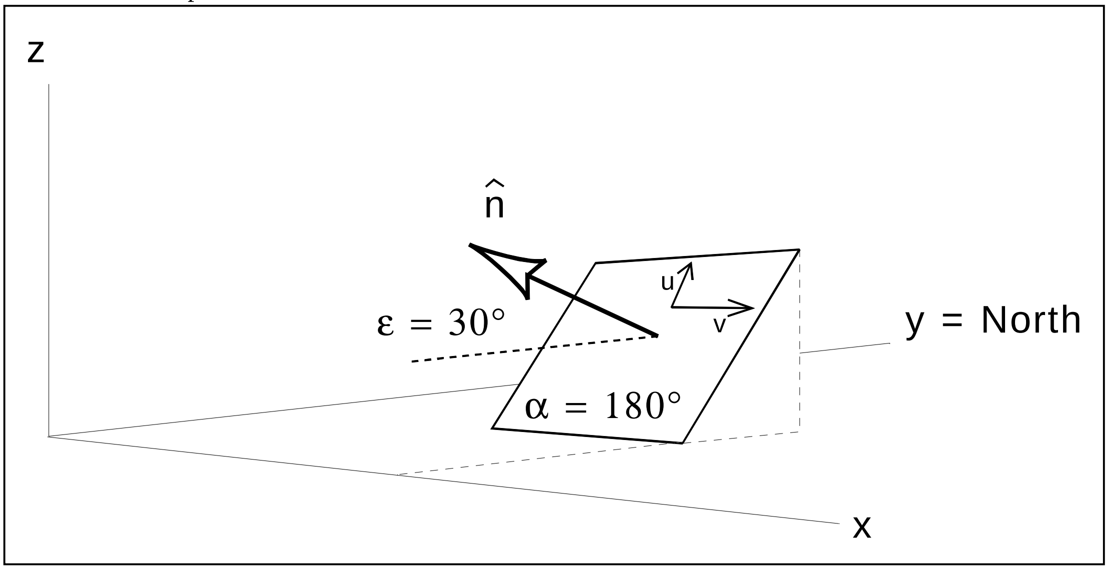


*Figure 2: **S**urface-**o**f-**e**arth-system (SOE-system) with an area oriented to the south. The azimuth α is counted clockwise from the north, i.e. a south-oriented area has an azimuth of 180°. The elevation angle of the example area is 30°. The front-side is facing the sky, which is indicated by the normal vector $\hat{n}$. The u-v-axes indicate the body-system (u-v-system).*

Figure 3 shows a view of a fassade with two windows. If we consider them as receiver areas for a thermal zone, we have to describe their positions and their dimensions. Because they are rectangles, each of them can be described by a lenght Δu and a height Δv and an origin position in the u-v-system (u_0, v_0). After the positioning within the u-v-system, the relative orientation of the u-v-system and the SOE-system has to be known. This is achieved by describing the azimuth and elevation of the fassade in the SOE-system. This fassade, for instance, shall have an elevation of 0° and an azimuth of 135°, which is a vertical wall oriented to the south-east. The last step is to tell the module, where the origin of the u-v-system is located within the SOE-system. Again we can get this information from a plan which shows the scenery from above, e.g. a plan of a town / site. So we have a description of the scenery in its natural coordinates. For receiver areas it is also possible to create overhangs and side-wings by declaration of their relative elevation or azimuth according to the u-v-system.

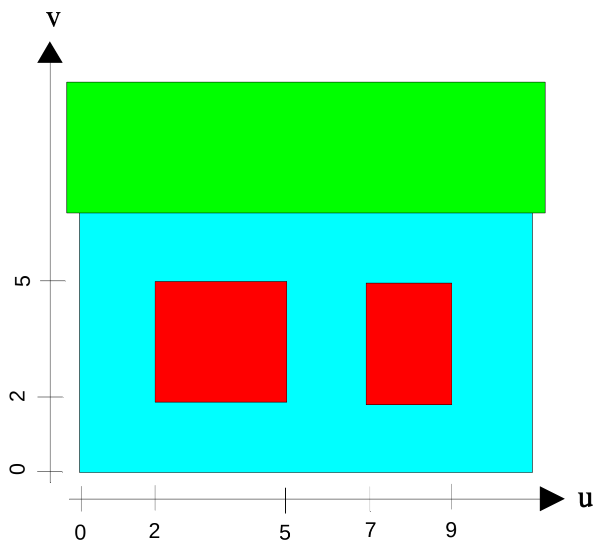
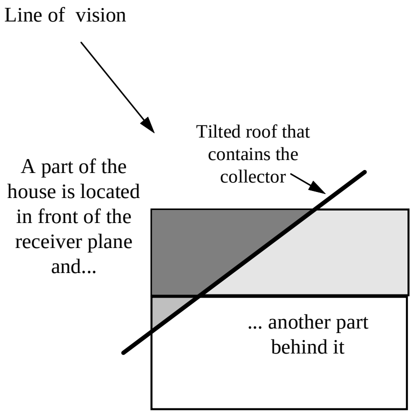


Figure 3: View of a fassade with two windows. They are described by their length, height and origin within the u-v-system. The u-v-system is regarded as the body-system of the fassade. Units are in meters.

For frequently occuring obstacles like houses or trees a simple generator has been written. A house, for instance, is described by its length, height, height of roof, its orientation and origin in the SOE-system. A maximum of 300 polygons with up to 12 points can be handled by the program. Shadows of trees are treated separately because of their variable amount of leaves. The user may define a monthly schedule for the opaque part of the tree.



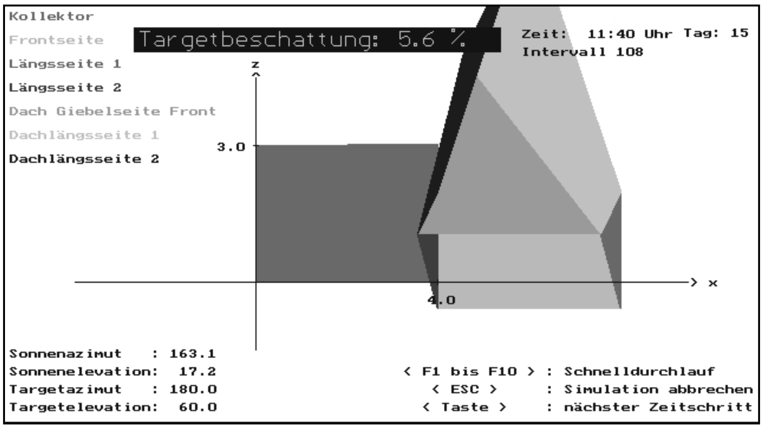


Figure 4: Online display of SOMBRERO. This picture shows the shadow simulation of a dormer on a pitched roof with a collector surface (rectangle, 3 m x 4 m on the left hand side). The pediment is modelled as a house which is placed partially behind the roof. The program reduces the polygons in a way that only the parts in front of the collector plane are printed on the display.

3 Application example: Coupling of SOMBRERO and TRNSYS

The transient system simulation program TRNSYS is able to read pre-processed hourly values for the shading coefficients of SOMBRERO from a data file. With some modifications[3] in the TRNSYS deck-file even the calculation of the shaded diffuse radiation on a tilted surface is possible by using the view-factors for sky and ground calculated in the shadow simulation. TRNSYS then calculates the temperatures and heating and cooling loads of the building under consideration.

To show the influence of shading through external buildings on the overheating risk in summer, we simulated the temperature evolution in an office room during a typical summer situation of five days length. In our example we considered a single zone only. The office room is part of a big building. Its window is facing the south-east (see Figure 5). The external wall is massive with 8 cm thermal insulation material on the outside surface. The U-value of the windows is 3.0 W/m²K. The airchange rate was set to 2/hour. The simulation period covers some hot, sunny days in august (climatic data of Essen, Germany). Opposite to the window several higher buildings are located in a distance of 8 m across the road. The evolution of the temperature in the room was simulated once with and once without the influence of the shading buildings. The results of the development of room temperatures are presented in Figure 6.

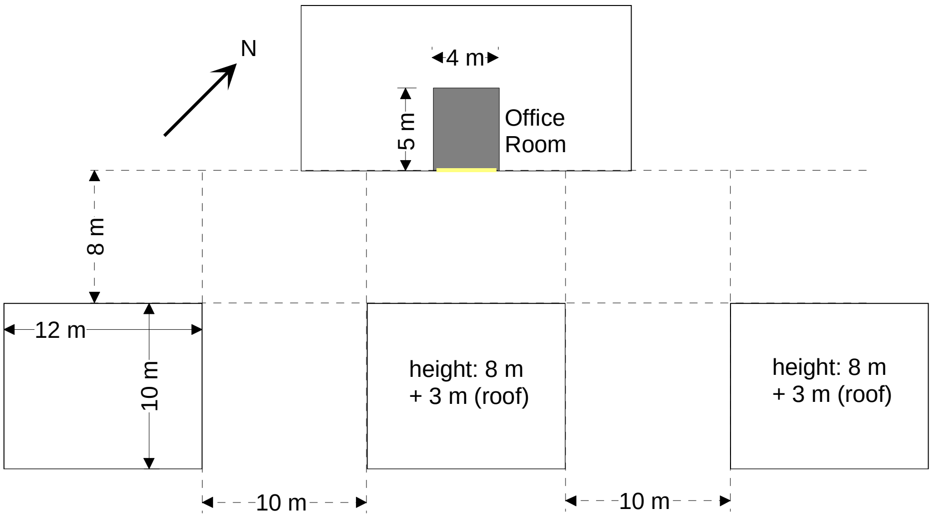


Figure 5: Site plan of an office room in a town. The room is surrounded by buildings. Window orientation is south-east. Window-size is 3.5 m x 2 m, height of window sill above ground is 3 m.

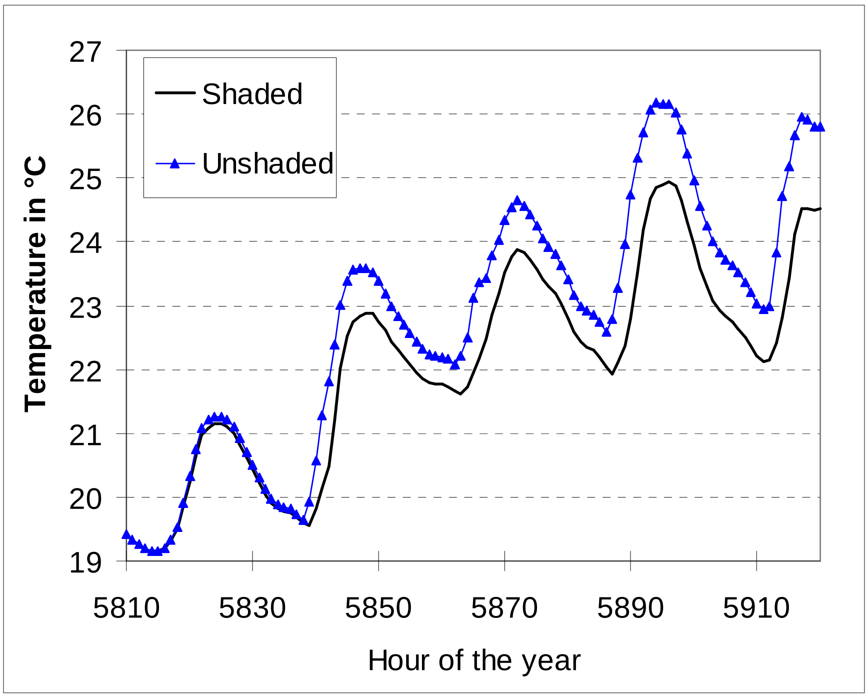


Figure 6: Development of the office room temperature during a five day hot and sunny weather period. The upper curve refers to the unshaded case.

The two curves of Figure 6 show that during the whole period the temperature of the partially shaded room rises slower than that of the room without shading and never exceeds 25°C. This difference in behaviour affects the thermal comfort as well as the cooling load of the building. Such results are important for the development of a strategy to keep the energy consumption for cooling at minimum values.

4 Conclusion

The PC-program SOMBRERO calculates the quantities and time dependency of the shadow coefficients for beam and diffuse radiation. Shadow simulation of complex sceneries can be carried out on a PC with a minimum expenditure in time and without the use of further programs. It was shown that the influence of shadows on thermal properties of buildings and solar energy equipment is substantial to the performance of these systems. Detailed output is available in formats which allow the coupling of SOMBRERO with other simulation programs. This was demonstrated in an example for thermal simulation with TRNSYS.

Acknowledgements

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