SOMBRERO - SHADOW CALCULATIONS ON ARBITRARILY ORIENTED SURFACES AS A PREPROCESSOR FOR SIMULATION PROGRAMS

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ABSTRACT

SOMBRERO, a PC-program running under the operating system Windows^{TM}, calculates the proportion of shaded area of an arbitrarily oriented surface surrounded by shading elements as a function of time and location. The reduction of (isotropic) diffuse radiation due to different kinds of obstacles is calculated by means of view-factors, too. Calculation results are displayed online, and ASCII output files are produced that can be read into dynamic thermal building simulation systems or spreadsheet programs.

Three examples for the practical use of SOMBRERO are presented:

1. The windows of an office are shaded by some surrounding buildings. With SOMBRERO, the influence of shading by these buildings on overheating in summer was investigated.

2. The optimum position of a solar collector on the roof of a one-family house was determined.

3. The effects of a number of deciduous trees that were to be planted in front of a two-story building on the heating energy demand, lighting in the rooms and overheating were examined.

INTRODUCTION

Detailed thermal simulation of buildings has become increasingly common during the past few years. With transient simulations of buildings, planners may determine what the climate in a future building will be like for different external conditions, which amount of overall heating or cooling energy will be consumed and how heating, cooling and air conditioning devices have to be dimensioned.

As daylighting and the passive use of solar energy become more and more important in present architecture, planners need exact data about the shading of windows. When site plans for solar buildings are being established, a shading analysis should be performed [1]. The same is, of course, true for the installation of solar thermal collectors or photovoltaic modules. Some dynamic building simulation programs provide a means to calculate certain special kinds of shading by overhangs, sidewings or skyline profiles. However, with most simulation programs it is either impossible or at least inconvenient to calculate when and to what extent a certain area will be shaded from direct and diffuse sunlight by 3-dimensional external objects. For example, *SUNCODE-PC* [2] and *TRNSYS 14.1* [3] do not incorporate this feature. In *DOE-2* [4], shadows due to external plane objects may be modeled. *TAS* [5] offers quite convenient possibilities for shading analyses.

SOMBRERO, a PC-program running under the operating system Windows^{TM}, calculates the GSC (geometrical shading coefficient), that is the shaded proportion of the area of an arbitrarily oriented surface surrounded by shading elements [6], as a function of time and location. Shading elements are treated as polygons (not necessarily rectangles) in a plane. They can be combined to bodies such as buildings or trees and may also represent overhangs and sidewings of the building under consideration. Some algorithms used in *SOMBRERO* are based on [7] and [8]. A complete, detailed description of the program can be found in [9].

By means of the integrated geometry generator the user can easily enter standardized trees and houses. The effects of partially or temporarily transparent objects can be investigated, too. Time schedules for shading objects and ground reflection may be provided. This is especially useful for the treatment of shading by vegetation.

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. A utility for exporting results into the dynamic simulation programs TRNSYS and SUNCODE as well as into EXCEL is available.

In the following, three examples for the practical use of SOMBRERO are presented.

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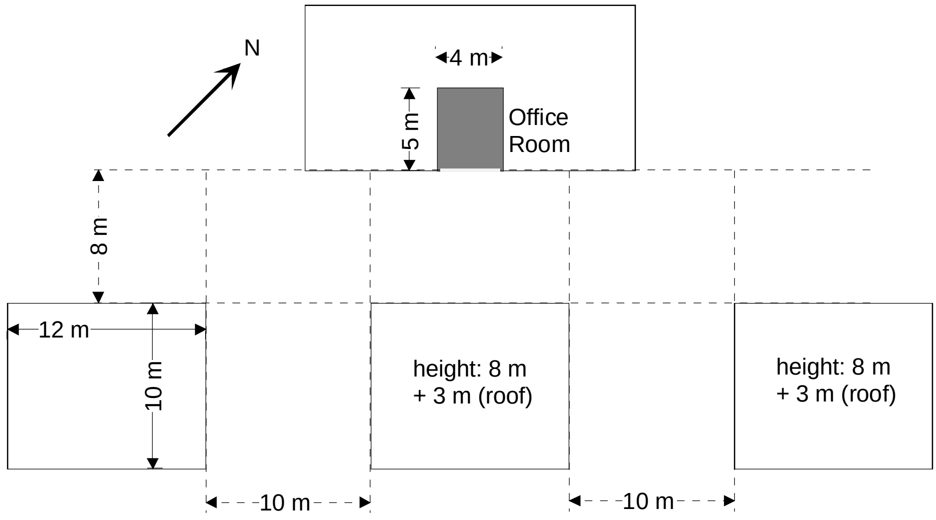

Figure 1: Site plan of the office room. Window orientation is south-east, the size of the window is 3.5 m x 2 m, the window-sill is situated 3 m above the ground.

OVERHEATING IN AN OFFICE BUILDING

To demonstrate the influence of shading by external buildings on overheating in summertime, the temperatures in an office with high internal gains during a typical summer situation were simulated. The room considered is part of a large building, its window is facing south-east. The external wall of the building is massive with 8 cm thermal insulation on the outside surface. The U-value of the window is 3.0 W/m²K and the air change rate is 2/hour. The simulation period covers some hot, sunny days in august (climate of Essen, Germany). Opposite to the room, at a distance of 8 m across the road, several higher buildings are situated (see Figure 1).

The simulation was performed with the transient system simulation program TRNSYS. A data file

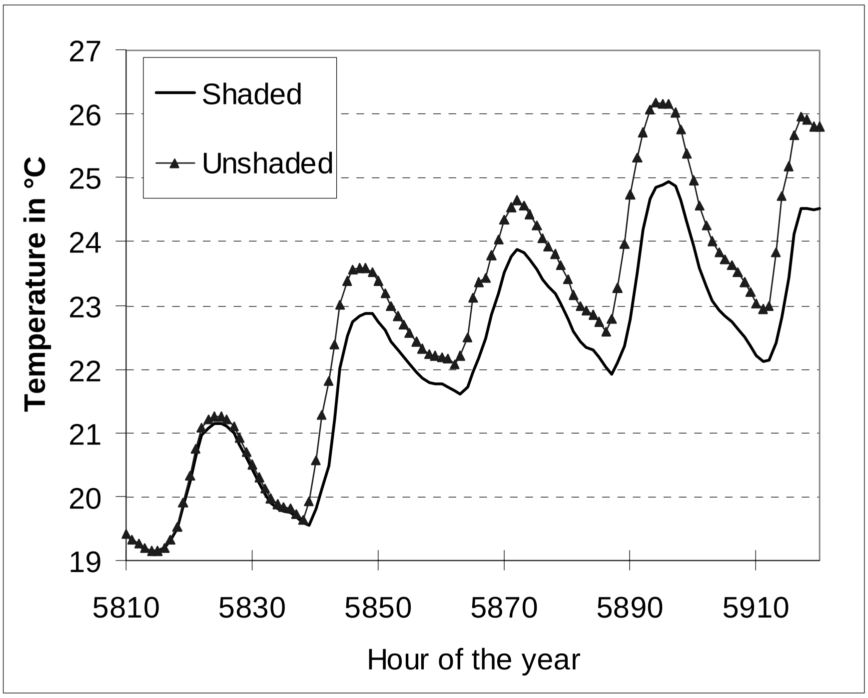

Figure 2: Development of the office temperature during a period of five hot and sunny days.

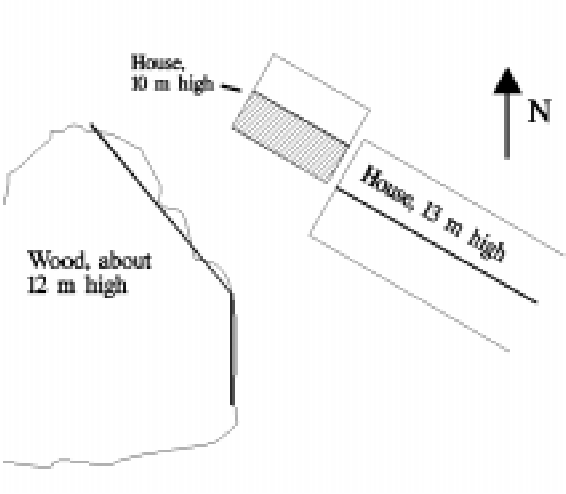

Figure 3: Ground plan of the building on which the collector shall be mounted and of the shading elements.

with hourly shading coefficients produced with SOMBRERO can be read into TRNSYS. After some modifications within the TRNSYS deck (modifying the output of the solar radiation processor with the shading coefficients and the view-factors for sky and ground as calculated in the shadow simulation, then feeding the results into the multizone building model TYPE 56) the shading for direct and diffuse radiation is taken into account by the simulation program. TRNSYS then calculates the temperatures and heating and cooling loads of the building under consideration.

The temperatures in the room were calculated twice, once with and once without the influence of the surrounding buildings. Figure 2 shows the results.

One finds that, taking shading into account, during the whole period the rise in temperature inside the room is significantly smaller than without shading. In the shaded case, the room temperature never exceeds 25°C. This difference in behavior affects the thermal comfort as well as the cooling load of the building. Such results are important for developing a strategy to keep the size of air conditioning systems and their energy consumption at a minimum.

POSITIONING A FIELD OF THERMAL SOLAR COLLECTORS ON A ROOF

A module of thermal solar collectors for the production of domestic hot water (4 m × 2 m) is to be positioned on the roof of a one-family house. Figure 3 shows the building and the relevant surroundings. The part of the tilted roof where the installation of the collector appears feasible (hatched in Figure 3) has an area of 10 × 5 m. The house is 10 m high from the ground to the top of the roof, the roof itself is 4 m high and tilted by 40°. It is facing about south-west, but is often shaded during the day by the nearby building in the south-east and a small wood in the south-west. There is some doubt about whether there would be enough sun for producing solar hot water in this situation.

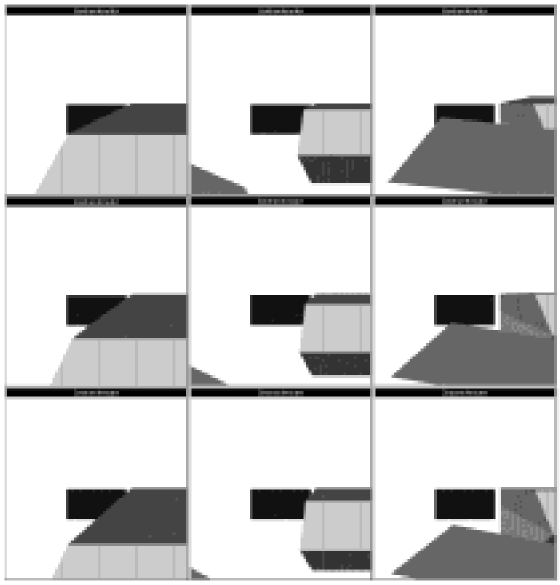

Figure 4: View of the target plane with the relevant shadows on the 15th of April, May and June (from top to bottom) at 9.30, 12.00 and 18.00 hours (from left to right). The rectangle in the middle of the sketches represents the roof where the collector is to be positioned. The original screen drawings are colored.

SOMBRERO was employed to determine a position for the collector module with minimal shading in the period from April to September. The focus lies on these months because the collector is, in principle, able to deliver the whole energy required for domestic hot water during this period. In this case, the conventional heating system can be turned off, standby losses do not occur anymore and considerable savings are achieved. In the heating period, the heating system is running throughout anyway, and thus possible savings are significantly smaller.

SOMBRERO contains a geometry file generator which facilitates the input of standardized houses and trees. The shading building south-east of the target could easily be entered as a standard house. The shape of the wood was approximated by two vertical planes, each 12 m high. After the geometry has been entered, SOMBRERO calculates views of the target plane (in this case the plane of the roof in question) for different points of time. By displaying these views for the relevant months the parts of the

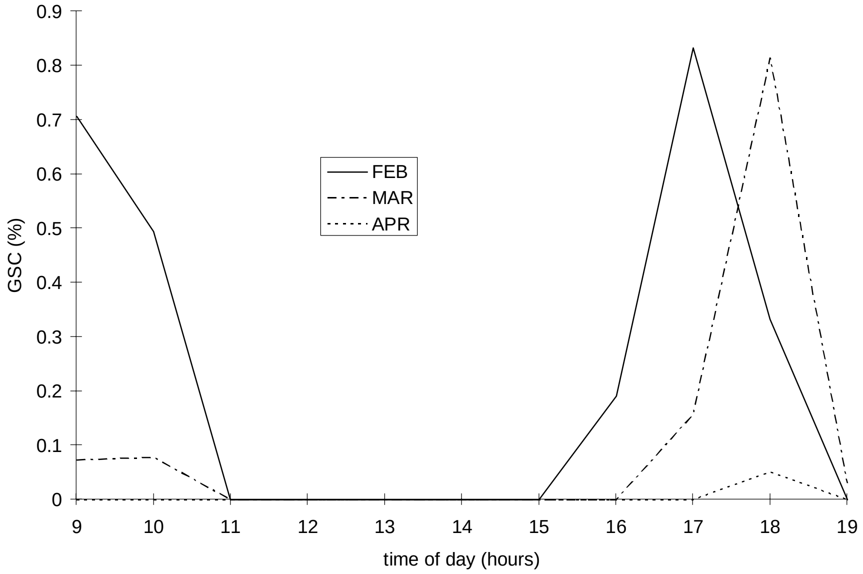

Figure 5: GSC as a function of time of day for the months of February to April. The shaded target is an area of 2 m height times 4 m width in the upper left corner of the roof. The diagram is similar to SOMBRERO's online output window.

roof with the least shading can be determined. Figure 4 shows screenshots for April, May and June at different times of the day. During the months of July to September shading is similar, of course. Therefore the corresponding sketches are not presented separately.

From the pictures, it appears that the top left corner of the roof would be the best location for mounting the collector. Indeed: Performing a simulation for a target area of 4 m width by 2 m height in the top left corner revealed that only a small amount of shading is present during the summer months. This occurs in the evening when the sun has nearly set. Thus very few energy is lost. During the rest of the year (months of October through March) , however, considerable shading appears. Figure 5 displays the GSC values for the months of February to April.

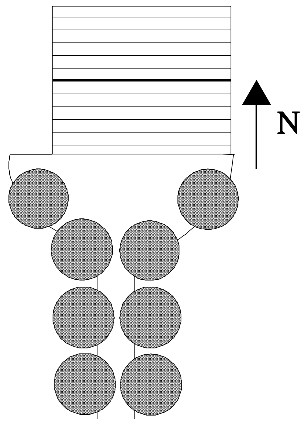

Figure 6: Ground plan of the building with the projected trees and the beginning of the avenue.

PLANTING TREES IN FRONT OF A 2-STORY BUILDING

The two-story rectangular building in Figure 6 has been designed for the passive use of solar energy. It has a floor area of 192 m² and is oriented to true south. It is fairly well insulated with 16 cm of insulation in the walls and 20 cm in the roof. For a TRNSYS simulation the house was divided into a northern and southern zone. A heating energy demand of 59.1 kWh/m²a was calculated with the climate of Freiburg in southern Germany. Large south-facing windows (39% of the south façade) with standard double glazing result in high solar gains as well as high transmission losses: Without solar gains, the heating energy demand would be 57.1 kWh/m²a higher. On the other hand, overheating is a serious problem: Temperatures in the south zone rise above 26°C during 1325 hours per year.

Around a yard in front of this building and along an avenue leading to the house a number of big deciduous trees should be planted. With SOMBRERO, we investigated the effects of this project on the heating energy demand, lighting and overheating in the rooms. Calculating the shadows of trees with SOMBRERO is an easy task: The user simply has to enter the position of the tree, the height of its trunk, the diameter of its crown (assumed to be spherical) and a time schedule for the transparency of the crown. Table 1 shows the degree of transparency of the crown assumed in the simulation.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Transparency (%)	90	90	50	5	5	5	5	5	30	60	90	90

Table 1: Ground plan of the building with the projected trees and the beginning of the avenue.

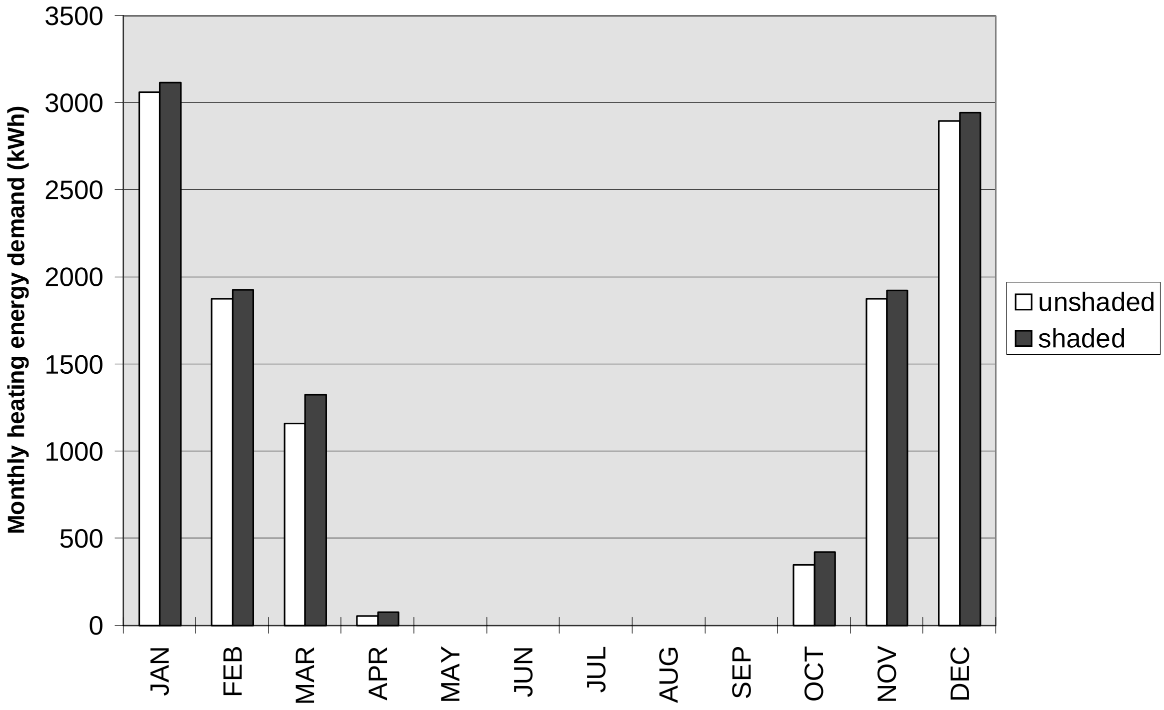

Figure 7: Total monthly heating energy demand for the building with and without the shading trees.

The results of the shading calculations were exported to a file with hourly values and read into the TRNSYS-deck. Figure 7 displays the monthly heating energy demand for the whole building. As the trees are not in leaf during the winter season, there is nearly no shading and the heating energy demand is hardly affected. The yearly heating energy demand of the building rises by only 3.7%. Overheating hours, however, are significantly reduced (Table 2).

	unshaded	shaded
South zone	1325	1050
North zone	488	442

Table 2: Hours when overheating (temperatures above 26°C) occurs in the two zones of the building for the cases with and without trees.

The fear that daylighting in the rooms might become too poor turns out to be groundless, too (Figure 8). Global radiation on the façade is hardly ever reduced by more than one third. The average shading coefficient does never exceed 25%; in the morning and evening hours, when the radiation intensity is low, the average values of the shading are smaller.

To sum up it can be said that, based on the simulation, the projected trees must be strongly recommended. Heating energy demand and lighting are only weakly affected, whereas the existing problem of overheating is reduced by a cost-effective and reliable measure.

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CONCLUSIONS

The above examples demonstrate that SOMBRERO is a useful tool with relatively simple operation. Within a few minutes, standard trees and houses, schedules for ground reflectance and transparency, shading planes and arbitrary plane target areas can be entered, and GSC-values are determined even for geometrically complex circumstances. Users can check their input and

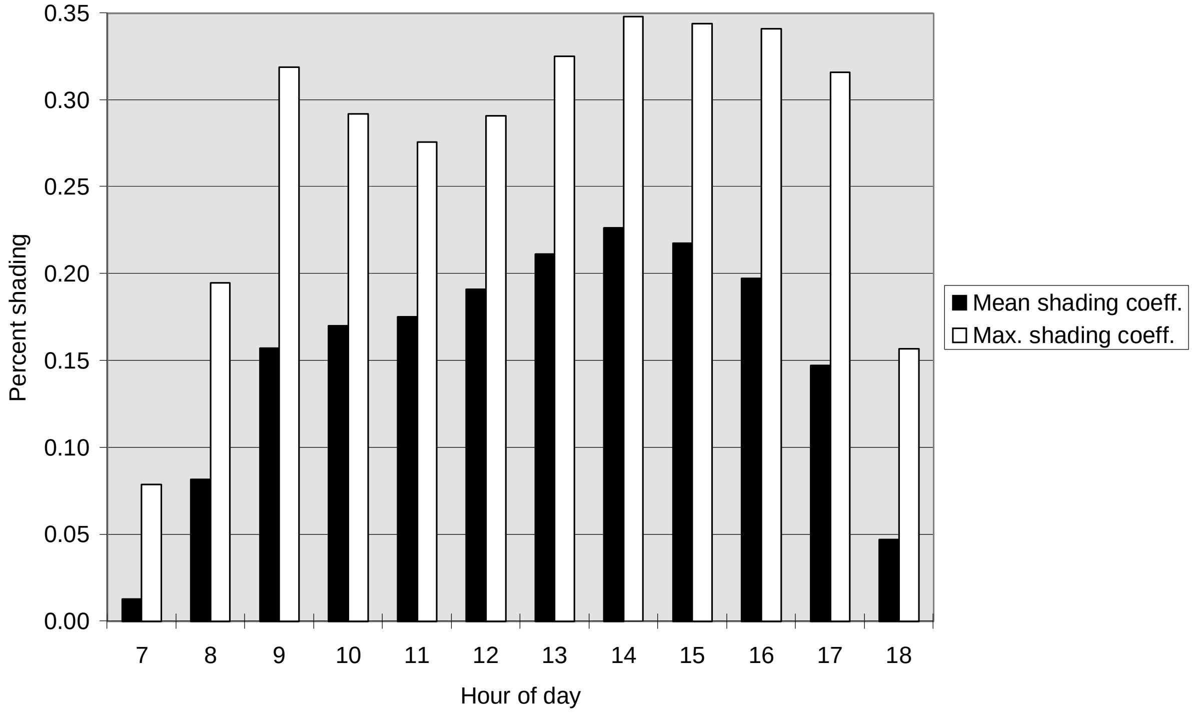

Figure 8: Mean and maximum values of shading of the south façade for the whole year.

get an impression of the actual positions where shading occurs by means of a graphic representation of the shadows in the target plane. Two online displays and several output files provide detailed information.

By coupling SOMBRERO to dynamic building simulation systems, e.g. TRNSYS or SUNCODE, the capabilities of these programs are extended to treating the shading effects of 3-dimensional objects. Thus, a realistic assessment of solar building concepts under real-life circumstances is made easier. Planning of cooling equipment or active solar systems becomes more reliable, too.

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