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A SIMPLE METHOD OF DETERMINING THE INFLUENCE OF THE OVERHANG ON WINDOW SOLAR GAINS

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ABSTRACT

This paper presents a simple tool (in the form of nomograms) for the preliminary design of solar gains of a window shaded with a horizontal overhang. The nomograms were based on the results obtained from the previously published, experimentally validated anisotropic model of shaded window solar gains and developed using the least squares method.

The nomograms were verified using the Design Builder (ver. 1.2) simulation software. The numerical simulations corroborated the relationship between window and shading system dimensions and solar gain reduction in the room. As the vertical distance of the overhang from the window increases, agreement between the analytical model results and the numerical simulation results deteriorates. Nevertheless, considering the significant differences between the input climatic data for the analytical model and those for the simulation program, the agreement can be regarded as satisfactory.

INTRODUCTION

In the times when fossil fuels resources are being depleted the cost of energy use in houses is constantly rising. Due to this fact passive cooling methods become increasingly popular among architects. One of the most commonly used passive cooling methods is shading by overhangs.

One of the goals of energy conscious building design is to prevent buildings from overheating during summer months by reducing solar heat gains through the use of external shading devices. Whereas in winter as little solar radiation as possible should be blocked by the external fixed shading devices from reaching the building's facade. Due to the variable nature of solar radiation, however, such a goal cannot be fully achieved. Therefore the designer of a building's facade with external fixed shading devices should be aware of their effect on the building's annual energy balance. An improper design can result in underheating or overheating of the building's interior.

The amount of solar gains through the window shaded by an overhang depends on: the projection of the overhang, the distance between the window and the overhang and the height of the window. A special anisotropic model of the solar gains of a window shaded by an overhang was developed and validated by solar radiation measurements. When analyzing the results obtained from this model (Włodarczyk, 2008), we observed that the solar gain functions were similar for the various window and overhang dimensions. Taking this observation into account, a set of nomograms for the whole year and the warm and cold half of the year for the Polish climatic conditions has been developed. The nomograms are based on the dimensionless relationship between: window height H, overhang projection P and the distance between the window and the overhang G. The nomogram equations were derived by the least square method.

ANALYTICAL MODEL OF SHADED WINDOW SOLAR GAINS

Theoretical basis

Because of the complexity of the model of shaded window solar heat gains (its description is more than a few pages long), only its main assumptions are presented here. The model in its entirety can be found in (Włodarczyk, 2008).

The model is based on Perez's assumption about anisotropic solar radiation onto an inclinded plane (Perez et al., 1990). The geometric conditions stemming from the relationship between window dimensions and shading overhang dimensions, determining the shadow zone on the window, were imposed on the model. In order to calculate the availability of diffuse radiation onto the windowpane the Siegel and Howell equations (Seigel & Howell, 1972) were used. The diffuse radiation reflected from the ground's surface and the overhang's bottom and incident on the shaded window was calculated from the geometry equations proposed by Jones (Jones, 1980).

The main input data for the model are the total solar radiation onto a horizontal plane and the diffuse solar radiation onto this plane. However, very often only total radiation intensity is measured. In such a case, in order to generate data on diffuse radiation onto a horizontal plane one should use the k_T-f model (the brightness coefficient – the diffuse radiation content in the total radiation). An analysis of the accuracy of such models for the territory of Poland was presented in (Włodarczyk, Nowak, 2008).

The solar gains of a building with horizontal shading overhangs were divided into the following radiation components: the direct radiation, the solar diffuse radiation, the diffuse radiation from the region above the horizon, the isotropic sky radiation, the radiation reflected from the ground's surface and the radiation reflected from the ground's surface and then from the overhang's bottom. Hence the equation describing the intensity of solar radiation onto the surface of a window shaded by a horizontal overhang is as follows:

$$I^o = I^o_b + I^o_{d,c} + I^o_{d,h} + I^o_d + I^o_g + I^o_{g,o} \qquad (1)$$

where (shown also on figure 1):

I^o – the intensity of the total solar radiation onto a window shaded by a horizontal overhang, [W/m^2],

I^o_b – the intensity of the direct solar radiation onto the window shaded by the horizontal overhang, [W/m^2],

$I^o_{d,c}$ – the intensity of the sun disc's diffuse radiation, [W/m^2],

$I^o_{d,h}$ – the intensity of the diffuse solar radiation from the region above the horizon onto the window shaded by the horizontal overhang, [W/m^2],

I^o_d – the intensity of the diffuse solar radiation from the rest of the sky onto the window shaded by the horizontal overhang, [W/m^2],

I^o_g – the intensity of the solar radiation reflected from the ground's surface onto the window shaded by the horizontal overhang, [W/m^2],

$I^o_{g,o}$ – the intensity of the solar radiation reflected from the ground's surface and then from the overhang's bottom onto the window shaded by the horizontal overhang, [W/m^2].

In order to calculate the internal solar gains of the rooms the theory of heat losses for radiation passing through glazing was applied.

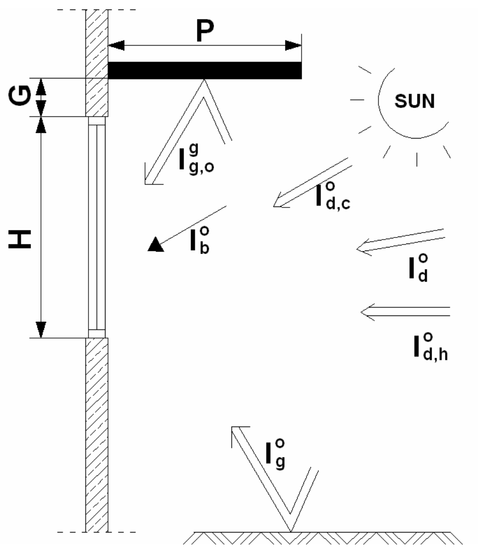

Figure 1. A diagram showing basic assumption of the model : H – window height, G – gap between window and overhang, P – overhang projection.

Experimental validation

The anisotropic model of the solar gains of a room shaded by a horizontal overhang was experimentally validated on a research station (figure 2) in the SolarLAB Photovoltaic Laboratory at Wrocław University of Technology (Poland).

A steel cantilever with an projection of 0.50 m, from the bottom encased in galvanized sheeting (with an albedo coefficient of 0.50 in conformance with (ASHRAE, 1997)) had been secured to a steel frame. Two CM21 pyranometers manufactured by Kipp&Zonen had been mounted under the horizontal overhang in order to measure the intensity of solar radiation onto a vertical surface (representing a windowpane) oriented towards the south. Thanks to the two pyranometers mounted at two different heights not only the number of measurement data was doubled, but also solar gains could be analyzed at different positions of the overhang's edge relative to the position of the Sun in the sky. The pyranometers had been mounted at a distance of respectively 0.30 and 0.60 m from the horizontal overhang. Also a Kipp&Zonen CM7B albedometer for measuring albedo and the total intensity of solar radiation onto the horizontal plane had been mounted. Data were read off the instruments at every two seconds and then, if needed, integrated to longer time steps.

Figure 2. Solar gain research station in SolarLAB Photovoltaic Laboratory in Wrocław (Poland).

Data were acquired from 24 May 2007 to 10 December 2007. Since actinometric measurements are usually averaged to a one hour step, a special integrating computer program was written in C^{++}. In total, 5138 hour measurement data were obtained from the two CM21 pyranometers. The data were used for the statistical verification of the anisotropic model of the solar gains of a room with horizontal shading overhangs.

A comparative analysis of the measured data and the data obtained from the model was carried out. As figure 3 shows, the results firmly validated the use of the model for calculating the solar gains of a window shaded with an overhang. The statistical analysis showed the anisotropic model of window solar gains to be characterized by very good statistical indicators (mean bias error MBE[%] = -1.22 %, correlation coefficient CC = 0.9399) (Włodarczyk, 2008)).

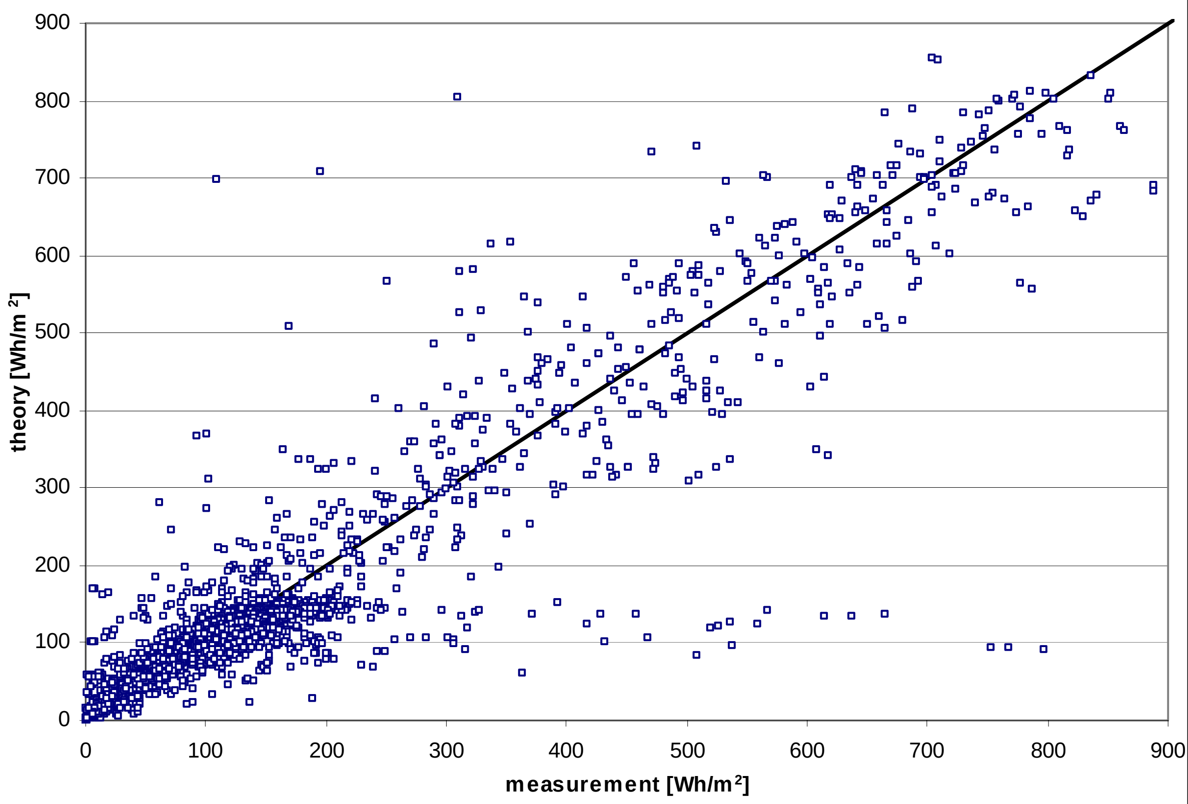

Figure 3. Measurements of total solar radiation on plane shaded by horizontal overhang as compared with results generated by anisotropic model of solar gains.

DEVELOPMENT OF NOMOGRAMS

The model calculations showed that room solar gains depend on both the overhang's projection and its distance from the window's upper edge. It was also found that the solar gain function curves for the different configurations of window-shading device dimensions were similar. Therefore solar gain nomograms for the specific dimensionless relations between the particular shading system variables (window height H, overhang projection P, overhang-window distance G) were developed. The nomograms can be used to roughly estimate (already at the predesign stage) solar gains for typical window and overhang dimensions (window dimensions: H – 1.50-3.00 m, overhang projection P – 0.00-1.50 m, overhang-window distance G – 0.00-0.50 m). The model of solar gains of a window with a shading overhead (Włodarczyk, 2008) was used for the calculations.

First, the percentage drop in window (a 2 × 6 mm double pane set) solar gains depending on the P/H ratio was analyzed. The calculations were done for four values of ratio G/H: 0.00, 0.10, 0.20 and 0.30. The values of the variables were selected for each P/H interval with a width of 0.02.

Using the calculation results and the least squares method, nomogram curves were determined. They are shown in fig. 4 (the annual gains), fig. 5 (the warmer half year gains) and fig. 6 (the colder half year gains).

All the curves in the nomograms are for specific G/H ratios (Włodarczyk, 2008):

$$I^{o}_{red} = a_0 + a_1\left(\frac{P}{H}\right) + a_2\left(\frac{P}{H}\right)^2 + a_3\left(\frac{P}{H}\right)^3 + a_4\left(\frac{P}{H}\right)^4$$

(2)

where:

I^{o}_{red} – solar gains reduced by windows with a horizontal overhang [-],

a_i – polynomial coefficients of equation (2) [-],

P – overhang projection [m],

H – window height [m],

G – the overhang-window distance [m]. Coefficients a_i for the given G/H ratios together with correlation coefficients CC for each of the equations are shown in the table below.

Table 1
Coefficients a_i and correlation coefficients CC of nomogram equations shown in figs 4-6.

G/H	a_0	a_1	a_2	a_3	a_4	CC
annual gains						
0.00	1.0000	-0.8663	-0.4225	1.4296	-0.7180	0.9955
0.10	1.0000	-0.1121	-2.5642	3.7747	-1.6287	0.9975
0.20	1.0000	0.1411	-2.6422	3.3313	-1.3041	0.9984
0.30	1.0000	0.1968	-2.1045	2.1980	-0.7134	0.9988
summer gains						
0.00	1.0000	-1.0427	-0.7348	2.1942	-1.0701	0.9952
0.10	1.0000	-0.2205	-3.2135	4.9627	-2.1587	0.9974
0.20	1.0000	0.1995	-3.8958	5.1681	-2.0683	0.9986
0.30	1.0000	0.3295	-3.3792	3.7730	-1.2814	0.9989
winter gains						
0.00	1.0000	-0.5834	0.0785	0.2034	-0.1534	0.9962
0.10	1.0000	0.0617	-1.5229	1.8693	-0.7785	0.9973
0.20	1.0000	0.0473	-0.6368	0.3852	-0.0785	0.9973
0.30	1.0000	-0.0161	-0.0600	-0.3283	0.1976	0.9972

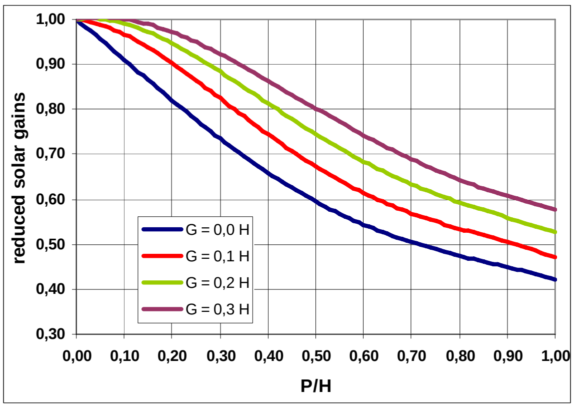

Figure 4. Nomogram of annual window solar gains for determined relationships between variables P, H, G.

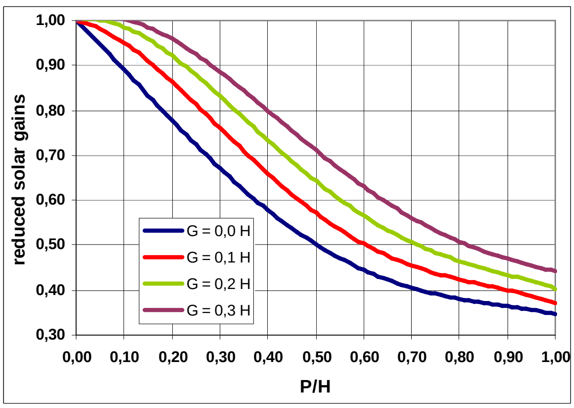

Figure 5. Nomogram of summer window solar gains for determined relationships between variables P, H, G.

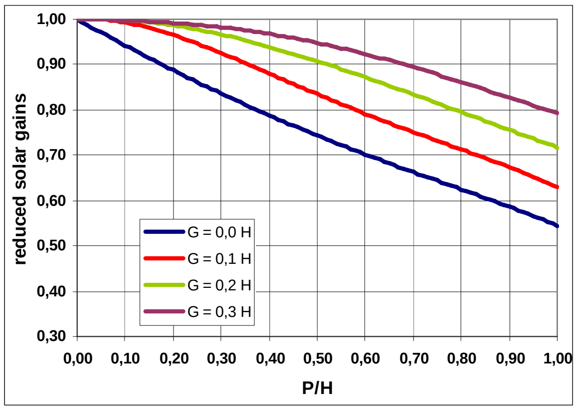

Figure 6. Nomogram of winter window solar gains for determined relationships between variables P, H, G.

The correlation coefficients (Table 1) for the nomogram equations and the data derived from the model indicate that the nomogram equations are suitable for calculating solar gain reductions during the preliminary design of shading overhang systems.

VERIFICATION OF NOMOGRAMS BY SIMULATION SOFTWARE

The nomogram curves were verified using the Design Builder (ver. 1.2) simulation software. Several simulations were run for buildings with typical windows and shading overhangs (window dimensions: H – 1.50-3.00 m, overhang projection P – 0.00-1.50 m, overhang-window distance G – 0.00-0.50 m). The standard climatic data for Poland found in the Energy Plus (ver. 1.4) simulation environment were used in the simulations. Unfortunately, the data do not fully correspond to the typical meteorological conditions in Poland. As yet the Typical Meteorological Year (Gawin & Kossecka, 2002) for the Polish climatic conditions has not been prepared in the format of Energy Plus weather files.

The nomogram values and the numerical simulation results for different G/H ratios are compared in figs 7-10.

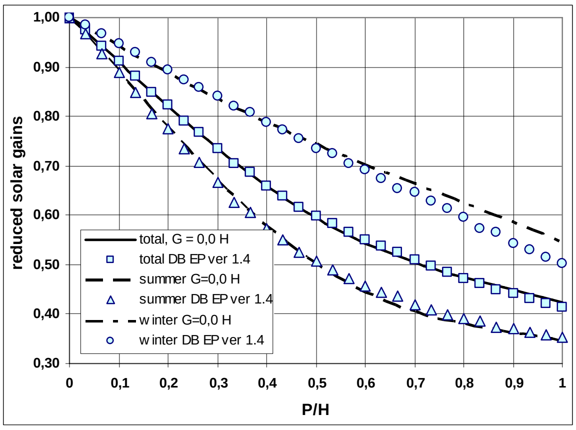

Figure 7. Degree of solar gain reduction for particular seasons at G/H ratio of 0.00.

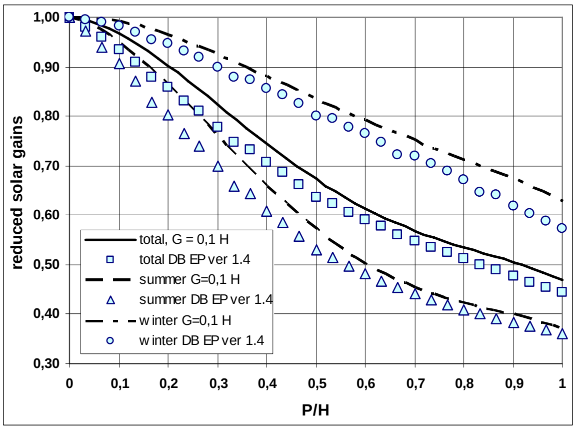

Figure 8. Degree of solar gain reduction for particular seasons at G/H ratio of 0.10.

The effect of shading overhangs on solar gain reduction per annum (marked "total" in the graphs) and for the summer half year (April-September) and the winter half year (October-March) was investigated.

The numerical simulations corroborated the relationships between window and shading system dimensions and solar gain reduction in the room, determined by the shaded window solar gain model. There was very good agreement between the nomogram results and the numerical calculation results for overhang mounting immediately above the window (the G/H ratio equal to 0.00). This is shown in figure 7.

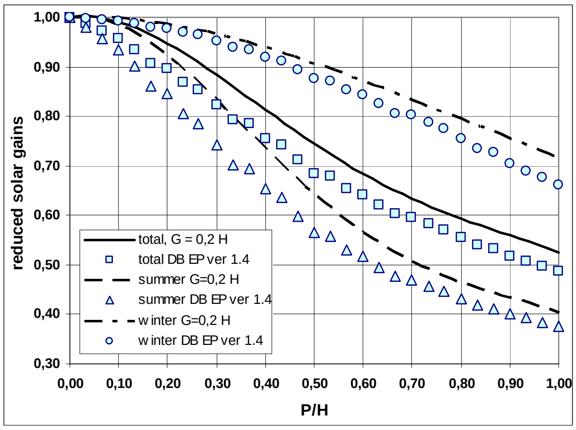

Figure 9. Degree of solar gain reduction for particular seasons at G/H ratio of 0.20.

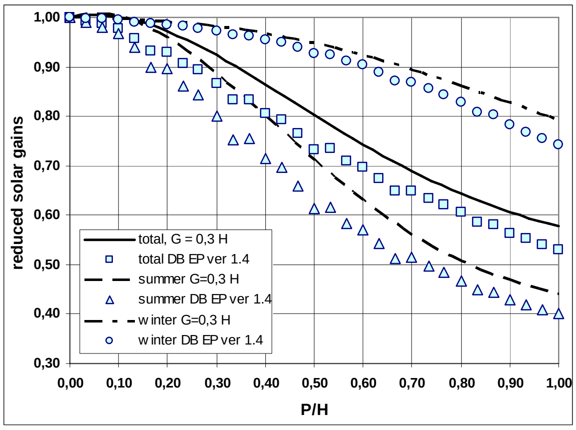

Figure 10. Degree of solar gain reduction for particular seasons at G/H ratio of 0.30.

As the vertical distance of the overhang from the window increases (figs 8-10), agreement between the analytical model results and the simulation results deteriorates. Nevertheless, considering the significant differences between the respective input climatic data: the analytical model uses the Typical Meteorological Year (Gawin & Kossecka, 2002) for the Polish climatic conditions (30-year averages from real data), whereas the simulation model uses the Energy Plus weather data, the agreement can be regarded as satisfactory.

CONCLUSION

As the fossil fuel resources become exhausted and as energy prices on the world markets rise, the proper design of buildings aimed at reducing their energy consumption becomes increasingly more important. Since the air conditioning system puts a heavy strain on the energy balance it seems reasonable to equip the building with passive shading systems.

A set of nomograms for the preliminary design of building shading systems (in the form of horizontal overhangs) was developed using a model of the solar gains of a window shaded with a horizontal overhang. The model had been developed as part of research (Włodarczyk, 2008) and validated on a measuring station in the SolarLAB Photovoltaic Laboratory (http://solarlab.wemif.net) at Wrocław University of Technology (Poland).

Nomogram relationships between the particular shading system variables (window height H, overhang projection P, overhang-window distance G) were determined. The nomograms were developed for four values of overhang-window distance/window height ratio G/H: 0.00, 0.10, 0.20 and 0.30. Similar nomograms were developed on the basis of the results obtained from computer simulations run in the DesignBuilder ver. 1.2 program (http://www.designbuilder.co.uk).

A comparison of the two kinds of curves corroborated the relationships between window and shading system dimensions and solar gain reduction in the room, determined using the shaded window solar gain model. For the overhead mounting immediately above the window (the G/H ratio equal to 0.00) the nomogram results and the numerical calculation results showed very good agreement. As the overhang-window distance increases, the agreement between the analytical model results and the simulation results deteriorates. Nevertheless, considering the significant differences between the analytical model climatic data and the computer program data, the agreement can be regarded as satisfactory.

Developed nomograms showed good performance compared to detailed computer simulation software, thus they can be incorporated to preliminary design of buildings with passive cooling performed by overhangs. Of course they cannot replace detailed simulation design, but can save time of designer when searching for optimal set of geometric dimensions of overhangs.

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