THE ANALYSIS OF SOLAR GAINS CALCULATION METHODOLOGY DEFINED IN SRPS EN ISO 13790, THROUGH THE USE OF SOFTWARE FOR NUMERICAL SIMULATION

by

Vladimir V. BOJOVIĆ *

Faculty of Architecture, Belgrade, University of Belgrade, Serbia

Original scientific paper
https://doi.org/10.2298/TSCI170523124B

By regulations on energy efficiency from 2011, the simplified methodology for calculating solar gains has been defined by the adopted values of solar radiation for whole of Serbia. This paper presents two different methods of solar gains calculation, with the support of the software package KnaufTerm 2, which relies on existing regulations in Serbia, and Ecotect software package, intended for 4-D simulations. The problem has been analyzed in the case of a residential building in Belgrade, by calculating solar gains obtained through one window, for 36 different orientations. Different orientations of the window have shown significant variations in the obtained results, which have been ignored by the rulebook, because it defines only 4 orientations. By this, it was established that four more orientations have to be defined by regulations, with separate values of solar radiation for each position. As the differences in solar gains are most visible in the east, and deviate up to 61%, in the paper then was analyzed calculation method of shading for eastern orientation, which is defined by the rulebook on energy efficiency through a variety of shading factors. The analysis has shown that the methodology defined in the regulations has given drastically lower levels of solar gains at the shaded positions, where the most visible differences were observed in the presence of three shading elements. Also, it is necessary to reconsider the values of the defined shading factors, which are, as showed by 4-D simulations, oversized.

Key words: *solar gains, regulation on energy efficiency, shading factor, orientation, 4-D method*

Introduction

In recent years energy performance of buildings and energy saving issues have attracted a very large attention from the scientific community [1]. The importance of these topics comes from the need to reduce fossil fuels consumption and necessity to reduce pollutant emissions [2]. In Serbia, by regulations on energy efficiency in 2011, has been defined the energy performances and method of calculating the thermal characteristics of buildings, as well as energy requirements for new and existing buildings [3]. All analyses are based on the standard SRPS EN ISO 13790 [4].

This regulation defined the methodology for calculating the energy performance of buildings, through determination of the annual energy need for heating, the total annual final and primary energy, annual emissions of CO_2, climatic data, and recommended values of the

* Author's, e-mail: vladimirb.arh@gmail.com

input parameters for calculation. Solar gains are an important part of the calculation of the energy performance of the building, and have a large impact on the calculated values of annual needs of energy, $Q_{h,an}$, and therefore, the energy class of the building. Methodology of solar gains calculation, defined by the rulebook, is very simplified and mostly relies on the adopted values of solar radiation and defined values of shading factors [3]. It defines the mean sums of solar radiation per month, for whole Serbia, for only 4 orientations, while all other orientations are assigned to the corresponding orientation (±45°). The main objective of this research is to check validity of this simplified methodology and the calculated results, through comparison of solar gains obtained by two different methods. It is very important to emphasize that this study relates solely to the shading correction factors and does not take into account the purity of the glass, the existence of the internal curtains and various gain coefficients, *g*, which are considered in some papers [1].

Method of research

In this paper, two completely different methodological approaches have been compared. Solar gains of the building have been calculated for climate conditions of Belgrade, by the use of the 4-D simulations method on one hand [5], and the methodology defined in the regulations on the other [6]. As an input data of climatic conditions, it was used the data from US Department of Energy, available on their web site [6, 7].

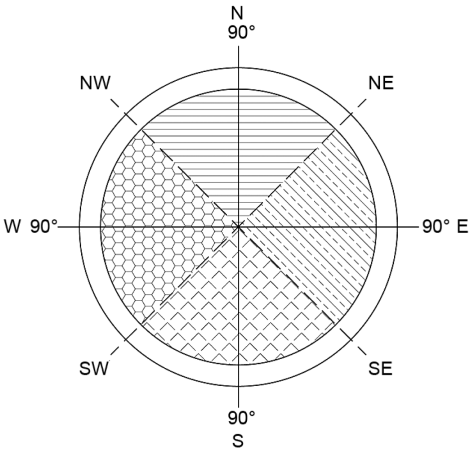

Figure 1. Corresponding orientations of window defined by the rulebook

The methodology defined in the regulation is based on mean monthly sums of solar radiation for 4 orientations (north, east, west, and south), while other orientations were not taken into the consideration, fig. 1. Therefore, the results may not always be reliable and in many ways depend on the orientation of the object. Also, it is unclear how to treat the other orientations (±45°), which leaves a free choice for engineers in the selection of orientation. Many shading factors were defined by regulations, depending on the size and position of shading elements. This calculation method is very complex and requires a lot of time, especially in large buildings. As an alternative to this approach has been proposed shading factor f_s = 0.9, for the unshaded position or shading factor f_s = 0.6 for fully shaded position.

The advantages of 4-D simulations method, are simulation of the real path of the Sun, the real climate conditions, including the time factor in analysis, taking into account all the shadows that have been modelled according to the actual conditions. Ecotect combines analysis functions with an interactive display that presents analytical results directly within the context of the building model. So by simulation of the real conditions, reduction factors of solar gains (such as shading factor, the reduction factor due to an indirect radiation, or because of radiation equipment for protection against the sun) that are adopted by the rulebook, have been avoided. In this way, the software treats the generic model as a 3-D structure and calculate very precise solar gains through the certain period of time, in this case the heating season (October 15 to April 15).

The case study

This problem was analyzed in the generic model of the room with the window size of 0.9 m/1.8 m, for the climatic conditions of Belgrade according to the data US Department of Energy, fig. 2, [7]. In this work first was done an analysis of solar gains for 36 different orientations, in order to detect discrepancies in the results, within the corresponding orientation (±40°), fig. 3. This analysis has revealed significant variations in the context of the corresponding eastern and western orientation, and a little less in the northern and southern orientation. As it is presented in tab. 1, the results obtained by the method defined by the rulebook are the same for all 9 variations under the corresponding orientation. In this way, as more the observed window deviates from its corresponding orientation, the differences in the obtained results are larger. The most expressed differences have been identified in the context of eastern and western orientation, which was expected.

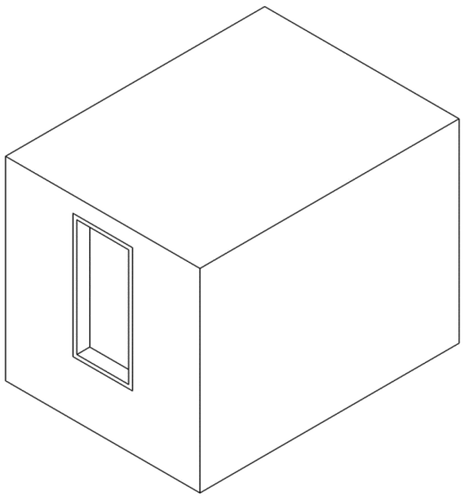

Figure 2. Generic model of the room with one window

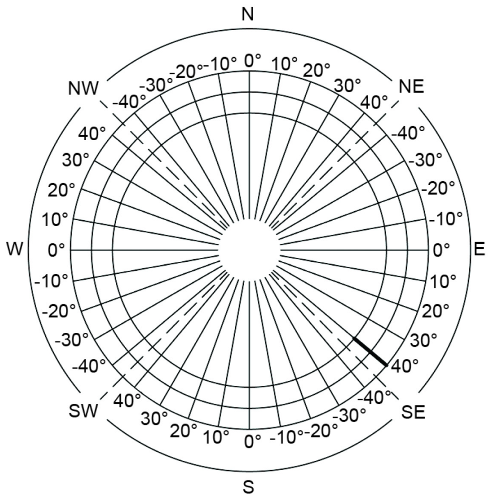

Figure 3. Analyzed 36 orientations of the window

Table 1. Solar gains during the heating season following orientations

Method	4-D analysis	2-D analysis	4-D analysis	2-D analysis	4-D analysis	2-D analysis	4-D analysis	2-D analysis
Orientation	North [kWh]		East [kWh]		West [kWh]		South [kWh]	
+40°	**173**	146	**430**	314	**162**	242	**403**	503
+30°	160	146	402	314	175	242	436	503
+20°	152	146	376	314	194	242	465	503
+10°	148	146	348	314	216	242	489	503
±0°	146	**146**	314	**314**	242	**242**	503	**503**
–10°	146	146	282	314	271	242	505	503
–20°	147	146	248	314	301	242	494	503
–30°	149	146	218	314	333	242	481	503
–40°	**154**	146	**192**	314	**367**	242	**463**	503

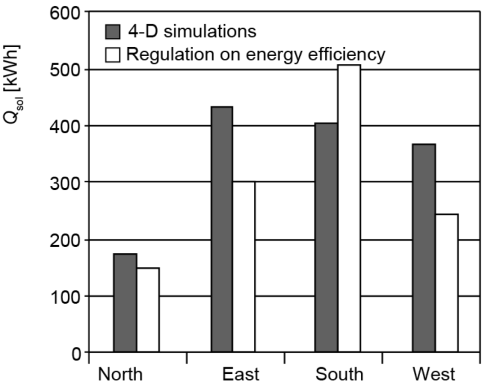

Figure 4. Display the variances in the results obtained by the orientations

In further analysis, the scenario of maximum differences of solar gains has been examined, by the method of 4-D simulations on one side and the methodology defined in the regulations or the 2-D analysis on the other. Thus, for further analysis was adopted orientation from +130° (east +40º) which according to 4-D simulations amounts Q_{sol} = 429.626 kWh, and according to the 2-D analysis is adopted Q_{sol} = 313.634 kWh, which represents the average sum of all values in the corresponding eastern orientation, fig. 4. This comparative analysis showed that the greatest variations in the results were obtained for windows deviating ±40°, from the eastern orientation, and this difference can vary from 37-61%.

Shading elements analysis

Then solar gains have been analyzed in the presence of various shading elements. Three distinct shading elements were defined by regulations, the shading due to the presence of surrounding buildings, due to the existence of overhangs, and due to the existence of vertical elements on the façades. For each of these elements, depending on the angle that central axis of the transparent surfaces (windows) closes with the final edge of the shading element, were defined the various correction factors for each of the orientations. Therefore, it has been simulated each situation that is defined by regulations, in order to check the values of the correction factors and compare them with those obtained by method of 4-D simulations, eq. (1).

Shading of the window due to the presence of surrounding buildings

Firstly, it has been simulated the shading of window due to the surrounding building for the angles of 0, 10, 20, 30, and 40° (figs. 5 and 6). Total solar gains are accounted as a product of solar gains for the unshaded position and the adequate value of shading correction factor, for each angle, as it is defined by the rulebook, eq. (1). The method of 4-D simulations has been shown that the values defined by the regulations are oversized and are not realistic indicator of the shading.

$$Q_{sol'} = Q_{sol} F_{sb} \quad (1)$$

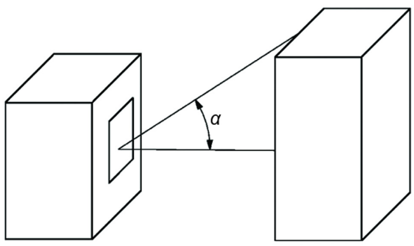

Figure 5. Shading of the window due to the presence of surrounding buildings

Figure 6 shows the values of solar gains, Q_{sol}, depending on the angle, through these two different methodologies. Then, each value of correction factor is accounted as the quotient of the both calculated values of solar gains. Table. 2 shows new calculated values of correction factors based on the results obtained by 4-D simulations, eq. (2).

$$F_{hor} = \frac{Q_{sol}}{Q_{sol'}} \quad (2)$$

Table 2. Correction factor, F_{sb} (East)

Angle	2-D	4-D
0°	1.00	**1.00**
10°	0.95	**0.96**
20°	0.82	**0.93**
30°	0.70	**0.90**
40°	0.61	**0.87**

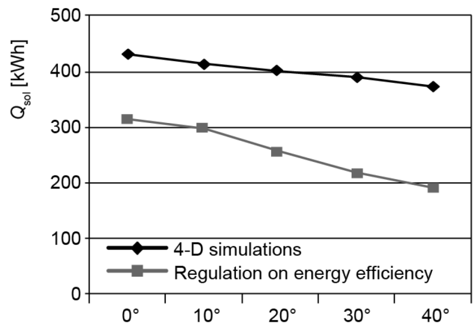

Figure 6. Shading of the window due to the presence of surrounding buildings

Shading of window due to the existence of overhangs

Then it has been simulated shading of window, due to the existence of the overhangs, observed for three different angles of 30, 45, and 60°, eq. (3). The analysis has shown, the larger angle, the greater deviations in the solar gains are obtained by these two methods, figs. 7 and 8.

$$Q_{sol'} = Q_{sol} F_{ov} \tag{3}$$

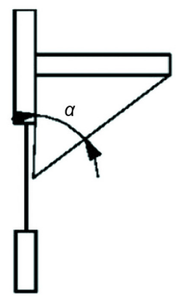

Figure 7. Shading of the window due to the existence of overhangs (vertical section)

Table 3 shows the newly calculated values of the correction factors, which are far greater than those that are defined by the rulebook, eq. (4). The values of correction factors for angle of 60° (in the presence of overhangs), is even lower than the value of shading

Table 3. Correction factor, F_{ov} (East)

Angle	2-D	4-D
0°	1.00	**1.00**
30°	0.89	**0.91**
45°	0.76	**0.87**
60°	0.58	**0.83**

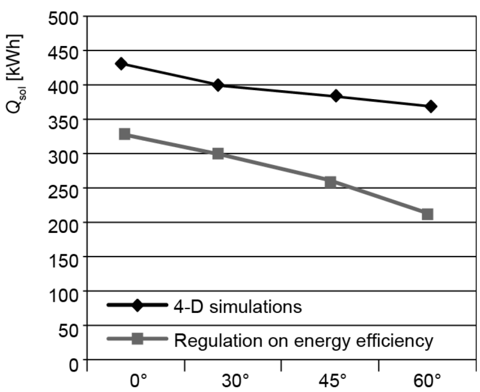

Figure 8. Shading of the window due to the existence of overhangs

factor f_s = 0.6, also defined by the rulebook for completely shaded position, which is definitely not the case here. Considering that this is not a very rare form of shading in buildings, this calculation method, besides not being completely certain, it is very complex, especially in large buildings with a large number of openings. In this case, each transparent position would require a separate analysis of shading, which final result would be calculated as the product of all correction factors. So, many engineers in calculating of energy performances of buildings are using a simplified calculation methodology of shading factors, which reduces to a choice of one of the three offered: unshaded position (f_s = 0.90), moderately shaded position (f_s = 0.75), and completely shaded position (f_s = 0.60).

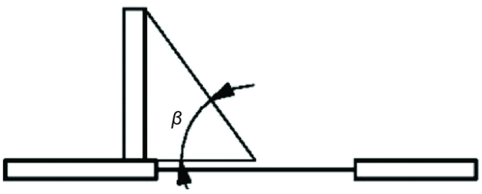

Figure 9. Shading of the window due to the existence of vertical elements on the façades (horizontal section)

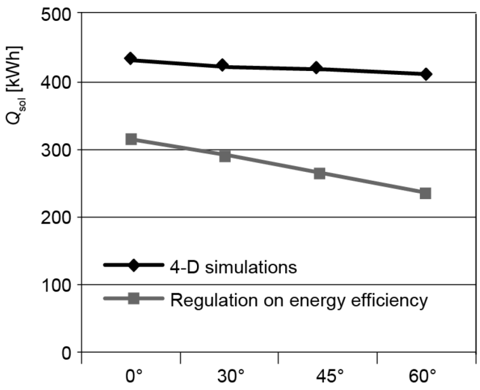

Figure 10. Shading of the window due to the existence of vertical elements on the façades

Table 4. Correction factor, F_{fin} (East)

Angle	2-D	4-D
0°	1.00	**1.00**
30°	0.92	**0.98**
45°	0.84	**0.97**
60°	0.75	**0.96**

$$F_{ov} = \frac{Q_{sol}}{Q_{sol'}} \tag{4}$$

Shading of the window due to the existence of vertical elements on the façades

Finally, in the third case of shading, vertical elements on the façade have been modelled, with the angles of 0, 30, 45, and 60°, eq. (5). As the sides of shading elements are not defined by the rulebook, in the model they are positioned on the southeast side, in order to have a greater impact on changing results. The figs. 9 and 10 shows minimal differences in the solar gains obtained by method of 4-D simulations, which for result have, as it can be seen in tab. 4 below, high values of correction factors, eq. (6).

$$Q_{sol'} = Q_{sol} F_{fin} \tag{5}$$

$$F_{fin} = \frac{Q_{sol}}{Q_{sol'}} \tag{6}$$

Discussion and validation of the results

In further research it has been modelled the case of completely shading of window, which is achieved through the combination of all types of shading elements. Through calculating the solar gains, Q_{sol}, by method defined by the rulebook, in the Case 2, as a shading factor was adopted the value of f_s = 0.6, which has been designed for a fully shaded transparent position. In the Case 3 the shading factor F_{tot} = 0.27 was calculated as a product of the maximum values of the three previously analyzed shading elements, eq. (7), which is also defined by the rulebook [3].

$$F_{tot} = F_{sb} F_{ov} F_{fin} \tag{7}$$

Case 1. Unshaded position

Figure 11 shows the values of solar gains obtained by the method of 4-D and 2-D analysis for both, the unshaded and the shaded position, for two different values of correction factors. In the first Case the result obtained by method of 2-D analysis is lower by 37% which is a direct consequence of only 4 orientations defined by the rulebook. Therefore, differences in the results are negligible at the northern and southern orientation, while in the case of the eastern and western, the result can range from drastically lower to drastically higher, depending on the position of the window (closer to the south or north).

Case 2. Shaded position

In the second Case it was calculated the total value of direct solar gains, Q_{sol}, in the case of complete shading of window. The value calculated by the method of 4-D simulations amounts $Q_{sol} = 317$ kWh, while this value calculated by the method of 2-D analysis is $Q_{sol} = 189$ kWh. It has been adopted a value of $f_s = 0.6$ as a shading factor, which is defined by the rulebook for the fully shaded position, fig. 11. The difference in results is even more visible and amounts 68%. This was caused by drastically lower values of the correction factors defined by the regulations in relation to the calculated values obtained by the method of 4-D simulations, which is $f_s = 0.74$. So, as observed window has more shading elements, the differences in the calculated solar gains are larger. When differences in the results due to orientation are taken into consideration, the final result is quite unreliable.

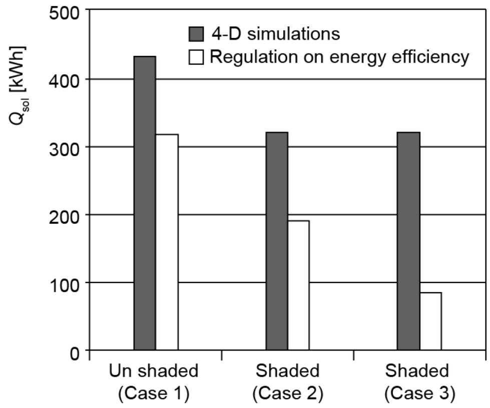

Figure 11. Comparison of the obtained results

Case 3. Shaded position

In the third Case, the previously calculated values of solar gains have been compared with the calculated solar gains through the shading factor $F_{tot} = 0.27$, which is the product of the maximum values of the three previously analyzed elements for shading. In this Case, the difference in achieved results is the most evident, and the method of multiplication of different values of correction factors, in the presence of several shading elements, turned out to be completely incorrect, fig. 11. Despite being extremely complex, especially for large objects, this method has been given far worse results than the simplified method of adoption of different shading factors. The reason is that the shadows due to the presence of various shading elements can coincide, partly or as a whole [8]. Consequently, adding the shading reduction factors can significantly overestimate the shading. Therefore, as the final step of this research, the calculation methodology of solar gains has been tested in a variety of overlapping shadows, with shading factors calculated by the method of 4-D simulations.

Analysis of shading overlapping

Three Cases of shading have been analyzed; shading overlapping due to the surrounding building and overhangs, surrounding buildings and vertical elements on the façade, and finally due to the overhangs and the vertical element on the façade. As shown in fig. 12, the situation of shading has been modelled due to surrounding objects at an angle of 40°, and due to the existence of overhangs at an angle of 60°. This situation has led to partial overlapping of shading, so at the calculation of the total value of the correction factor has been adopted $F_{sb} = 0.9$ which corresponds to an angle of 30° in order to compensate the overlapping of shadings. Total shading factor F_{tot} was calculated as a product of the values of shading correction factors for each shading element, eqs. (8) and (9).

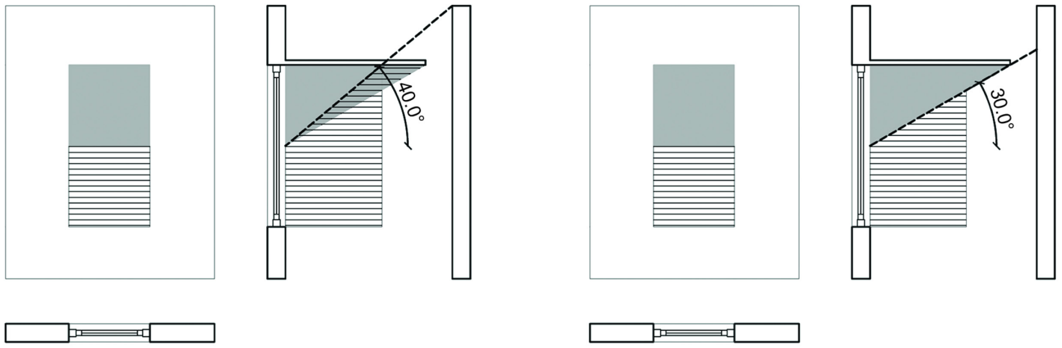

Figure 12. Shading due to the surrounding building and overhangs

$$F_{tot} = F_{sb} F_{ov} = 0.9 \cdot 0.83 = 0.747 \tag{8}$$

$$Q_{sol'} = Q_{sol} F_{tot} = 430 \cdot 0.747 = 320 \text{ kWh} \tag{9}$$

In the second Case it has been analyzed shading overlapping caused by surrounding buildings at an angle of 40° and a vertical element on the façade at an angle of 60°, fig. 13. It has led to partially overlapping, which was avoided by reducing the ratio of the vertical element on the façade at 45° in order to reduce the shading surface for the required 50%, eqs. (10) and (11).

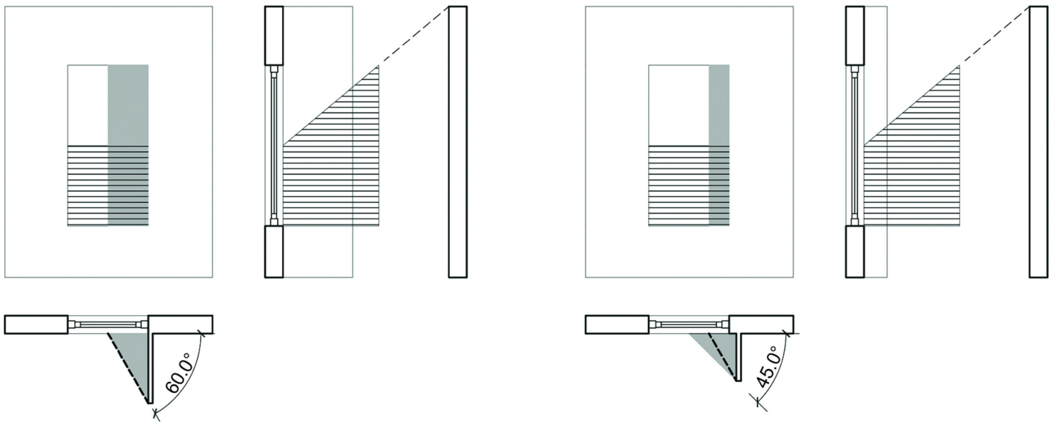

Figure 13. Shading due to the surrounding building and vertical element on façade

$$F_{tot} = F_{sb} F_{fin} = 0.87 \cdot 0.97 = 0.844 \tag{10}$$

$$Q_{sol'} = Q_{sol} F_{tot} = 430 \cdot 0.844 = 363 \text{ kWh} \tag{11}$$

In the third Case, it has been observed the situation of shading overlapping due to the overhangs at an angle of 60° and the vertical element on the façade at an angle of 60°, eqs. (12) and (13). As in the previous case, this has led to a partial overlapping, so it was adopted the angle of 45° again, in order to reduce the shading surface for the required 50%, fig. 14.

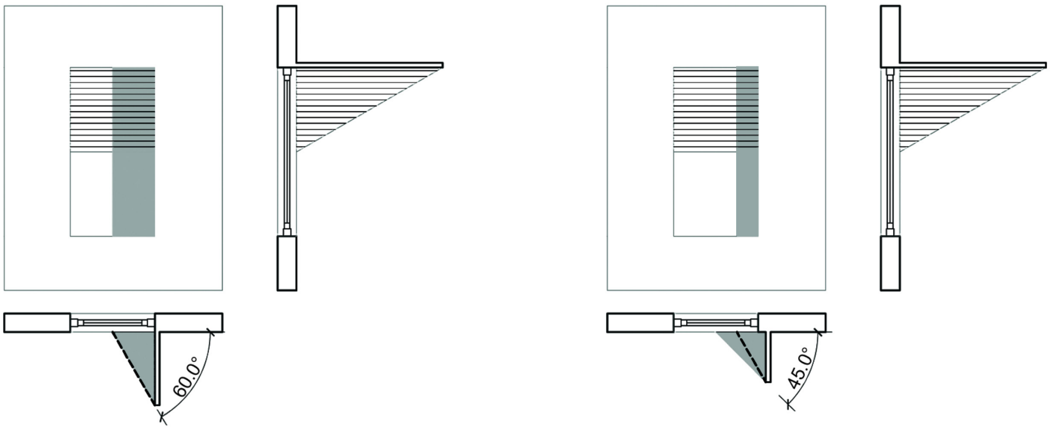

Figure 14. Shading due to the overhangs and vertical element on façade

$$F_{\text{tot}} = F_{\text{ov}} F_{\text{fin}} = 0.83 \cdot 0.97 = 0.805 \qquad (12)$$

$$Q_{\text{sol}'} = Q_{\text{sol}} F_{\text{tot}} = 430 \cdot 0.805 = 346 \text{ kWh} \qquad (13)$$

Table 5. Calculated annual solar gains by two different methods

	4-D simulations	Calculation method
Case 1. Surrounding buildings and overhangs	320 kWh	320 kWh
Case 2. Surrounding buildings and vertical elements	367 kWh	363 kWh
Case 3. Overhangs and vertical elements	350 kWh	346 kWh

As it is presented in tab. 5, the results of solar gains obtained by this method of calculating the final value of the shading correction factor are almost identical to those obtained by method of 4-D simulations. In this way, it was established that the method of calculating solar gains defined by the rulebook by using various correction factors, depending on the position and size of shading elements, gives adequate results if the values of correction factors are correct, and if at the calculation of solar gains through each window is done an adequate analysis of shading overlapping, in order to avoid an overestimating of shading.

Conclusion

The research presented in this paper has shown specific disadvantages of the methodology of solar gains calculation, defined by regulations, and it has pointed out the most problematic items of the calculation. In the first part of the research it was found by the method of 4-D simulations, that simplified method that involves only 4 orientations requires certain complexity, and the introduction of four more orientations, with each value of solar radiation per month. Thus the difference in the results, in the worst case, would not exceed 15%, and the obtained results would be far more reliable. In the further course of the research, the objective was the case of the maximum differences in the results, so that all the disadvantages of the methodology defined by regulations would become visible, and therefore in further research the orientation of +130° has been adopted. The analyzed correction factors, defined by the rulebook, have been shown as oversized and gave drastically lower scores. The multiplication method of different factors, in positions with more shading elements, by an adequate analysis of shading overlapping, can be very reliable, but it is still very complex. On the other hand, the simplified method, which involves the adoption of certain values of shading factors has been proven as more adequate, but it is necessary to adjust the values of shading factors. By the method of 4-D simulations, it has been shown that adequate values of correction factors are $f_s = 0.95$ for the unshaded position, $f_s = 0.85$ for moderate shaded position, and $f_s = 0.7$ for completely shaded position.

Nomenclature

Q_{sol} – total solar gains, [kWh]
F – correction factor, [–]
f – shading factor, [–]

Subscripts

sol – solar
tot – total
ov – overhang
fin – external shading devices/fins
sb – surrounding buildings

References

[1] Bruno, R., *et al.*, An Analytical Model for the Evaluation of the Correction Factor F_w of Solar Gains through Glazed Surfaces Defined in EN ISO 13790, *Energy and Buildings, 96* (2015), June, pp. 1-19
[2] Evangelisti, L., *et al.*, Analysis of Two Models for Evaluating Energy Performance of Different Buildings, *Sustainability, 6* (2014), 8, pp. 5311-5321
[3] ***, Rulebook on Energy Efficiency of Buildings *Official Gazette of RS*, No. 61/11, Belgrade, 2011
[4] ***, EN ISO 13790, Energy Performance of Buildings – Calculation of Energy Use for Heating and Cooling, 2008
[5] ***, Ecotect Analysis – Sustainable Building Design Software – Autodesk, 2011
[6] Rajcic, A. (2011): „KnaufTerm2“, The Software for Calculating Energy Performances of Building, Knauf Insolation, 2015
[7] ***, Monthly Energy Review, U S Department of Energy, Washington, D. C., Energy Information Administration, 2004, available on https://energyplus.net/weather
[8] Dutta, A., *et al.*, Influence of Orientation and the Impact of External Window Shading on Building Thermal Performance in Tropical Climate, *Energy and Buildings, 139* (2017), Mar., pp. 680-689

Paper submitted: May 23, 2017
Paper revised: November 5, 2017
Paper accepted: December 11, 2017