Journal of International Scientific Publications: Materials, Methods and Technologies
Volume 8, ISSN 1314-7269 (Online), Published at: http://www.scientific-publications.net

FACADE EXTRUSIONS' INFLUENCE ON THE BUILDING SOLAR INSOLATION PERFORMANCE

Marko Jovanovic
University of Novi Sad, Faculty of Technical Sciences, Department of Architecture,
Trg Dositeja Obradovica 6, Novi Sad, Serbia

Abstract

Mid-rise and high-rise buildings in dense urban areas have higher exposure to sunlight and heat, due to heat island gain, flatness of facades and improper use of insulation materials with regards to thermal comfort. Use of proper materials and adequate facade design methods, as building specific parameters, can optimize the solar insolation to suit a specific geographical location. This paper will focus mainly on the influence of various facade extrusion types, specifically balconies, horizontal and vertical extrusions. Their influence on the solar insolation and sunlight exposure of the accompanying facade throughout the year, for a specific geographic location and orientation is analyzed and compared amongst one another. Such information can further be used as input parameters for optimizing urban planning algorithms on a major scale, focusing on desired solar exposure, considering orientation.

Key words: *extrusion, balcony, solar exposure, insolation, cornice*

1. INTRODUCTION

Mid-rise and high-rise housing units and buildings experience great problems regarding thermal comfort, sun glare, heat islands and high sunlight exposure. This is due to improper design approaches, mainly considering material application, insulation and inadequate building envelope and as a consequence energy is being utilized even more than necessary on ventilating and heating. Such conditions present a dire problem of today's architecture. Facade extrusions, balconies, galleries, awning and cornices that form the building's envelope can provide a more uniform spread of solar exposure and provide appropriate shading and energy preservation (Toudert &Mayer 2007; Caruso et al 2013). Determining how various facade envelopes and extrusion types influence the solar exposure will be the core interest in this research paper. Balconies in particular can supply multiple benefits when applied to living conditions (Chan & Chow 2010). Shape and size of shading elements on a facade as well as street aspect ratio, void to solid ratio (Alkhresheh 2012) or facade aspect and surface to volume ratio (Hachem et al 2011) are important for dimensioning purposes. They need to be evenly propagated on the facade plane as to obtain a more equal spread of sunlight hours on the facade itself during exposure. A rectangular facade layout is suited best for energy efficiency (Hachem et al 2011) and will be used for the analysis in this research paper. Base layout and building height for optimal energy efficient approach to building's design envelope specify a square base layout and high-rise envelope, when calculated as an isolated building (Lobaccarro et al 2012). This research explores the denser and closely situated building layout in an urban block, consequently allowing only the front and back facades to be exposed to sunlight, either direct or diffuse. For the purposes of this research, the influence of opposing neighboring facades is omitted, as well as implementation of windows in the facade plane, due to existence of myriad of parameters that might blur the findings of this research. The results procured in such a manner are applied for determining the best suited facade envelope for optimal sunlight hours. Also it can serve as a guideline for determining solar insolation and PV potential on facades. Facades have a high potential for applying solar panels or PV cells on its surface, thus enabling the production and preservation of energy (Hsieh et al 2013; Redweik et al 2013). The research will focus on examining and calculating solar exposure for different facade envelopes depending on their orientation.

2. METHODOLOGY

For the purposes of this research, only one building is taken under consideration, varying multiple facade extrusion parameters - facade types, for eight orientations. In such a manner, the results procured are more controlled and precise, since the surrounding geometry influence is omitted. Implementation of windows is omitted since they do not impact the facade extrusion, merely the area of impact. Since the area is the same in all analysis examples, the windows can be inserted upon completion and determination of results, for a more

thorough finding on the matter. The building has a rectangular facade layout, with a street front of 17m, consisting of 5 floors, each with a height of 3m. The facade is also divided into 8 horizontal columns, each having an equal span and one meter of extrusion length where applied. The building is depicted as a mesh grid, where precision is manipulated by adjusting the number of faces, after which solar exposure for each orientation is calculated, based on predetermined geographical location. Average daily values for each orientation form a graph specific for a facade envelope. An accompanying algorithm is designed which allows for manipulation and automation of all the above mentioned parameters, thus making a more culturally and geographically specific approach to research. Facade types and their parametric depiction will be described further on.

2.1. FACADE TYPES

Three facade types are chosen for this research paper, mainly focused on the position of extruded facade parts. Facade type A has extruded parts on every odd column. Facade type B merely represents a singular column, with 8 possible positions on the facade. Facade C consists of two columns, with adjustable position and distance between one another, based on the column span. Columns represent extrusions either in form of balconies, meaning that their surface is not used for solar exposure calculation, or in form of extruded facade parts, where their surface area falls under calculation of solar exposure. This is based on facade elements being a connection to the outside world or enclosing a living space, respectively. Each one of these facade types is attributed by a cornice as an additional parameter (Figure 1). The entire process is automated via an algorithm, thus providing more control and overview of data, which will be explained further on.

2.2. WORKFLOW

In this research, an amalgamation of several programs is exploited for generating the geometry and analyzing the performance. The combination of Rhinoceros and Grasshopper is utilized for generating geometry and manipulating it via parameters, respectively. Rhinoceros gives geometry as an output, while Grasshopper serves as programming language for parametric and algorithmic modeling. After a facade type has been chosen as a parameter - A, B or C, another parameter defines choice of balconies or extrusions and the existence of a cornice. Facade generated in such a manner is converted into a mesh grid, with the possibility of adjusting the resolution of the grid, by manipulating the face count via parameters as well. Afterwards, the grid is exported into a performance based analysis program. Ecotect 2011 is used for solar exposure simulation and analysis. The solar exposure calculation is conducted for the duration of the entire year, from 5am to 8pm. The program is set to procure average daily values. The geographically specific weather data, with the .wea extension, is set to Belgrade, Serbia. The advantage of an algorithm applied for this research is that any other weather data for any geographical location can be procured (EnergyPlus n.d.), applied and still provide adequate analysis. The precision of the analysis can be set to higher or lower, depending on the sky subdivision parameter, which is also adjustable from Grasshopper. The lower the number is, the more time the program needs to calculate the results thus the more accurate the results are. For this research, a value of 20 is chosen for the sky subdivision parameter. After the results have been calculated, they are imported back into Grasshopper and averaged for a specific facade type envelope.

This entire process is done automatically for each of eight orientations - SE, E, NE, N, NW, W, SW, S, and documented by generating quick graph views and writing the values in an excel file for a more thorough depiction of graphs. Results generated in such a manner are compared.

3. RESULTS

The results are presented by, firstly, comparing values within a single facade type in order to determine the influence of extruded parts on the solar exposure performance - balconies, balconies with a cornice, extrusions and extrusions with a cornice. Afterwards, the average facade type values are compared amongst themselves for the purposes of defining differences between facade envelopes. In the end, all facade type values are compared to values calculated for a planar facade in order to determine the benefits of utilizing these facade types.

3.1. SINGLE FACADE TYPE

3.1.1. FACADE TYPE A

The first facade type, facade type A, has only one possible position of its extrusions, as specified earlier in the paper. The values calculated for such a facade type reveal that this facade ranges from 5.82 to 6.3 sunlight hours for the most exposed orientation, the south facing facade. For the north facing facade, as the least exposed, the values range from 1.27 to 1.89 sunlight hours. The minimum values are attributed to facade variation A12,

mainly showing that mere utilization of balconies, with a cornice will result in values of 1.27 sunlight hours for north orientation, and 5.82 for south facing facades, respectively. Facade variation A22, which has extrusions and a cornice, presents the maximum values amongst all types, ranging from 1.89 sunlight hours for north and 6.3 sunlight hours for south orientation. An amount of half an hour of sunlight is noticeable between these two extremes. The other type A facade variations have almost interpolated values between these two examples, which can be seen in Figure 2.

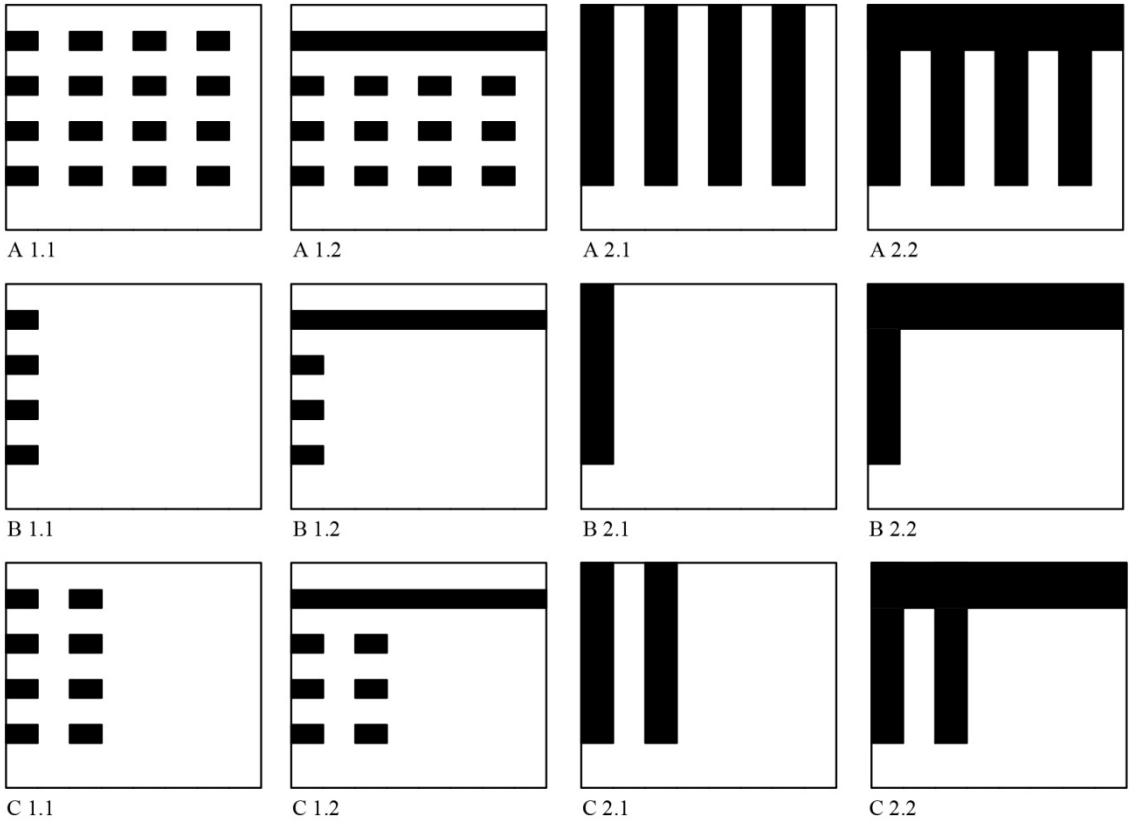


Figure 1 - Depiction of all facade types used for research in this paper. 1.1 Balconies; 1.2. Balconies with a cornice; 2.1. Extrusions; 2.2 extrusions with a cornice

3.1.2. FACADE TYPE B

This facade type has only one column extruded at any given type, thus having 8 possible positions. The positions range from the first position, on the left, as seen in Figure 1, to the last viable position on the far right. For the first position, the facade type B ranges from 7.51 to 8.52 sunlight hours for south and from 1.71 to 2.21 sunlight hours for north orientation (Figure 3). For the fourth position, where the column is extruded near the center of the facade, chosen as the most different from the first position, the values range identically to the first one. There is, however, a minor discrepancy between the first and the fourth position in the NW orientation, where the first position has half an hour of sunlight more than the fourth position, and the values decrease as the building's orientation moves counterclockwise to the southern orientation (Table 1). This is due to the mid extruded column shading the rest of the facade, as opposed to the column positioned on the edge. The variation with the highest amount of sunlight hours is B11, while the lowest is B12, meaning that the existence of a cornice with a singular extruded column makes a difference of more than 40 minutes of sunlight.

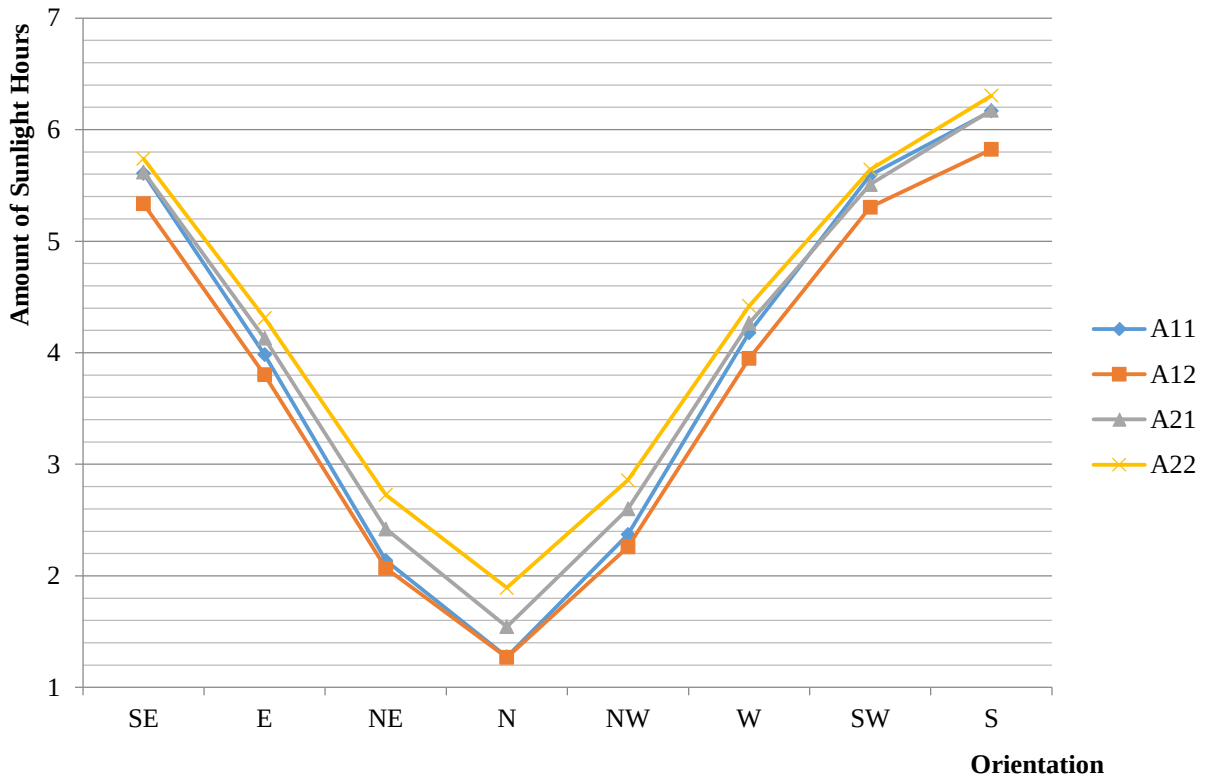


Figure 2 - Facade type A variations

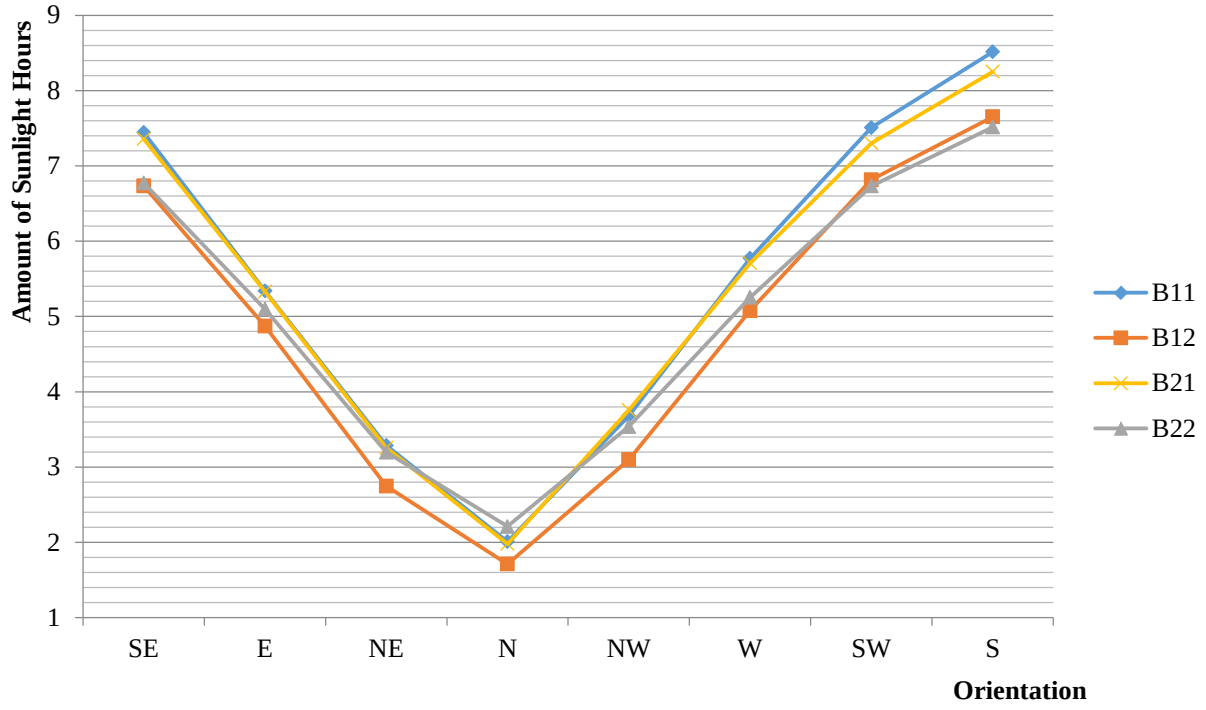


Figure 3 - Facade type B variations for the first position

Amount of Sunlight Hours			Orientation							
			SE	E	NE	N	NW	W	SW	S
Façade Type B	B11	Position 1	7.45	5.34	3.29	2.01	3.68	5.77	7.51	8.52
		Position 4	7.35	5.32	3.31	2.02	3.31	5.44	7.29	8.42
	B12	Position 1	6.74	4.87	2.75	1.71	3.10	5.08	6.82	7.65
		Position 4	6.69	4.88	2.89	1.81	2.88	4.85	6.65	7.61
	B21	Position 1	7.36	5.33	3.26	1.98	3.76	5.71	7.30	8.25
		Position 4	7.08	5.14	3.14	1.88	3.15	5.26	7.01	8.08
	B22	Position 1	6.77	5.10	3.20	2.21	3.54	5.25	6.73	7.51
		Position 4	6.60	4.97	3.20	2.22	3.20	4.99	6.55	7.44

Table 1 - Facade Type B - Position 1 and Position 4 Sunlight Hour Comparison

3.1.3. FACADE C

This type has, at any given moment, two columns extruded. Since there is a myriad of solutions in reference to the column position, one column is fixed in the first position, on the left and the second is placed in the 7 remaining positions, slowly increasing the gap between the two extruded columns (Figure 4).

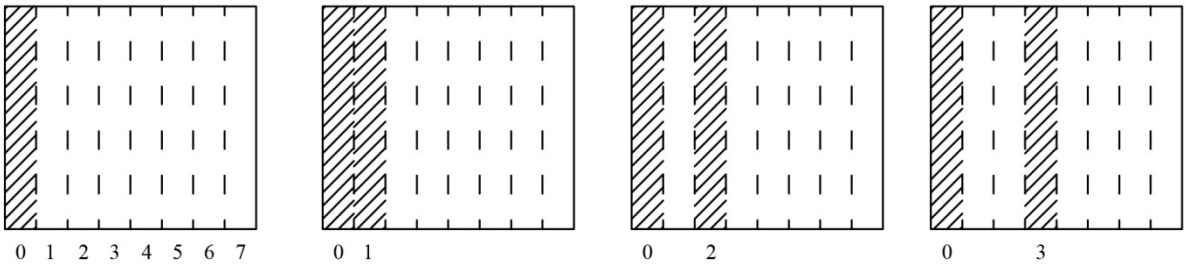


Figure 4 - (From left to right) Facade's horizontal division and column numeration, column choice for different positions

In such a way all important column positions are checked and calculated, without the need to analyze all possible solutions. The highest amount for this facade type ranges from 7.03 to 8.07 sunlight hours for southern orientation. The lowest amount of sunlight hours ranges 1.51 to 2.28 for the northern orientation. With the exception of facade type at position 0-1, all other positions, 0-2, 0-3, 0-4, 0-5, 0-6 and 0-7 clearly show that, on average, the highest amount of solar exposure is attributed to the variation C11. The gap increase between the two columns is followed by a minor decrease in the values as the second column approaches the center of the facade. At positions 0-5, the values have a slight increase, after which, at position 0-6 they decrease again. As the position changes to 0-7, the values start to increase again, reaching higher values than at position 0-2 (Figure 5). Even though the variation C11 exhibits the highest values on average, Figure 6, clearly shows that as the orientation reaches north - NE, N, NW, maximum values are attributed to the variation C22.

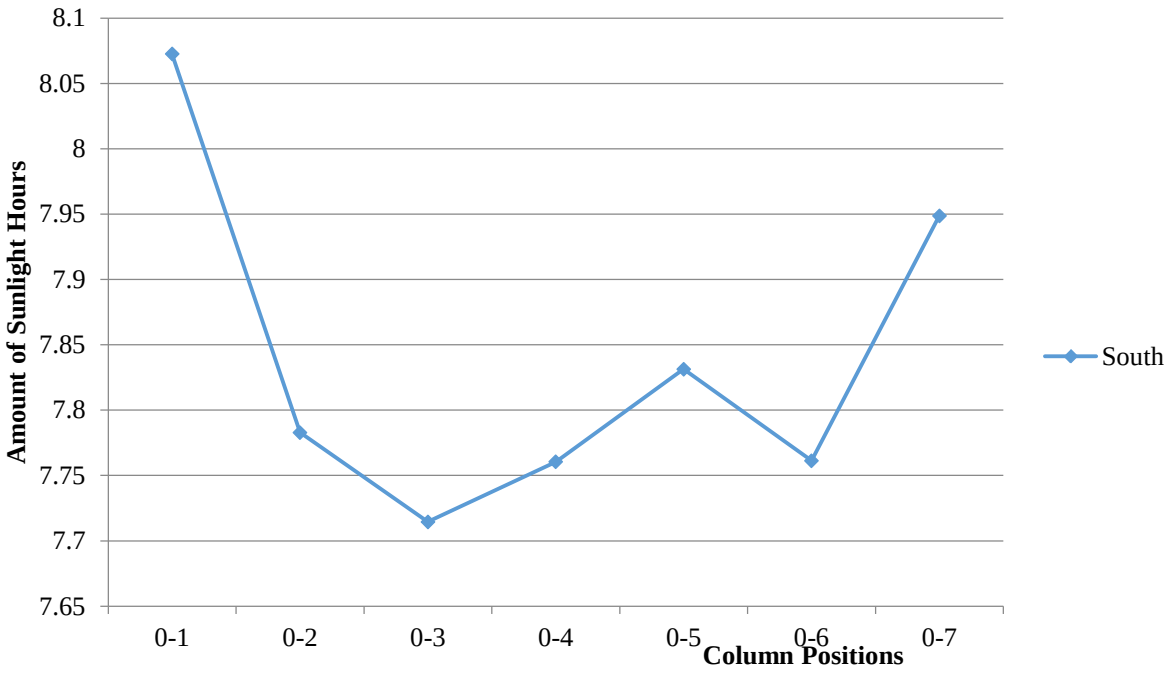


Figure 5 - Discrepancies for variation C11 in southern orientation for all positions

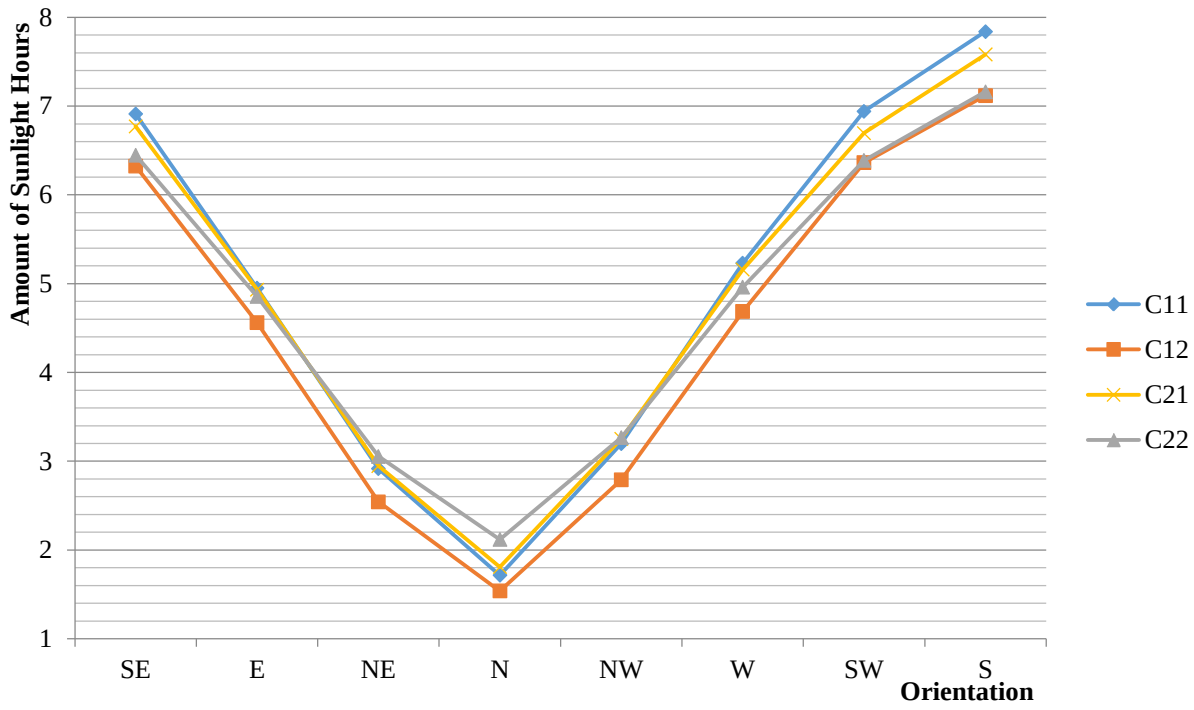


Figure 6 - Facade type C variations on average, for all positions

Variation C12 depicts the lowest values for solar exposure, regardless of the position or orientation. The difference between the highest exposure and the lowest exposure is in the range of around half an hour, depending on the orientation.

The three facade types and their lowest and highest values, respectively, are compared in the next section.

3.2. FACADE TYPES COMAPARISON

The evaluation of single facade types, when compared to one another, has presented an interesting result. All facade types have lowest exposure to sunlight for the facade variation 12, meaning that positioning balconies on the facade and adding an overshadowing cornice on the last floor, leads to minimum values. The maximum exposure to sunlight hours is attributed mostly to the variation 11 and 22. The variation 11 procures highest amount of sunlight hours for a single extruded column on the facade, namely facade type B. Regarding facade type C, which has two extruded columns, highest values are attributed to variation 11, except for near north orientation, namely NE, N and NW, where they are attributed to variation 22. Facade type A, having 4 extruded columns, has the highest solar exposure for variation 22. There is a significant relation between the number of columns and the change in variations that procure highest exposure. The larger the number of extruded columns the more it is that variation 22 will obtain higher values as opposed to variation 11. By comparing the highest and the lowest facade type values in accordance to their variations, it's noticeable that by increasing the number of columns, the overall solar exposure decreases (Figure 7).

In order to verify the impact of utilizing these facade types, the highest and lowest values for each facade type are compared to values generated for a planar facade (Figure 7). It shows that a planar facade has higher exposure than any of the analyzed facade types, as is to be expected.

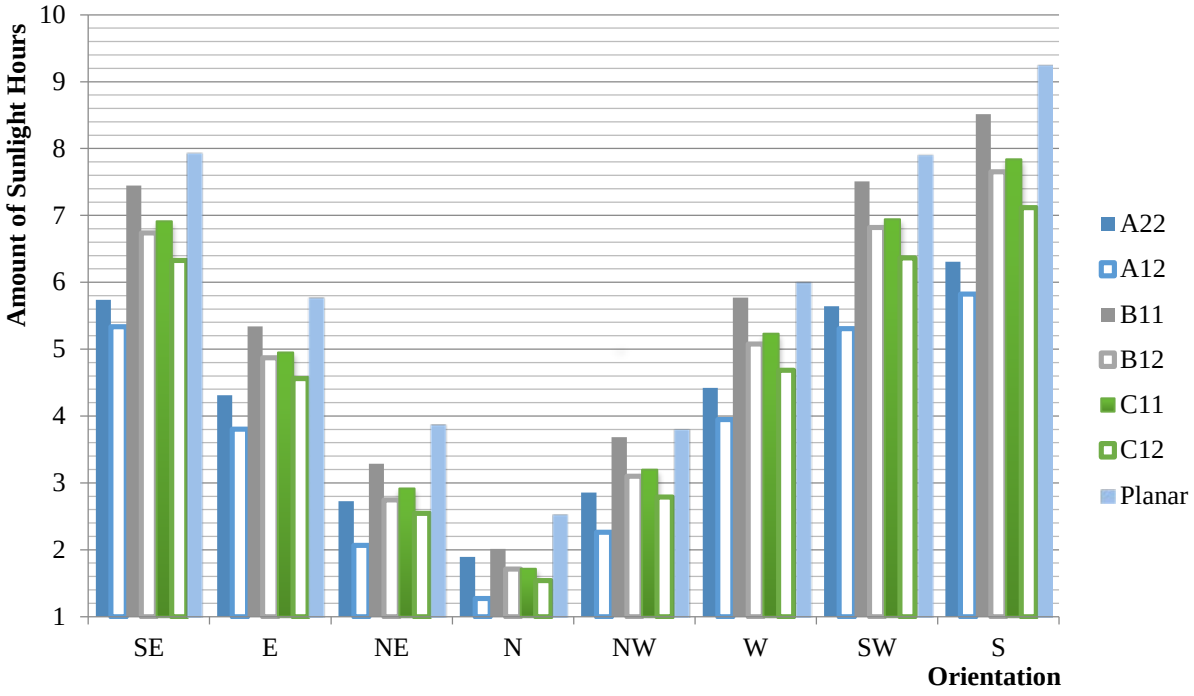


Figure 7 - Comparison between highest and lowest solar exposure for all facade types and a planar facade

4. FUTURE WORK

Since the influence of neighboring buildings is omitted for the purposes of this research, future work will focus on generating a street and analyzing a building positioned in the middle for the above mentioned facade types. Major parameters in this research will be the street aspect ratio and facade type choice. Results acquired from the research in this paper present a great set of input information for an urban planning and design project. They can be utilized as parameters as well, in reference to a predetermined or desired number of sunlight hours and facade orientation. Future work will focus on an urban block and it's appearance, in reference to solar exposure as well.

5. CONCLUSION

In this paper, three types of facades are analyzed and compared, varied by the type of facade envelope - balconies, extrusions and/or cornices. Facades are evaluated within a single type, in order to determine the highest and lowest solar exposure per facade type. Afterwards, all facade types are compared amongst themselves in order to determine the difference in solar exposure between each facade type. As a result, regardless of the facade type, minimum amount of solar exposure is attributed to a facade variation 12, consisting of balconies and a cornice. As for the highest solar exposure, this paper reached a significant finding. Namely, by increasing the number of extruded vertical columns, the facade envelope needs to change from 11 to 22, from pure balconies to extrusions with a cornice, respectively, in order to have the highest solar exposure. Also, the increase in extruded columns is followed by a decrease in overall solar exposure. This means, that facade type A has the lowest solar exposure, since it has 4 extruded columns. Facade type C has 2 extruded columns and an increase in solar exposure in regards to the latter. Facade type B has the highest solar exposure amongst the analyzed facades, since it only has one extruded column and is close to a planar facade. Utilization of facade extrusions can benefit the thermal comfort in a building, procure optimal solar exposure and overshadowing. Also, in reference to the desired number of sunlight hours or overshadowing, the research results can be used as input parameters for a building design.

ACKNOWLEDGEMENT

This research was supported by the Serbian Ministry of Education and Science (project no. TR36042).

REFERENCES

Ali-Toudert, F, Mayer, H 2007, ' Effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons', Solar Energy, Vol. 81, pp. 742-754.

Caruso, G, Fantozzi, F & Leccese, F 2013, ' Optimal theoretical building form to minimize direct solar irradiation', Solar Energy, Vol. 97, pp.128-137

Chan, ALS & Chow TT 2010, ' Investigation on energy performance and energy payback period of application of balcony for residential apartment in Hong Kong', Energy and Buildings, Vol. 42, no. 12, pp.2400-2405

EnergyPlus Energy Simulation Software (n.d.). Retrieved July 18 2013 from

http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm

Hachem, C, Athienitis, A & Fazio, P 2011, ' Parametric investigation of geometric form effects on solar potential of housing units', Solar Energy, Vol. 85, pp. 1864-1877

Hsieh, C et al 2013, ' Potential for installing photovoltaic systems on vertical and horizontal building surfaces in urban areas' , Solar Energy, Vol. 93, pp. 312-321

Lobaccaro, G et al 2012, ' District geometry simulation: a study for the optimization of solar façades in urban canopy layers' , Energy Procedia, Vol. 30, pp.1163-1172

Reweik, P, Catita, C & Brito, M 2013, ' Solar energy potential on roofs and facades in an urban landscape', Solar Energy, Vol. 97, pp.332-341