World Transactions on Engineering and Technology Education
Vol.13, No.3, 2015

Innovative building design with solar radiation analysis

Lorant Krajcsovics, Jana Gregorová & Lukáš Šíp

Slovak University of Technology in Bratislava
Bratislava, Slovakia

ABSTRACT: The potential to utilise solar radiation is predetermined by site location, surrounding structures and building shape. The Institute of Ecological and Experimental Architecture at the Faculty of Architecture has verified building designs in different urban structures with respect to a range of parameters during several semesters. Various building designs on examined site locations were analysed by solar index defined by Morgenstein [1]. These analyses exposed the potential and limitations of the given site locations. The projects examined revealed incompatibility between the requirement to maximise the use of solar radiation and the requirement to respect cultural and social context in typical urban block structures. In such structures, the character and dimension of new buildings are rather pre-defined. Higher potential for the use of solar radiation was found in modern settlement structures of the second half of the 20th Century.

INTRODUCTION

Zero energy building designs assume the use of solar radiation. Active solar thermal cells and photovoltaic cells can supply electricity and thermal energy especially during the summer period. Passive use of solar gains through windows is desired during the heating season, which in Europe starts in October and ends in April. This period varies according to the energy performance of the building and the climate situation. A general rule applies: the more efficient the building's energy performance, the shorter the heating season and the higher the ratio of solar gains in the heating. It is especially true for residential buildings. Other types of buildings have their own specifics.

Active utilisation of solar energy is efficient during summer and the period between seasons. The Sun's altitude in Bratislava, Slovakia, is as much as 65°30´ over the horizon at those days (21 June at 12.00 astronomical time). The building's surface having the biggest absorption potential is the roof.

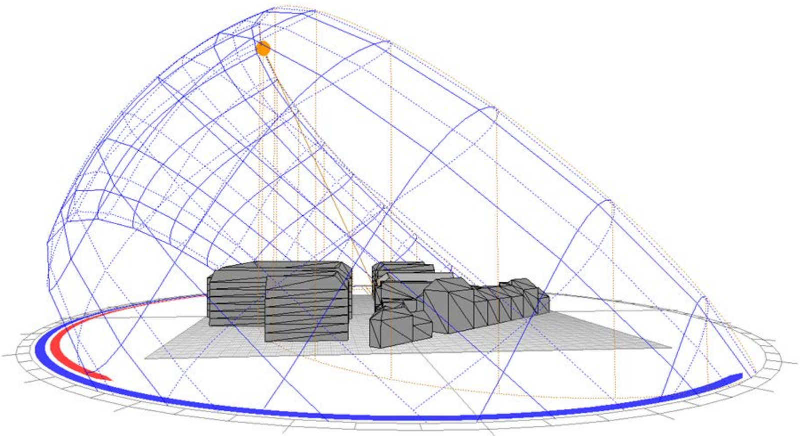

Figure 1: The Sun's path for Bratislava.

Solar radiation availability for a piece of land is dependent on its location and shading by surrounding building density. Moreover, a designed construction/building may have a major influence on excessive solar exposure of the neighbouring buildings. In Slovakia, the direct insolation requirement for the period from 1 March till 14 October is protected by law. In particular, this legislative measure stipulates the hygienic minimum regarding the solar radiation availability.

ASSESSMENT METHOD

This article deals with the analysis of solar radiation availability from the energy (not merely hygienic) point of view. The solar index (SI) has been used to assess the examined sample of designed urban structures. The solar index describes the amount of total solar radiation incident on a specified area (related plot) that can be captured and potentially utilised by the surface of urban structure (or neighbourhood, district, city quarter). The purpose of the solar index, expressed in percent values, is to increase urban density, while maintaining optimal access to solar energy in order to provide full land utilisation [1].

For the purposes of this research two locations, which differ in urbanistic concepts, within the city of Bratislava were selected. The urban structures at Žilinská Street was formed in the middle of the 19th Century and later in the period between the two world wars. It is a typical example of classic urban block structure. The second examined location was Cyprichova Street in the Krasňany city district. This area was formed in the course of the 1950s and is characterised by a loose building development. Garden City principles were applied in designing this housing estate. The ground space index (GSI) reaches 0.18 and the floor area ratio (FAR) has the value of 0.7.

INSOLATION ANALYSIS

Variants of building shapes were developed by students from the Institute of Ecological and Experimental Architecture at the Faculty of Architecture in various design studios during the semester studies. They were tasked to design architectural structures in consideration of a maximum use of solar radiation. The simulation program Ecotect 2011, VASARI REVIT and climatic data for Bratislava were used to assess the individual variants. Comparing the latter to climatic data used in the Slovak Technical Standards (STN) showed a high level of concordance. Values of solar radiation falling on a horizontal surface are almost identical. The values for vertical façades are underrated compared to the STN standard by 20% at the most, which deviation one regards as acceptable. The coloured effects on Figures 1 - 9 indicate the volume of falling radiation. Yellow and orange shades stand out for high intensity values and blue and violet represent lower intensity values.

ŽILINSKÁ AREA

The area is located in the city’s central urban zone at Žilinská Street, characterised by block-type structures. A market place is currently situated on the land analysed. The land is substantially overshadowed by the adjacent buildings, restricting up to 20% of the available solar radiation during the year.

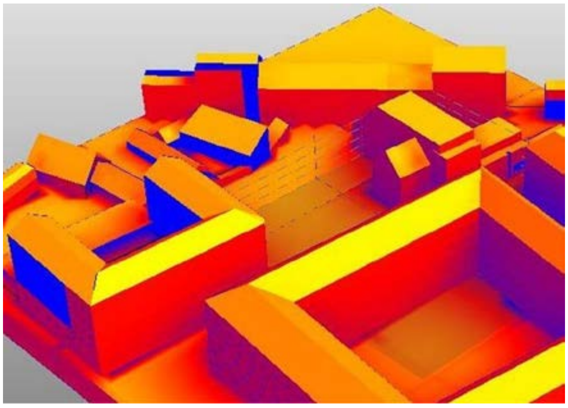

Figure 2: Insolation of structures at Žilinská Street; 20% shading ratio due to surrounding structures.

Several building shapes were experimentally placed on the land. Each alternative was evaluated in terms of the potential for using the solar radiation. Individual variants were compared to one another by means of solar index throughout the year.

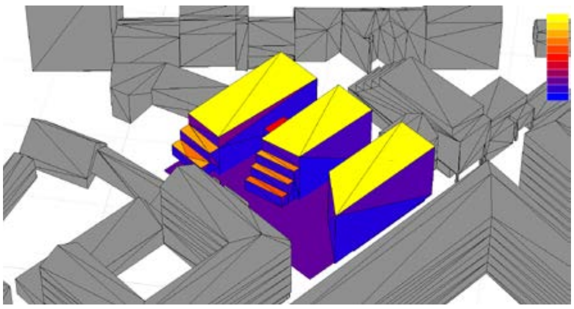

Figure 3: Variant No. 1 - author/student: Bc. Martina Ulrichová; shading ratio 76%, building envelope 7,639 m^2, solar index (SI) 1.0.

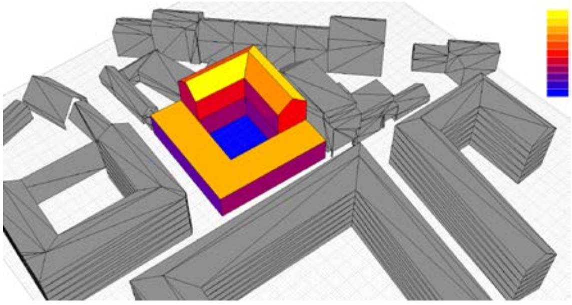

Figure 4: Variant No. 2 - author/student: Bc. Černeková; shading ratio 83%, building envelope 5,344 m^2, solar index 1.47.

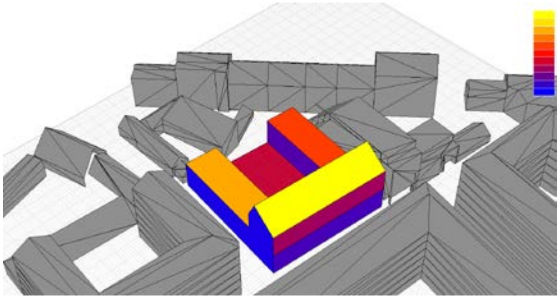

Figure 5: Variant No. 3 - author/student: Bc. Černeková; shading ratio 86%, building envelope 4,789 m^2, solar index 1.01.

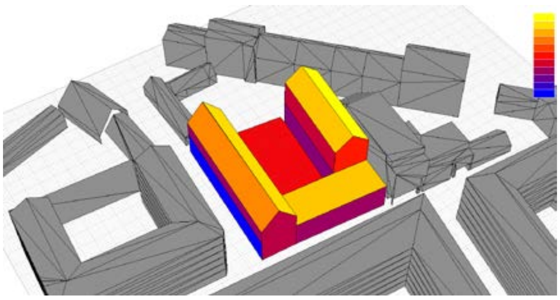

Figure 6: Variant No. 4 - author/student: Bc. Černeková; shading ratio 86%, building envelope 6,019 m^2, solar index 1.28.

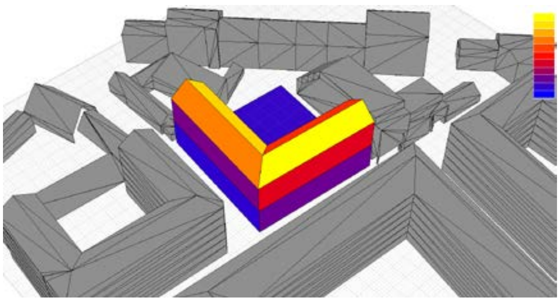

Figure 7: Variant No. 5 - ledge 21m high; shading ratio 90%, building envelope 4,907 m^2, solar index 1.06.

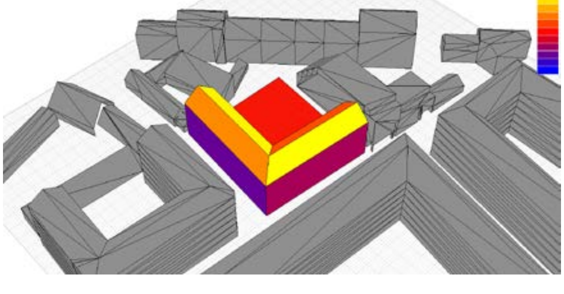

Figure 8: Variant No. 6 - ledge 16m high; shading ratio 75%, building envelope 4,180 m^2, solar index 0.90.

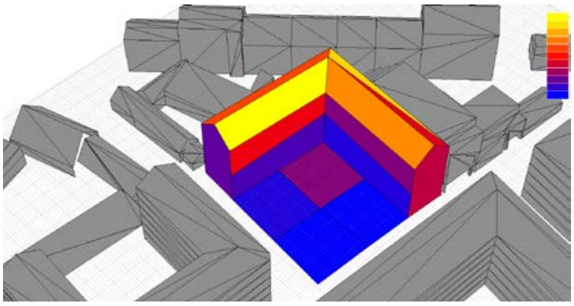

Figure 9: Variant No. 7 - shading ratio 92%, building envelope 4,907m^2, solar index 0.89.

In this urban structure, the maximum solar radiation falls onto the flat level roofs in all the variants. This opens up the opportunity to use the solar energy. Shading of the designed façades by the surrounding buildings is significant. For hygienic reasons, lower storeys may only house premises not requiring direct sun radiation.

Out of the examined samples, the most of solar radiation comes onto the surface of the building under variant No. 2 (SI = 1.47) and variant No. 4 (SI = 1.28). Where the SI value is above 1, the building catches more solar radiation than would be falling on the ground area. This means that such buildings cause a lack of sunshine for the surrounding structures and lands (deprives them of solar radiation). Given the construction volumes of buildings, these variants create a disturbance in the area's urban structure.

The Žilinská area is located in the heritage sites zone of Bratislava's Central Urban Area (abbreviated in Slovak to CMO). Therefore, under Act No. 49/2002 on the protection of monuments and historic sites, there are frameworks for possible development in the existing building gap (in area under examination) contained in the principles for heritage sites protection. The document suggests that all building gaps be completed. Suggested structures should close up the block, the height should not exceed the level of the highest adjacent building. The character of new structures should be inspired by traditional structure types.

Based on such regulative provisions, the abovementioned requirements are best satisfied by variants 3, 5 and 6. These variants respect the characteristic articulation of traditional structure - significant volumes are oriented towards the street, secondary volumes towards the inner courtyard.

Variant No. 2, thus, violates the mentioned articulation principle - placing a significant volume into the inner courtyard and less significant one towards the street.

Variant No. 4 presents a compromise between the said approaches - it works with high-rise and low-rise volumes, so as to create a segue among surrounding structures of varying heights.

Even though variant No. 7 does not respect traditional articulation, yet it enables to preserve the market place function (of many years' tradition) by keeping the area from the street without buildings.

One can conclude that the best solar index is achieved in the variants, which did not observe the traditional building articulation in urban block structures. Here, the principles for preservation of heritage sites and the effort to maximise the utilisation of solar radiation are in conflict.

KRASŇANY AREA

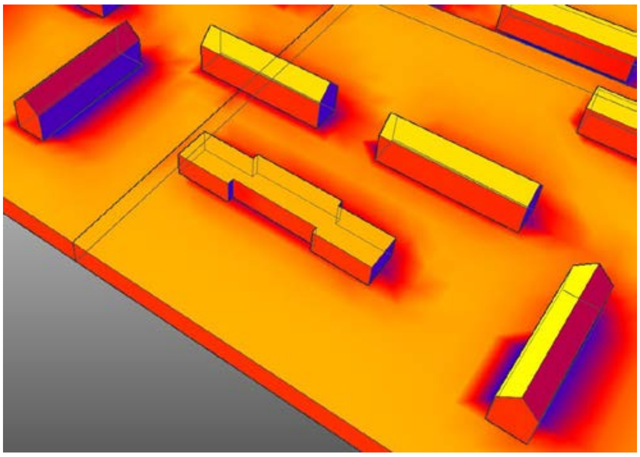

Figure 10: Insolation of structures at Cyprichova Street in Krasňany; 2% shading ratio by surrounding structures.

The total area surface is 7,106 m^2. The land has a minimum shading by the surrounding structures with 98% impact of available solar radiation. The research focused on one urban block structure, framed by four residential buildings.

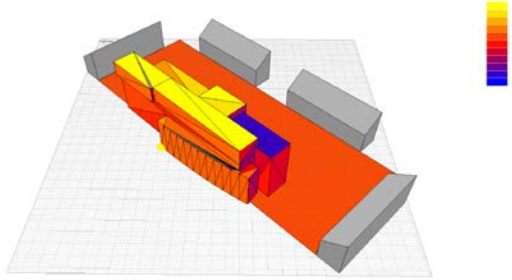

Figure 11: Variant No. 8 - author/student: Bc. Szabó; shading ratio 35%, building envelope 13,122 m^2, solar index 0.6.

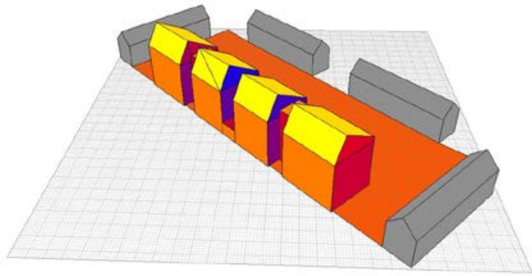

Figure 12: Variant No. 9 - author/student: Bc. Rantová, shading ratio 62%, building envelope 9,545m^2, solar index 0.61.

Both variants placed the designed building in the south-western part of the land, thus, forming a semi-open urban block. In terms of height regulation, emphasis was put on the surrounding structures in order to avoid shading the neighbouring façades as prescribed under the applicable legislation (c.f. above). The designed building absorbs the maximum of 20% from the aggregate solar radiation falling on the surrounding structures in winter. Roofs and southern façades were sun-radiated year-round in either case; and the solar radiation may be utilised with the help of passive and active elements.

CONCLUSIONS

The design of building shapes in classic urban block structures with regard to the maximised utilisation of solar radiation is far more complicated than usually envisaged. Roof surfaces have the biggest potential in terms of insolation. If the aim is to achieve an even distribution of solar radiation onto the whole area in question, inclusive of the surrounding buildings, then, regulating the heights of structures is essential. In conclusion, the assessed variants demonstrate a conflict between the preservation principles applied to heritage sites and the effort to maximise solar radiation use.

Placing buildings in a lower urban density scheme, typical for the second half of the 20th Century, is considerably simpler. However, when designing the position and shape of a building, it is required that the architect verifies the levels up to which a new object will overshadow the surrounding structures and *vice-versa*, i.e. how overshadowed the designed building will be by the structures in its surrounds. The objective is to achieve optimal sun exposure of the roof and façades of both the designed and existing urban structures. Intensification of development density and potential placement of high-rise buildings in the area would restrict the universal right to the Sun.

One of the outcomes of the simulations is the conflict between the current trend of increasing urban density in the city and increasing the level of solar radiation use, in particular, in dense urban structures. Introducing stricter and more comprehensive regulative standards, such as a solar index will, therefore, become imperative. Where the building development is less dense, the area's traditional urban character disappears, public transport accessibility becomes poorer, and there is an increased need for an expansion in the capacities of public transportation and technical infrastructures.

ACKNOWLEDGEMENTS

This article was prepared within the grant project: Architecture and Urban Planning 2020 - towards a zero energy standard, VEGA č. 1/0559/13.

REFERENCES

1. Morgenstein, P., Typology of Solar Urban Design: Energy Cooperativeness of Urban Structures. Dissertation Thesis. Bratislava: Faculty of Architecture at Slovak University of Technology (2013).