ISES International Solar Energy Society

Conference Proceedings

EuroSun 2014
Aix-les-Bains (France), 16 – 19 September 2014

Solar Potential in the Existing Slovenian Building Stock

Mitja Košir[1], Mateja Dovjak[1] and Živa Kristl[1]

[1] Faculty of Civil and Geodetic Engineering, Chair for Buildings and Constructional Complexes, University of Ljubljana, Ljubljana (Slovenia)

Summary

Implementation of sustainable construction in the EU is one of the key issues for reducing energy dependence. In this framework the efficient use of solar potential incident on the building envelope is essential. The goal of the study is to check the influence of new Slovenian legislation requirements on the existing design practice and to propose general site planning guidelines. The study is carried out on seven representative urban layouts, which are assessed according to the shape of layout, density, building orientation and design. The calculations are carried out with the program SHADING. The study showed that the existing layouts are not as problematic as had been expected and that the form and orientation of buildings present a major challenge. Nevertheless, the quality and duration of insolation are highly dependent on the specifics of each case. The study showed that if the basic rules of good practice in conjunction with the existing requirements are respected, there is no need to introduce any essential changes in the existing design principles.

Key-words: insolation, solar potential, solar access, urban patterns, legislative measures.

1. Introduction

In the recent years implementation of sustainable construction in the EU has intensified. The recast Directive on energy performance of buildings (EPBDr, 2010) presents the reboot in this field. Considering renewable solar energy, Slovenia (latitude between 45°25'N and 46°52'N) has a medium-sized potential, which is not well utilized. The goal of the study is to define the potential and feasibility for the utilization of solar radiation in urban areas in order to enhance the use of solar energy. The existing building stock, which is due for refurbishment, is of special interest, because this might close the gap between the existing state and the goal of nearly zero energy buildings (nZEB) by using solar technologies such as direct solar gains, solar collectors (SC) and building integrated photovoltaic panels (La Gennusa et al., 2011). According to the data provided by Slovenian Environmental Agency the average global solar irradiation on the horizontal plane for Slovenia is 1120 kWh/m^2 (ARSO, 2012). A slightly higher value of 1250 kWh/m^2 is reported by the Joint Research Centre Institute for Energy and Transport, Renewable Energy Unit (PVGIS, 2012). They also state that the average value of solar irradiation on an optimally inclined surface in Slovenia is approximately 1425 kWh/m^2. The majority of Slovenia belongs to a humid continental climate with warm summers and cold winters (Köppen-Geiger climatic classification: Dfb), although in the south west part of the country a Mediterranean climate (Köppen-Geiger climatic classification: Dwa) is present. For the central part of Slovenia relatively high cloud coverage is characteristic. The average yearly cloud coverage is 63 %, with lowest coverage of 47 % during the month of August and highest values of 81 % during December. The available solar potential can either be utilized on the level of individual buildings or on a larger urban scale. The problem of large-scale renewable electricity generation in the context of the urban area of Helsinki was addressed in a study conducted by Peter Lund (2012), where it was established that a 40–65 % solar fraction of yearly electricity could be reached. It has to be stressed that this refers to a climate that has far lower solar potential than Ljubljana. However, when we study individual buildings or individual city blocks the effect of building envelope shading becomes an increasingly important aspect of the potential for solar energy

Selection and/or peer review under responsibility of EuroSun2014 Scientific Committee
doi:10.18086/eurosun.2014.18.04 Available at http://proceedings.ises.org

utilization. This role of urban setting on the overall energy performance of a specific building is often overlooked, although it was shown by Futcher and Mills (2013) as well as Capeluto (2003) that it can have a large impact on the heating, cooling and lighting energy demand of buildings. This is mainly due to the influence of urban topography on the potential for solar energy utilization (Bojić and Blagojević., 2006).

The presented study was carried out in seven typical neighborhoods in Slovenia. Potential duration of solar exposure on building envelope was calculated using SHADING (Yezioro and Gutman, 2009), which enables the calculation of solar exposure of building envelope in a selected time interval and the acquired results present the percentage of solar exposure. The result of the simulations is the percentage of solar exposure upon building envelope in half an hour intervals at three critical days (21st of December, 21st of March and 21st of June). Solar exposure of building envelopes was observed on the basis of specific influential factors: density, orientation and shape. Special attention was given to the relative influence of roofs and facades, therefore identifying which part of the envelope should present the focus in future scenarios of solar energy utilization. We expected that some of the studied urban patterns would not reach the legally required solar exposure.

2. Background

In the recent years many studies have been done in the field of solar energy utilization assessment. On the level of policy making Gadsden et al. (2003) proposed and developed the underlying methodology of a solar energy planning system for energy advisers. The proposed methodology determines the baseline energy consumption of domestic properties and evaluates the potential for its reduction, using the available solar technologies (e.g. passive solar design, PV systems). Okeil (2010) states that a holistic approach to energy efficient building forms is needed. He proposes a Residential Solar Block (RSB) which can maximize solar energy received by buildings façades during winter, thus optimizing solar energy utilization. Indeed, it has been shown by Strømann-Andern and Sattrup (2011) that buildings in a relatively densely built up area compared to unobstructed one can exhibit up to 30% larger energy consumption for commercial buildings and up to 19% increase for residential buildings. These results as well as the results presented by Kanters et al. (2014) in their study of renewable solar energy utilisation in typical Swedes city blocks, emphasise the importance of evaluating the solar potential of planned as well as of the existing buildings in urban environments. Similarly Sarralde et al. (2015) have shown that the solar irradiation optimisation of urban neighbourhoods can result in 9 % increase of irradiation for the roofs and up to 45 % increase for the facades. Because a major obstacle in evaluating the solar potential in the urban environments is the availability of credible and accessible data, Mardaljevic and Rylatt (2003) proposed an approach for determining the annual/monthly irradiation of building façades with the help of irradiation “maps”. On the other hand, Capeluto and Shaviv (2001) proposed the introduction of solar rights and solar collection envelopes in order to protect the solar potential of existing buildings from future developments as well as to maximize solar exposure of the envelope of new buildings. In a similar context of urban insolation Yezioro et al. (2006) elaborated design guidelines for achieving appropriate insolation of open urban areas (i.e. squares), which is interlinked with the insolation of surrounding buildings. In Slovenia only basic solar exposure analyses were conducted in the past by Kristl and Krainer (2001, 2006) and even these for the cases of suburban developments. No analyses of how much solar radiation can be utilized in actual urban cases were carried out. Additionally, we also have to bear in mind that since these studies were conducted the legal requirements in Slovenia and in fact also in the EU, have changed.

On the EU level the most important document concerning the energy efficiency of buildings and the utilization of renewables is the recast Directive on energy performance of buildings (EPBDr, 2010) and also the Energy efficiency Directive (EED, 2012) and Directive on the Promotion of the use of energy from renewable sources (PUER, 2009). The mentioned documents constitute a system of legal requirements that are enabling the execution of the 20-20-20% by 2020 climate and energy package outlined by the European Commission in January 2007 (LGCC, 2007) as well as promote sustainable building design. On the national level the requirements regarding building positioning on plots, solar exposure and allowed overshadowing are regulated in several documents, firstly in the Construction Act (ZGO-1, 2002) and the Spatial Planning Act (ZPNacrt, 2007), then several regulations and ordinances and finally in norms, recommendations and municipal acts. The most important among them is the Slovenian Rules on efficient use of energy in buildings (PURES 2010, 2010), supported by the Technical Guidelines, TSG-1-004:2010 – Efficient energy use (TSG4, 2010), which among energy performance of buildings also is intended to change the existing practice and introduce more Passive Solar Architecture (PSA), PV and SC into the existing practice in order to get closer to the nZEB goal. The area of solar potential of buildings is directly regulated through TSG4, which sets a requirement that the “collecting area” of a building has to be insolated (average) 1 meter above the ground (lower areas are not considered due to natural and built obstructions) at least 2 hours on December 21st (allowing for solar azimuth South ±30°). On the equinox (March 21st and September 21st) at least 4 hours (allowing for solar azimuth South ±60°) and on summer solstice (June 21st) at least 6 hours (allowing for solar azimuth South ±110°) of solar exposure have to be reached. The restrictions of the TSG4 (i.e. the azimuth restrictions) were developed in order to facilitate the usage of solar irradiation during its maximum on the given critical days and therefore excludes low incident angles from the calculation period. More detailed explanation of the TSG4 criteria is given in the paper by Košir et al. (2014). According to the TSG4 definition “collecting areas” of a building are all surfaces intended for collecting solar energy either by direct gain (PSA) or by other means (e.g. SC, PV modules).

3. Method

For the analysis of the solar potential of the existing building stock in Slovenia seven representative examples were chosen. These were selected according to the statistical data provided by the Geodetic Institute of Slovenia (2008) and represent the most frequent building types used in Slovenian residential building stock. After defining the type of analysed buildings a real world example was selected as a basis for generating an idealised geometrical model that was later used for solar potential calculations. Storey heights were unified to enable easier comparison of cases. The assumed terrain slope was horizontal. The effect of surrounding vegetation (e.g. trees) as well as of topography (e.g. hills) on the insolation of the studied buildings was omitted. The examples were selected according to their share in the structure of the Slovenian building stock and the density of built up area. Therefore, the ratios between the gross floor area of buildings and the total area of the lots on which the buildings are situated (i.e. floor space indexes - FSI) were calculated and are stated for each example. The selected types and corresponding examples are presented in Table 1. The calculations were executed with the computer application SHADING (Yezioro and Gutman, 2009), which enables the calculation of solar exposure of building envelope in a selected time interval.

Tab. 1: Representative building types of Slovenian residential building stock.

BUILDING TYPE	STUDIED EXAMPLES
TYPE A: Detached family houses The most common type of residential buildings in Slovenia comprising 89 % of all residential buildings.	**Example 1** (FSI: 0.84) **Example 2** (FSI: 1.06)
TYPE B: Longitudinal apartment blocks Generally up to four storeys high, rarely higher. This is the second most common type of residential buildings in Slovenia	**Example 3** (FSI: 1.33) **Example 4** (FSI: 3.09)
TYPE C: Perimeter apartment blocks Usually rectangular in shape, comprising of four to six storey high buildings. Relatively uncommon type in Slovenian residential building stock.	**Example 5** (FSI: 2.04)
TYPE D: Apartment towers Individual units or organized in smaller groups. Usually six to ten storeys high. They do not represent any significant part of the Slovenian building stock	**Example 6** (FSI: 1.46)
TYPE E: Mixed building type Buildings of different shapes, heights and types. This type can be found in locations where towns spread into the surrounding suburban or rural areas.	**Example 7** (FSI: 3.12)

The percentage of solar exposure on building envelope was calculated in half an hour intervals on three critical days (i.e. December 21st, March 21st and June 21st) specified by the TSG4. September 21st was omitted due to almost symmetrical disposition with March 21st. The results are expressed in minutes and represent equivalent duration of 100 % solar exposure on building surface during the specific day. Surfaces facing east, south and west were considered as “collecting surfaces”.

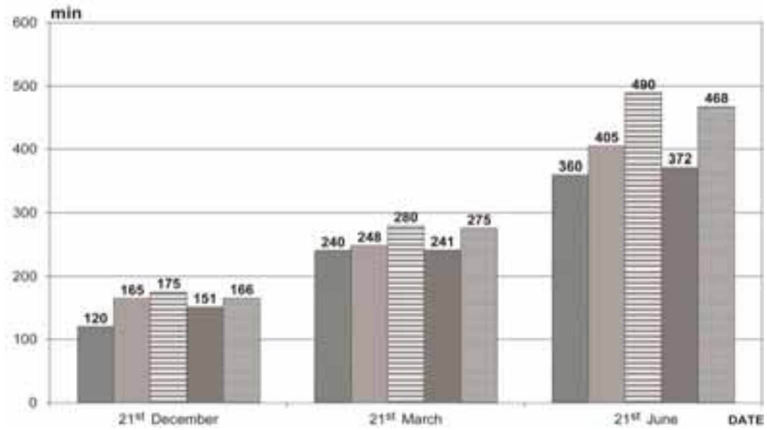
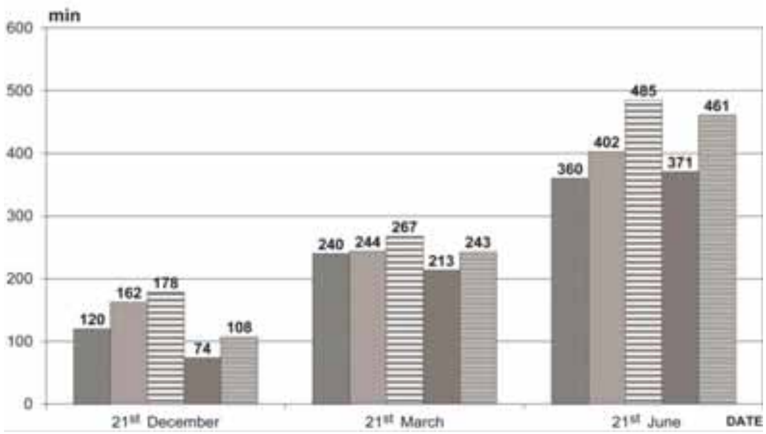
4. Results of the study

4.1. Detached family houses – Examples 1 and 2

Examples 1 and 2 represent a typical Slovenian neighbourhood comprised of individual single family detached houses. In the case of example 1 the houses are nearly cubical in form with floor plan dimensions of 11 by 11 m and a height of 9 m. Double pitched roofs have a slope of 30° with ridges running in north-south direction. The minimal distance between buildings is 6 m in the southeast-northwest direction. The buildings in example 2 are similar, with dimensions of 11 by 8.5 m and a height of 7.8 m. The longer façades are facing southwest. Double pitched roofs have a slope of 30° with ridges running in the northeast-southwest direction. The minimal distance between buildings is 5 m in the southwest-northeast direction. In both cases the main orientation of the buildings is 30° offset from the south. Example 2 has a higher density with FSI 1.06 (Table 2). In the solar exposure calculations all surfaces were included, except the northeast façade and in the example 2 also the northeast part of the roof.

Tab. 2: Idealized geometrical model and results of the simulations for Examples 1 and 2 (detached family houses).

<table>
<tr><th>GEOMETRICAL MODEL</th><th>RESULTS

</th></tr>
<tr><td>Example 1
Latitude: 45°96'N
Longitude: 14°64'E
FSI: 0.84</td><td rowspan="2">
</td></tr>
<tr><td>
</td></tr>
<tr><td>Example 2
Latitude: 46°03'N
Longitude: 14°51'E
FSI: 1.06</td><td rowspan="2">
</td></tr>
<tr><td>
</td></tr>
</table>

Calculated results for both examples are presented in Table 2. The minimal legal requirement is represented in the diagrams by the first column from the left, denominated TSG4. The second two columns represent the maximum solar potential for the selected building on the site taking into account the TSG4 restrictions and omitting the influence of the surrounding buildings. The last two columns represent the insolation with the influence of the surrounding buildings (taking into account the TSG4 restrictions). In both instances the results are presented separately for the façades and the façades with roofs. The comparison between the two calculated sets of results enables the evaluation of the influence of the surrounding buildings on the received solar exposure of the studied building. In case of Example 1 building we can see that the minimal requirements of TSG4 are exceeded in all three days and that the surrounding buildings have a relatively small effect on the actual achieved insolation of the envelope. A different situation can be observed in

Example 2 building were we can see that minimal requirements are not met during December 21st and are just met during March 21st (it is exceeded only by 1 percentage point) if the roof is also included (Table 2).

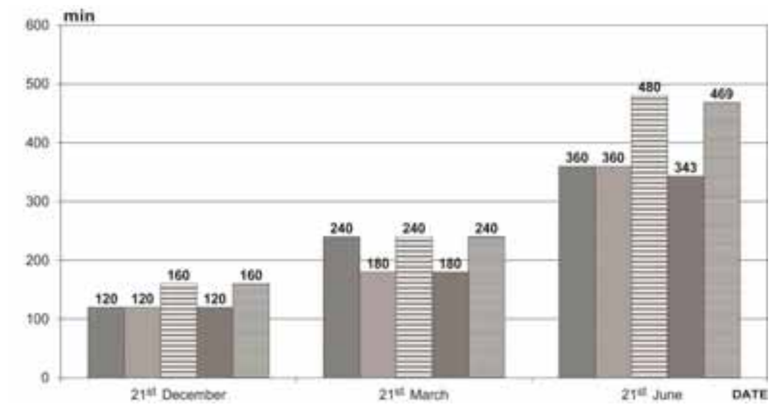
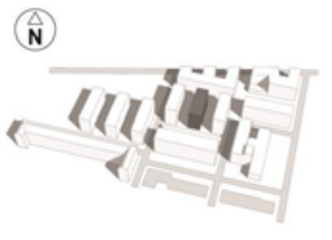
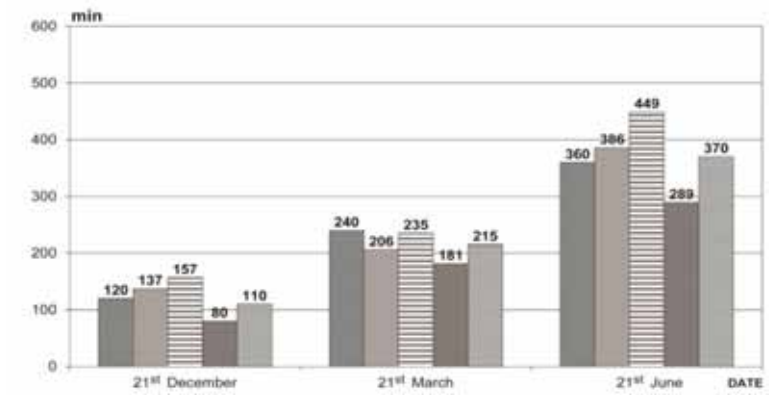
4.2. Longitudinal apartment blocks – Examples 3 and 4

The second most common type of residential buildings in Slovenia is longitudinal apartment blocks represented in this study by two examples. In the case of Example 3 the buildings are oriented in the direction north-south with dimensions of 140 by 11 m and height of 18 m. The buildings have flat roofs. The distance between the buildings in all directions is 30 m. The buildings in Example 4 have their major orientation offset by 15° from the south and are 37 m long, 12.5 m wide and 24 m high. They have flat roofs. The distance between the buildings in east-west direction is 13.2 m (Table 3). The solar exposure calculation in both examples took into account east, south and west façades as well as the roof. The layout density of the Example 4 is extremely high, with an FSI of 3.09, while Example 3 has a FSI of 1.33.

Tab. 3: Idealized geometrical model and results of the simulations for Examples 3 and 4 (longitudinal apartment blocks).

<table>
<tr><th>GEOMETRICAL MODEL</th><th>RESULTS

</th></tr>
<tr><td>Example 3
Latitude: 46°03’N
Longitude: 14°51’E
FSI: 1.33

</td><td>
</td></tr>
<tr><td>Example 4
Latitude: 46°05’N
Longitude: 14°51’E
FSI: 3.09

</td><td>
</td></tr>
</table>

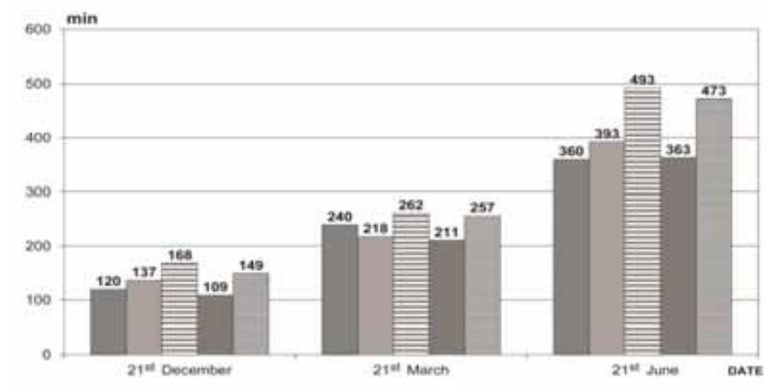
From the diagram presented in Table 3 it can be observed for Example 3 building that the minimal requirements of TSG4 are not met during the 21st of March. On this date the actual insolation is 25 percentage points lower than the minimum requirement in the case of solar potential calculation and also in the case of actual situation when only façades are considered. When the influence of the roof is included, the requirement is only just met. Identical values for solar potential and actual situation on the site (Table 3) show that the buildings in Example 3 have adequate spacing and do not cause excessive mutual shading. The influence of the roof is more significant than in the previous cases, partly due to the building geometry and partly due to façade orientation. In the case of building in Example 4 it is inadequately insolated during December and March 21st, even if the influence of the roof is considered. During the 21st of June the building exceeds the minimal requirements only by 2 percentage points in case when the façades and the roof are considered. The mutual shading of the buildings in Example 4 strongly reduces their solar potential.

4.3. Perimeter apartment blocks – Example 5

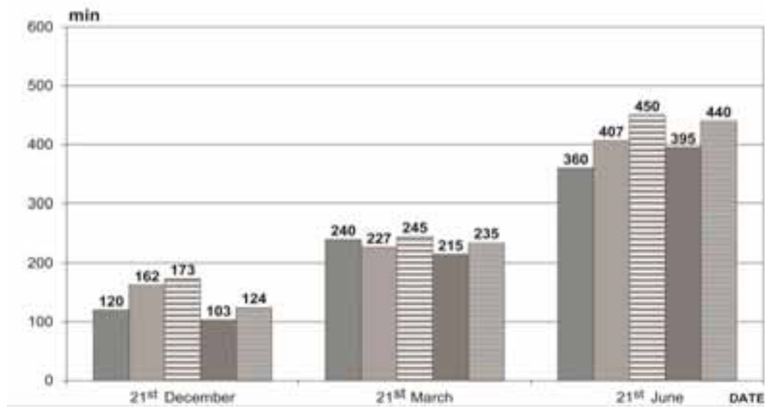
Example 5 building represents the perimeter apartment block type of building with dimensions of 105 by 75 m and the height of 18 m. The building's longer façades are facing east and west, the roof is flat. The inner court has dimensions of 81 by 51 m (Table 4). The distance between neighbouring perimeter blocks is 16 m. The FSI is 2.04. The solar exposure calculation took into account all of the façade surfaces as well as the roof, with the exception of the north oriented façades. Due to the building dimensions, layout configuration and relatively close proximity of surrounding buildings, low insolation values are expected during winter.

The results of the calculations for Example 5 presented in Table 4 show that the building in question is not adequately insolated if the influence of the roof is not included. On the 21st of December the actual insolation is 9 percentage points and on the 21st of March it is 19 percentage points below the TSG4 requirement. In case of the 21st of June the requirement is exceeded by 1 percentage point. When the roof is considered, the requirements are fulfilled during all critical days, when the results exceed the minimum requirements in the span of 10 to 30 percentage points. A relatively small difference between the results of potential and actual situation indicates that mutual shading has little influence. In this case the shape of the building is the prevailing factor. Detailed analyses show that shading is not equally distributed, but mainly occurs on the street facing façades. Although the street façades have larger potential, this is nullified by the shading of neighbouring buildings. The overall favourable result is therefore the result of well insolated courtyard façades.

Tab. 4: Idealized geometrical model and results of the simulations for Example 5 (perimeter apartment blocks).

GEOMETRICAL MODEL	RESULTS
	TSG4 · POTENCIAL OF THE FACADES · POTENCIAL OF THE FACADES & ROOF · SHADED FACADES · SHADED FACADES & ROOF
Example 5 Latitude: 46°06'N Longitude: 14°51'E FSI: 2.04	
	

Tab. 5: Idealized geometrical model and results of the simulations for Example 6 (apartment towers).

GEOMETRICAL MODEL	RESULTS
	TSG4 · POTENCIAL OF THE FACADES · POTENCIAL OF THE FACADES & ROOF · SHADED FACADES · SHADED FACADES & ROOF
Example 6 Latitude: 46°04'N Longitude: 14°51'E FSI: 1.46	
	

4.4. Apartment towers – Example 6

Apartment high-rise towers are the building type studied in Example 6. They are organised on an irregular grid spatial plan with the major orientation offset 16° from south. The floor plan dimensions of the buildings are 14 by 20 m, while the height is 33m (Table 5). The smallest distance between the buildings is 41 m in the east-west direction and the FSI is 1.46. The solar exposure analyses took into account east, south and west oriented façades and roofs.

As in the case of Example 5, also here the studied building is inadequately insolated on the 21st of December and March. Without the influence of the roof the façade envelope solar exposure is 14 percentage points below the minimum requirement. If the influence of the roof is included into the calculated results, the TSG requirement is exceeded by 4 percentage points during December, but is still inadequate during March (Table 5). In the presented example the insolation during winter months is strongly influenced by mutual shading between the buildings. This can be observed if the values of potential and the actual insolation are compared. On the other hand, the inadequate insolation during spring and autumn months is the result of the shape and orientation of the buildings. The problem of this layout is unfavourable orientation of the major façades.

4.5. Mixed building type – Example 7

The mixed type of building site layout is represented in Example 7, where new high-rise residential and commercial buildings are planned to fill the void left by demolished industrial buildings. New buildings will be surrounded by existing family houses to the north end and residential apartment blocks on the east and west side of the site. The major orientation of the layout is offset by 26° from the south direction toward east. The high-rise buildings are organised on the principle of a regular grid of residential towers placed on lower commercial bases (Table 6). The tower floor plan dimensions are 14 by 19.5 m, while the height varies from 45 m to 63 m, and the analysed tower is 57 m high. The smallest distances between the towers are 15.8 m in the north-south direction. The tower bases have an average floor plan dimension of 30 by 34 m and a height of 9 m. The FSI of Example 7 building is 3.12. All of the façade surfaces with the exception of the north one were included into the calculation of the solar exposure of the building. The new development is quite high and will presumably have influence over a large area. That is why in this case we analysed one of the residential buildings situated north of the new development (Table 6).

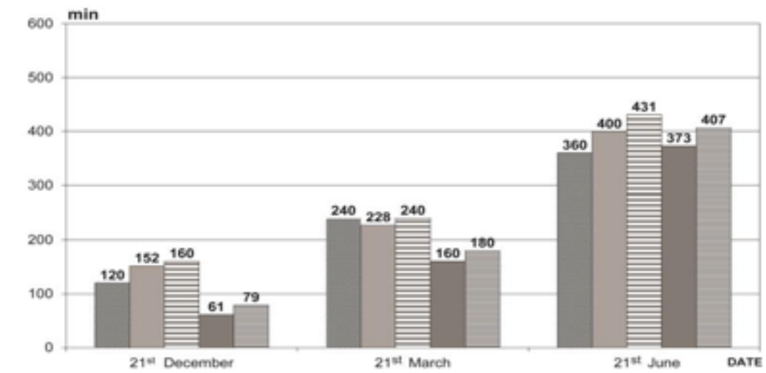
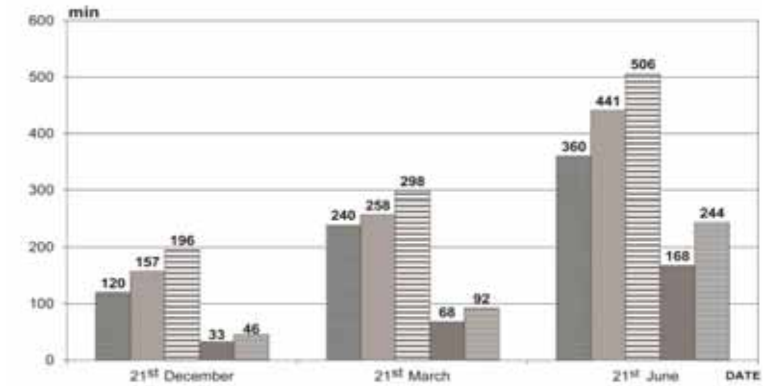
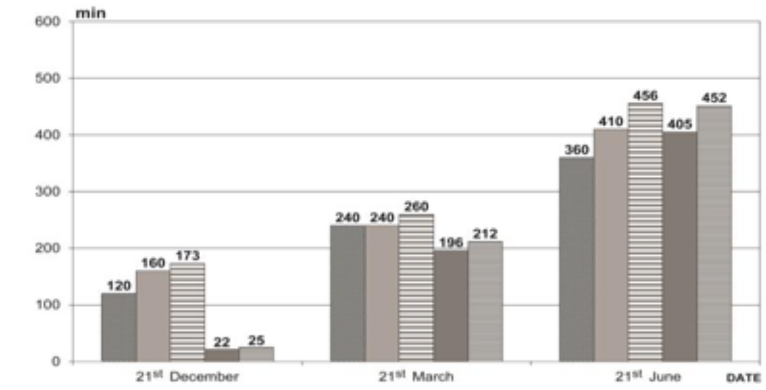
The residential tower in Example 7 is inadequately insolated during 21st of December and March, regardless of whether the influence of the roof is included or not (Table 6). During winter the solar potential of the building is 30 percentage points higher than the minimum requirement. But the actual state is 51 percentage points lower than the solar potential and 35 percentage points lower than the TSG4 requirement. The situation in the case of the tower base is, as expected, even worse. Although the bases have a high solar potential due to the large roof area, this is dramatically reduced by the influence of shading from the surrounding apartment towers. The minimal requirements are not met in any of the cases (Table 6). As in the case of the towers, the detached house situated north of the new development is inadequately insulated during the 21st of December and March (Table 6). The actual received insulation is extremely low during December, as it is 85 percentage points lower than the potential, including the influence of the roof. The analysis of the performed calculation results showed that practically the entire shading is accounted for by the new development. From the performed calculations we can conclude that at least from the standpoint of the availability of solar radiation the proposed development is extremely bad. The question that arises is not only how to reach nZEB in cases like these, but also how to ensure healthy and quality living conditions to residents in the influenced areas.

5. Discussion and conclusions

In Slovenian traditional settlements solar exposure was one of the most important design factors (Kristl and Krainer, 2005). The presented overview of the typical post WW II. building layouts shows the complexity of ensuring adequate insolation according to the requirements of TSG4, which are not merely technical but extend to other areas as well. On the basis of the above presented examples it is possible to divide the factors that influence the amount of insolation on the building envelope into two groups: the influence of the surroundings and the influences of the building morphology. The most decisive factor among the influences of the surroundings is density of the layout (distance between the buildings and their height) and geometry (site layout), assuming that we neglect the impact of the terrain. Influence of the building morphology depends on the shape (articulation, indentation of the building envelope) and orientation (solar exposure) of the specific surface.

Tab. 6: Idealized geometrical model and results of the simulations for Example 7 (mixed building type).

<table>
<tr><th>GEOMETRICAL MODEL</th><th>RESULTS

</th></tr>
<tr><td>Example 7 - tower
Latitude: 46°04’N
Longitude: 14°49’E
FSI: 3.12
</td><td>
</td></tr>
<tr><td>Example 7 – tower base
</td><td>
</td></tr>
<tr><td>Example 7 – existing house
</td><td>
</td></tr>
</table>

The results show that layout density and building orientation in general had the most important impact on the insolation. Diminishing the distances among buildings causes non-linear increase of mutual shading, due to shadows cast by the neighbouring buildings, which can be seen in the comparison of FSI and insolation of the building envelope in Figure 1. Generally speaking, Example 1 is an example of good urban planning, where low FSI results in adequate insolation, especially on the southern oriented façades. While high FSI values in Examples 4 and 7 resulted in insolation values far bellow minimum requirements placed by the TSG4. The unfavourable results of such cases are a combination of three influential factors; building orientation and geometry cause low potential insolation; high layout density further deteriorates the situation with year-round shading. The impact of high FSI values was also emphasized by Kanters et al. (2014). Therefore tendencies of municipal policies to increase the density of urban areas should be examined with great care. The geometry of building becomes an important factor when buildings have distinctly longitudinal forms (e.g. Example 3 and 6). The Effect of layout geometry in the analysed cases proved to be minimal. However, this aspect should be analyses further and in more detail. The last influential factor is the impact of shading due to the shape of the building itself. Its impact showed to be relatively small compared to other influential factors. However, due to a range of possible building forms its effect should be assessed for each case individually.

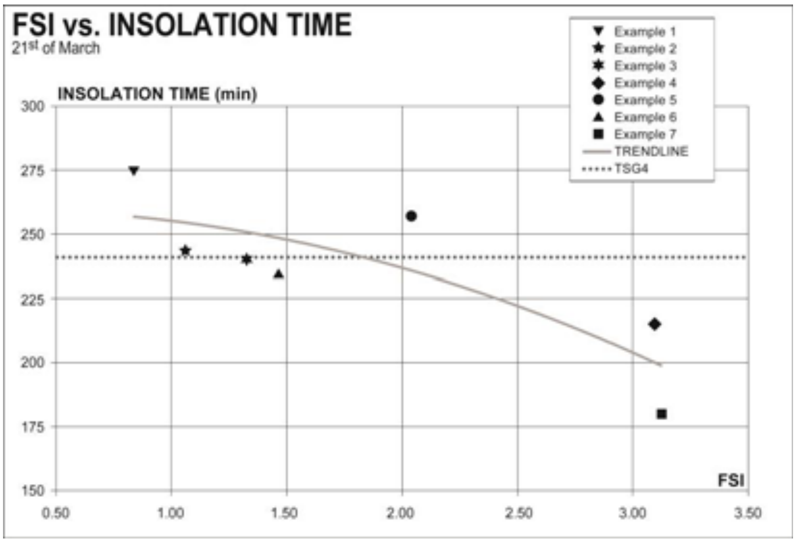


Fig. 1: Comparison of FSI and insolation time of all seven examples on the 21st of March. The TSG4 minimal requirement is denominated by the dotted line.

The study showed that the existing layouts are not as problematic as had been expected, provided that the buildings' height and urban density are kept at relatively low values (i.e. FSI < 1.50). Here again parallels can be drawn with the conclusions by Kanters et al. (2014). If the basic principles of good practice (e.g. appropriate orientation of building) are combined with low urban density we can presume that buildings will be adequately insulated according to the TSG 4 criteria. However how to achieve higher density and achieve good insolation is still an open debate.

6. References

ARSO, 2012. Slovenian Environmental Agency. http://meteo.arso.gov.si/met/sl/climate/tables/, accessed 20.10.2012.

Bojić, M., Blagojević, M., 2006. Photovoltaic electricity production of a grid-connected urban house in Serbia. Energy Policy 34, 2941-2948.

Capeluto I.G, 2003. The influence of the urban environment on the availability of the daylighting in office buildings in Israel. Building and Environment 38, 745-752.

Capeluto I.G. and E. Shaviv, 2001. On the Use of Solar Volume for Determining the Urban Fabric. Solar Energy 70, 275-280.

EED, 2012. Directive 2012/27/EU of the European Parliament and of the Council on Energy efficiency. Official Journal of the European Union L315: 1-28.

EPBDr, 2010. Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings (recast). Official Journal of the European Union L153: 13-35.

EPBDr, 2010. Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings (recast). Official Journal of the European Union L153: 13-35.

Futcher, J. A., Mills, G., 2013. The role of urban form as an energy management parameter. Energy Policy 53, 218-228.

Gadsden, S., Rylatt, M., Lomas, K., Robinson, D., 2003. Predicting the urban solar fraction: a methodology for energy advisers and planners based on GIS. Energy and Buildings 35, 37-48.

Kanters, J., Wall, M., Dubois, M.-C., 2014. Typical values for active solar energy in urban planning. Energy Procedia 48, 1607-1616.

Košir, M., Capeluto, I., G., Krainer, A., Kristl, Ž., 2014. Solar potential in existing urban layouts – Critical overview of the existing building stock in Slovenian context. Energy Policy 69, 443-456.

Kristl, Ž., Krainer, A., 2001. Energy evaluation of urban structure and dimensioning of building site using iso-shadow method. Solar Energy 70, 23-34.

Kristl, Ž., Krainer, A., 2005. Site organisation in Karst region as a function of insolation. ISES 2005 Solar World Congress: Conference Proceedings, Orlando. Orlando: American Solar Energy Society, 1-6.

Kristl, Ž., Krainer, A., 2006. Solar Planning for Suburban Areas. EuroSun 2006: Conference Proceedings, Glasgow. Abingdon: International Solar Energy Society, 1-9.

La Gennusa, M., Lascari, G., Rizzo, G., Scaccianoce, G., Sorrentino, G., 2011. A model for predicting the potential diffusion of solar energy systems in complex urban environments. Energy Policy, 39, 5335-5343.

LGCC, 2007. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions: Limiting Global Climate Change to 2 degrees Celsius. The way ahead for 2020 and beyond. COM(2007) 2 final.

Lund, P., 2012. Large-scale urban renewable electricity schemes – Integration and interfacing aspects. Energy Conversion and Management 63, 162-172.

Okeil, A., 2010. A holistic approach to energy efficient building forms. Energy and Buildings 42, 1437-1444.

PUER, 2009. Directive 2009/28/EC of the European Parliament and of the Council on the Promotion of the use of energy from renewable sources. Official Journal of the European Union L140: 16-62.

PURES 2010, 2010. Rules on efficient use of energy in buildings. Official Journal of the Republic of Slovenia, No.52/2010.

PVGIS, 2012. Joint Research Centre Institute for Energy and Transport, Renewable Energy Unit, http://re.jrc.ec.europa.eu/pvgis/cmaps/eu_cmsaf_opt/G_opt_SI.png, accessed 20.10.2012.

Geodetic Institute of Slovenia, 2008. The statistics of the input data of the Real Estate Register, http://e-prostor.gov.si/fileadmin/REN/Statistike_REN_01082008_popravljeno.pdf, accessed 20.8.2011.

Sarralde, J. J., Quinn, D. J., Weismann, D., Steemers, K., 2015. Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. Renewable Energy 73, 10-17.

Strømann-Andern, J., Sattrup, P. A., 2011. The urban canyon and building energy use: Urban density versus daylight and passive solar gains. Energy and Buildings 43, 2011-2020.

TSG4, 2010. Technical Guidelines, TSG-1-004:2010 – Efficient energy use. Ministry of the Environment and Spatial Planning, Republic of Slovenia.

Yezioro, A., Capeluto, I. G., Shaviv, E., 2006. Design guidelines for appropriate insolation of urban squares. Renewable Energy 31, 1011-1023.

Yezioro, A., Gutman, T., 2009. SHADING Tools Plugin v1.0, http://ayezioro.technion.ac.il/Downloads/ShadingII/index.php, accessed 16.11.2011.

ZGO-1, 2002. Construction Act. Official Journal of the Republic of Slovenia, No.110/2002.

ZPNacrt, 2007. Spatial Planning Act, Official Journal of the Republic of Slovenia, No.33/2007