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GENERALIZED CRITERIA OF ENERGY PERFORMANCE EVALUATION IN EARLY DESIGN STAGES OF NEARLY ZERO-ENERGY BUILDINGS

Ivanova St.

Chief-Asst. Prof. Dr. Arch.
Department of Computer-Aided Engineering
University of Architecture, Civil Engineering and Geodesy
Sofia, Bulgaria

Abstract. *According to Directive 2010/31/EC the member states of the EU shall ensure that by 31 December 2020 all new buildings will be nearly zero-energy buildings (nZEB). They are characterized with very high energy performance, but they still need to meet the energy demand associated with their typical use, which includes energy for heating, cooling, ventilation, hot water and lighting. This energy should be covered to a significant extent by renewable energy. In the early design stages the generalized criteria of the energy performance of the building have to be used. The performance of the building envelope could be evaluated with the Form Factor as a measure of the compactness of the building and the average thermal transmittance U-value of the building envelope. A grid of roses of solar radiation is recommended as a method to evaluate the distribution of solar resources for a plot, situated in a complex urban environment and to guide the architect about the best exposure of the main facades of the building or the group of buildings. The solar potential of a variant building shape could be evaluated with the building shading factor.*

Keywords: *Energy performance simulation, Early design stage, nZEB, Form Factor, Rose of radiation, Building shading factor, Average U-value*

1. Introduction

In the EU the buildings are consuming about 40% of the energy produced and 72% of the electricity produced. So they contribute to 30% of the carbon emissions of Europe. According to Directive 2010/31/EC [1] the member states of the EU shall ensure that by 31 December 2020 all new buildings will be nearly zero-energy buildings; and after 31 December 2018 new buildings occupied and owned by public authorities will be nearly zero-energy buildings (nZEB). Nearly Zero-Energy Building [1] means a building with a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

Every building needs to meet the energy demand associated with its typical use, which includes energy used for heating, cooling, ventilation, hot water and lighting. According the Bulgarian national building regulations for nZEB with energy performance class A [2] this energy should not exceed 48 to 95 kWh/m^2 annually for residential buildings and from 70 to 140 kWh/m^2 annually for public buildings. At least 55% of this energy must come from renewable energy sources.

For this purpose in the design stage all possible means to achieve this goal have be reviewed and implemented. The leading role of the architect in the design process gives him a possibility to contribute to the following important project tasks:

1) Design of a compact building shape that contributes to a lower heat exchange with the outdoor environment; this means low heat loss in winter and low heat gains in summer;

2) Design of a building envelope with low average thermal transmittance coefficient ***U***;

3) Design of facades with suitable exposures that contribute to greater passive solar gains in winter and less solar gains in summer;

4) Design of the building openings (windows, glazed facades or parts of facades) to provide natural solar lighting and radiation;

5) Design of systems for natural ventilation in buildings to reduce the cost of mechanical ventilation.

2. Review of generalized criteria of the energy efficiency of the building envelope

In the early design stage the architect needs generalized criteria to guide him in the right direction to design a building with high energy performance. Normally the initial choice of building shape depends on the following factors:

- Approach to the building and its location in the urban environment;
- Functional tasks that the building performs;

- Composition considerations;
- Engineering considerations and support structure;
- Compactness, that helps to reduce heat losses;
- Favorable exposures of the external building surfaces.

The last two factors reduce heat losses and increase solar gains. The compactness of the building shape is usually evaluated with the Form Factor.

2.1. Form Factor

The Form Factor (FF) is the ratio of the thermal envelope surface area ***A*** to the heated volume of the building ***V***. A higher value of FF usually corresponds to higher heat losses. A lower value of FF means more compact building shape and lower heat losses. The thermal envelope surface area ***A*** is the sum of the areas of building facades, roof and foundation. However, these areas have different contributions to the heat losses that are still difficult to be specified in the early design stage. Therefore the calculation of the area ***A*** often does not include the area of the foundation of the building.

The form factor is an easy to calculate criterion that describes mostly the compactness of the building and does not reflect the possible favorable exposures and how the building could utilize the incoming solar energy. It does not reflect the characteristics of the building envelope also. Anyway FF is suitable for the initial evaluation of the building shape. A study of different building shapes and their form factors is done in [3]. This value is named "compactness ratio" in [4].

2.2. Average thermal transmittance coefficient *U*

Nowadays the form factor is related with the average thermal transmittance coefficient ***U***. The times are gone, when the heat losses caused by poorly designed building form or building envelope were compensated by more produced heat or by more energy consumption. The new European Directive 2010/31/EC restricts the amount of the primary energy that is consumed per unit area (or volume) annually. The restriction on the heating energy leads to desired minimum possible heat losses. Therefore this directs to an existing relationship between the obligatory integrated numerical indicator of primary energy use of nZEB, the form factor and the average thermal transmittance coefficient ***U***. This relationship still needs to be studied for Bulgarian conditions.

Such interdependence already exists in the Passivhaus Standard [5]. A graphic of the relationship between the Heat Loss Form Factor (HLFF) and the required average U-value for Passive House (red curve) and Low Energy House (blue curve) is given in figure 1 [5]. There is a difference between already defined term FF in section 2.1 and the term HLFF in Passivhaus Standard. The last one is the ratio of thermal envelope surface area to the treated floor area and is a dimensionless value (this value is named "building shape factor" in [4]). For this reason the correlation, displayed with red trend curve for Passive House in figure 1 cannot be used directly.

The energy performance of the building envelope of nZEB can be realized in the following several ways that reduce the heat exchange with the outdoor environment:

- Increasing the thickness of the building envelope;
- Use of materials with lower thermal transmittance coefficients (for walls, floors, ceilings, windows, etc.);
- Use of additional external and/or internal insulation;
- Reducing the significant heat losses through thermal bridges [6] with additional insulation.

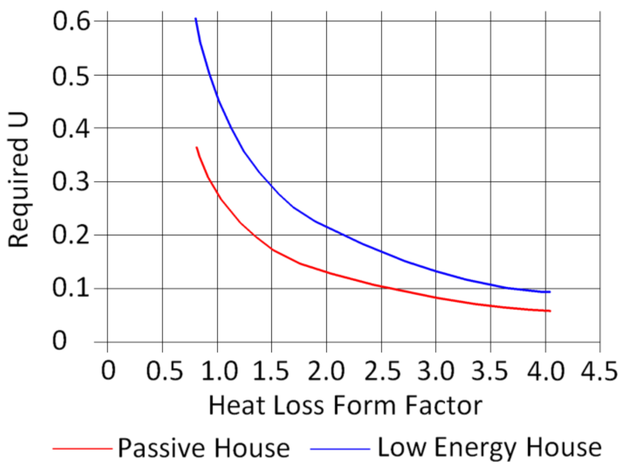


Fig. 1. Required U-value vs HLFF according [5]

The mandatory requirements for a natural lighting and contact with the outdoor environment act in the opposite direction, because the glazed surfaces and windows lead to bigger heat losses. This contradiction makes project decisions more difficult – the building cannot exist without enough windows even if they make its energy performance worse.

From the mentioned above relationship between FF and the obligatory integrated numerical indicator of annual primary energy use of nZEB the desired average thermal transmittance coefficient $\boldsymbol{U_{av}}$ shall be estimated. Once this value is known, it has to be calculated again with a gradual adjustment of the types of the elements of the building envelope and their characteristics, using Eq. (1):

$$U_{av} = \frac{\sum U_i A_i + \sum \psi_k L_k}{\sum A_i}, \qquad (1)$$

where:

U_i – maximum value of thermal transmittance coefficient of element *i* of the building envelope, [W/m^{2}K];

A_i – area of element *i* of the building envelope, [m^2];

ψ_k – maximum value of linear thermal transmittance of thermal bridge *k*, [W/mK];

L_k – length of thermal bridge *k*, [m].

Therefore if the architect selects a building shape that is not compact, in the next step he has to design a building envelope that will keep very well the building heat. Contrariwise, if the building shape is compact enough, then the average building U-value can be higher. If there is the most unfavorable combination of incompact shape and high average building U-value, then the building has to absorb actively or passively more solar energy and/or to produce more its own renewable energy to compensate the heat losses, but most probably such building will not be of energy performance class A (nZEB).

3. Review of generalized criteria of the available solar resources

The solar resources are important for every building, even more for nZEB where a very significant amount of energy has to come from renewable sources produced on-site or nearby. The solar energy is most accessible among these sources. The solar potential is important because of the natural lighting, the active solar systems, the passive solar heat gains and the solar protection of the building. The passive solar heating reduces the annual energy that is consumed to improve the indoor climatic conditions. The following factors are important to the control of the passive heating and cooling:

- Choice of suitable exposure of the building facades;
- Use of more glazed surfaces with southerly exposure could attract more solar energy into the building in winter;
- Use of less glazed surfaces with easterly/westerly exposure will contribute to less heating of the building in summer;
- Purposeful choice of color of building surfaces – the albedo of the building surfaces depends on their color. A lower albedo means less reflected solar energy reflected and more absorbed heat, and vice versa.

The estimation of the solar resources in a complex urban environment is not so simple mathematical problem as the calculation of Form factor and average *U*-value. It can be solved with programs that calculate effectively and precisely the incident long-term averaged solar radiation on the building surfaces under sky that is partially obstructed by other buildings and urban objects. Recently the number of such programs increases. This was a first step, and the next step is to create generalized criteria that evaluate the available solar resources for every considered building shape and in this way to direct the architect to a variant with best solar potential.

3.1. Grid of roses of solar radiation

One of the first design steps of the architect is to choose where on the plot to place the designed building. The articles [7, 8, 9] recommend the Rose of the solar irradiation as an indicator of the available solar resources. It like the rose of the winds is a vector diagram and illustrates the amount of the incident solar irradiation on vertical surfaces with different exposure for different periods of time (months, seasons, year). With its help it is possible to evaluate the available solar resources in the nodes of a uniform orthogonal grid, placed in the plot [9], where the designed building will be located.

Such information could guide the architects and urban architects about the best position and exposure of the main facades of the designed building or group of buildings.

As an illustration a rectangular plot among tall neighboring buildings is considered. An orthogonal grid with 3 × 3 nodes is placed over it. In each node a virtual tall testing parallelepiped with very small square section is considered (see figure 2). Its vertical virtual walls are oriented towards the main cardinal directions (north, east, south and west). The average daily seasonal global irradiation incident to each of these 4 vertical walls of 9 testing parallelepipeds is calculated.

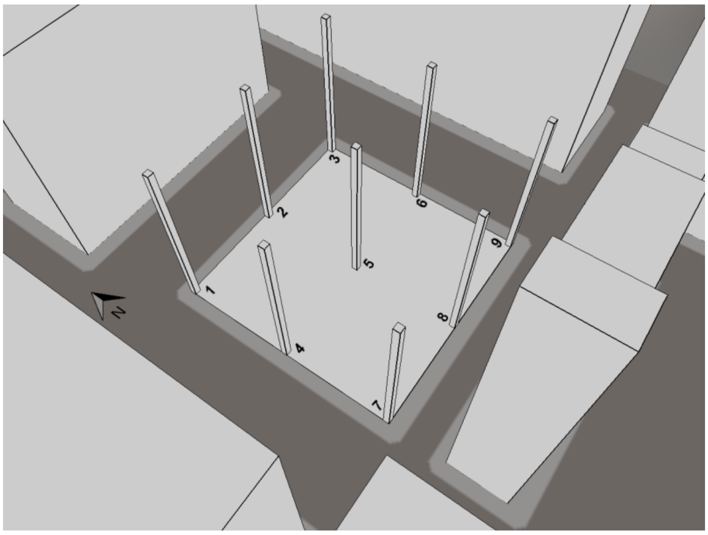


Fig. 2. Composition of a considered plot and tall buildings around it.

For countries with continental climate (with cold winters and hot summers) like Bulgaria, the average annual rose of solar radiation masks and hides the different importance of solar radiation in summer and winter season. Therefore, as it is suggested in [9], it is correct to make the calculations and analyses separately for each critical season.

Two grids of nine roses of irradiation are displayed in figure 3. They are created using the numeric results from the program 3D-SOLARIA [8]. The maximum daily winter global irradiation under non-obstructed sky is displayed in blue (figure 3a); the maximum summer irradiation is in red (figure 3b). The green contours in figure 3 display the incident vertical irradiation under the real sky, partially obstructed by other buildings and urban objects. The distance between blue (or red) contours and the green contours illustrates the amount of the blocked irradiation because of the urban shading.

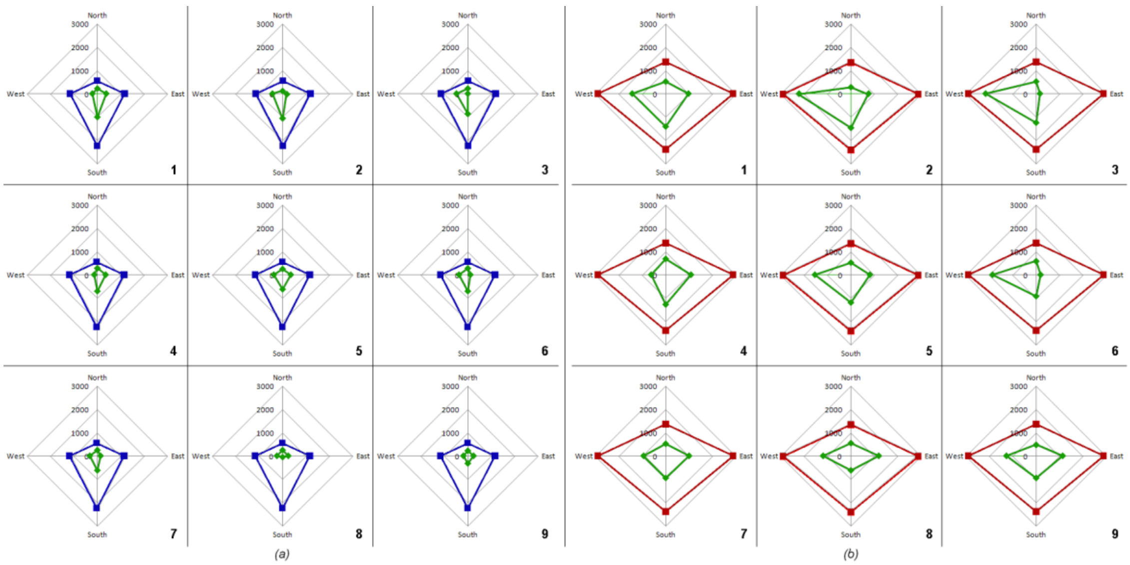


Fig. 3. Roses of average daily global solar irradiation in considered 9 nodes.
The plot is located in Sofia (a) winter; (b) summer.

It was explained in [9] that if we need significantly incident winter radiation and reduced amount of summer radiation, we get the best results for walls whose difference between summer and winter values of the incident irradiation is minimal. This means that the solar radiation incident on them is relatively even in the seasons, which case is recommended. The opposite option (maximum difference between summer and winter radiation) means that there is a shortage of radiation in winter (this case needs more energy for heating), and excess of heat in the summer (it leads to additional costs for cooling).

Using these differences between summer and winter global vertical irradiation we get the graphic in figure 4a. The desirable positions are those where there is a minimum difference. Such position for easterly exposure exists in the northeastern part of the plot. A minimum difference for westerly exposure exists in the southwest part, and for southerly exposure – in the central or northern part of the plot. The difference for the northerly exposure is nearly constant everywhere.

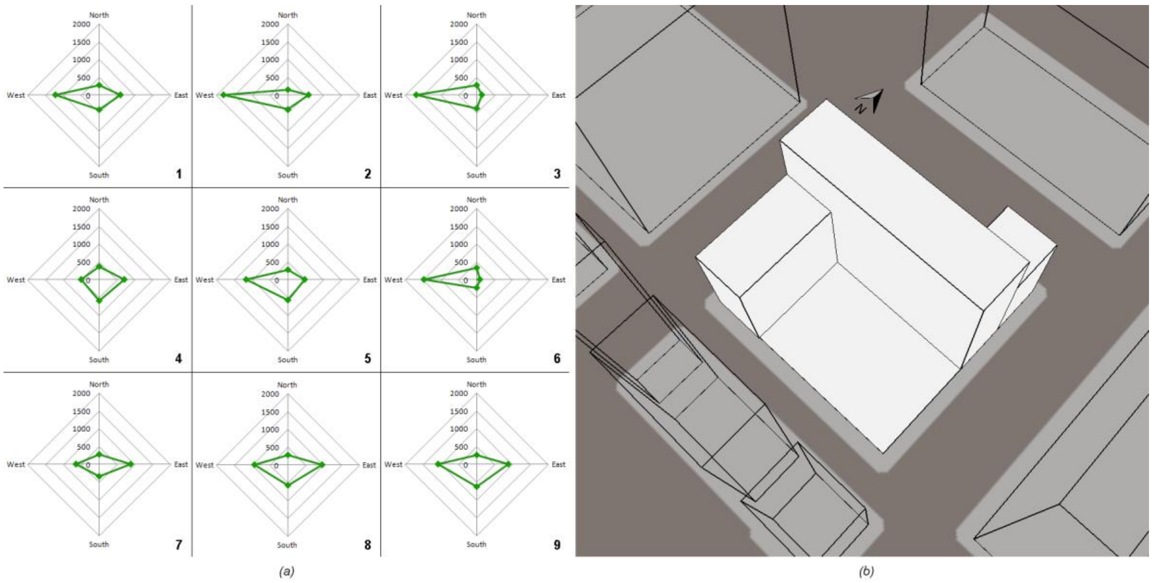


Fig. 4. (a) Roses of the differences between average daily winter and summer solar irradiation for nine considered testing parallelepipeds; (b) the proposed building form according to the analysis of roses differences.

Based on these guidelines, we can formulate a proposal for the building shape in figure 4b composed of 3 units. The largest of them has a southerly exposure and is sufficiently distant from the buildings to the south of the plot to get more direct solar radiation. The height of the western unit is less because of the unfavorable difference for the eastern wall in the southwest corner of the plot. The same is valid for the height of the eastern unit. Another suitable shape is a building in the form of the letter "Г" situated in the western and northern part of the plot, but it will be too close to the building north of the plot and would cause too large shadows on it in winter.

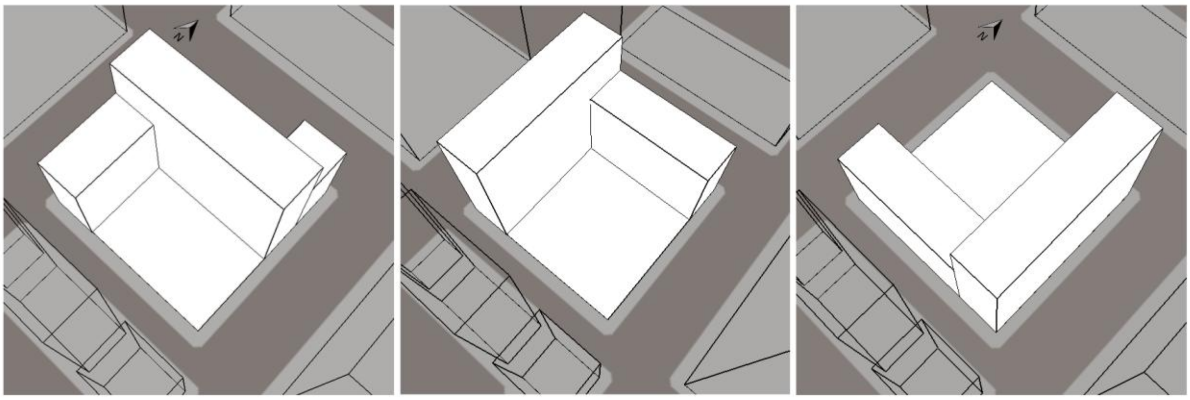
The proposed shapes reflect both the normal expectations for shading in environment with tall buildings and the irregularity in the shading due to the uneven locations of neighboring buildings and their various heights. The proposed two building shapes have to be checked in the next stage with detailed calculation of their building shading factor.

3.2. Building shading factor

The article [10] proposes the interaction between the available solar energy, the shape of the future building and the obstructing objects in the surrounding urban environment to be evaluated quantitatively with the help of a Building Shading Factor (BSF), which represents the ratio of the blocked solar energy that fails to reach the explored building surfaces and the maximum possible incident solar energy on these building surfaces under unobstructed sky. Architects can use the calculated numeric value to assess the shading effect caused by surrounding urban environment and the self-shading effect caused by building elements participating in the composition of the studied building. The methodology is implemented in the computer program 3D-SOLARIA.

The building shading factor has different meaning in winter and summer. It has higher values in winter due to low sun. Therefore, the better building shape will have a smaller value of the factor. BSF in summer has lower values than in winter due to high sun. Logically the better building shape that offers better shading, is with correspoding higher value of BSF. There are buildings and complexes with seasonal use (for instance summer and winter resorts), and buildings that are used all year round. In these buildings the sought compromise between winter and summer shading factors is different. For buildings for summer living the architect will seek a maximum value of BSF while for buildings for winter habitation – a minimum BSF. In buildings for perennial habitation the best solutions have minimal difference between summer and winter values of BSF.

As an example three buildings variants (figure 5), placed in the same considered plot will be evaluated. Their volume is equivalent V=18000 m^3, the external surface is A=4900 m^2. The calculated value of their form factors is also equivalent FF=A/V= 4900/18000=0.2722, and HLFF=0.8167. According section 2.2 and figure 1 for a Passive House with HLFF=0.8167 the required U-value has to be around 0.314.



(a) Variant 1 *(b) Variant 2* *(c) Variant 3*

Fig. 5. Three variants of building shapes with equivalent values of volumes, external areas, FF and HLFF

First variant (figure 5a) is the proposed after the analysis of the grid of roses of irradiation in section 3.1 (see figure 4b). Second variant (figure 5b) was the other recommended there. Third variant has a shape, equivalent to second shape, but rotated at 180°.

After the estimation of the incident radiation on the building surfaces for both most critical dates (21 December and 21 June), the following results were calculated and illustrated in figure 6:

- Variant 1 – BSF_{winter} = 0.715; BSF_{summer} = 0.553; difference 0.162;
- Variant 2 – BSF_{winter} = 0.712; BSF_{summer} = 0.546; difference 0.166;
- Variant 3 – BSF_{winter} = 0.743; BSF_{summer} = 0.534; difference 0.209.

According these results the first of the considered three building variants is best, because it has a minimum difference between the summer and winter value of BSF (0.162). Second variant has a valuation that is very close after the first (difference 0.166). The third variant, even if it has the same shape as the second but rotated, is worst (difference 0.209).

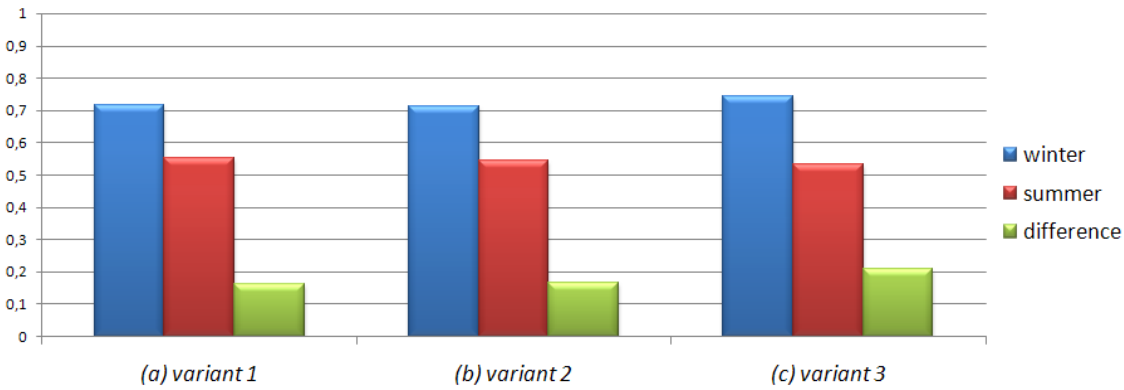


Fig. 6. Values of BSF for winter (in blue), summer (in red) and the difference between them for the considered three variants of building form

The first building variant will receive most relevant seasonal amount of solar energy on its surfaces in comparison with two other considered variants.

The research in [11] shows that the installation of rooftop PV systems increases the building shading factor and positively influences the building energy performance during winter and summer.

4. Conclusions and future work

This article recommends four generalized criteria for building energy performance that are very important for nZEB. First two of them are related with the building envelope. The Form factor evaluates the compactness of the building shape.

For nZEB a relationship between the obligatory integrated numerical indicator of primary energy use, the form factor and the average thermal transmittance coefficient *U* exists. Therefore FF determines the desired average *U*-value of the building envelope. Once this value is known, it has to be calculated again with a gradual adjustment of the types of the elements of the building envelope and their characteristics. Anyway the mentioned interdependence between the obligatory integrated numerical indicator of primary energy use of nZEB, FF and the average ***U***-value still needs to be studied for Bulgarian conditions.

The solar resources are very important for nZEB, where a significant amount of energy has to come from renewable sources produced on-site or nearby. Two criteria are recommended to evaluate the available solar resources. First of them is grid of roses of solar irradiation that helps to determine which positions on the building plot are most suitable to place building parts on them. Then the proposed variants of building shapes have to be ranked with calculation of Building Shading Factor. The variant with most relevant energy resources is that with largest difference between summer and winter values of BSF.

REFERENCES

1. Directive 2010/31/EC, Available online at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0031
2. Наредба № 7 за енергийна ефективност на сгради – 2004, 2009, 2015 г.
3. Milkov S., Chobanov Pl., Penev B. (2009) Opportunities for thermal insulating capability evaluation of building envelopes by the total thermal transmittance coefficient, International Conference UACEG2009: Science & Practice, Sofia, Bulgaria
4. Capozzoli A., Mechri H.E. and Corrado V. (2009) Impacts of architectural design choices on building energy performance – applications of uncertainty and sensitivity techniques, Eleventh International IBPSA Conference Building Simulation 2009, Glasgow, Scotland
5. Burrell E. (2015) What is the Heat Loss Form Factor? Available online at: http://elrondburrell.com/blog/passivhaus-heatloss-formfactor/
6. Milkov S. and Chobanov Pl. (2007) Evaluation of the Thermal Bridges in the Building Envelope, Jubilee scientific conference 65 years, UACEG, Sofia, Bulgaria
7. Robinson, D. (2006) Urban morphology and indicators of radiation availability, Solar Energy, 80 (12) pp. 1643-1648.
8. Compagnon R. (2004) Solar and daylight availability in the urban fabric, Energy and Buildings 36, pp. 321–328.
9. Ivanova S. (2015) Rose of solar irradiation as an indicator of available solar resources for a plot in an urban environment, VII International scientific conference "Architecture, civil engineering – modernity", Varna, Bulgaria, pp. 255-264
10. Ivanova S. (2014) Estimation of a building shading factor in an urban environment, International conference on Civil Engineering, Design and Construction: Science and Practice, Varna, Bulgaria, pp. 588-596
11. Ivanova S. (2014) Impact of the roof top PV systems on the building shading factor, First scientific – applied conference with international participation "Project management in construction"/PMC/, Sofia, Bulgaria, pp. 369-375