IMPACT OF ORIENTATION AND BUILDING ENVELOPE CHARACTERISTICS ON ENERGY CONSUMPTION
Case Study of Office Building in City of Nis

by

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Buildings are one of the biggest energy consumers in urban environments, so its efficient use represents a constant challenge. In public objects and households, a large part of the energy is used for heating and cooling. The orientation of the object, as well as the overall heat transfer coefficient (U-value) of transparent and non-transparent parts of the envelope, can have a significant impact on building energy needs. In this paper, analysis of the influence of different orientations, U-values of envelope elements, and size of windows on annual heating and cooling energy for an office building in city of Nis, Serbia, is presented. Model of the building was made in the Google SketchUp software, while the results of energy performance were obtained using EnergyPlus and jEplus, taking into account the parameters of thermal comfort and climatic data for the area of city of Nis. Obtained results showed that, for varied parameters, the maximum difference in annual heating energy is 15129.4 kWh, i. e per m^2 27.75 kWh/m^2, while the maximum difference in annual cooling energy is 14356.1 kWh, i. e per m^2 26.33 kWh/m^2. Considering that differences in energy consumption are significant, analysis of these parameters in the early stage of design process can affect on increase of building energy efficiency.

Key words: *energy consumption, office building, orientation, building envelope, EnergyPlus*

Introduction

Increasing of energy consumption in the world leads to serious concerns for the future of the world's population over difficulties in energy supply, deficit of energy resources, and environmental pollution. Population growth, higher demands for building services, as well as the rise in time spent inside buildings, caused the upward trend in energy demand [1]. For this reason, considering the alarming situation caused by various factors, in recent decades, different measures and activities in all areas of technology and science is taken.

Architectural objects consume 32% of the total final energy, while the share of primary energy consumption is 40%, which exceeded energy consumption in other major sectors: industrial and transportation [2]. During the last two decades primary energy input has grown by 49% and CO_2 emissions by 43% [3], which is also the averaged value for the city of

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Nis [4]. In year 2010, in countries of the EU (fig. 1), space heating account for about 66% of residential buildings final energy consumption, and 39% of final energy consumption in service sector. Considering that objects of different types are one of the largest consumers of final energy, its efficient use represents a constant challenge.

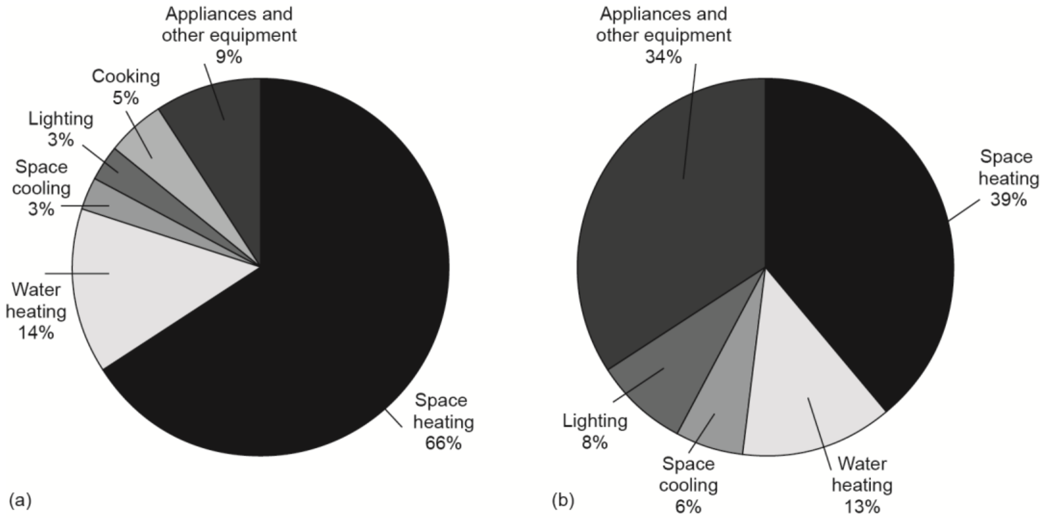

Figure 1. Energy consumption in residential and service sector in EU, in year 2010 [8]; (a) residential 12.8 EJ, (b) services 6.5 EJ

Based on the energy balance of the Republic of Serbia for year 2009, energy consumption by different sectors is determined. From all three sectors (heating and cooling, electricity, and transport), biggest consumption of 4144 ktoe final energy is in heating and cooling sector, which represents 45.3% of total energy consumption [5]. According to Eurostat statistics [6], final energy consumption in Serbia, for commercial and public services, in the year 2014 was 739 ktoe (8.59 TWh), while the average annual growth rate for a period of 14 years (1990-2014) is +11.03 ktoe.

Utilization of sustainable architectural principles and methods in the design process is one of the most important activities in the construction of the object. Building energy efficiency can be achieved by improving thermal performance of the different parts of a building envelope, area and localization of the transparent components in the façade. Appropriate design of a building envelope can significantly lower the use of energy through daylighting, reduced HVAC loads, *etc.* [7]. A high performance building envelope in a cold climate requires just 20% to 30% of the energy required to heat the current average buildings. In hot climates, the energy savings potential from reduced energy needs for cooling are estimated at between 10% and 40% [8].

Impact of orientation, overall heat transfer coefficient (U-value) of transparent and non-transparent parts of the envelope, as well as size of windows, have been examined by many authors. Sadineni *et al.* [7] reviewed impact of building envelope components on passive building energy savings. In paper, they analyzed advanced construction systems of walls, windows and roofs, and how they affect building energy consumption. Considering that improvements of building envelope elements are generally classified as passive energy efficiency strategies, they are highly sensitive to meteorological factors and require a better understanding of the climatic factors by architect. Eskin and Turkmen [9] investigated the interactions between different conditions, control strategies and heating and cooling loads in office buildings in four major climatic zones in Turkey, using the EnergyPlus program simulation tool. Impact of the parameters like the climatic conditions, insulation and thermal mass, color of external surfaces, shading, window systems, including window area and glazing system, on annual building energy requirements was examined. Based on the simulation results, they concluded that the effect of the window area on annual energy requirement of the building was the most significant for all examined cities. Urbikain and Sala [10] analyzed the relation between window characteristics and energy savings in residential buildings for two climatic zones in Spain. Boyano *et al.* [11] explored the energy saving potentials in office buildings in Europe based on a review of relevant literature, and EnergyPlus simulations of a reference office building that can be considered as a representative office building across Europe. Two aspects were investigated in this paper: improvement of the insulation of windows and the external walls, and orientation of the building. They concluded that energy savings due to the orientation of office building for examined climates can be maximum 10-14%, and that higher insulation factors are recommended in cold and medium climate zones. Singh *et al.* [12] have done energy rating of different window glazing, available in the Indian market. The study has been performed for three different buildings and five different climatic zones of India. Varied parameters included four orientations, ten types of windows, and different values of the overall heat transfer coefficient (U-value) of walls and roof. They concluded that the annual energy saving by a particular window depends upon several factors: window's U-value and solar heat gain coefficient, its orientation, climatic conditions and building parameters, especially U-values of walls and roof. Poirazis *et al.* [13] studied the impact of glass on the energy use, by performing energy simulations on office building alternatives with 30%, 60%, and 100% window to external wall area, while the other varied parameters were building's orientation, floor plan type, type and size of windows, type and position of shading devices, *etc*. Although it was concluded that highly glazed single skin buildings are likely to consume more energy, the most energy efficient 100% glazed alternative results in only 15% higher total energy use compared with the reference building with 30% window to external wall area. As for characteristics of windows, low U-value of windows is a good choice since it decreases the heating energy demand, while the cooling demand is not influenced much. Sozer [14] did a research-design project of hypothetical model of hotel buildings located in Izmir-Turkey, based on the effect of passive solar design techniques for designing the building envelopes. The proposed building uses 40% less energy on heating and cooling loads than most conventional hotels in Turkey, which also translates into a reduction in the size of the mechanical system. Persson *et al.* [15] investigate how decreasing the window size facing south and increasing the window size facing north would influence the energy consumption of terraced houses near city of Gothenburg, Sweden. Other parameters, like different orientations and types of window were also included. The obtained results show that the size of the energy efficient windows does not have a major influence on the heating demand in the winter, but is relevant for the cooling needs in the summer. Hassouneh *et al.* [16] investigated the influence of windows on the energy balance of apartment buildings in city of Amman, Jordan, using self developed simulation software. Variations consisted of eight types of glazing, as well as four different orientations and window area. Based on the simulation results it is concluded that if energy efficient windows are used, there is bigger flexibility of choosing the glazed area and orientation. Ballarini and Corrado [17] investigate the effect of thermal insulation on space cooling energy performance of residential and office building. Simulation results showed that the influence of the opaque envelope on energy need for cooling is limited, while the transparent parts of envelope have important contribution on building cooling energy needs, with reference to the size and thermal and solar parameters of the glazed surface. Smeds and Wall [18] compared heating energy demand in cold climates of reference houses and proposed high performance houses. The results of simulation showed that heating energy demand can be reduced by up to 83% for single-family houses and by up to 85% for apartment buildings by improving envelope insulation. Grynning *et al.* [19] examined effects of varying U-values of windows in connection with solar heat gain coefficients on office building in city of Oslo, Norway. It was found that a reduction of the window U-value from 1.2 to 0.8 W/m^{2}K can reduce the energy demand for heating and cooling about 5-15% depending on the solar heat gain coefficients. Wang *et al.* [20] studied possible solutions for zero energy building design in UK by varying different parameters: U-values of external walls, window to wall ratios, and orientations. The simulation results indicate that with the increase of U-values of external walls, cooling loads decrease while heating loads increase. Harmati *et al.* [21] investigated influence of building envelope on the annual energy performance of office building in city of Novi Sad, Serbia. They compared the heating and cooling energy performance of referent office building with values simulated from EnergyPlus softver for model with improved U-values of envelope and reduced window to wall ratio. Decrement of 25.42% in annual heating energy demand can be achieved by reducing U-value of windows from 1.18 W/m^{2}K to 1.13 W/m^{2}K and solar heat gain coefficient from 0.62 to 0.36. Compared to the referent office building, the modified building has 81% lower annual energy demand for heating.

Energy consumption in building sector will continue to grow until objects are designed in order to use energy more efficiently. In case that there is no action taken to improve energy efficiency in the building sector, energy demand is expected to rise by 50% by year 2050, which shows the importance of activities in this field, with the goal to decrease energy consumption in buildings [8]. The increasing number of energy efficient objects indicates spreading the awareness about this problem and finding many ways through analysis and investigations for its solving. In this paper, analysis of the influence of different orientations, U-values of envelope elements and window parapet height, on annual energy consumption for an office building, is presented. Investigation of building energy performance was conducted in order to minimize the amount of energy required for its heating and cooling. Model of the building was made in the Google SketchUp software using the OpenStudio Plug-in, while the results of energy performance were obtained using EnergyPlus and jEplus.

Analyzed building – simulation model

In this paper, the examined building represents an example of semi-detached office building, with the entrance facing south. With approximately rectangular shape, the building is consisting of basement, ground floor, first floor and attic, figs. 2 and 3. The entire building model has 43 zones, while 33 zones are conditioned. Total area of external walls is 211.94 m^2, while the total area of windows is 143.83 m^2. The main part of the window surface (88.52 m^2) is located on the longer, west oriented façade, and south oriented façade (40.63 m^2), while on the east side is attached another object. The smallest amount of window surface is on the north façade (14.68 m^2). The gross floor area of the building is 699.55 m^2, while the conditioned area is 545.21 m^2.

The analyzed building is located in the street Vizantijski bulevar in Nis, Serbia. The elevation of Nis is 202 m, and its latitude and longitude are 43°20 N and 21°54 E. The city has a continental climate with four different seasons: summer, autumn, winter, and spring. Simulations were performed with weather file for city of Nis. The heating season in Nis runs from October 15th to April 15th.

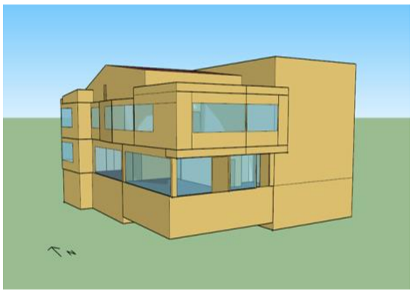

Figure 2. Building model-southwest view

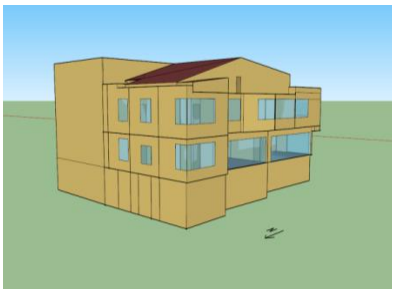

Figure 3. Building model-northwest view

The following parameters were considered in the parametric analysis.

– Twelve orientations, starting from building entrance oriented south, east, west, north, southeast, southwest, northeast, northwest, as well as ±15° south and ±30° south, fig. 4.
– Four different types of exterior walls, with different U-values: 0.15 W/m^{2}K, 0.22 W/m^{2}K, 0.25 W/m^{2}K, and 0.29 W/m^{2}K.
– Four different types of windows, with different U-values: 1.04 W/m^{2}K, 1.08 W/m^{2}K, 1.19 W/m^{2}K, and 1.25 W/m^{2}K (U-values of the frames are not considered).
– Two types of flat roof construction with U-values 0.13 W/m^{2}K and 0.15 W/m^{2}K.
– Parapet height of ground floor windows: 0 cm, 10 cm, 20 cm, 50 cm, 70 cm, 80 cm, and 90 cm.

The simulations were performed according to the purpose of identifying the influence of orientation and building envelope characteristics on the annual heating and cooling energy consumption. The different parameters have been varied in order to consider a combination of values, so 2688 configurations were obtained. The results comprise both energy demands for heating and cooling for yearly output.

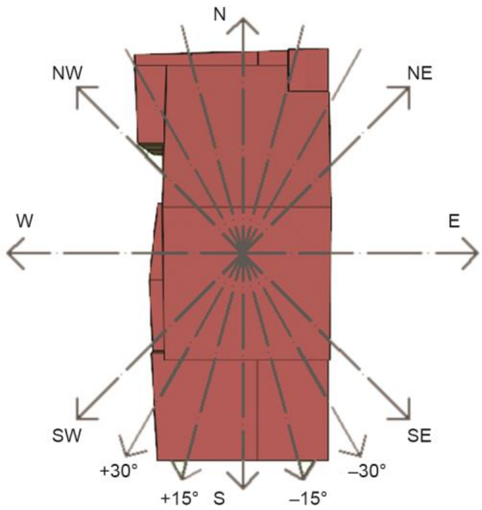

Figure 4. Building orientation – presumed positions of the analyzed building

Results and discussion

In order to increase building energy efficiency, based on the different orientations, U-values of envelope elements and parapet height of windows on the ground floor, results of annual building energy need for heating and cooling were obtained. Considering variations of the selected parameters and results of energy consumption, combinations of parameters with minimal and maximal energy needs were selected and analyzed. The maximum difference in annual heating energy consumption is 15129.40 kWh, where energy per m^2 is 27.75 kWh/m^2, while the maximum difference in annual cooling energy consumption is 14356.10 kWh, and per m^2 is 26.33 kWh/m^2. The average annual energy consumption for heating is 21861.11 kWh and per m^2 40.10 kWh/m^2, while the average energy consumption for cooling is 15944.44 kWh and per m^2 29.24 kWh/m^2. Also, minimal and maximal results for heating and cooling energy for building oriented south are analyzed.

Minimal and maximal values of annual heating energy consumption

Based on obtained results, it can be concluded that minimal energy for heating is achieved when object entrance is oriented east, tab. 1, while the parapet height of windows is 0 cm, and amounts annual 14436.39 kWh and per m^2 26.48 kWh/m^2. In these cases, the biggest part of the window surface is oriented south, so during the winter maximum utilization of solar heat gain is achieved. Also, in almost all cases with minimal heating energy, U-value of external walls is 0.15 W/m^2K, so this factor significantly influences energy consumption for heating in winter period. The highest energy consumption for heating, which is 29565.79 kWh annual and per m^2 54.23 kWh/m^2, is when object orientation is northwest and U-values of exterior walls are the highest – 0.29 W/m^2K, which was expected, tab. 2. As for windows characteristics, in this case, U-value of the windows is also the highest, while the parapet height is 0 cm. Heating energy need is only marginally affected by the roof U-values.

Parameters that have a significant impact on reduction of heating energy consumption are orientation and U-value of exterior walls and windows. Lower parapet has an impact on decreasing heating energy in winter period, but only in cases when most part of windows are oriented south, otherwise it contributes heat losses.

Based on the results of the simulations, the reduction of annual heating energy consumption up to 51.18% can be achieved by choosing the orientation where most windows will be facing south, and building envelope components with a smaller U-value.

Table 1. Minimal values of annual heating energy consumption

Parameters					Annual heating energy consumption [kWh per year]	Annual heating energy consumption per m^2 [$kWhm^{-2}$]
Orientation	U-value of external walls [$Wm^{-2}K^{-1}$]	U-value of windows [$Wm^{-2}K^{-1}$]	U-value of flat roof [$Wm^{-2}K^{-1}$]	Parapet height [cm]		
East	0.15	1.04	0.13	0	14436.39	26.48
East	0.15	1.04	0.13	10	14556.99	26.70
East	0.15	1.04	0.15	0	14569.86	26.72
East	0.15	1.04	0.15	10	14692.06	26.95
East	0.15	1.04	0.13	20	14699.54	26.96
East	0.15	1.04	0.15	20	14834.65	27.21
East	0.22	1.04	0.13	0	14939.44	27.40
East	0.22	1.04	0.13	10	15064.70	27.63
East	0.22	1.04	0.15	0	15066.62	27.63
Southeast	0.15	1.04	0.13	0	15119.05	27.73

Table 2. Maximal values of annual heating energy consumption

Parameters					Annual heating energy consumption [kWh per year]	Annual heating energy consumption per m^2 [kWhm^{-2}]
Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
Northwest	0.29	1.25	0.15	0	29565.79	54.23
Northwest	0.29	1.25	0.15	10	29565.79	54.23
Northwest	0.29	1.25	0.15	20	29555.72	54.21
Northwest	0.29	1.25	0.15	90	29530.06	54.16
Northwest	0.29	1.25	0.15	50	29527.98	54.16
Northwest	0.29	1.25	0.15	70	29511.18	54.13
Northwest	0.29	1.25	0.15	80	29503.32	54.11
Northwest	0.29	1.25	0.13	0	29496.17	54.10
Northwest	0.29	1.25	0.13	10	29485.82	54.08
Northwest	0.29	1.25	0.13	20	29475.75	54.06

Minimal and maximal values of annual cooling energy consumption

As for annual cooling energy, minimal consumption of 8728.07 kWh, and per m^2 16.01 kWh/m^2, is achieved for building oriented west. In that case, the biggest part of the windows is oriented north, which means that solar heat gains are minimized. Maximal annual energy for cooling of 23084.17 kWh and 42.34 kWh/m^2, is when the object is oriented southeast, because façade with the biggest window area is oriented southwest, so in this case solar heat gains are the highest.

Except orientation, another significant factor for reducing energy consumption for cooling is parapet height. As it can be seen in tabs. 3 and 4, cases with minimal cooling energy all have biggest parapet height, while combinations with maximum cooling energy have parapet height 0 cm. It is obvious that direct sunlight has a huge impact on building cooling needs, so the reduction of annual cooling energy consumption up to 62.19% can be achieved by choosing the orientation where windows will not be directly exposed to Sun.

Annual heating and cooling energy consumption for predominantly south orientation

In case of building entrance facing south, even small changes in orientation can have an impact on energy consumption. Analysis of the results for three orientations (strictly south and bioclimatic recommended ±15° south) showed that minimum energy needs for heating is achieved if the building is oriented –15° south: 16752.25 kWh annual and per m^2 30.73 kWh/m^2. For all three orientations with minimal heating energy, all other parameters are the same: U-values of envelope elements are low, and parapet height of windows is 0 cm, tab. 5. Considering that all parameters, except orientation, have the same values, it can be concluded that choosing building orientation –15° south can impact on heating energy savings up to 13.73%, comparing to other orientations. Maximum values for heating energy are just slightly above 21861.11 kWh, which is the average energy consumption for heating for all varied parameters, tab. 6, fig. 5.

Table 3. Minimal values of annual cooling energy consumption

Parameters					Annual cooling energy consumption [kWh per year]	Annual cooling energy consumption per m^2 [kWhm^{-2}]
Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
West	0.22	1.25	0.13	90	8728.07	16.01
West	0.22	1.25	0.15	90	8813.96	16.16
West	0.29	1.25	0.13	90	8845.45	16.22
West	0.29	1.25	0.15	90	8930.87	16.38
West	0.22	1.25	0.13	80	8932.82	16.38
West	0.15	1.25	0.13	90	8936.49	16.39
West	0.22	1.25	0.15	80	9018.71	16.54
West	0.15	1.25	0.15	90	9025.37	16.55
West	0.29	1.25	0.13	80	9048.63	16.60
West	0.15	1.25	0.13	80	9142.24	16.77

Table 4. Maximal values of annual cooling energy consumption

Parameters					Annual cooling energy consumption [kWh per year]	Annual cooling energy consumption per m^2 [kWhm^{-2}]
Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
Southeast	0.15	1.04	0.15	0	23084.17	42.34
Southeast	0.15	1.04	0.13	0	23013.41	42.21
Southeast	0.29	1.04	0.15	0	22810.97	41.84
–30° South	0.15	1.04	0.15	0	22791.71	41.80
Southeast	0.25	1.04	0.15	0	22778.17	41.78
Southeast	0.29	1.04	0.13	0	22742.01	41.71
–30° South	0.15	1.04	0.13	0	22718.44	41.67
Southeast	0.22	1.04	0.13	0	22708.93	41.65
Southeast	0.15	1.04	0.15	10	22544.70	41.35
Southeast	0.15	1.19	0.15	10	22542.93	41.35

As for cooling energy, minimal consumption is for object oriented +15° south, while the other parameter values are the same, tab. 7. This way, annual cooling energy can be reduced up to 13.26%, compared to annual cooling energy for orientation south and –15° south.

For Cases 10-12, values for maximum cooling energy are very close to the value of maximum cooling energy for all varied parameters (23084.17 kWh) so, in cases of predominantly south orientation, should be taken care of reduction of solar heat gains by raising the parapet height, or by placing systems for sun protection on Sun exposed windows, fig. 6. Shadings on the south oriented configurations will help to keep the cooling energy need to the optimum levels.

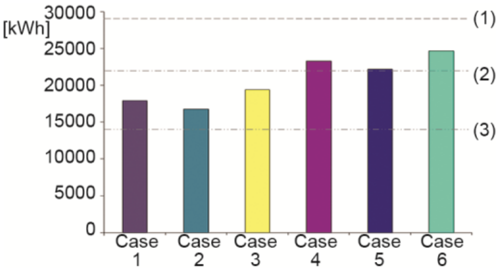

Figure 5. Minimal and maximal values of annual heating energy consumption for predominantly south orientation compared to maximal (1), average (2), and minimal (3) values of annual heating energy for all varied parameters

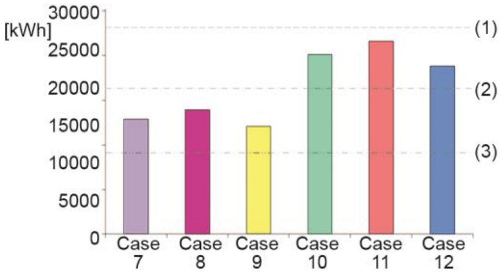

Figure 6. Minimal and maximal values of annual cooling energy consumption for predominantly south orientation compared to maximal (1), average (2), and minimal (3) values of annual cooling energy for all varied parameters

Table 5. Minimal values of annual heating energy consumption for predominantly south orientation

Case	Parameters					Annual heating energy consumption [kWh per year]	Annual heating energy consumption per m^2 [kWhm^{-2}]
	Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
Case 1	South	0.15	1.04	0.13	0	17899.89	32.83
Case 2	–15° South	0.15	1.04	0.13	0	16752.25	30.73
Case 3	+15° South	0.15	1.04	0.13	0	19418.79	35.62

Table 6. Maximal values of annual heating energy consumption for predominantly south orientation

Case	Parameters					Annual heating energy consumption [kWh per year]	Annual heating energy consumption per m^2 [kWhm^{-2}]
	Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
Case 4	South	0.29	1.25	0.15	90	23279.49	42.70
Case 5	–15° South	0.29	1.25	0.15	90	22185.88	40.69
Case 6	+15° South	0.29	1.25	0.15	90	24641.88	45.20

Table 7. Minimal values of annual cooling energy consumption for predominantly south orientation

Case	Parameters					Annual cooling energy consumption [kWh per year]	Annual cooling energy consumption per m^2 [kWhm^{-2}]
	Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
Case 7	South	0. 22	1.25	0.13	90	12897.71	23.66
Case 8	–15° South	0. 22	1.25	0.13	90	13933.89	25.56
Case 9	+15° South	0. 22	1.25	0.13	90	12085.63	22.17

Table 8. Maximal values of annual cooling energy consumption for predominantly south orientation

Case	Parameters					Annual cooling energy consumption [kWh per year]	Annual cooling energy consumption per m^2 [kWhm^{-2}]
	Orientation	U-value of external walls [Wm^{-2}K^{-1}]	U-value of windows [Wm^{-2}K^{-1}]	U-value of flat roof [Wm^{-2}K^{-1}]	Parapet height [cm]		
Case 10	South	0.15	1.04	0.15	0	20089.95	36.85
Case 11	–15° South	0.15	1.04	0.15	0	21565.89	39.55
Case 12	+15° South	0.15	1.04	0.15	0	18816.98	34.51

Conclusion

Growth of population leads to increased need for new residential and public buildings. Which consequently results in a greater demand for energy. Considering that buildings are one of the largest consumers of final energy, their energy efficient use should be one of the main goals in design process. Architectural design represents process that requires analytical multi-criteria decision-making. Quantification of the performance of the building thermal envelope, through its adequate materialization, is one of the standard design procedures, regulated by the standards and regulations. However, the first step in architectural decision making is exclusively urbanistic, through selecting the location and orientation of the future object. Analytical research of significance of the synergy of architectural-thermal and urban design, presented in this paper, indicate the importance of applying passive measures in the early stage of the design process, with the aim of the indirect influence on the additional investments for achieving energy efficiency of buildings.

At first, characteristic parameters that can have impact on building energy efficiency were chosen: building orientation, U-values of exterior walls, windows and roof, as well as parapet height. By varying these parameters, energy consumption for an office building located in city of Nis, Republic of Serbia, is analyzed through simulations in EnergyPlus software. Based on obtained results, it can be concluded that, by choosing the right parameters, the reduction of heating energy up to 51.18%, and reduction of cooling energy up to 62.19%, can be achieved. For reduction of heating energy consumption the most effective measures are exterior walls and windows with lower U-values. Furthermore, building orientation where the biggest part of the window surface is oriented south also contributes to reduction of annual heating energy consumption, but values of annual cooling energy consumption are very high. In that case, shading systems should be installed to improve cooling energy performance, without affecting the heating one. Considering that direct sunlight has a significant impact on building cooling energy consumption, the most effective measures for its reduction is building orientation where windows will not be exposed to direct sunlight, as well as raising the parapet height. Results displayed in section *Annual heationg anc cooling energy consumption for predominantly south orientation* indicate that even the small change in building orientation could result in decrease of energy consumption. For cases of predominantly south orientation (south and ±15° southwest *i. e.* southeast), by choosing the right orientation heating energy demand can be reduced by up to 13.73% and cooling energy demand can be reduced by up to 13.26%.

Building envelope, except aesthetical, should fulfill requirements for increasing energy efficiency. Results of this analysis showed that the precise design of the building envelope elements based on detailed simulations in the initial stage, can significantly help achieving the optimal heating and cooling energy. According to this, the first step toward energy efficient buildings should be design of building envelope. After that, mechanical systems and lighting should be designed in accordance with the remaining load. High energy efficiency of objects cannot be achieved if mechanical systems have to solve problems resulted from architectural design.

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