THE EFFECT OF ARCHITECTURAL FAÇADE DESIGN ON ENERGY SAVINGS IN THE STUDENT DORMITORY

by

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There are many reasons for adequate use of natural light inside students' dormitories. Intensity of light required for student activities and temperature inside the rooms are the major factors for an occupant's comfortable work and life. Design of building façades has a significant impact both on the use of natural light and energy consumption. In this paper, a comparative analysis of student rooms with different orientations and different façade designs was performed in order to investigate what type of refurbishment in the façade is necessary. The goal of the refurbishment was generation of optimal thermal and lighting comfort for students' work with maximal energy saving for a new student dormitory in Nis, Serbia. An analysis of annual energy consumption of the newly designed student dormitory and proposed replacements on the exterior façade was performed by using the software EnergyPlus. Based on the energy consumption analysis it could be concluded that significant energy savings would be possible by upgrading the shading devices across the width of the window. In other words, changing the façade of the dorm could generally improve students' comfort, while the energy costs would be reduced.

Key words: *façade design, daylighting, eaves upgrading, thermal comfort, visual comfort, energy consumption, EnergyPlus*

Introduction

Sunlight is a free resource used all over the world. There are many potential advantages of the daylight in buildings if it is properly controlled and distributed, especially in terms of visual comfort, health, productivity, as well as in terms of energy consumption. However, successful organization of the daylight is a complicated task due to the numerous relevant design variables, such as the look of façade, disposition of the structure supporting elements and organization of the internal rooms, which are specific for each project [1].

The amount of daylight in a building is one of the key factors in the design and depends directly on its distribution system; therefore, it is necessary to pay a lot of attention to facade design in a functional sense in order to minimize energy consumption. Due to such complexity of the daylighting many different tools were developed to help architects find the best possible solution. Traditional tools include: models, heuristics (the rule of thumb or the knowledge acquired from the experience), design guides, and case studies [2]. Such tools are popular even today, especially computer simulations, which is more frequently used in an early phase of designing, in comparison with other methods.

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There are numerous studies that confirm a positive influence of daylight on human beings [3, 4]. For this reason it is very important to pay attention to the daylight while designing for the sake of health improvement, satisfaction, and productivity of students who are tenants in student dormitories [5].

Natural daylight in indoor rooms is a positive and free resource which should be used completely. However, there are some limitations when using daylight. Namely, excessive insolation leads to the overheating of rooms, and, therefore, to the need for their cooling and consumption of energy (mainly electricity). On the other hand, insufficient natural daylight is compensated by the usage of artificial lights and consumption of electricity. For this reason it is desirable to find the optimal solution in order to minimize the energy consumption.

In already existing student dormitory near the location where the analyzed one will be placed, some investigations of thermal and lighting comfort were carried out two years ago. Based on the performed measurements, questionnaires and interviews with the occupants, overheating in the summer time was identified as a main drawback due to excessive solar radiation in the dormitory [6].

The analyzed dormitory will be located near the existing dormitory of Technical Faculties in Nis. The dormitory is in the design phase and this study represents an attempt for energy efficient façade design by means of upgrading the shading devices and changing window type and size in order to create better working and living conditions. The aim of this paper is to define the optimal solution for the facade of the dormitory in order to achieve better utilization and control of daylight. Four excluded rooms (ER) with different orientation have been selected with and without the façade upgrading and annual energy consumption of them was assessed.

Model

In order to obtain precise annual energy consumption data for the desired object some measurements are required during the year. Each measurement requires adequate equipment (*e. g.* calorimeters, thermometers, lux-meter, *etc.*), whose purchase is necessary to allocate significant funds. Another way to obtain a less accurate data is a simulation by using one of the available software packages for this purpose. However, in cases when the considered object is still in the design phase and there is a need to analyze the energy efficiency after some specific changes in the façade, simulations occur as the only solution. Accordingly, in this paper software package EnergyPlus was used to determine the energy consumption in the excluded student rooms. Namely, the student dormitory in its design phase was evaluated in terms of energy savings after façade and window changes, thereby paying attention to maximum utilization of sunlight.

EnergyPlus software

To simulate heating, cooling, lighting, ventilation, water net-work, and other mass and energy flow in a built environment, EnergyPlus software can be successfully used [7]. This software can model energy use in a residential building [8, 9]. EnergyPlus takes into account all factors that in influence thermal loads in the building, such as: electricity devices, lighting, pipes in the building, solar radiation, wind, infiltration and shading of open rooms. This software enables designers to simulate energy behavior of the residential building for a selected period and propose some ways for energy saving [10]. The software is intensively validated by groups of authors [11, 12]. EnergyPlus was already used for the study of a positive-net-energy residential building in Serbian conditions by Bojic *et al.* [13]. Moreover, the software was used by Chidiac *et al.* to investigate multi-storey buildings in similar moderate climates like in Serbia [14]. The geometry of the model was created by using OpenStudio plug-in for Google Sketch Up environment [15]. Google Sketch Up is a program for 3-D modeling. One way to define the geometry of the building in EnergyPlus is by using the text editor; however, the OpenStudio plug-in saves a lot of time which is useful when modeling this student dormitory building. In addition, it is important to use relative co-ordinates in order to save time.

Object and model description

The considered dormitory will be located near the existing dormitory of Technical Faculties in Nis. The new dormitory is in the design phase and this study represents an attempt to achieve energy efficient façade design by using shading devices in order to create better working and living conditions. Since the aim of this paper was to find the "optimal" solution of the façade, 3-D model of the entire building with 11 floors and 18 student rooms per floor was created. One excluded (representative) room from the fifth floor is selected for each of the façade orientations (ER1 – southwest, ER2 – northwest, ER3 – northeast and ER4 – southeast), approximately the same size and floor area of 20 m^2. Each room represents a separate thermal zone. Other rooms are grouped as another thermal zone; a hallway with a staircase and an elevator are designed as a separate thermal zone. The remaining floors, except for the ground floor and the attic, are modeled in the same way as the fifth floor. The entire ground floor and the loft are design as a special thermal zone. The overview of the floor schedule and excluded zones of the fifth floor is shown in fig. 1.

Figure 1. Overview of the floor schedule with excluded zones

Heat transfer occurs on outside walls and windows in each room. The analysis assumes that in each of the zones constant internal design temperature is maintained (during winter 22 °C, during summer 26 °C). Ideal HVAC system was adopted to cover the heating requirements of the zones. Object IdealLoadsAirSystem, makes it possible for each zone to bring as much energy as it is needed at any moment. This model is primarily used at the stage of a preliminary architectural project in order to check the different architectural design solutions, as is the case with natural light and insolation.

Each of the ER has the area of the internal envelope (internal walls, floor and ceiling) of 82.8 m^2 and the area of the external envelope of 14.37 m^2 (that is 16.7% of the entire envelope). The main envelope constructions used in the building project are shown in tab. 1.

Table 1. The main constructions used in the building project (thicknesses of layers are given)

Construction	Outside layer	2nd layer	3rd layer	4th layer
Exterior wall	Brick 12	Stone wool 7	concrete 15	Plaster
Interior wall	Plaster	Brick 12	Plaster	–
Interior floor	Plaster	Prefabricated concrete 25	Plaster	Wood floor piles
Interior ceiling	Wood floor piles	Concrete	Prefabricated concrete 25	Plaster

The building will be insulated with the stone wool of 7 cm. According to the projects, the windows contain 34.8% of the external envelope of the ER. They are double glazed with float glass and filled with air (4-12-4). The window frames are made of wood.

The main activities of the students within the ER are studying, reading, and drawing; therefore, the criteria for necessary light intensity of 500 lux on the desktop was imposed [16, 17]. For this reason, the analysis assumes that within each thermal zone the minimum luminous intensity on the desktop amounts 500 lux.

In order to achieve proposed conditions, one Daylighting: Controls is set in each of ER, in the place where desks are placed at 80 cm height from the floor. In case of lack of natural light on Daylighting: Controls, artificial lighting is automatically turned on. Lighting Control Type is continuous, the overhead lights dim continuously and linearly from (maximum electric power, maximum light output) to (minimum electric power, minimum light output) as the daylight illuminance increases. The lights stay on at the minimum point with further increase in the daylight illuminance. Schedule of lighting (Schedule: Compact, Lighting Schedule), which defines the percentage of available lighting power, depending on the time of day is the created in order to ensure a more realistic view of electricity consumption for lighting. A heat meters are created and used to measure annual heat consumption at the zone level.

Climate

Considered dormitory will be located in the city of Nis, Balkan Peninsula in the state of Serbia, Europe, fig. 2. Simulations were performed with weather file for City of Nis. The city has the average height above sea-level of 202 m. Its latitude is 43°19' N, longitude 21°54' E, and time zone GMT +1.0 h. The city features moderate continental climate with a gradual transition between the four distinct seasons (winter, spring, summer, and autumn). From May to September the temperatures are recorded with over 30 °C; in July and August with over 35 °C [18]. The summers are warm and humid; July is the warmest month of the year with an average temperature of 21.2 °C. Average day-night temperature difference in summer is about of 10 °C. In the winter part of the year the average absolute minimum temperatures are below –10 °C.

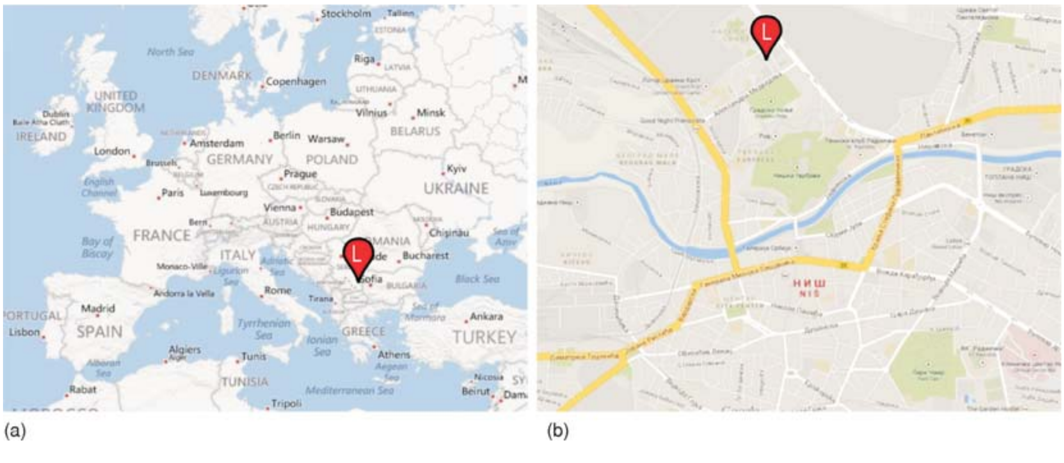

Figure 2. Planned location for the analyzed project of the new student dormitory; (a) map of Europe, (b) map of the city of Nis

Average annual insolation in Nis lasts 1,993 hours, analyzing the period from 1990 to 2010, (excluding year 2008). The highest number of insolation hours is in June, July, and September, with average monthly insolation hours of over 250. The lowest insolation is in December with the average value for this period of 51.2 h per month.

The average annual cloudiness in tenths is 5.5. Months with the highest cloudiness are December and January with average cloudiness in tenths per month, 7.3 and 6.8, respectively, while months with the lowest cloudiness are June and July with average cloudiness in tenths per month, 3.8 and 3.5, respectively.

In EnergyPlus, both external (*i. e.*, weather files supplied from others) and internal (*i.e.*, solar position, design day temperature/humidity/solar profiles) data are used during simulations. Weather files have hourly data for each of the critical elements required during the calculations (*i. e.*, dry-bulb temperature, dew-point temperature, relative humidity, barometric pressure, direct normal radiation, diffuse horizontal radiation, total and opaque sky cover, wind direction and wind speed) as well as some auxiliary data such as rain or snow that can help in certain calculation aspects.

Parametric study

In order to accelerate the simulation process and avoid errors, jEPlus, a batch shell for parametric studies was used in the research [19]. jEPlus is an open source tool originally developed for managing complex parametric simulations by using EnergyPlus [20].

Three parameters that can vary among discrete values were selected. The parameters are: P1 – the type of the window, P2 – the window size, and P3 – the size of the shading devices. In this way, a total of 385 simulations that represent all possible combinations of these three parameters were performed.

Parameter P1 – the type of the window has 7 discrete values; the current window type (level 1) and 6 more others (tab. 2) which satisfy the requirements of Ordinance on Energy Efficiency of Buildings in Serbia [21].

Table 2. Parameter P1 – type of window

Level	1	2	3	4	5	6	7
1st layer	Float 4 mm	Low emission 4 mm	Low emission 4 mm	Low emission 4 mm	Low emission 4 mm	Low emission 4 mm	Low emission 4 mm
2nd layer	Air 12 mm	Air 16 mm	Argon 15 mm	Krypton 12 mm	Xenon 12 mm	Krypton 8 mm	Xenon 8 mm
3rd layer	Float 4 mm	Float 4 mm	Float 4 mm	Float 4 mm	Float 4 mm	Float 4 mm	Float 4 mm
4th layer	–	–	–	–	–	Krypton 8 mm	Xenon 8 mm
5th layer	–	–	–	–	–	Float 4 mm	Float 4 mm

Parameter P2 – the size of the window has 5 discrete values (tab. 3) which represent the window height, while the width remains constant of 3.1 m. The current size of the windows 3.1 × 1.6 m, *i. e.*, level 5.

Table 3. Parameter P2 – size of windows

Level	1	2	3	4	5
Height of the window [m]	1.2	1.3	1.4	1.3	1.6

Parameter P3 – the size of shading devices contains 11 discrete values (tab. 4), which actually represents the length of the shading devices placed directly over the whole width of the window. The first level represents the current state of the façade.

Table 4. Parameter P3 – length of the shading devices

Level	1	2	3	4	5	6	7	8	9	10	11
Length of the shading devices [m]	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

Results and discussion

Table 5. Total annual energy consumption of the base case and the case of minimal cooling energy consumption

	Energy consumption [kWh per year]		Parameters level		
			P1	P2	P3
ER1					
	Base case	The best solution			
Lights electric	343	395	6	1	11
Heating	567	461			
Cooling	1390	535			
ER2					
	Base case	The best solution			
Lights electric	351	417	1	1	11
Heating	739	794			
Cooling	680	389			
ER3					
	Base case	The best solution			
Lights electric	349	401	6	1	11
Heating	613	499			
Cooling	1419	535			
ER4					
	Base case	The best solution			
Lights electric	350	376	1	1	11
Heating	250	532			
Cooling	1267	381			

It total, 385 annual energy simulations were performed for 4 thermal zones, 11 length of shading devices, 5 window sizes, and 7 types of the windows. The simulations modeled lighting, heating, cooling, and total energy consumption per year for each of the thermal zones.

Based on the variation of the selected parameters (window size, glazing type and size of shading devices) and resulting energy consumption, combination of parameters with minimal cooling energy consumption for each of the four thermal zones was selected as the best case. Criterion of the minimum cooling energy consumption is taken because the cooling takes part in the greatest percentage in the total energy consumption. Moreover, the results of the previous study made by the group of authors [6] noted that the thermal conditions deteriorated during the summer period in the student dormitory near the location where the considered one will be placed. The outcomes for the total annual energy consumption of the base case and the proposed solutions (improvements) are listed in tab. 5.

The simulations demonstrated that highest energy consumption occurred during the cooling of the interior zones ER1, ER,3 and ER4. On the contrary, the most energy was spent for heating the zone ER2; it was expected, since the ER2 has a northwest orientation and is drawn in without the direct sunlight exposure in the hottest parts of the day. Façade design of the both the base and the best case is given in fig. 3.

Figure 3. Overview of the dormitory with "base" and "optimal" façade design with shading devices upgrading in terms of energy saving

The reduction of energy consumption for cooling about three times and reduction of heating energy consumption (about 100 kWh per year) for both ER1 and ER3, with a slight increase in the electric power consumption for additional lighting (about 50 kWh per year) is evident. In this regard, the shading devices with length of 1 m should be upgraded and the windows should be replaced with another ones (type 6, according to tab. 2, with reduced height for 40 cm) in the ER1 and ER3. By upgrading the shading devices with length of 1 m and by reducing the window height for 40 cm cooling energy consumption would be more than 3 times lower (about 886 kWh per year), while the consumption of heating energy would be increased in 283 kWh per year and electricity consumption would be increased of 26 kWh per year in the ER4. The same changes of the ER2 façade as described for ER4 should reduce cooling energy consumption for 300 kWh per year, increase heating energy consumption for 55 kWh per year, whereas amount of the natural lighting would be reduced and electricity consumption for additional artificial lighting would be increased from 351 kWh per year to 417 kWh per year.

Electric energy consumption for additional lighting per months for each of the considered thermal zones is shown in fig. 4. It is obvious that the proposed changes of the façade casually lead to the higher need for additional lightening. The total annual consumption is the highest for ER2 and the lowest for ER4.

Based on the energy consumption for heating and cooling per months, which is given in fig. 5, it can be concluded that there is a negligible increase in energy for heating after changes to the facade of the zones ER1, ER2, and ER3. The heating energy consumption significantly increases only for the period from January to March in the area of ER4. In contrast, the proposed improvements on the facade reduce significantly heat gains within the analyzed zones during the summer period. It clearly indicates the simplest way to solve the thermal overheating in the

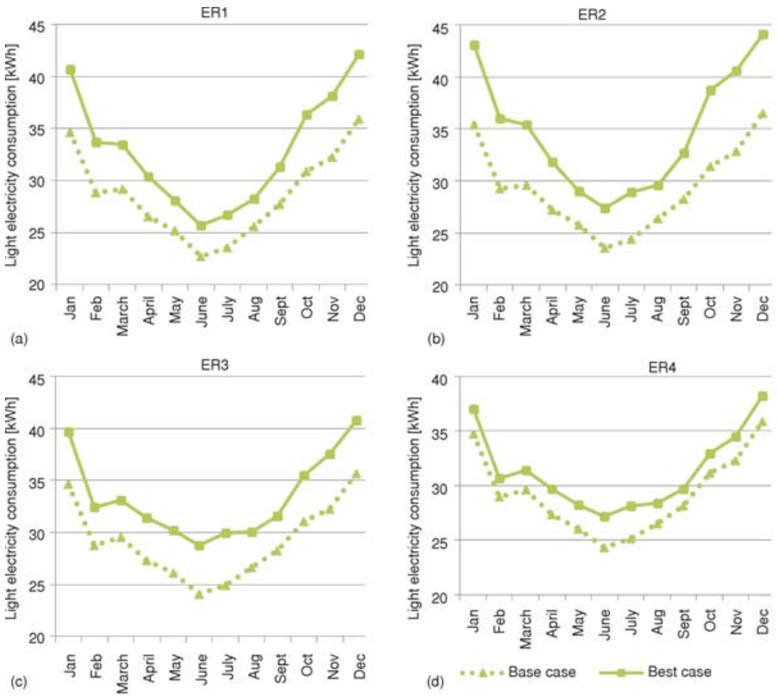

Figure 4. Light electricity consumption in kWh per months

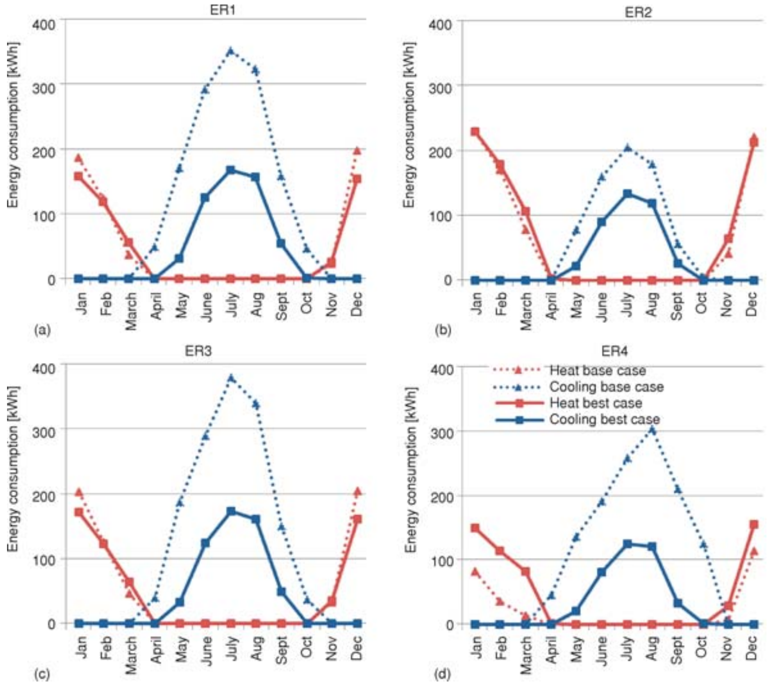

Figure 5. Energy consumption for heating and cooling in kWh per months

rooms. Therefore, the proposed upgrading of the façade, fig. 3 (b), provides greater thermal comfort with a slight increase in demand for light electricity.

If one takes into account the fact that during the occupants' stay in the room, if the room is not used only for learning, then the need for additional lighting is significantly less than in the idealized case treated in the simulation. In other words, validity of the proposed facade changes becomes even more important.

Conclusions

In this paper, an analysis of the annual energy consumption of the four excluded thermal zones of the new student's dormitory in design phase was performed by using EnergyPlus software package. Following that, the analysis of the annual energy consumption after some architectural changes on the exterior façade, such as upgrade of the shading devices and change in window type and size, was carried out too. Based on the analysis of energy consumption it could be concluded that significant energy savings would be possible by upgrading the shading devices across the width of the window (entire length of the outer wall) with length of 1 m. Also a significant saving of the cool energy consumption would be scored by reducing the window height for 40 cm in the analyzed thermal zones. In addition, the windows in the zones ER1 and ER3 it should be replaced with the energy efficient ones. Without neglecting the importance of the natural light, these façade changes would not significantly increase the need for additional lighting and electricity consumption. However, the proposed changes of the façade can greatly improve the working conditions for future occupants of the new dormitory.

Further research will be focused on the possibility for improving residential comfort and energy efficiency in the already existing dormitories. Also, an impact of newly built objects in the neighborhood of the dormitories on energy efficiency of the existing ones due to shielding of direct sunlight will be studied.

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