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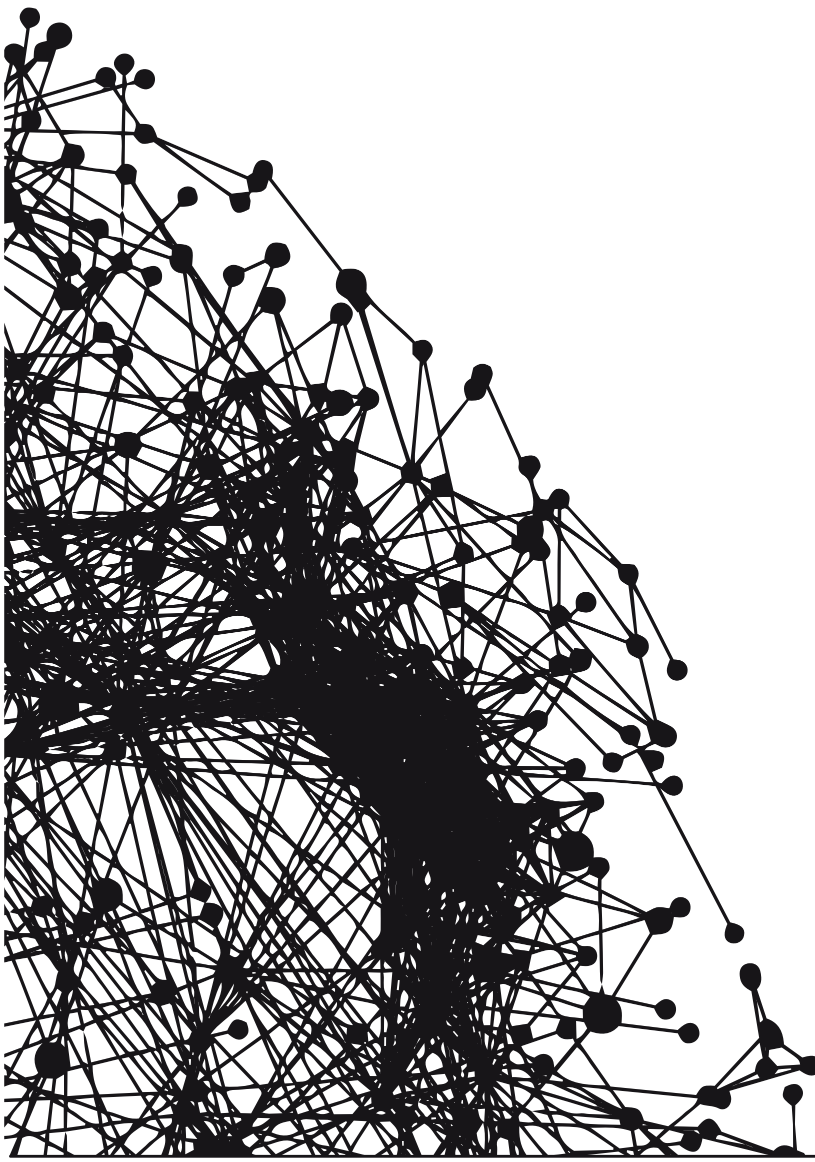

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DESIGN SCENARIOS FOR AN OFFICE BUILDING - ENERGY AND ENVIRONMENTAL ASPECTS

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ABSTRACT

The main concern of this research is to estimate energy performances of different scenarios of the hypothetical model of the office building in downtown of Belgrade. Specific conditions of sites in downtown make limitations in building design and application of energy efficient systems, but also represent a provocation for architects. Methodological approach entails three steps: design of different models of the office building, numerical simulations of the models in PHPP'2007 software and comparison of the results. For each hypothetical model of the office building three scenarios are created: basic scenario and scenarios of different solutions of envelope design regarding shading devices types. The design of hypothetical models and various scenarios is carried out through the educational process on the Master studio design project. Results are considered and presented through the heat and cooling energy demands as well as reduction of energy consumption for cooling in summer period by implementation of different shading devices. CO_2 emissions are also discussed. Design methodology as well as results could generally be applicable for new office building design, both in Belgrade and in similar climatic conditions.

Keywords: Energy efficiency, CO_2 emissions, Office building design, Numerical simulations of energy efficiency, Heat and cooling energy demands.

INTRODUCTION

New energy-efficient buildings represent yearly a small percentage in relation to total building stock. In Belgrade, construction of office buildings is on the rise in last decade. Office buildings have one of the highest levels of energy consumption when compared with energy consumption in other buildings sectors (Burton, 2001). Specific conditions of sites in downtown make limitations in building design and application of energy efficient systems, but also represent a provocation for architects. In the paper the solutions for overcoming the problem are discussed. In addition to the aspect of energy performances of the office building, architectural aspect is also taken into consideration. According to these aspects, different design solutions are discussed and the most appropriate solutions regarding all aspects are selected. In order to design energy efficient houses, students of architecture, as well as architects, have to be informed about systems, materials, supporting systems, coatings and design principles. In that sense, different scenarios of the energy efficient office building design are discussed in the paper and accompanied with examples of student works.

METHODOLOGY

The main concern of this research is to estimate different scenarios of energy performances of the hypothetical model of office building in downtown of Belgrade. Methodological approach entails three steps:

- design of different models of the office building,
- numerical simulations of the models in PHPP'2007 software and
- comparison of the results (models).

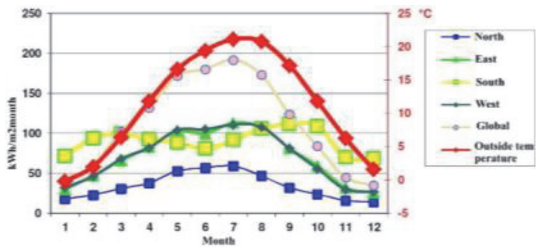
The design of hypothetical models and various scenarios is carried out through the educational process on the Master studio design project M5, entitled Design of energy-efficient office building in the urban milieu of Belgrade (authors of the paper conducted design process with students). Program is designed to contribute to the development of competent professionals and the dissemination of ideas of energy efficiency in practice.

Characteristics of the building location

Different hypothetical models of the office building are created according to Belgrade climatic conditions and site orientation. Energy efficiency of models is estimated through numerical simulations.

Climatic conditions of the location. Generally, climatic conditions strongly influence building design. Students' task was to design an office building in specific climatic conditions of Belgrade, characterised by extreme summer and winter differences. Belgrade is located at latitude 44°49'14"N. Data about Belgrade climate, relevant for numerical simulations, are taken from the Report prepared by Republic Hydrometeorological Service of Serbia. Belgrade has a moderate continental climate, with four seasons. Autumn is with longer sunny and warm periods than spring. Winter is not so severe, with an average of 21 days with temperature below zero. January is the coldest month, with average temperature of 0.1°C. Spring is rainy. Summer arrives abruptly. The average annual air temperature is 11.7°C. The hottest month is July (22.1°C). The average annual number of days with temperature higher than 30°C is 31 and that of summer days with temperature higher than 25°C is 95. Belgrade is the city with global irradiance of 1,341.8kWh/m^2 (Polysun 4), and 2,123.25 sunny hours per year. Solar radiation for different facade orientations is shown in the Figure 1. The highest insolation of about 10 hours a day is in July and August, while December and January are the cloudiest, with insolation of 2 to 2.3

hours per day. Figure 2 shows mean annual temperature for GMS Belgrade, through its deviation from the normal. The black line is the 5-year sliding mean and blue pillars are the deviation from the normal for each year. Increase of temperature is evident (Krstic-Furundzic and Djukic, 2009; Republic Hydrometeorological Service of Serbia).



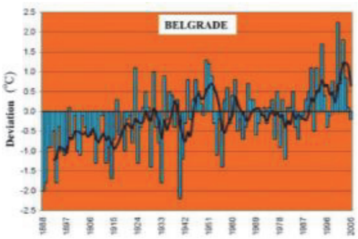


Figure 1. Solar radiation for different facade annual orientations in Belgrade climatic conditions period 1888-2005 and Figure 2. Deviation of mean temperature in the

The characteristic of Belgrade climate is also Kosava - the southeast wind, which brings clear and dry weather. The average speed of Kosava is 25-43 km/h but certain strokes can reach up to 130 km/h. The average annual rainfall on Belgrade and its surroundings is 669.5 mm. The rainiest months are May and June. The average number of snowy days is 27. Mean atmospheric pressure in Belgrade is 1,001 millibars and mean relative humidity is 69.5%.

Building location. The building site is located in a high density urban structure surrounded by buildings that are under protection as cultural property of great importance (Figure 3 and 4). The hypothetical multi-storey office building has to be integrated into the front of the existing buildings.

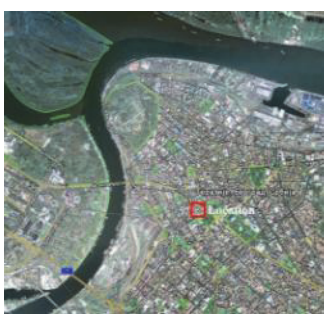
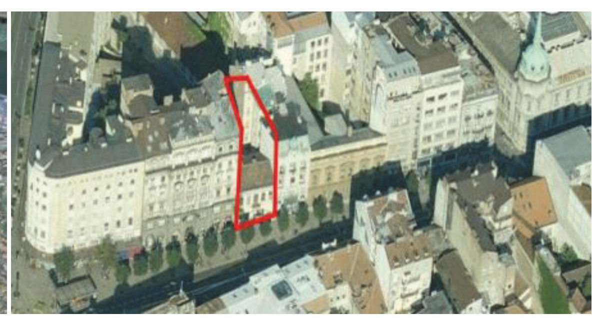
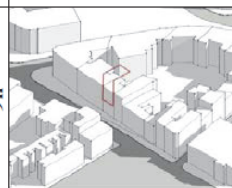
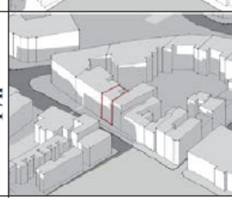



Figure 3. Site location on the city map and Figure 4. Location of the building in the closed block

The building is situated along the NE-SW direction (Figure 4). Building insolation for different seasons and periods of the day is presented in the Table 1.

Street facade is the south-west orientation, yard northeast, while the gables of the building, adjacent to its neighbours, are northwest and southeast. Gable oriented towards the south rises above the neighbour's roof giving the potential for solar energy usage. The building is relatively well-protected from dominant wind by its position and neighbouring buildings.

Table 1. Building insolation for different seasons and periods of the day

	sunrise-sunset	Equinox	Summer solstice	Winter solstice
		~7.30h–16.30h	~4.00h–19.30h	~6.00h– 18.00h
Period of the day	9h			
	12h			
	15h			
	17h			

Design of models of the office building

The work highlights the problems of energy efficient office building design. Consideration of energy efficiency of office buildings is still not in practice in Belgrade, as well as in Serbia. The purpose of this research is to estimate different design solutions of office building in terms of energy efficiency in specific climatic conditions. In this paper, the authors evaluate a few hypothetical models of the office building created by students. Students solved the task through three causal steps: an analytical phase, the phase of development of the concepts-models of the building, and checking of achieved results as the final phase. For each hypothetical model three scenarios are created: basic scenario and scenarios of different solutions of envelope design regarding shading devices types. The results of the preliminary energy balance of the building show: energy consumption for heating and cooling, share of passive solar energy and CO_2 emissions. Based on the results, the comparative analysis of different models is carried out. This approach, as well as results, could generally be applicable for new office building design, both in Belgrade and in similar climatic conditions. Diversity of facade types was the criteria for students' projects (models) selection. Most commonly used types of facades in the design of office buildings in local practice were adopted in order to assess their energy performances, point out the disadvantages and form recommendations. Three facade concepts were selected: massive (traditional) facade – Model1 (M1) and two different types of glass facades - Models 2 and 3 (M2 and M3).

Characteristics of hypothetical models. The location caused narrow facade fronts (Figure 5). For this reason the inner atrium is formed for the purpose of natural lighting and ventilation of space. According to urban planning regulations the building of six floors is planned. The reinforced concrete skeleton structure is adopted for all models. Both office layout concepts, open-plan and classical type, are accepted. Design concepts of three selected models are shown by plan of a typical floor, elevation and cross-section of the street facade (Figures 6, 7 and 8).

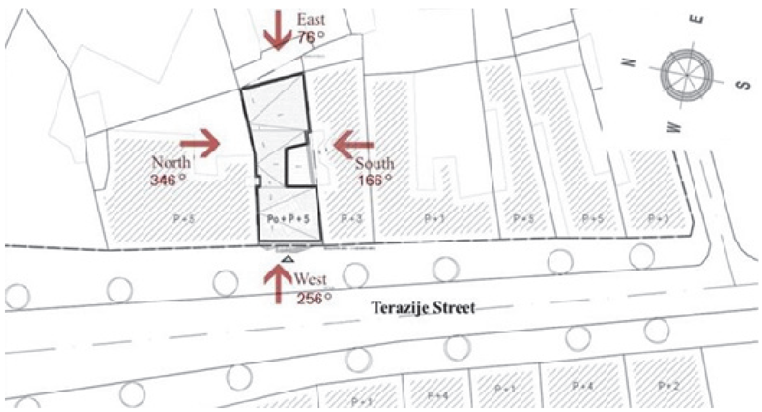


Figure 5. Location of the building in the closed block

Office building is designed for 100 users. Appropriate inside thermal comfort includes indoor air temperature of 20°C in winter and 22°C in summer (a temperature of 25°C is maximum which does not require additional mechanical cooling). Internal and solar gains are taken into account in the calculation of energy demands for heating and cooling. District heating is predicted for this location. Ventilation system with heat recovery of 88.0% efficiency is specified. The fresh-air demand results from the requirements of the DIN 1946 Part 6 and presents $30m^3/h$ per person. The air change rate is related to available space area per user. The average air change rate per hour for the M1 and M2 is 0.41 while for the M3 is 0.49. In summer period the natural ventilation is predicted. Night-time and daytime window ventilation types are accepted. Cross-ventilation through east-west windows (daily average air change rate–0.36/h), as well as facade and atrium windows–"chimney effect" (daily average air change rate–0.62/h) is proposed. Night ventilation includes average air change rate of 0.29/h. The daily temperature fluctuation caused by the solar gains during the design day is taken into consideration and should not exceed 3°K, otherwise the calculated cooling load might not be enough; if the frequency of temperatures above the comfort limit (25°C) exceeds 10% of the year, additional measures for protection from summer heat are necessary (Feist, 2007). Electricity consumption for lighting, appliances and water heating is not considered.

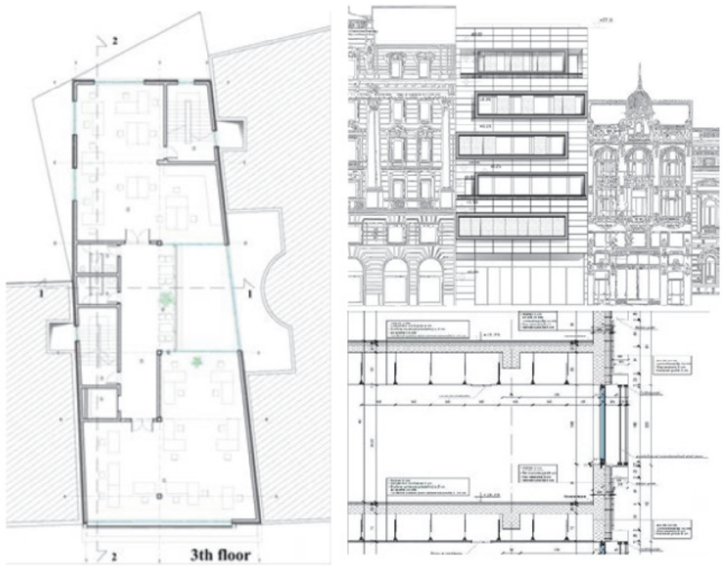


Figure 6. Plan of a typical floor, elevation and cross-section of the street facade of Model 1

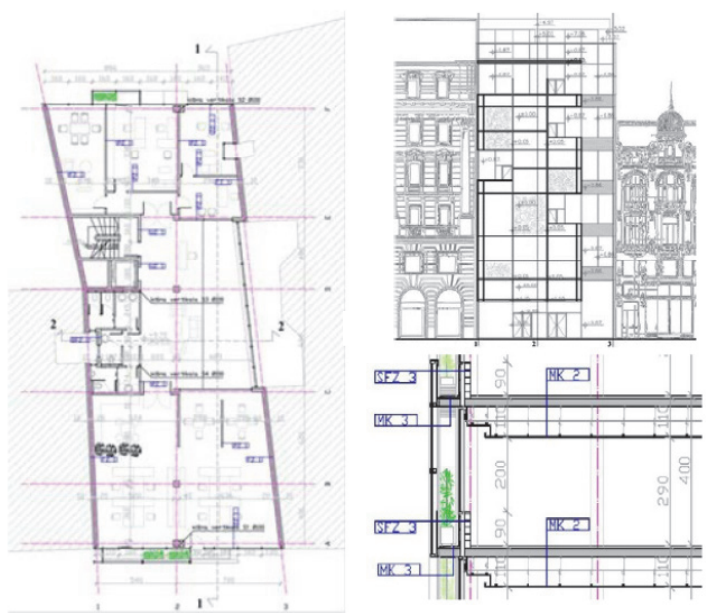


Figure 7. Plan of a typical floor, elevation and cross-section of the street facade of Model 2

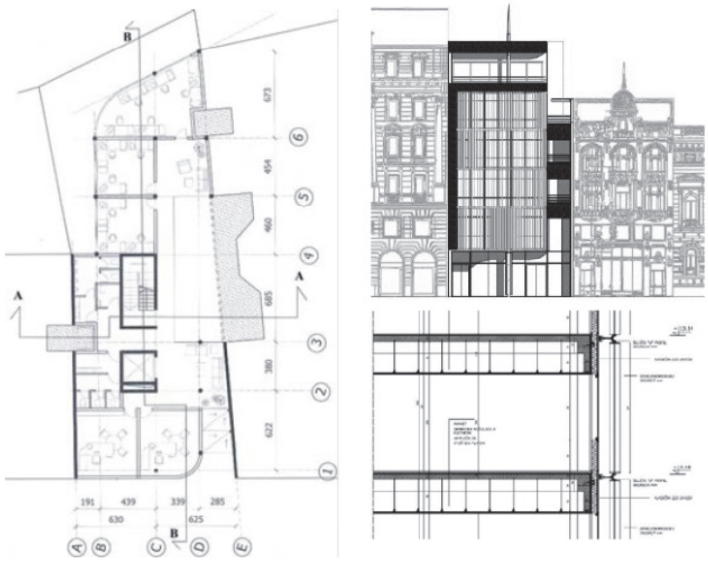


Figure 8. Plan of a typical floor, elevation and cross-section of the street facade of Model 3

As the energy requirements for heating and cooling are discussed in the paper, data relevant for calculation of these demands for different models are shown in the Table 2.

Table 2. Models data relevant for calculation of heat and cooling demands (1-basement ceiling; 2-basement external wall; 3-facade wall; 4-gable wall; 5-roof; 6-ground slab)

Model	Heated space area	Heated space volume	Office space height	Facade surfaces			Envelope massive str. types and U-values						Glazing U-values		Glazing areas				
				Glazed	Massive	Total	1	2	3	4	5	6	glazing	frame	North	East	South	West	Horizontal
	m^2	m^3	m	m^2			W/m^2K						W/m^2K		m^2				
M1	1963.0	5889.0	3.0	492.89	2194.67	2687.16	--	0.32	0.35	0.35	0.31	0.33	2.8	0.75	66.74 (51.8)	54.36 (43.1)	204.11 (193.5)	154.63 (136.6)	13.05 (11.3)
M2	1898.1	5694.3	3.0	909.71	1861.9	2771.6	0.31	1.93	0.28	0.54	0.28	1.67	2.70	0.83	11.20 (5.6)	300.64 (287.3)	267.81 (255.6)	306.78 (293.2)	23.28 (21.7)
M3	1560.0	4680.0	3.0	840.39	1898.91	2739.30	0.30	1.93	0.32	0.32	0.32	1.61	0.70	0.80	138.28 (115.8)	108.41 (90.2)	263.30 (239.1)	292.67 (265.9)	37.74 (33.7)

Following differences are characteristics of proposed models envelope structures that influence the energy performances of each model:

- as the M1 has heated basement, thermal insulation is placed on the ground slab and basement walls, while in case of M2 and M3 it is not heated and thermal insulation is placed on basement ceiling;
- for the M1 the street and courtyard facades are massive walls with thermal insulating panels and glazing and stone slabs as finishing layer (Figure 6), for the M2 glass protection layer at distance of 86cm is suspended in front of the glass facade made of thermal insulating panels (Figure 7), and in the case of the M3 the street glass facade is made of triple low-e glazed panels with gas fills of krypton while the courtyard facade is a massive structure (Figure 8);
- flat roofs are applied for all models; in addition the M2 has a green roof with planting layer in order the reduction of the surface temperature to be obtained.

Contribution of heat gains in compensation of the total heat losses in the winter period is significant and represents 39% (passive solar gains 17%+internal gains 22%) in case of the M1, 52% (39%+13%) in case of the M2 and 73% (55%+18%) in case of the M3.

Table 3. Glazing orientation and shading factors

Type of shading	Orientation	Glazing orientation and summer shading factors					
		M1 [%]		M2 [%]		M3 [%]	
No shading device (M10, M20, M30)	North	M_{10}	58	M_{20}	41	M_{30}	54
	East		47		45		63
	South		22		58		57
	West		42		63		60
	Horizontal		97		97		97
Internal shading device (temporary shading reduction factor 60%) (M11, M21, M31)	North	M_{11}	35	M_{21}	41	M_{31}	32
	East		28		27		38
	South		13		35		34
	West		25		38		41
	Horizontal		50		58		58
External shading device (temporary shading reduction factor 10%) (M12, M22, M32)	North	M_{12}	6	M_{22}	41	M_{32}	5
	East		5		4		6
	South		2		6		6
	West		4		6		7
	Horizontal		10		10		10

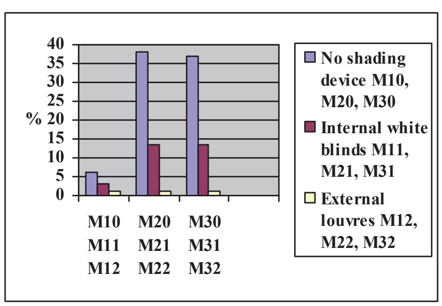


Figure 9. Frequency of overheating

Energy demands for cooling purposes are calculated for each model in three variants: no shading devices (M10, M20, M30), internal movable white blind - temporary shading reduction factor 60% (M11, M21, M31) and external movable louvers inclined 45°- temporary shading reduction factor 10% (M12, M22, M32) as shading devices. Shading factors for listed variants are given in the Table 3. Frequency of overheating in relation to different types of shading devices is presented in the Figure 9. Clear glass is selected for window glazing in order appropriate daylighting to be obtained.

RESULTS

As a national software package is not yet adopted, numerical simulations were performed in *PHPP'2007* software to evaluate the heat and cooling energy demands and reduction of energy consumption for cooling in summer period by implementation of shading devices. Additionally, monthly heat and cooling demands are calculated and graphically illustrated using monthly method based on EN 13790 (Figures 10, 11, 12). Comparative analysis of energy performances of design variants is carried out and annual final energy demands for heating and cooling per m^2 (Figures 13 and 14), as well as primary energy demands for heating and cooling per m^2 (Figures 15 and 16) are presented for all models.

Analysis of CO_2 emissions is conducted according to the Regulations on Energy Efficiency of Buildings with assumption that district heating is predicted which includes the use of fuel oil (specific emission is 0,265 $kgCO_2/kWh$) for water heating, while for cooling the use of electricity (specific emission is 0,53 $kgCO_2/kWh$ for Serbia) is proposed. Emissions are shown in the Table 4.

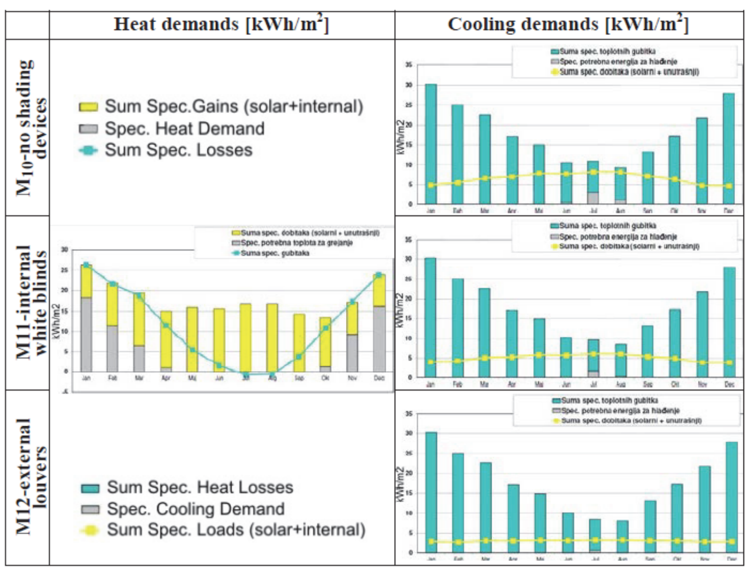


Figure 10. Specific annual heat and useful cooling demands for Model 1 – monthly method

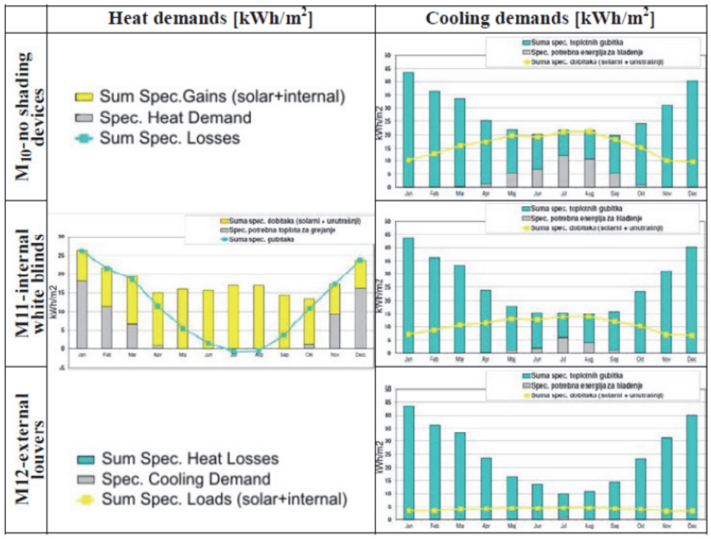


Figure 11. Specific annual heat and useful cooling demands for Model 2 – monthly method

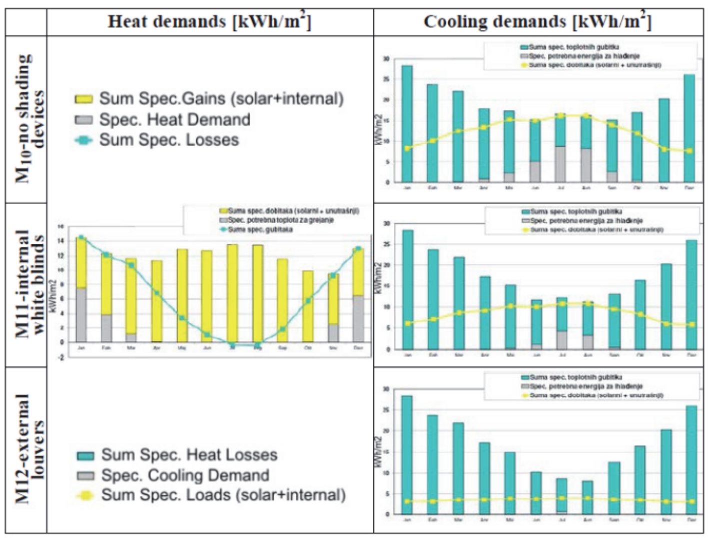


Figure 12. Specific annual heat and useful cooling demands for Model 3 – monthly method

The analysis shows that transmission losses for the M2 (121.5kWh/m^{2}a) are almost twice higher than for of M1 (71.7kWh/m^{2}a), i.e. M3 (63.7kWh/m^{2}a), due to the type of the facades. This is the consequence of the facts that the glass facade of M2, made of thermal insulating panels, has lower thermal performances than glass facade of M3, made of triple low-e glazed panels with gas fills of krypton, and that the glazing area in case of the M1 is less than twice the glazing areas of M2 and M3, resulting in less thermal losses. As can be noted, a glass facade provides more than twice the solar gains (Figures 11 and 12) than a traditional façade (Figures 10).

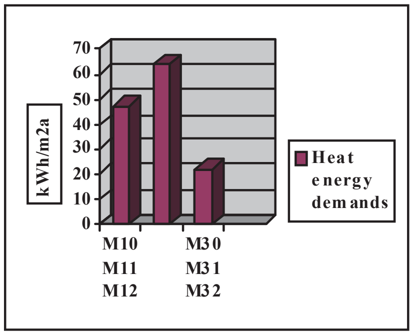


Figure 13. Annual final energy demands for heating [kWh/m^{2}a]

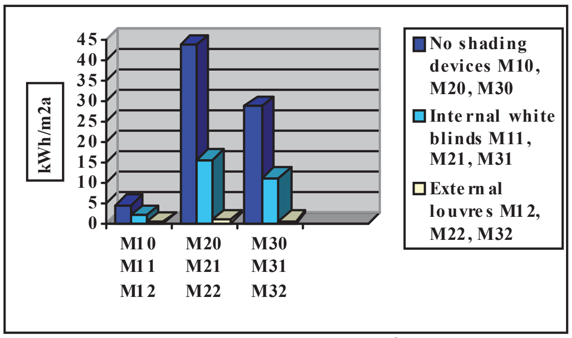


Figure 14. Annual final energy demands for cooling [kWh/m^{2}a]

At the yearly basis, it is evident that design models M1 and M2 (Figure 13) do not exceed the maximum value of annual energy consumption for heating for new office buildings of 55kWh/m^{2}a (according to the Regulations on energy efficiency of buildings).

By using the conversion factor of 1.2 for fuel oil as a heat source for space heating and 2.5 for electricity as a heat source for space cooling, the annual primary energy demands for heating and cooling are calculated.

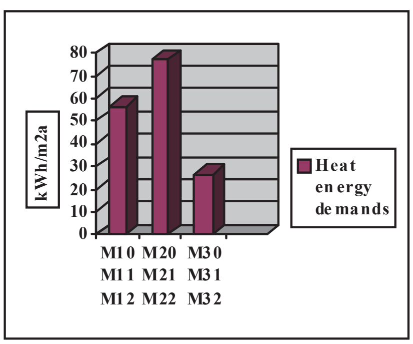


Figure 15. Annual primary energy demands for heating [kWh/m^{2}a]

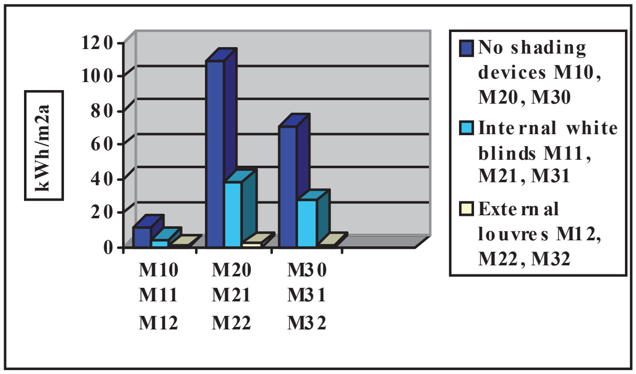


Figure 16. Annual primary energy demands for cooling [kWh/m^{2}a]

It is noticeable that the presence of a higher percentage of internal gains is in the case of the massive facade. Despite significant differences in the facade concepts, primary energy demands for heating are similar for the M1 (56.4kWh/m^{2}a) and M2 (76.8kWh/m^{2}a) as the solar gains are smaller in case of the M1 while transmission losses are higher in the case of the M2. The minimum primary energy for heating is required for M3 (26.4kWh/m^{2}a) due to glazing type and significant solar gains resulting in the lowest CO_2 emissions for heating compared to M1 and M2 (Table 4 and Figure 17).

The lowest frequency of overheating is in the case of traditional facade-6% and consequently the lowest primary energy demands for cooling-12kWh/m^{2}a. In the case of glass facades frequency of overheating (almost 38%) and the primary energy demands for cooling (109kWh/m^{2}a for M2, i.e. 71.5kWh/m^{2}a for M3) are much higher and therefore CO_2 emissions (Table 4 and Figure 18). For all models significant reduction of frequency of overheating is achieved by internal white blinds and thus the reduction of cooling energy demands and CO_2 emissions, but still advantage of the massive facade is evident. By external movable louvers, cooling demands are reduced to the same level (about 1kWh/m^{2}a) for all models.

Table 4. Annual primary energy demands for heating and cooling and CO_2 emissions

Model		Annual primary energy demands for heating (kWh)	CO_2 emissions (kg/year for heating)	Annual primary energy demands for cooling (kWh)	CO_2 emissions (kg/year for cooling)
M1	M10	112,645	29,850.98	23,445	12,425.85
	M11			10,438	5,532.14
	M12			2,995	1,587.35
M2	M20	146,071	38,708.86	207,070	109,747.10
	M21			74,725	39,604.25
	M22			4,605	2,440.65
M3	M30	36,418	9,650.66	111,618	59,157.54
	M31			38,402	20,353.06
	M32			2,568	1,361.04

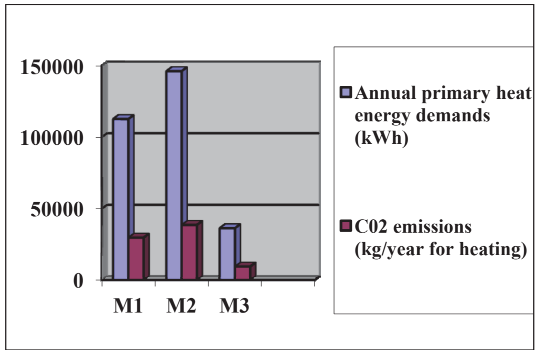


Figure 17. Annual primary energy demands for heating and CO_2 emissions

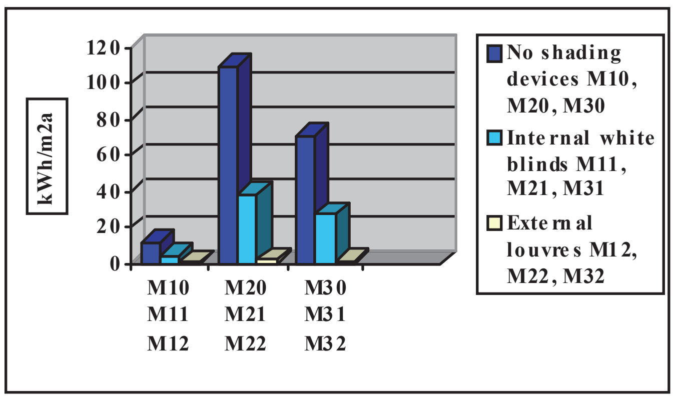


Figure 18. Annual primary energy demands for cooling and CO_2 emissions

Due to the significantly greater conversion factor in case of electric energy than fuel oil, annual primary energy demands for cooling (in case of glass facade with no shading device) are almost doubled in case of M2 and tripled in case of M3 in comparison to the annual primary energy demands for heating (Figures 17 and 18). Consequently significantly higher CO_2 emissions for the cooling than for heating are noticed.

Conclusion

The focus on energy efficiency and a high-quality indoor environment was the primary objective of students' office building design in Belgrade climate. According to analyses presented in the paper following conclusions can be made:

- From the aspect of energy efficiency, office buildings with properly insulated massive (traditional) facades are suitable for Belgrade climatic conditions contributing to low heat and cooling demands and thus CO_2 emissions.
- Glass facades which are most commonly used in office building design have to be with triple low-e glazing (particularly with gas fills of argon or krypton) and external movable shading devices contributing to energy efficiency

(reduction of transmission losses, frequency of overheating, heat and cooling demands and CO_2 emissions). According to the Regulations on terms, content and method of issuing certificates of energy performance of buildings, in relation to specific annual heating energy consumption for office building, model M3 is classified as energy class B and may be considered as the most energy efficient.

- Contribution of heat gains in reduction of the heat demands in the winter period is significant. By night ventilation (night cooling) heat can be dissipated resulting in reduction of cooling demands in the summer period.

Research methodology as well as obtained results, presented in the paper, could generally be applicable for new office building design, both in Belgrade and in similar climatic conditions.

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