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Determination of Glazing Material’s Influence on the Energy Performance of Office Buildings Using Dynamic Simulation Techniques

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Abstract. This investigation presents a detailed analysis in an effort of building energy performance improvement from the aspect of building envelope and glazing influence on the annual heating and cooling energy demand. This work is the continuance of our previous envelope optimization investigation and elaborates the influence of five different glazing types on the annual heating and cooling energy demand of the reference office building in compliance with energy efficiency regulations. Total annual energy demands were determined according to the building envelope’s thermal performance and glazing characteristics. Findings from the dynamic simulations indicated the influence of glazing parameters (U-value, Solar heat gain coefficient) on the annual heating and cooling demand of the multi-zone building model. From the five simulated envelopes it was concluded that with adequate window application the annual heating demand could be reduced by 27% and the annual cooling demand by approximately 40%.

1 Introduction

Our previous investigations cover building envelope optimization in the function of indoor daylight quality in offices in order to determine preferable window to wall ratios and window geometries. This work is the continuance of the envelope optimization investigation and elaborates the influence of five different glazing types on the annual heating and cooling energy demand of the reference office building in compliance with energy efficiency regulations [1-5].

Thermal and lighting simulations from the energy perspective were investigated in previous researches applying energy modeling. Envelope glazing’s transmittance dependence on the solar radiation in order to reduce building energy demand was investigated respectively from wavelength and economic aspects respectively. Daylight analysis has been a widespread topic investigated in numerous papers using daylight coefficient concept, daylighting schemes, window properties, building design and climate conditions [6 - 10]. The research was conducted on a typical not rehabilitated 10 level reference office building which is part of the Faculty of Technical Sciences complex in

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Novi Sad. The adopted best case indoor illumination performance model from the previous research [11-16] was simulated in EnergyPlus with the aim to explore and determine the annual heating and cooling energy demand for five different glazing types. Double and triple pane, low-E coated windows with Argon filling, were simulated on an annual basis with hourly time steps. The improved reference building's heating and cooling energy demand was determined and analyzed for five glazing types, for the previously inherited window to wall ratio and window geometry. The research goal was to conduct the influence of window construction and parameters, such as solar heat gain coefficient (SHGC) and overall heat transfer coefficient (U-value) on the annual heating and cooling demand. The possibility of application could be enabled in the decision making process in early design stages and during building envelope rehabilitation stages of existing office buildings. Throughout the research, the simulated exterior wall's thermal properties and window parameters complied with the Serbian and EU regulations [17-20].

Materials and methodology

The research was conducted on a reference multi-level office building which is part of the Faculty of Technical Sciences complex in Novi Sad, Serbia. The total building area is 3430 m2 consisting of 10 levels. An aerial view with the building is presented in Fig. 1.

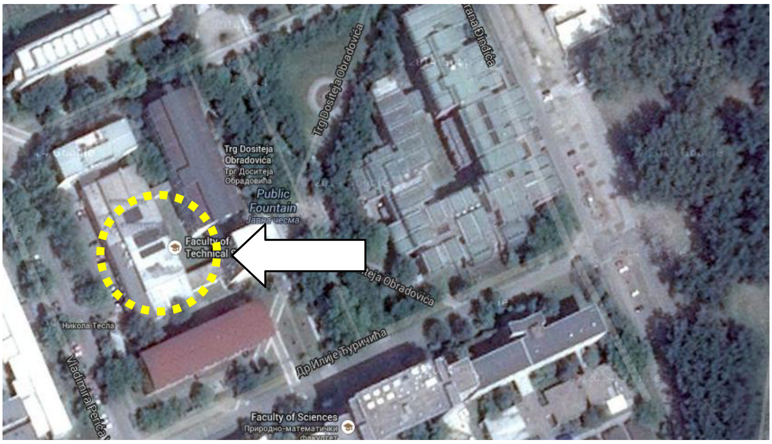

Fig. 1 Multi-level reference office building of the Faculty of Technical Sciences

Energy expenses for district heating and electricity were gathered for the year 2013 in order to compare them with the results from the simulation, as shown in Table 1 and Table 2. The building used in total 338 MWh/a (100 kWh/m^2/a) for district heating on an annual basis, and 204 MWh/a (59 kWh/m^2/a) for electricity; combined cooling, lighting and equipment.

Table 1. Heating energy consumption

Month	Heating [kWh]	Month	Heating [kWh]
Jan	115993	Oct	9551
Feb	63473	Nov	45003
Mar	42323	Dec	61030
Apr	1415	Annual Sum	338788

Table 2. Electricity consumption

Month	Cooling, lighting and equipment electricity [kWh]	Month	Cooling, lighting and equipment electricity [kWh]
Jan	19214	Aug	16652
Feb	17478	Sep	14113
Mar	18519	Oct	17245
Apr	16918	Nov	15282
May	14375	Dec	20230
Jun	16706	Sum [kWha^{-1}]	203810
Jul	17078	[kWhm^{-2}a^{-1}]	59

The location and climate data for Novi Sad city were imported from the global climatological database Meteonorm (~150 000 parameters, 15 min intervals) [23] as shown in Table 3 and Fig. 2.

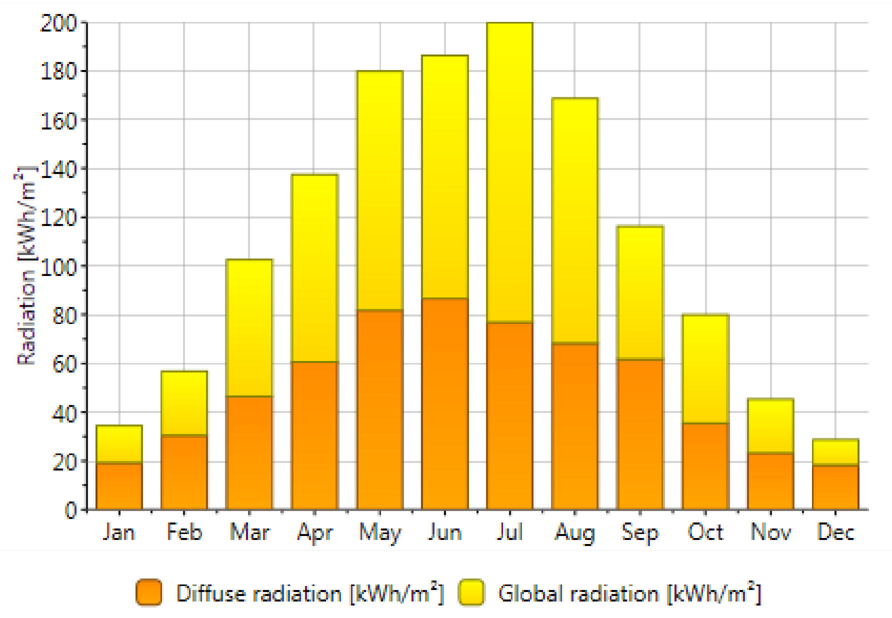

Fig. 2 Solar radiation and air temperature data for the city of Novi Sad

Abbreviations: Ta: Air temperature, G_Gh: Mean irradiance of global radiation horizontal, RH: Relative humidity, G_Dh: Mean irradiance of diffuse radiation horizontal, FF: Wind speed, SD: Sunshine duration, PAR: Photosynthetically active radiation

Table 3. Climate data – monthly average values for Novi Sad.

Month	Ta	G_Gh	RH	G_Dh	FF	SD	PAR
Jan	0.4	46.3	81.9	26	2.6	70	20.1
Feb	2.3	84.5	76.8	41.1	2.8	89	36.2
Mar	7.3	137.7	65	60.5	3.1	145	58.7
Apr	12.7	191	62.7	93.5	2.9	180	82.3
May	18	241.8	63.3	105.5	2.4	230	104.7
Jun	20.8	258.8	65.9	118.4	2.1	251	112.9
Jul	22.4	268.5	64.2	100.2	2.1	289	117
Aug	22.2	226.8	63.3	98.3	1.9	269	99.6
Sep	16.9	161.5	68.6	77.1	2	207	71.5
Oct	12.6	107.5	73.6	58.8	2.3	170	47.9
Nov	7.1	63	78.7	35	2.6	87	28.2
Dec	1.7	38.7	83.8	23.2	2.6	60	17.3
Year	12	152.2	70.7	69.9	2.5	2047	66.4

In order to determine annual heating and cooling loads a multi-zone thermal model was constructed using OpenStudio plug-in for Sketchup. Each thermal zone was assigned with internal load properties typical for a large office building. The thermal zones were formed and named according to their function and position in the building. According to the investigation phases and complexity of the model and simulation processes, three programs were applied in this research, which are the following:

- Google Sketchup (Multi-zone thermal model construction) [34];
- OpenStudio (multi-zone model properties; construction, materials, occupancy, internal loads and schedules) [35] and,
- EnergyPlus (dynamic energy simulation) [36].

The overall energy performance of five multi-level office building models (tot. area per model 3430m^2) was simulated in EnergyPlus engine. Factors influencing the energy demand were modeled together with the various glazing types. Energy demands were determined according to the energy efficiency regulations of the building construction's thermal performance.

Inherited envelope properties from previous Radiance illumination research

The daylight quality was evaluated according to three criteria; spatial illumination dispersion, average daylight factor during occupied hours, and photo-electric lighting simulation for electricity reduction. The daylight intensity analysis and daylight dispersion required numerous simulations which depended on the analyzed period, time, sky conditions and zone orientation. 720 simulations were performed in Radiance (3 WWR x 3 WG x 4 orientations x 6 months x 3 intervals = 648 and 72 simulations for the reference model consisting of 4 orientations x 6 months x 3 intervals).

All output images were evaluated according to the illumination intensity between 350 and 500 lx. The calculation of average daylight factor (DF) was performed in zone centre points as BRE DF calculation for WWR of 20%, 25%, 30%, and base case 50%. Results closest to 2.0 DF were adopted since it satisfies the minimal illumination quality in an office environment. DF simulations were applied for previously selected vertical rectangular window geometry and the total number of conducted calculations was 16 (4 orientations x 4 WWR's) [31].

From the comparative analysis the vertical rectangular window geometry presented the most preferable results due to window height which contributed to deeper daylight dispersion in the indoor environment resulting in qualitative natural illumination in offices [31]. Illumination intensity detectors were setup and adjusted that if lighting level in the center zone point falls below 350 lx the sensors automatically turn on electric lights or switch to dimming mode. Findings indicated the best performance if dimming mode is applied. In conclusion, considering the average daylight factor (DF) and annual percentage of unnecessary usage of electric lighting the adopted models of WWR for vertical WG are presented in Table 4 [31].

Table 4. Daylight factor [-], adopted WWR [%] and photoelectric dimming

East Offices	Percentage working year lighting OFF (%)	
DF 1.97	69	WWR **30%** / 30° rotated floor plan
South Offices	Percentage working year lighting OFF (%)	
DF 2.05	70	WWR **25%** / 30° rotated floor plan
West Offices	Percentage working year lighting OFF (%)	
DF 1.78	66	WWR **30%** / 30° rotated floor plan
North Corridor	Percentage working year lighting OFF (%)	
DF 1.89	67	WWR **25%** / 30° rotated floor plan

Energy simulation - construction, occupancy and operation schedules

The building envelope applied in the simulation was selected according to the thermal insulation requirements of the Serbian Directive - Official Gazette RS no. 61/2011 and EU Standard [37-39]. The overall heat transfer coefficient of existing exterior walls have 2.32 W/(m2K) and existing exterior glazing has 2.78 W/(m2K). The U-value of the modified exterior wall is significantly reduced to 0.22 W/(m2K) by adding 14cm of expanded polystyrene. Further, internal gains from occupants were assigned in OpenStudio in the "people definition" dialog. The number of occupants and internal gains were implemented in the energy simulation setup by the following steps:

- Expectable number of occupants was calculated;
- Occupied office areas were calculated;
- Unoccupied areas were calculated.

The expectable number of occupants on building levels is shown in Table. 5.

Table 5. Occupant number and approximated office areas

No. of occupants	Building level	Office area approx. [m^2]	
(18 x 6) 108 pers.	4th – 9th level	(196 x 6) 1176	Office area: 1897 m^2 Other: 1533 m^2 (Entrance, hall, corridor, staircase, elevators, WC, sub-station spaces, installation spaces, archive)
8 pers.	3rd level	196	
12 pers.	2nd level	196	
16 pers.	1st level	196	
10 pers.	Ground level	133	
Rarely occupied	Basement	0	
Total 154 (adopted 160 pers.)	Total no. 11 levels	Total area: 3430 m^2	

Occupancy is defined according to the occupancy intensity in the function of occupied period, and people activity in the function of the occupied period.

The “Run Period Profiles” were formulated as a Priority 1 profile for weekdays (8 hours) followed by Priority 2 for Saturday (4 hours) and Priority 3 (0 hours) for Sunday. Electric lighting, electric equipment and thermostat schedules for heating and cooling were also assigned according to the occupancy intensity and building operation hours.

Applied glazing types and parameters

Glazing types were applied according to window properties (parameters: U-value, Solar Heat Gain Coefficient, Visible Transmittance) as shown in Table 6.

Various double and triple pane window constructions were applied in the simulations. U-values were in the range from 1.5 W/(m^{2}K) to 0.7 W/(m^{2}K) high performance tri-pane Pilkington windows with low-E [40].

The Guardian Clima Guard window construction was simulated respectively, which is mainly applied in cold climate conditions [41].

Table 6. Window properties

Model	Windows	Parameters
W1	Dual pane; Pilkington, Optifloat clear	U-value 1.30 W/(m^{2}K); SHGC 0.50; Visible transmittance 0.73
W2	Tri-pane; Pilkington, One pane with Sun-Stop coating & Ag	U-value 1.05 W/(m^{2}K); SHGC 0.34; Visible transmittance 0.63
W3	Tri-pane; Pilkington, Planar + Optifloat + Optitherm glass	U-value 0.70 W/(m^{2}K); SHGC 0.26; Visible transmittance 0.52
W4	Tri-pane; Pilkington, Planar + Optifloat + K Glass	U-value 0.90 W/(m^{2}K); SHGC 0.34; Visible transmittance 0.57
W5	Dual pane; Guardian Clima-Guard 80/70	U-value 1.53 W/(m^{2}K); SHGC 0.69; Visible transmittance 0.81

From the dynamic energy simulation the heating and cooling demands were assessed and the influence of window parameters was determined.

Results and evaluation – heating and cooling demands

Prior to heating and cooling demand determination the building envelope glazing was improved according to the aforementioned multi-criteria analysis in the previous research. The annual heating and cooling energy demands of the five models are shown in Table 7, Fig. 3 and Fig. 4.

Model W2 presented the highest heating energy demand, in total 39 MWh/a. The lowest heating energy demand was determined in case of W3 model.

The heating energy demand reduction of model W3 was 27% lower compared to model W1 and W2, 24% lower compared to W4, and 19% lower compared to W5.

Table 7. Simulated monthly heating and cooling energy demands

Mon.	Heating Energy W1 [kWh]	Cooling Energy W1 [kWh]	Heating Energy W2 [kWh]	Cooling Energy W2 [kWh]	Heating Energy W3 [kWh]	Cooling Energy W3 [kWh]	Heating Energy W4 [kWh]	Cooling Energy W4 [kWh]	Heating Energy W5 [kWh]	Cooling Energy W5 [kWh]
Jan	14349	0	14387	0	10445	0	13737	0	13477	0
Feb	9052	0	9264	0	6924	0	8816	0	8143	1
Mar	984	146	1434	37	834	55	1218	59	384	922
Apr	0	6073	0	4553	0	4881	0	4914	0	9970
May	0	18661	0	16083	0	14197	0	16440	0	24580
Jun	0	26459	0	23719	0	20685	0	24002	0	32703
Jul	0	32210	0	29105	0	24960	0	29355	0	39079
Aug	0	29602	0	26644	0	22917	0	26891	0	35761
Sept	0	15045	0	13371	0	12369	0	13662	0	18927
Oct	2	4782	5	3918	1	4127	3	4158	0	6938
Nov	1190	0	1396	0	631	0	1170	0	715	30
Dec	12468	0	12478	0	8939	0	11873	0	11618	0
Sum	38045	132978	38963	117430	27773	104191	36819	119481	34337	168912
Max	14349	32210	14387	29105	10445	24960	13737	29355	13477	39079

The cooling demand in all models presented significantly higher values compared to heating due to specifically high internal gains and highly insulated building envelope. Model W5 presented the highest cooling energy demand, in total 169 MWh/a. The lowest cooling energy demand, 104 MWh/a, was determined in case of W3 model. The cooling energy demand reduction of model W3 was 21% lower compared to model W1, 11% lower compared to model W2, 12% lower compared to W4, and 38% lower compared to W5. The highest SHGC value 0.69 in W5 model contributed to high cooling demands of the building. The cooling demand was highly influenced by the SHGC value since the cooling demand was approximately 40% higher compared to W3 model with 0.26 SHGC.

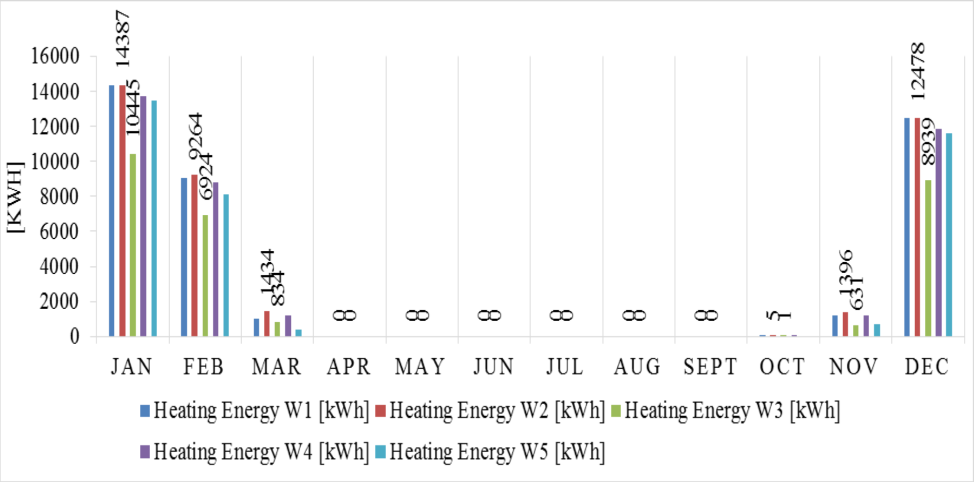

Fig. 3 Annual heating energy demand (W1-W3)

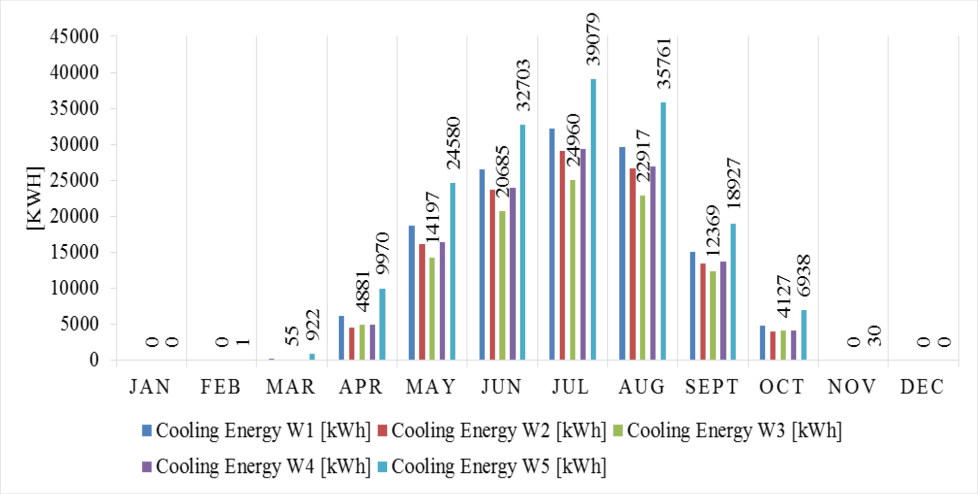

Fig. 4 Annual cooling energy demand (W1-W3)

The W3 model was adopted as the most preferable among the simulated and was compared with the reference office building's energy performance as presented in Table 8, below. The total energy demand of the Best Case Model (W3) could be reduced roughly by 80% in case of annual heating. Simulated cooling energy demand was 40% higher compared to annual heating due to internal heat gains of occupants and electric equipment, which are specific for office environments.

The calculation of annual heating and cooling demand for the Best Case Model was performed according to the EN 15251 Annex B; Basis for the criteria for indoor air quality and ventilation rates; B.1 Recommended design ventilation rates in non-residential buildings [39], as seen in Table 8.

Table 8. Energy performance comparison

Reference FTS office tower energy expenses (2013)			Best Case Model energy demand – W3		
	Heating energy [kWh]	Cooling, lighting and equipment electricity [kWh]	Heating energy [kWh]	Cooling energy [kWh]	Energy demand for lighting and equipment [kWh]
Sum	338788	203810	27773	104191	
			EN 15251; air ventilation amount + 37325 (for heating) +7330 (for cooling)		106330
[kWh/m^2/a]	100	59	19	32	31

According to the climatic conditions of Novi Sad and EN 15251, 37 MWh/a, was added to the simulated heating energy and 7 MWh/a, for the cooling energy, because an ideal air load system was simulated in EnergyPlus, without taking into account the air preparation procedure.

Conclusion

The investigation presented the significance on the reduction of annual energy performance of building envelope's thermal properties and the application of adequate windows in the function of climate conditions and building type and compliance to energy efficiency regulations.

The improved reference building's heating and cooling energy demand was analyzed in case of five glazing types with various parameters, using the previously inherited window to wall ratio and window geometry. From the dynamic energy simulations the annual heating and cooling demands were determined and the influence of window parameters was assessed. During the simulation the main criteria was the maintenance of indoor occupant comfort according to EN 15251 in compliance with the building envelope's thermal properties according to the Serbian Regulations RS no. 61/2011. From the five simulated envelopes it was concluded that with adequate window application the annual heating demand could be reduced by 27% and the annual cooling demand by approximately 40%. If compared to the reference building's energy expenses the annual heating demand could be reduced drastically by 80%.

Further directions of investigation will cover the thermal comfort parameters in the function of minimizing annual heating and cooling loads. In order to find a reasonable solution for cooling energy demand reduction, further research will include the simulation of night time ventilation to determine the cool air accumulation capacity of the building. The simulation and analysis of solar shading systems will cover further directions of investigation respectively.

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