BUILDING ENVELOPE INFLUENCE ON THE ANNUAL ENERGY PERFORMANCE IN OFFICE BUILDINGS

by

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The objective of the research is to determine the quantitative influence of building envelope on the annual heating and cooling energy demand in office buildings demonstrated on a reference office-tower building located in city of Novi Sad, Serbia. The investigation intended to find preferable and applicable solutions for energy performance improvement in currently inefficient office buildings. A comparative and evaluative analysis was performed among the heating energy expenses and simulated values from the multi-zone model designed in EnergyPlus engine. The research determines an improved window to wall ratio using dynamic daylight simulation and presents the influence of glazing parameters (U-value, solar heat gain coefficient) on the annual energy performance. Findings presented window to wall ratio reduction down to 30% and point out the significance of the solar heat gain coefficient parameter on the overall energy performance of buildings with high internal loads. The calculation of the air-ventilation energy demand according to EN 15251 is included, respectively. Results offer effective methods for energy performance improvement in temperate climate conditions.

Key words: *energy performance, building envelope, daylight simulation, EnergyPlus*

Introduction

The World's energy demand is increasing progressively with the request to fulfil growing energy needs. Enormous energy consumption is even more serious due to lack of natural resources and expressive ecological instability. The built environment evidently has the highest energy demand in the world, which is a contemporary problem of consideration. Therefore, the goal is finding an alternative solution in order to reduce the energy demand and losses. Building energy efficiency and performance topics were elaborated via investigations of existing office buildings and computational models respectively [1]. The current energy consumption in the building sector is approximated to 40% of the total energy consumption in the world. Therefore, the primary parameters that mostly affect the commercial buildings energy performance are heating and cooling requirements during the working hours [2].

The Republic of Serbia is characterized by enormous inefficient energy consumption in the building sector. The major problem is the unadjusted building sector to energy efficient

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requirements and the high percentage of energy derivation from non-renewable sources. Problems considering energy efficiency in Serbia are elaborated systematically in order to analyze and explore the most suitable energy policy instruments for improvement. Gvozdenac *et al.* [3] elaborated the energy policy situation in Serbia and in the European Union [4, 5], where authors determined that Serbia lags behind in the process of improving energy efficiency due to inadequate and slow institutional organization and application of state instruments in order to implement strategies. Authors, also refer to markets as complex systems of supply and demand referring to changeable interactions which should be directed towards efficiency, environmental benefits and social wellbeing.

Numerous researches investigated buildings energy performance in the non-residential sector [6-8]. The impact of building design on comfort and energy performance of offices was simulated and evaluated for different climates [9]. The paper presents a parametric study for a typical cellular office room with two different occupant scenarios in three different location and climate: moderate, hot, and humid climate. Thermal performance simulations can be conducted with various dynamic simulation engines, for example, in [10] TRNSYS simulation tool was applied for heating energy demand calculations for residential buildings in Belgrade.

Thermal mass impact on the energy demand has also been analyzed in the function of occupant comfort to investigate the reduction of the energy requirements from mechanical systems [11]. Studies have been conducted for energy performance assessment in the early design stages since energy simulation was not integrated into the decision-making process [12]. Furthermore, methodologies for comparison of measurements and simulations were also elaborated in order to assess the energy performance [13]. Building envelope construction and window to wall ratio was considered previously in researches with various approaches, in the function of overall envelope U-value and ambient temperature amplitude [14] with the result of maximum glazing ratio determination for seven USA cities with different climatic conditions. The configuration of facade modules was also considered as integral part of envelope and total energy performance improvement [15] from the aspect of lighting and thermal simulation. This research was performed for horizontal rectangular windows for various window to wall ratios (*WWR*) from which it was concluded that the best results were in the range of $35\% < WWR < 45\%$. The admission of numerous aspects interpretation plays a key role in energy performance assessment. A detailed energy simulation requires all phases of the project to be designed carefully and precisely, so the integrated parameters create an environment approximated to real conditions.

The investigation intended to find preferable answers for energy performance improvement of current inefficient office buildings in Serbia. The aim is to determine the heating and cooling energy demand in the function of building envelope properties (window to wall ratio, glazing type, GT, and exterior wall) in order to offer effective methods for energy performance improvement. The primary goal of the investigation was to monitor and analyse the heating and cooling energy performance of a 3430 m^2 B + Gf + 9 level reference office building on the territory of Novi Sad, Serbia. The secondary goal was to find possible interventions for energy performance improvement by increasing the quality of the building envelope and reduce the *WWR*.

Methodology and materials

Research methodology

Research methodology consists primarily of the analysis of the collected location and climate data from Meteonorm 7 [16], reference building technical data and annual heating

energy consumption [17]. The annual heating and cooling demand are explored through the next eight steps:
(1) parametric modelling of the reference building via building information modeling (BIM) technology,
(2) development of a simulation base multi-zone 3-D model with assigned internal loads,
(3) designing the building envelope with improved *WWR* in the function of lighting dispersion analysis in radiance,
(4) exporting the multi-zone 3-D model to open studio in order to implement an energy efficient envelope, assign material properties, thermal zone properties, and typical interior loads for offices,
(5) implementing various glazing types (GT) with different properties (U-value and solar heat gain coefficient, *SHGC*)
(6) model conversion to numerical data,
(7) performing multiple simulations in EnergyPlus on annual basis using the Meteonorm 7 climate data (Novi Sad climate data) and calculating zone heating and cooling demands, and
(8) evaluating the annual energy performance and determining the influence of glazing parameters.

Location and climate data

The location and climate data were imported from the global climatology database Meteonorm 7 [16], since the climate data needs to be converted into EnergyPlus weather extension file, importable into EnergyPlus for dynamic energy simulation. The location of the building is Novi Sad, latitude = 45.333°, longitude = 19.850°, altitude = 84 m, and climatic zone = III, 3. The imported data are: radiation model = default (hour), temperature model = default (hour), tilt radiation model (Perez) = default (hour), radiation: new period = 1986-2005, temperature: new period = 2000-2009. The monthly average values are shown in tab. 1. The annual Sun path and building location are shown in fig. 1.

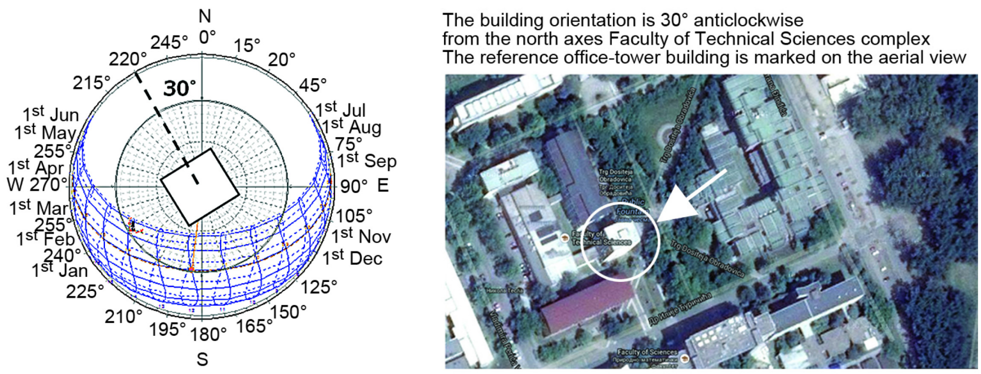


Figure 1. Annual Sun path and building location

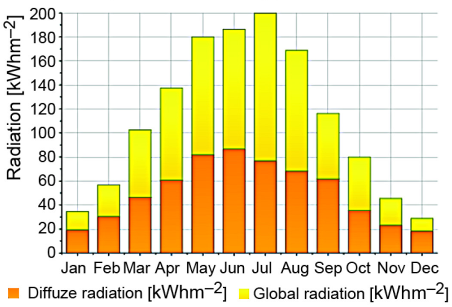
Energy expenses

The reference office-tower building is equipped with district heating system which receives hot water from the *Novosadska toplana,* power plant in Novi Sad. Heat in the winter period is released through radiators beneath the windows in all offices. However, the cooling procedure is manually operated since each office has a separate electric air-conditioning unit.

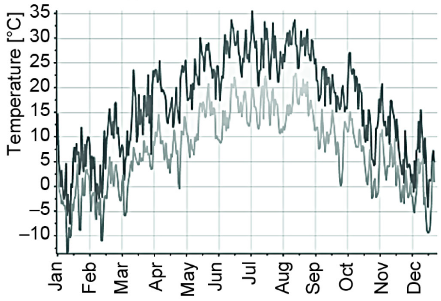
Table 1. Climate data – monthly average values for Novi Sad

Month	T_a	$G–G_h$	*RH*	$G–D_h$	*FF*	*SD*	*N*	B_n	G_{hmax}	$G–G_{ex}$	*PAR*	*Snd*
Jan.	0.4	46.3	81.9	26	2.6	70	6	65.3	94	139	20.1	5.2
Feb.	2.3	84.5	76.8	41.1	2.8	89	5	110	139	202	36.2	0.8
Mar.	7.3	137.7	65	60.5	3.1	145	5	149.8	214	292	58.7	2.7
Apr.	12.7	191	62.7	93.5	2.9	180	5	171.4	288	384	82.3	0
May	18	241.8	63.3	105.5	2.4	230	4	214	341	453	104.7	0
Jun.	20.8	258.8	65.9	118.4	2.1	251	4	216.4	358	482	112.9	0
Jul.	22.4	268.5	64.2	100.2	2.1	289	4	259	349	467	117	0
Aug.	22.2	226.8	63.3	98.3	1.9	269	4	208.7	302	411	99.6	0
Sep.	16.9	161.5	68.6	77.1	2	207	5	155	242	328	71.5	0
Oct.	12.6	107.5	73.6	58.8	2.3	170	5	111.9	166	235	47.9	0
Nov.	7.1	63	78.7	35	2.6	87	5	86.5	107	158	28.2	0.4
Dec.	1.7	38.7	83.8	23.2	2.6	60	7	50.5	79	122	17.3	15.2
Year	12	152.2	70.7	69.9	2.5	2047	5	150.1	223	306	66.4	2

Monthly radiation energy for Novi Sad



Daily air temperature oscillation for Novi Sad



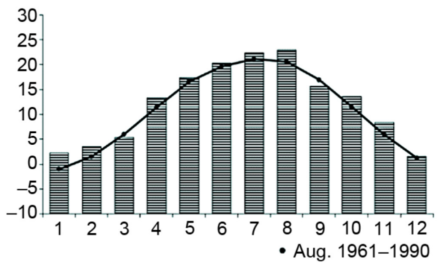
Monthly heating energy expenses of the reference office-tower were collected from 2013, together with monthly air temperature values from the Republic Hydrometeorology Service of Serbia, database for Novi Sad (Location in Serbia, Rimski sancevi) [18].

Table 2 shows the monthly heating energy values for the year 2013. The annual heating energy consumption per m^2 of floor area was 99 kWh/m^{2}a, which is relatively high for an office building. The highest heating demand was recorded in January, 34 kWh/m^2 per month, when the average outdoor temperature was 2.5 °C, yet during March only 12 kWh/m^2 per month while the average outdoor temperature was 5 °C. Unfortunately, precise comparison of the energy expenses and the simulated values could not be compared precisely due to: unknown building operation, manual heating system operation, and manually controlled natural ventilation.

Considering the monthly electricity expenses, tab. 3, for cooling, lighting and equipment energy consumption cannot be determined since monthly expenses are issued in total. Therefore, the precise separate consumption of consumers is unknown. Another problem occurs considering the determination of relational values among these three loads, since the following data are unknown: precise occupancy schedules and intensity, cooling system operation (operated manually), cooling intensity (operated manually), lighting schedules and intensity (operated manually), and electric equipment (operated manually).

Table 2. Monthly heating energy consumption and outdoor air temperatures for 2013

Month	Heating, [kWh]	Month	Heating, [kWh]
Jan.	115993	Oct.	9551
Feb.	63473	Nov.	45003
Mar.	42323	Dec.	61030
Apr.	1415	Annual sum	338788
District heating was turned off over the period from the 15th April 2013 until the 15th of October 2013.			
Monthly average air temperatures for 2013 [°C]		Absolute maximum air temperatures for 2013 [°C]	



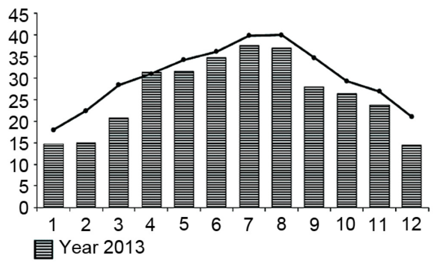


Table 3. Monthly electricity consumption for 2013

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**

Modelling and simulation

The BIM programs and simulation engines

According to the investigation phases and complexity of the model and simulation processes, five programs were applied for this study as presented in fig. 2.

Modelling methodology

The research presents a parametric study of an office building, B + Gf + 9 level located in Novi Sad, Serbia. A multi-zone thermal model was constructed in order to determine the heating and cooling loads. 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. Zone-temperature set points were included and ideal air loads were assigned for the multi-zone building model. The HVAC system was not simulated in this investigation, while the aim was to determine the amount of heating and cooling energy requirements for preferable microclimatic conditions. The energy performance improvement is explored through the following steps, fig. 3.

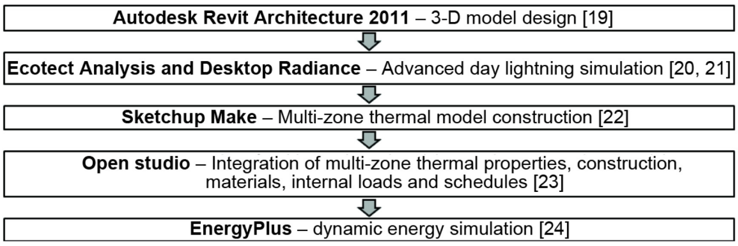


Figure 2. Modelling process – flow chart

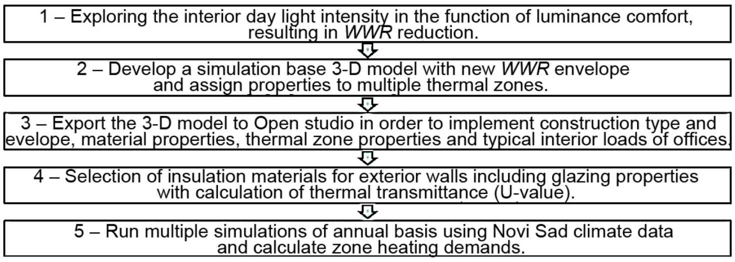


Figure 3. Energy performance improvement methodology

Monitored and simulated results are analysed and compared in terms of annual energy demands. Since the building was constructed in the 1960's of the last century no data was available for the mechanical system. The inefficiency of the system is demonstrated through the recorded data from the sub-station. Therefore, the annual heating and cooling energy requirements are calculated for an ideal air load environment with improved building envelope. The monitored and simulated results are compared in terms of energy specific intensity [kWh] and [kWhm^{-2}].

Daylight simulation and WWR

In the 1st phase of the daylight simulation a single 3-D building level was modelled in Autodesk revit architecture, as shown in fig. 4. Three models were created with *WWR* values of 50%, 30%, and 20%. Table 4 shows the adopted window surface, dimensions, and *WWR*.

Table 4. Single office *WWR*, glazing surface and geometry

WWR, [%]	Glazing surface, [m^2]	Single window surface, [m^2]	Dimensions, [m]
20	1.79	0.89	Square 0.94 × 0.94
30	2.68	1.34	Square 1.16 × 1.16
50	4.48	2.24	1.4 × 1.6

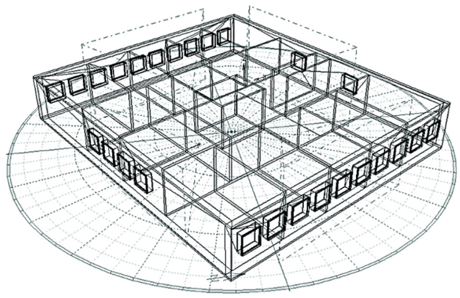


Figure 4. Single building level

In the 2nd phase the 3-D Revit building model was converted into geometry analysis data with .dxl extension and it was imported into Ecotect Analysis. Data of location, orientation, and climate were imported and building material properties were assigned to the 3-D geometry analysis model. The lighting intensity assessment was conducted via the advanced simulation method for detailed analysis. Model properties and lighting environment were set-up in radiance control panel (CP). Numerous simulations were run according to the orientation, sky condition, date, and time. The simulation was performed for the mean period of three months: January, March, and September due to three main sky condition scenarios in radiance CP. Sky conditions required parameters for cloudy sky (January), intermediate sky (March), and sunny sky (September). The simulation was conducted within intervals of 4 hours for weekdays to determine the daylight intensity in offices at 8.00, 12.00, and 16.00 hours. The *WWR* analysis was performed in accordance with visual comfort/lighting intensity boundaries in office buildings.

Visual comfort is satisfied if the lighting intensity holds a constant value between 350 and 500 lx throughout the occupied working schedule, which in this study is set from 8.00 to 16.00 hours. The lighting quality is demonstrated through daylight intensity analysis, where the illumination scale was set from 0-1000 lx. Only selected south camera views and illumination intensity dispersion outputs are presented in tab. 5.

Window frames were disregarded in this simulation. All simulation outputs as camera views of office interior daylight were comparatively analysed and the 30% *WWR* had shown the best dispersion performance. In correlation with its luminance performance, the demand for heating and cooling energy compared with the base case presents an effective solution. The base case 50% *WWR* had in most orientations higher interior lighting intensity than the upper limit of 500 lx which is inadequate for a working environment. Finally, the 20% *WWR* presented a lighting intensity lower than the demanded 350 lx in most of the simulated orientations.

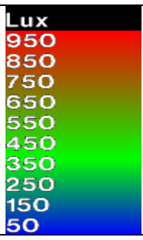
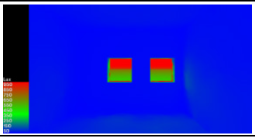
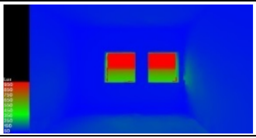
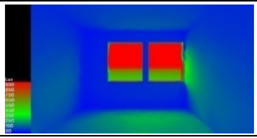
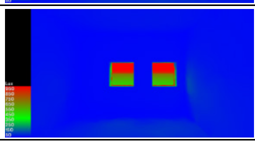
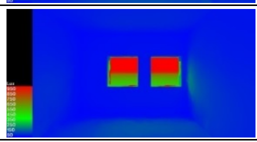
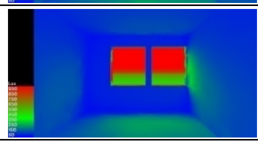
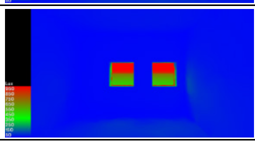
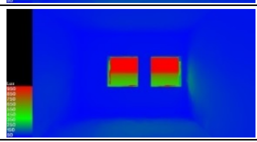
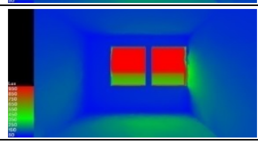
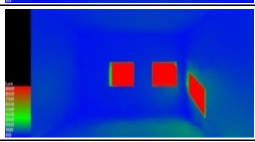
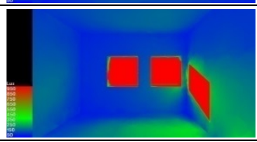
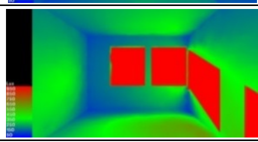
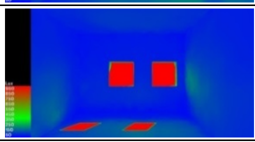
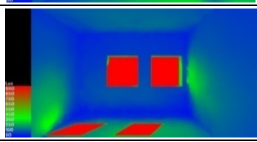
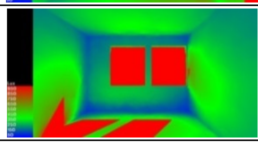
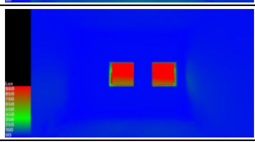
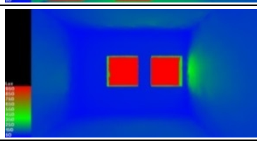
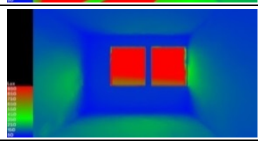
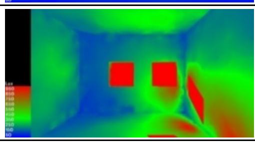
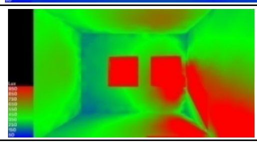
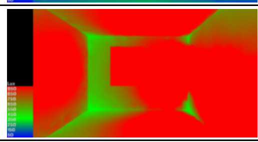
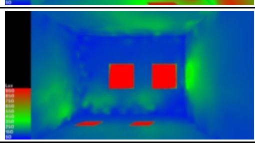
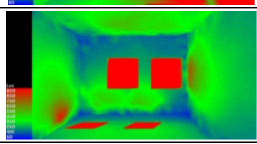
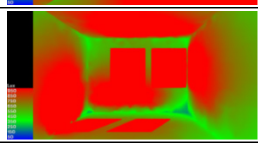
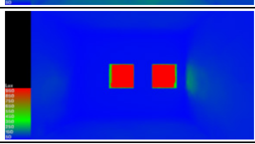
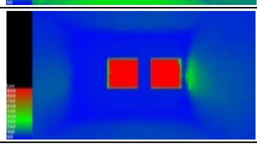
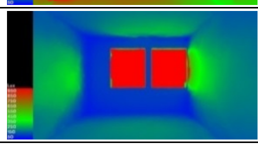
Building construction properties and internal energy loads

Building envelope improvement and optional window application

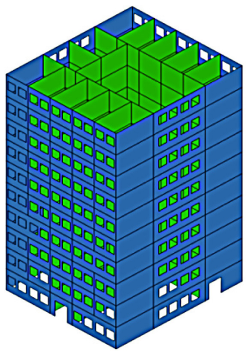
The building envelope construction was improved in order to reduce the heat transfer coefficient, U-value. The U-value of the existing office building's exterior walls is 2.32 W/m^{2}K, since the walls are constructed from 25 cm clay brick, without insulation layer. Furthermore, it was recorded that the existing total 37.5% glazing also has a high U-value, 5.89 W/m^{2}K. The modified exterior wall construction compared to the existing is presented in tab. 6. Table 7 shows the existing glazing properties and three new window types which were applied in simulation [25].

For the existing building envelope, the *WWR* is 37.5%. The simulations were performed for the modified building envelope where offices have 30% transparent surface; exceptions are corner offices with two orientations where the 30% glazing was applied for only one orientation; south and north oriented exterior walls were left without glazing, fig. 5. The total *WWR* for the building is 15.43%, as shown in fig. 5.

Table 5. Daylight and *WWR* – luminance intensity and 3-D dispersion for south orientation

Simulation properties Illumination intensity		**Illumination intensity scale from 0 to 1000 lx** Adopted scenarios presented the highest indoor daylight quality for office environment 350-500 [lx]	
Date/time	*WWR* [20%]	*WWR* [30%]	*WWR* [50%] (base case)
January 15th 8.00 h Cloudy sky condition			
January 15th 12.00 h Cloudy sky condition			
January 15th 16.00 h Cloudy sky condition			
March 15th 8.00 h Intermediate sky condition			
March 15th 12.00 h Intermediate sky condition			
March 15th 16.00 h Intermediate sky condition			
September 15th 8.00 h Sunny sky condition			
September 15th 12.00 h Sunny sky condition			
September 15th 16.00 h Sunny sky condition			

3-D building model



Building envelope properties

Gross envelope area	2336.4 m^2
Glazing area	360.6 m^2
Office *WWR*	30%
Corner office *WWR*	5.98%
Total *WWR*	15.43%

Figure 5. Modified building envelope with 15.43% *WWR*

Table 6. Exterior wall construction with material properties

Existing		Modified (optional)	
Exterior wall	Material properties	Modified exterior wall	Material properties
10 mm cement mortar	U = 1.73 W/m^{2}K	10 mm cement mortar	U = 0.93 W/m^{2}K
		120 mm fired clay brick	d = 0,1016 m, c = 0,89 W/mK, ρ = 1920 kg/m^3, Q = 790 J/kgK
250 mm fired clay brick	d = 0,1016 m c = 0,89 W/mK ρ = 1920 kg/m^3 Q = 790 J/kgK	100 mm insulation	d = 0,1016 m, c = 0,03 W/mK ρ = 24 kg/m^3, Q = 1210 J/kgK
		250 mm fired clay brick	d = 0,1016 m, c = 0,89 W/mK ρ = 1920 kg/m^3, Q = 790 J/kgK
5 mm cement mortar	U = 1.73 W/m^{2}K	5 mm cement mortar	U = 0.93 W/m^{2}K
U = 2.32 W/m^{2}K (with film) U = 3.56 W/m^{2}K (no film)		U = 0.28 W/m^{2}K (with film) U = 0.29 W/m^{2}K (no film)	

Table 7. Windows with material properties

Existing		Modified (optional)	
Windows	Material properties	Modified windows	Material properties
4 mm Single panel	U-value 5.89 W/m^{2}K *SHGC* 0.860 Visible transmittance 0.890	TYPE 1 Dual panes of glass Two panes with low E coating and Argon gas	U-value 1.187 W/m^{2}K *SHGC* 0.62 Visible transmittance 0.77
		TYPE 2 Dual panes of glass One pane with Sun-stop coating, one pane with low-E coating, Argon gas	U-value 1.136 W/m^{2}K *SHGC* 0.36 Visible transmittance 0.69
		TYPE 3 Tri-pane glass Two panes with low E coating and Argon gas	U-value 0.755 W/m^{2}K *SHGC* 0.56 Visible transmittance 0.70

Internal energy loads

Internal energy loads are heat gains from various sources in the building, such as occupants, electric lighting, and electric equipment. Occupant loads were assigned according to the human metabolic rate which is defined by the activity. In office buildings occupant activity is majorly sedentary where the metabolic rate is equal to 1.2 met (69.87 W/m^2), thus, a normal person will have the heat loss of approximately 120 W. The number of occupants and internal gains were implemented in the energy simulation set-up by the next steps: expected number of occupants – possibility analysis, occupied office areas, and unoccupied areas were calculated.

The expected number of occupants on building levels is shown in tab. 8. From the 4th-9th level the space floor area per person equals 10.8 m^2 per person. On the 3rd level equals 24.5 m^2 per person, and on the 2nd level is 16.33 m^2 per person. Finally, on the ground level if approximated to total office area on a single level, as done previously, the space floor per person is 13.3 m^2 per person.

Table 8. Occupants and areas

Number of occupants	Building level	Office area approximately, [m^2]
(18 × 6) 108 persons	4th-9th level	(196 × 6) 1176
8 persons	3rd level	196
12 persons	2nd level	196
16 persons	1st level	196
10 persons	Ground level	133
Rarely occupied	Basement	0
Total no. 154 persons	Total no. 11 levels	Total area: 3430 m^2, office area: 1897 m^2, other: 1533 m^2

Internal loads for lights and equipment have to be implemented in the simulation according to the schedules and operation intensity. Internal heat gains for an hourly run-time energy simulation are estimated on the annual basis. The weather data will significantly affect the internal gains in the indoor environment due to building envelope's thermal performance, infiltration, and ventilation.

Electric equipment definition was imported in Open studio from the building component library (BLC) as *ASHRAE_ 189.1-2009 Climate Zone 1-3 Large Office Whole Building Electric Equipment Definition* [26, 27].

The specified electric equipment energy requirements were imported as a default value from the BLC library, 5.812514 W/m^2.

Light definitions were imported identically from the BLC library in Open studio as *ASHRAE_189.1-2009 Climate Zone 1-3 Large Office Whole Building Lights Definition* [26, 27]. The energy demand of electric lights was 9.687519 W/m^2.

Energy performance comparison of scenarios and air-ventilation energy demand according to EN 15251

Energy performance comparison and evaluation without air preparation energy demand

Simulations were performed over a period of one year, *i. e.* 8760 hours, with hourly time steps. The obtained results for the heating energy loads were compared with the heating energy amount from the energy expenses, collected for the previous year. The simulated results present a drastic reduction of energy requirements for annual heating energy. The annual heating and cooling loads are presented and compared between three modified GT with identical 15.43% *WWR*, and the existing glazing, as shown previously in tab. 7. Findings indicate that the heating load can be reduced drastically, as shown in tab. 9.

Table 9. Simulated and monitored annual heating and cooling loads for GT

	Simulated heating loads for 15.43% *WWR*			Heating amount for 37.5% *WWR*, 2013
Glazing type	GT 1	GT 2	GT 3	Existing glazing
U-value [$Wm^{-2}K^{-1}$]	1.187	1.136	0.755	5.86
SHGC	0.623	0.36	0.56	/
Annual sum Heating [$kWha^{-1}$]	23592	29252	20052	338788
Annual sum Cooling [$kWha^{-1}$]	204725	141041	196841	/
Total [$kWha^{-1}$]	228317	170293	216893	338788 (only heating)
Total [$kWhm^{-2}a^{-1}$]	66.56	**49.64**	63.23	98.77 (only heating)

The simulated results in case of GT 2 presented the highest energy demand for heating and also the lowest energy demand for cooling. The total annual energy demand for both heating and cooling was recorded for GT 2, 49.6 kWh/m^{2}a, which is 25.4% lower than the annual demand for GT 1 and 21.5 % lower than the demand for GT 3. When compared to the annual heating energy expenses from 2013 the heating demand for GT 2 resulted with a 91.3% decrement per square meter.

The annual heating, cooling, and total energy demand for the three simulated GT is presented in fig. 6. In fig. 7 monthly energy demands are shown for heating, cooling lighting, and equipment. The high cooling demand and low heating demand results from the significantly high internal heat gain in the office building. Specific internal loads were modelled in EnergyPlus for 160 occupants, electric equipment and lights. Results indicated a significant influence of the *SHGC* parameter on the energy demand, since glazing with the lowest *SHGC* factor (GT 2 with 0.36) presented the lowest annual energy demand.

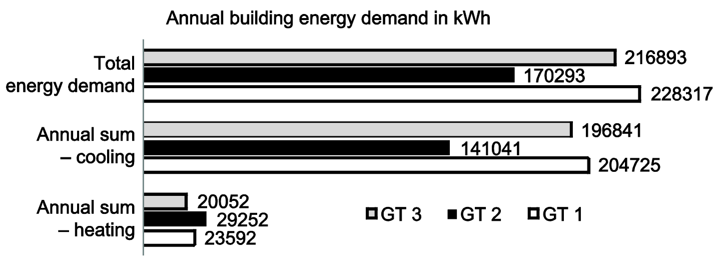


Figure 6. Annual heating, cooling, and total energy demand

Air-ventilation energy demand determination according to EN 15251

According to the European Standard EN 15251 *Annex B; Basis for the criteria for indoor air quality and ventilation rates; Recommended design ventilation rates in non- residential buildings* [28], the energy amount for air preparation was determined before entering the building's ventilation system.

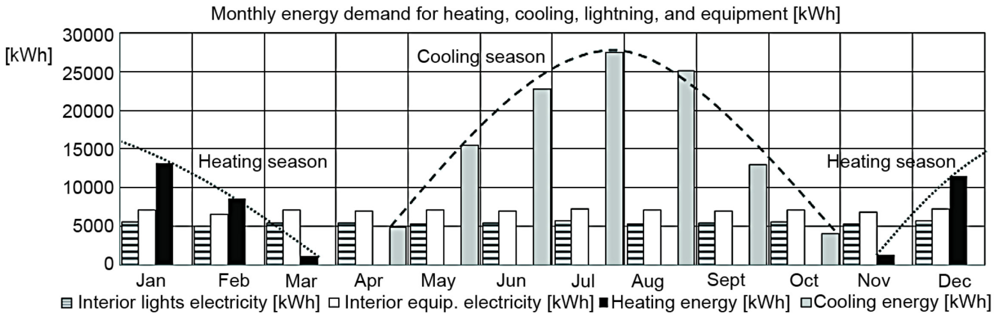


Figure 7. Monthly energy demand

The total ventilation rate for a space was calculated by the eq. (1):

$$Q_{\mathrm{tot}} = n\, q_{\mathrm{p}} + A\, q_{\mathrm{B}} \tag{1}$$

where Q_{tot}, [m³h^{-1}] is the total ventilation rate of the room, n, [–] – the design value for office occupancy, q_{p} [m³h^{-1}] – ventilation rate for occupancy per person, A [m^2] – room floor area, and q_{B} [m³h^{-1}] – ventilation rate for emissions from building.

Ventilation rates can be adjusted according to the ventilation efficiency if the performance of air distribution differs from complete mixing, and can be reliably proven (EN 13779) [28]. The people dependant air ventilation amount and area dependant air ventilation amount per m^2 was calculated for category II of recommended ventilation rates for non-residential buildings with default occupant density. Table 10 presents the annual energy amount for people dependant air ventilation amount where the calculated result is 25517 kWh if the ventilation is turned on for 8 hours daily. Significant energy requirement above 4 MWh was recorded for the three coldest months of the year; November, December, and January.

Table 10. People dependant air ventilation amount

Mon.	No. people	A [m²]	q_p [m³h^{-1}]	ρ [kgm^{-3}]	c [kJkg^{-1}°C^{-1}]	t_k [°C]	t_b [°C]	Δt [°C]	Q_{tot} [kJh^{-1}]	Q_{tot} [kJs^{-1}] [kW]	Q [kWh] – 8 hour per day
Jan.	160	1200	4032	1.27	1.005	0.4	21	–20.6	106013	29.4	4712
Feb.	160	1200	4032	1.26	1.005	2.3	21	–18.7	95477	26.5	4243
Mar.	160	1200	4032	1.24	1.005	7.3	21	–13.7	68838	19.1	3059
Apr.	160	1200	4032	1.21	1.005	12.7	21	–8.3	40696	11.3	1809
May	160	1200	4032	1.19	1.005	18.0	22	–4.0	19288	5.4	857
Jun.	160	1200	4032	1.18	1.005	20.8	23	–2.2	10519	2.9	468
Jul.	160	1200	4032	1.17	1.005	22.4	23	–0.6	2845	0.8	126
Aug.	160	1200	4032	1.17	1.005	22.2	23	–0.8	3793	1.1	42
Sep.	160	1200	4032	1.20	1.005	16.9	21	–4.1	19937	5.5	886
Oct.	160	1200	4032	1.21	1.005	12.6	21	–8.4	41186	11.4	1830
Nov.	160	1200	4032	1.24	1.005	7.1	21	–13.9	69843	19.4	3104
Dec.	160	1200	4032	1.26	1.005	1.7	21	–19.3	98540	27.4	4380
										Annual sum	25517

Table 11 presents the area dependant air ventilation amount where the calculated result is 19138 kWh if the ventilation is turned on for 8 hours per day. Significant energy requirement above 3 MWh was recorded for the three coldest months of the year; November, December, and January.

Table 11. Area dependant air ventilation amount

Mon.	No. people	A [m²]	q_b [m³h⁻¹]	ρ [kgm⁻³]	c [kJkg⁻¹°C⁻¹]	t_k [°C]	t_b [°C]	Δt [°C]	Q_f [kJh⁻¹]	Q_f [kJs⁻¹] [kW]	Q [kWh] – 8 hours per day
Jan.	160	1200	3024	1.27	1.005	0.4	21	–20.6	79509	22.1	3534
Feb.	160	1200	3024	1.26	1.005	2.3	21	–18.7	71608	19.9	3183
Mar.	160	1200	3024	1.24	1.005	7.3	21	–13.7	51629	14.3	2295
Apr.	160	1200	3024	1.21	1.005	12.7	21	–8.3	30522	8.5	1357
May	160	1200	3024	1.19	1.005	18.0	22	–4.0	14466	4.0	643
Jun.	160	1200	3024	1.18	1.005	20.8	23	–2.2	7890	2.2	351
Jul.	160	1200	3024	1.17	1.005	22.4	23	–0.6	2133	0.6	95
Aug.	160	1200	3024	1.17	1.005	22.2	23	–0.8	2845	0.8	32
Sep.	160	1200	3024	1.20	1.005	16.9	21	–4.1	14952	4.2	665
Oct.	160	1200	3024	1.21	1.005	12.6	21	–8.4	30890	8.6	1373
Nov.	160	1200	3024	1.24	1.005	7.1	21	–13.9	52382	14.6	2328
Dec.	160	1200	3024	1.26	1.005	1.7	21	–19.3	73905	20.5	3285
										Annual sum	19138

Finally, the annual energy demand according to the European Standards EN 15251 is 44655 kWh/a where the energy demand per m^2 is 37.2 kWh/m^{2}a. The total energy requirement for heating and cooling with the modified envelope construction and glazing is 214948 kWh/a where the energy demand per m^2 is 62.6 kWh/m^{2}a. If compared to the reference office-tower building's heating demand from the expenses which equal 338788 MWh/a, 98.77 kWh/m^{2}a the modified building has 81% lower annual energy demand for heating of only 63577 kWh/a, 18.53 kWh/m^{2}a. In order to reduce the demands even further a heat exchanger can be added to the supply system. Depending from the efficiency of the heat exchanger demands can be reduced, especially for the cooling season. The heat exchanger application will be part of further researches.

Conclusions

This investigation presented a case study of the building envelope's significance on the decrement of annual heating and cooling energy demand. The *WWR* can be analysed from the aspect of illumination intensity distribution in the function of window surface decrement. The *WWR* per single office was decreased from 50% to 30% per single orientation, which resulted in 15.32% as the final glazing decrement of the building envelope. The simulations have shown the importance of *SHGC* coefficient's influence on the energy demand, due to significantly high internal loads. The findings have presented a decrement of one quarter, 25.42%, of annual heating demand, if the windows' U-value is reduced from 1.18 W/m^{2}K to 1.13 W/m^{2}K and *SHGC* coefficient from 0.62 to 0.36. The total annual energy demand for both heating and cooling was recorded for GT 2, 49.6 kWh/m^{2}a, which is 25.4% lower than the annual demand for GT 1 and 21.5% lower than the demand for GT 3. Findings have underlined the significance of the *SHGC* coefficient's influence of windows on the annual energy performance. The total energy requirement for heating and cooling with the modified envelope construction and glazing is 214948 kWh/a where the energy demand per m^2 is 62.6 kWh/m^{2}a. If compared to the reference office-tower building's heating demand from the expenses which equal 338788 MWh/a, 98.77 kWh/m^{2}a the modified building has 81% lower annual energy demand for heating of only 63577 kWh/a, 18.53 kWh/m^{2}a.

The applied methodology outlines the significance of building energy performance simulation which should be conducted in the 1st stages of a developing project. The same method can be applied for further investigation although the climate parameters and internal loads are variable. Further investigation directions considering building envelope construction refer to the analysis of window geometry, *WWR* with 5% steps and exterior wall insulation properties. The heat exchanger application will be part of further researches, respectively, in order to analyse and evaluate its efficiency on the reference office-tower building. Thermal comfort parameters have an important role in further directions of investigation. Future goals will be developed in the direction of comfort analysis to optimize annual building energy performance in the function of microclimatic conditions.

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Nomenclature

B_n – direct normal radiation (beam),
c – thermal conductivity, [Wm^{-1}K^{-1}]
d – layer thikness, [m]
FF – wind speed, [ms^{-1}]
G–D_h – mean irradiance of diffuse radiation horizontal, [Wm^{-2}]
G–G_{ex} – extraterrestrial solar radiation (horizontal),
G–G_h – mean irradiance of global radiation horizontal, [Wm^{-2}]
G_{hmax} – maximum global horizontal radiation (on clear days),
N – cloud cover fraction, [–]
PAR – photosynthetically active radiation, [Wm^{-2}]
Q – specific heat, [Jkg^{-1}K^{-1}]
RD – days with precipitation, [–]
RR – precipitation, [mm]
SD – sunshine duration, [h per day]
Snd – snow depth, [mm]
T_a – air temperature, [°C]
t_b – inside air temperature, [K]
t_k – outside air temperature, [K]
U – overall heat transfer coefficient, [Wm^{-2}K^{-1}]

Greek symbols

ρ – material density, [kgm^{-3}]

Acronyms

BIM – building information modeling
BLC – building component library
CP – control panel
GT – glazing types
RH – relative humidity, [%]
SHGC – solar heat gain coefficient, [–]
WWR – window to wall ratio, [%]

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