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ORIENTATION DEPENDENT DIFFERENCES IN ENERGY BREAKDOWN FOR SINGLE OFFICES IN BELGRADE CONTINENTAL CLIMATE

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Energy breakdown information is an important factor in the process of building design. It gives the designer direction in the decision-making process of choosing the most adequate building design. Location parameters, thus the climate conditions, are the first determining factor for energy breakdown in buildings – it is determining whether we are dealing with a heating or cooling dominated climate. But in the real environment, there are further parameters that can influence energy breakdown in office buildings, such as site parameters. Site characteristics determine the available orientation of the building's facade and define obstructions to incoming solar radiation. This study deals with differences in orientation dependent energy breakdown in office buildings for Belgrade continental climate. The influence of site obstructions on incoming solar radiation was neglected due to the comparative nature of this study. A set of four different highly glazed facades of a single office was combined with a set of four different glazing types, resulting in sixteen models. The simulation was carried out with full and partial control of visual and thermal comfort. The results in this study show that energy breakdown for different orientations of a single office can have great variations. These variations in energy breakdown are primarily connected with the duration and intensity of insolation on the façade and properties of glazing, such as the percentage of glazed area on the façade (window-to-wall parameter (WWR)) and solar factor (g) and visual transmittance (τ) of glazing and the level of integrated systems for comfort control.

Keywords: energy breakdown, glazed facades, single offices, administrative buildings

1 INTRODUCTION

This research was part of the wider study related to energy performance of highly glazed single office spaces in Belgrade's continental climate [1]. The original study was carried out for highly glazed offices in order to investigate whether higher (conductive) heat loos can be compensated with solar heat gains in single offices in Belgrade climate. The definition of "highly glazed office space" was adopted from German legislation (Energy Conservation Act (EnEV 2004-12) [2]),also adopted by some EU countries, in which all residential buildings with more than 30% of transparent glazed façade area and all commercial buildings with more than 50% of transparent glazed façade area are considered to be "highly glazed".

The results of the study showed that highly glazed facades on administrative buildings in Belgrade can be applied on south and north oriented facades, since for these orientations of individual offices, the lowest overall energy demands happen in models with fully glazed facades. The reason for the lowest energy demand on south orientated highly glazed spaces is that south orientated spaces in Belgrade's latitude have high solar gains during winter. In offices, which are occupied during daytime, these solar gains compensate for the heat loss and radically reduce the highest energy demand – heating. North orientated spaces have almost no insolation during winter, so the energy demand for heating is very high. Almost no insolation on north oriented spaces results in very low energy demand for lighting and cooling (no insolation – no shading, negligible energy gains), thus the lowest value in total energy demand happens in cases of fully glazed office.

The complexity of energy demand in buildings in continental climates derives from two opposite strategies during winter and summer: in summer it is important to keep low energy demand for cooling, so there is a need for outside shading. When outside shades go down, luminous conditions on task area are reduced and lighting energy demand is rising. In winter, it is important to maintain minimal energy exchange (due to the conduction process) and benefit from high solar gains during the daytime (due to radiation) while maintaining comfortable conditions inside. To keep solar gains inside, shading should be placed on the inside plane of the glazing.

Many studies dealing with energy demand in highly glazed offices have the same conclusion: the shading selection (static - dynamic), its position in complex glazing (inside-outside) and type of its control (automated – manual) have crucial influence on prediction of energy demand ([3], [4], [5], [6], [7]). Also, the crucial point in prediction of energy demand in offices is user behavior. The user is adopting its surroundings by turning the lighting on and off and by pulling shades up or down. The user's reaction is most often triggered by illuminance intensity on the task area, brightness in the user's view area (luminance) or direct solar radiation falling on the user [4].

For the purpose of this analysis, the energy breakdown in a single office space is broken into only three main energy demands – lighting, cooling and heating energy demands. In this paper, the sum of these three energy demands is referred to as the total or overall energy demand. Numerical values of energy demand are not presented in this paper. The purpose of this paper is to show changes in single office energy breakdown due to change of orientation. So, energy demand is presented only as a percentage of total energy demand (Table 3, Figure 2) (for all three main sectors). It also doesn't mean that energy demand of 20% has larger numerical value than energy demand of 15% for the same sector, since the numerical value of total energy demand (in two examples mentioned above) might be very different. This comparative analysis does not require accurate numerical values of energy demands but rather relative accuracy, accuracy in values' change for each model orientation.

2 METHODOLOGY

The office space is modeled as a simple shoebox, according to Rinehart's reference office from 2013. [8], but with different dimensions, as presented in Fig. 1.

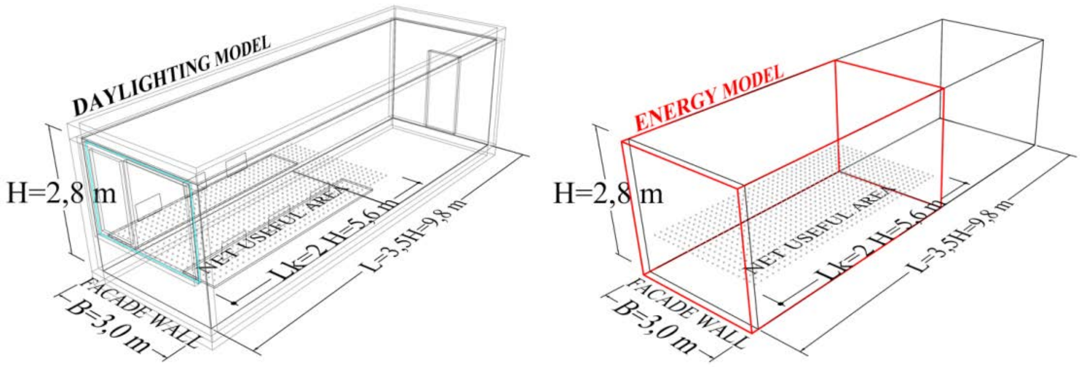


Fig. 1. Daylighting and energy model dimensions and arrangement

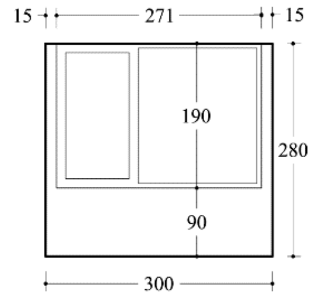
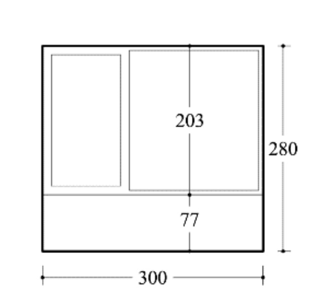
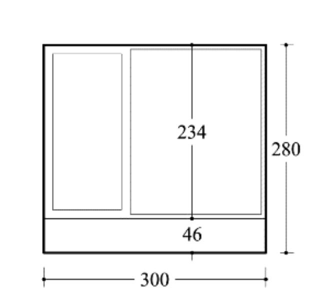
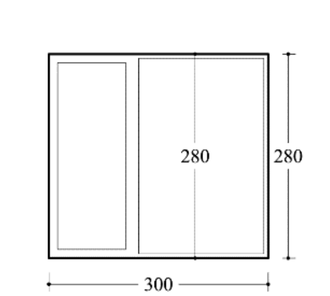
For the purpose of this study, four different glazings were selected. The glazings that are selective glazings were not included in this study since these glazings are not suitable for heating dominated climates and result in higher energy demand than glazings that are not selective and have higher solar factor [1]. Four selected glazing models (Table 1) differ in visual transmittance (τ) by around 10% (degrading from its maximum), have the same *U coefficient* (except for the glazing with the highest visual transmittance (τ=80%)) and, accordingly, have as much as possible high level of solar factor (*g*) for each glazing (also degrading by (around) 10%). The visual transmittance of 80% can be achieved only in glazing with two glass sheets, so the *U* coefficient of glazing named G01 is higher than all the other triple glazings (with 0,7 W/m²K).

Table 1. Parameters of selected glazings

Model name	Dimensions of layers in the glazing	glazing properties			
		visual transmittance*	solar factor*	coefficient U**	selectivity
G0X (*τ.g.U*)	[mm]	τ_v	*g*	*Ug*	*S*
		[%]	[%]	[W/m²K]	-
G01 *(80.73.1,3)*	10-16-6	80,2	73,0	1,3	1,1
G03 *(72.62.0,7)*	10-16-6-16-6	71,8	61,5	0,7	1,2
G05 *(62.50.0,7)*	10-16-6-16-6	62,4	49,4	0,7	1,3
G07 *(54.48.0,7)*	10-16-6-16-6	54,3	47,9	0,7	1,1
NOTE: glazing gaps are filled with 90% argon and 10% air * *EN 410 – 2011* ** *EN 673 – 2011*					

Selected glazing area, expressed as *window-to-wall ratio* (*WWR* parameter), are presented in Table 2. *WWR* was selected as net value (glazing area in relation to wall area perceived from inside). The facade aperture has lateral shape development, the upper edge of window is positioned right next to the ceiling and only 1/3 of the glazing area is positioned in operable windows (2/3 of glazing area cannot be opened). Glazings are a type of complex glazings with integrated inside textile blinds (to diffuse daylight inside) and outside venetian louvers (to reflect more daylight onto the ceiling and block incoming direct sunlight).

Table 2. Selected façade aperture: glazing area and its position on façade wall of single office

Selected facade aperture			
WWR 50%	WWR 60%	WWR 70%	WWR 85%
			

The occupancy schedule was adopted as 10 hours a day, including weekends and holidays. The eight hour working time was prolonged by one hour before working time starts and one hour after working time ends, in order to cover time when buildings need to reach thermally comfortable conditions and maintain the same conditions when users leave the building. The start of the occupancy schedule is at 7 o'clock, according to the Serbian official start of working time. Also, Daylight Saving Time (DST) was implemented (according to DST schedule in EU).

DIVA for Rhino [9] was used as a simulation tool for daylight and energy performances in office spaces. The daylighting and the thermal simulation of energy performance of any space are two separate simulation sequences, connected only by a shading schedule.

Four linear LED lighting fixtures with dimming options were selected. Each lighting fixture functions separately, depending on the illuminance value in the sensor located right beneath it. If the illuminance in the sensor drops under 500 lx, the dimming function of selected lighting is turned on, adjusting illuminance on the task area. Illuminance threshold on the task area is set to 500 lx, according to current standard for lighting of work places [10].

The illuminance values in these sensors also trigger shading in cases when the illuminance value exceeds the maximum adopted value. When applied, shading behavior is fully automated. The behavior of shading was modeled after standard requirements of minimum 500 lx on a task area – the shading system stays completely open – and after results from previous studies related to the desirable, ideal and maximum tolerant value of illuminance on the task area. Ideal and desirable levels of illuminance on the task area depend on the type of office work (traditional office work, like reading, writing or drawing, or work on a computer). These illuminance values vary between 300 lx and 500 lx. The maximum illuminance value, which triggers shading, was selected to be 1800 lx, which is perceived by most users as intolerable [11]. Shading automated behaviour is maintaining illuminance values on task area between 500 lx and 1800 lx.

Two simulation scenarios were selected: (1) without the use of shading to control visual comfort (glare, exceeded illuminance) and to control thermal comfort (direct sun on user), but with automated control of illuminance value on task area (with dimming lighting control) (this is partial comfort control in Figure 2 presented as energy demand under scenario of NO CONTROL of thermal and visual comfort) and (2) with automated shading control in order to control visual and thermal comfort (in Figure 2 presented as energy demand under scenario of AUTOMATED CONTROL of comfort). The results of energy breakdown (lighting, heating, cooling) under these two scenarios are presented in Table 3 and plotted in the diagram in Figure 2.

The closest result to real energy demands in offices in the Belgrade climate would be somewhere in-between these two extreme scenarios. The results would depend on the integration level of different systems for comfort control (high-tech systems like detection sensors and computer operated blinds and shades) or on user behaviour (low-tech state when a user is changing his environment manually in order to adopt daylighting/lighting or thermal conditions).

The sequence of energy simulation for heating and cooling was modelled using a temperature set point for summer of 26°C and for winter 22°C. Simulation of heating and cooling energy was calculated with an active option for natural ventilation of office space. The option of natural ventilation is treated in software as the option to open the windows at the right temperature difference (between inside and outside) and thus to cool down or to heat up the space to the level of temperature set point.

3 RESULTS AND DISCUSSION

The results of the energy breakdown study are presented in Table 3 and graphically plotted in Figure 2 in the next pages. The results in Table 3 and Figure 2 do not present a numerical value of energy demands for each model, nor are they showing the change in results with the change of one parameter (for example, change of glazing parameters etc.). Results in Table 3 present only a minimal and maximal percentage for each one of the basic energy demands (lighting, cooling, heating) for four different orientations of 16 model sets and for the sum of all orientations together. Since we are dealing with a minimal and maximal percentage of specific energy demand for the set of sixteen different models, statistical calculations are also included in the same table, as main, medial and modus value. In most cases, main and medial values are very close, so we can assume linear change in results. Modus value shows that dissipation of data is occurring in all energy breakdown sectors (occurs at about 50%).

Without applied shading, lighting energy demand for all four orientations has its mean value around 10% (plus/minus 2%) of total energy demand. The heating energy portion differs upon different orientations: for east and west, heating energy demands are around 65%, for south it is, of course, the lowest, around 55%, and for north orientated office spaces there are the highest demands for heating, almost up to 80%. The same but reversed potentials exist for cooling energy demand. For east and west orientations, the cooling energy demand is around 25%, for south ten percentage more (around 35%) and for north orientation, cooling energy demand is below 10% of total energy demand.

When shading is applied in order to control comfort, shading causes the portion of lighting energy demand to multiply and the portions of energy demand for heating and cooling are reduced for every orientation of office space. The mean and median value for lighting is rising around 30%, plus/minus around 5%, and the rest of the energy demand is reduced by (around) 10%. For facade orientations that are highly exposed to sunlight (like south orientation), minimum lighting energy demand occurs in spaces with maximum *WWR* and in the case of glazing with the lowest visual transmittance. This result is expected as low visual transmittance of glazing is producing the highest percentage of time that blinds and shades are open. This allows good utilization of solar gains during winter. North oriented facades have very low direct sun exposure, there is no need for the use of blinds and shades to control the user's visual comfort, so the resulting lighting energy percentage as minimum demand is almost the same as in a model with no visual comfort control.

Table 3. Energy breakdown - percentage of energy demands for each orientation and overall

Orientation	Energy	Comfort control	ENERGY BREAKDOWN				
			min	max	MEAN	MEDIAN	MODE
EAST	LIGHTING	no con.	6,2%	14,6%	9,8%	9,7%	8%, 10%
		control	22,3%	30,0%	27,0%	27,4%	26%, 29%
	HEATING	no con.	49,4%	71,8%	63,1%	63,9%	62%
		control	46,4%	58,9%	53,9%	54,1%	53%, 54%, 55%, 57%, 59%
	COOLING	no con.	14,9%	43,6%	27,2%	26,3%	23%, 26%
		control	12,1%	27,8%	19,1%	18,7%	17%
SOUTH	LIGHTING	no con.	6,8%	16,6%	11,8%	12,2%	8%, 10%, 12%, 13%, 14%, 15%
		control	29,8%	37,7%	34,9%	35,1%	36%
	HEATING	no con.	36,8%	67,2%	54,3%	54,5%	67%
		control	35,6%	52,7%	44,4%	44,7%	41%, 45%, 46%, 49%
	COOLING	no con.	16,5%	56,4%	33,9%	33,6%	35%
		control	11,7%	33,6%	20,7%	20,5%	12%, 18%, 22%
WEST	LIGHTING	no con.	6,2%	15,1%	10,4%	10,4%	9%, 11%, 13%
		control	21,5%	27,8%	25,3%	25,7%	27%
	HEATING	no con.	53,7%	72,6%	64,9%	65,7%	64%
		control	49,8%	62,2%	57,1%	57,1%	57%
	COOLING	no con.	13,5%	38,9%	24,7%	24,0%	14%, 21%, 24%, 26%
		control	11,3%	25,8%	17,6%	17,2%	19%
NORTH	LIGHTING	no con.	8,1%	17,7%	12,3%	12,5%	11%, 13%
		control	17,7%	24,1%	22,0%	22,6%	23%
	HEATING	no con.	76,1%	81,5%	79,0%	79,0%	79%
		control	70,9%	76,7%	72,8%	72,1%	72%
	COOLING	no con.	5,4%	13,2%	8,7%	8,2%	7%, 8%
		control	4,5%	6,6%	5,2%	5,1%	5%
ALL	LIGHTING	no con.	6,8%	16,0%	11,0%	11,1%	12%
		control	24,2%	31,4%	28,6%	29,0%	28%
	HEATING	no con.	55,6%	73,4%	66,4%	67,3%	66%
		control	44,5%	58,7%	52,4%	52,6%	50%, 52%, 54%
	COOLING	no con.	12,0%	36,9%	22,6%	21,8%	19%, 22%
		control	11,8%	28,7%	19,1%	18,7%	16%, 20%, 21%

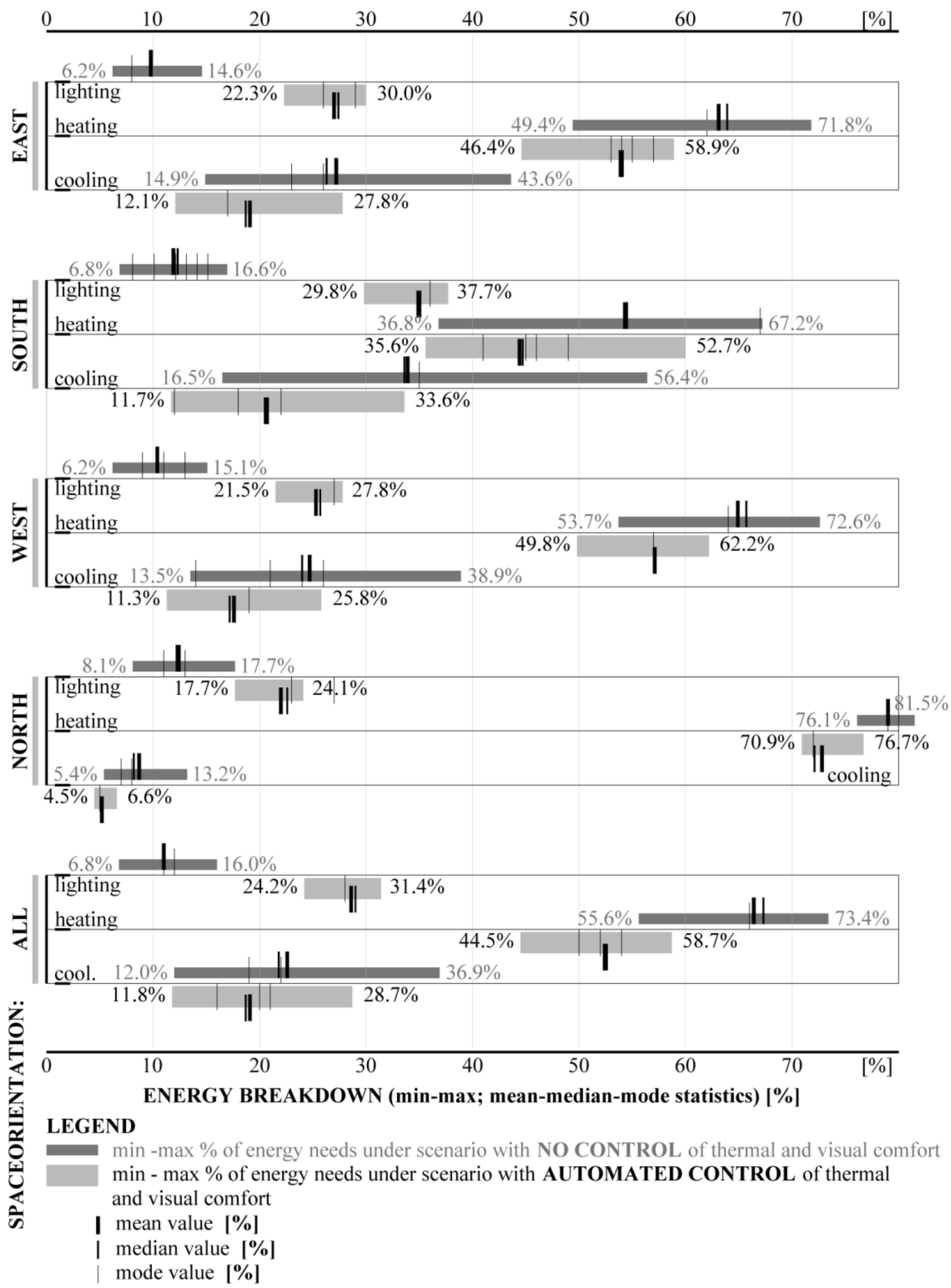


Fig. 2. Results of the study: plotted energy breakdown for simulation runs with and without control of users' visual comfort (plotted data from Table 3)

4 CONCLUSIONS

Summary results for all orientations in this study confirm that Belgrade's climate is a heating dominated climate with average heating demand for single offices from 53% (with fully automated control of thermal and visual comfort) to 67% (for maintenance of standard minimum of 500 lx on task area). Accordingly, for the same two levels of comfort control, lighting energy in energy breakdown is second and accounts for from 29% to 11% and cooling energy demand is the averagely the lowest energy demand and varies from 19% to 23% of total energy demand.

Compared by orientation, all extremes (highest and lowest energy demand) for all sectors of energy demand (lighting, heating, cooling) are connected with north and south oriented office spaces. Values of energy demand for east and west orientations are somewhere in-between these two extremes.

From this it can be concluded that combination of

- (1) duration and intensity of façade insolation,
- (2) glazing properties such as solar factor (g), visual transmittance (τ), glazing proportion (WWR) as well as
- (3) the level of integrated systems (sensors, shading) for comfort control

are crucial factors that determine energy breakdown for each orientation of office space.

The study was carried out for single offices, for one or two users, with unreal surroundings with no outside obstacles and with fully automated comfort control under Belgrade continental climate conditions. The use of presented energy breakdown results is limited to the above-mentioned conditions. The change of any parameter, such occupation hours, working time, climate conditions, number of users and so on, would provide different results of energy breakdown. Since the results are based on unreal conditions, the future study could introduce analysis conditions that are closer to the real environment (such as model of user behavior in offices, obstacles in real environment…), not in a way to radically change input parameters, but to tune them up, to see how small real world parameters could influence presented results in energy breakdown for offices.

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