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ENERGY-EFFICIENT PASSIVE DESIGN APPROACH FOR OFFICE GROUND-SCRAPERS IN A TEMPERATE CLIMATE

The research is dedicated to the early design stage optimization by energy-efficient passive design strategies to be applied for office ground-scrapers in the temperate climate of London, United Kingdom. As a method for the investigation, literature review and computer simulations by Sefaira software were used. The effect of the following passive design strategies on building energy-efficiency was investigated: building shape, building orientation, window-to-wall ratios (WWR), horizontal shading devices, day-lighting, and natural ventilation.

Keywords. Early design stage optimization, energy-efficiency, energy demand, passive design strategies, office ground-scrapers, building shape, building orientation, window-to-wall ratios, horizontal shading devices, day-lighting, and natural ventilation.

Problem statement. It is important at the early design stage to do building envelope optimization in order to achieve a better energy performance. Relationships between building form, its orientation, glazing-to-wall ratio, positioning of windows, self-shading, shading devices and building energy-efficiency can significantly influence future energy demand of the building. That's why proper early design studies have a great potential of future energy demand reduction. Passive design strategies have been widely implemented into small/medium-scale projects (mostly housing) and vast amount of research has been done in this area, which provides guidance for architects. Similar studies have been done for high-rise (office and residential) buildings; however, passive design approach for large-scale ground scrapers (low-rise and mid-rise) development is more likely to be experimental currently. Author is looking at the office buildings in temperate climate (Europe, North

America) suitable for the context of large (historical) cities; cities where urban policy promotes densification and at the same time regulates building height. That is why is concentrated on office ground-scrapers schemes as building type which is in high demand.

Literature review. Passive design strategies to reduce energy demand. (Okeil A. 2010) proposed a holistic approach for building energy efficiency, based on optimization of building form and orientation, utilizing solar energy in winter, mitigating urban heat island effect and implementation of the green roofs. (Chen X., Yang H., Lu L. 2015) presented the influence of building form, building envelope qualities (opaque and transparent), solar shading, natural ventilation and air tightness onto building energy efficiency and Green building rating tools. (Stevanovic S. 2013) provided a wide summary of previous research that focused on: Optimization of building form; Opaque envelope components; Glazing / Shading elements; Whole building passive solar design optimization indicating.

Building shape, compactness, building orientation and energy efficiency. (Depecker P., Menezo C., Virgone J., Lepers S. 2001) have been studied relations between building shape and its energy performance, to relate heating consumption of the buildings with their shape. The shape coefficients were defined as the ratio between the external skin surfaces and the inner volume of the building. Parallelepipeds have been selected as building shapes because of most frequent use in the construction industry. (Pessenlehner W., Mahdavi A. 2003) analyzed relationships of residential building energy consumption and building relative compactness by taking into account four different orientations and different glazing ratios. Results showed the respective correlation between heating load and relative compactness; however, no strong correlation (unless for high glazing ratios) between cooling load and relative compactness was detected. Additionally, the assumption has been proven that south-dominant glazing orientation requires the lowest heating load but highest cooling load, while north-dominant glazing orientation requires the highest heating load but lowest cooling load.

WWR, positioning of the windows and energy efficiency. (Geletka V., Sedlakova A. 2012) conducted analysis by using the dynamic simulation program Energy Plus for the Eastern European climate in Slovakia Five shapes with different aspect ratios, different orientations and WWR have been simulated. As a result, direct relation of relative compactness and energy efficiency has been proven, as well as significant influence of WWR and building orientation; however, usage of self shading and shading devices have not been considered. (Gonzalo R., Rainer V. 2014) researched positioning of the window in the walls. Amount of shade created by the reveal setting the window deep into the reveal leads to a considerable reduction of solar gain - this may however be desirable in summer. The opposite occurs if an exterior position is chosen. However, the reduced depth may be cause for a creative conflict if the necessary shading device is to be integrated into the wall. The space for a suitable connection of the insulation is simply not available in these circumstances.

Shading devices and energy efficiency. (Kirimtat A., Koyunbaba B., Chatzikonstantinou I., Sariyildiz S. 2016) analyzed various simulation tools used for computation of energy performance of shading devices in buildings. Numerous studies of different shading devices for different building types and glass types located in different climatic zones have been reviewed, including fixed devices: overhangs; horizontal louvers; vertical louvers; egg-crates; and movable shading devices: venetian blinds; vertical blinds; roller shades; deciduous plants. The study concluded that usage of simulation programs to solve complex relationships between climate, occupancy requirements, mechanical and electrical systems, energy-efficiency issues and design characteristics is a strong way of coping with these problems. (Manzan M. 2014) carried out a research of the office room with a south facing window in order to design an optimal fixed shading device. Two different locations have been analyzed as well as two glazing systems have been taken into account: standard double glass and glazing system designed to prevent high sun loads. The device shaded the window from direct sun penetration reducing the cooling loads in summer, but also affecting daylight and heat loads in winter limiting the sun gains, therefore the impact on the overall building energy consumption has been investigated. The results demonstrate that electrical energy consumed by the lighting has to be always taken into account in designing energy-efficient shading devices.

Day-lighting and energy efficiency. (Lechner M. 2009) stated in his research that around half of the all lighting energy used by buildings, office buildings in particular, can be saved trough day-lighting, furthermore, it can reduce the heating and cooling energy consumption, because it can passively heat the building in winter and it can cause les heat gains, than from electric lighting in summer. (Catalina T., Virgone J., Iordache V. 2011) pointed out deep floor plan solution, when desks are located far from the perimeter of day-lighting is negative for overall buildings energy-efficiency. That's why very compact buildings are not desirable from architectural and day-lighting point of view, because of high impact on the electrical consumption (especially for office buildings).

Natural ventilation and energy efficiency. (Liddament M. 1996) suggests that single-sided ventilation is less efficient and reliable, cross ventilation depends on the height of the space, stack and atria ventilation require careful design in order to perform correctly and wind towers are suitable to the hot climates mostly. Natural ventilation has certain advantages: reduced environmental impact; high energy savings can be achieved; suitable for many types of buildings located in mild or moderate climates; relatively inexpensive when compared to mechanical systems. However, it has disadvantages as well: unsuitable for noisy, windy and polluted locations; may not be applicable for severe climatic regions may present a safety risk; air delivery and distribution for large deep plan and multi roomed buildings may not be possible. (Ben-David T., Waring M. 2016) reflected the benefits of natural ventilation for office buildings confirmed by computer simulations by Energy Plus. For instance, natural ventilation decreased energy use, due to a wider temperature set point band for natural ventilation scenarios and somewhat lowered fan energy use. It was discovered that cooling energy was reduced under all ventilation strategies compared to the mechanical minimum strategy; furthermore, heating energy was often reduced by natural ventilation strategies as well.

Research aims. The main idea of the research is to define the ways how to reduce the energy demand for office ground-scrapers in a temperate climate (London, UK) by architectural passive design means. The author is going to analyze the energy-efficient passive design strategies and to find out to what extent they influence building energy demand reduction (separately and as a combined effect).

Research methodology and methods. A qualitative methodology was used for literature review; while quantitative methodology was used for computer simulations.

Literature review. The author searched through scientific journals and books in order to investigate the existing body of knowledge of the subject (to find out existing suitable passive design strategies for office ground-scrapers in a temperate climate for energy demand reduction). As a result of this review, the author synthesized the findings and identified the main trends.

Computer simulations using SketchUP and Sefaira. The author simulated approximately up to 5-10 different options of passive design strategies discovered by literature review, analyzed and compared the achieved results and created a framework.

For the research the author analyzes primary climatic data that may influence the analysis including: monthly average air temperature; monthly solar irradiance for vertical surface; sun-path diagrams of the site; annual wind rose diagram of the site. The author presents all the essential input data for further simulations including: general building parameters; different building shapes; different window-to-wall ratios; different orientations; fabric parameters; power density/rates; HVAC systems efficiency.

For design computer simulation the author took a model of 10-storey building modeled in SketchUP, with fixed floor area, fixed internal volume, fixed width and fixed floor-to-floor height. As for the building shapes for the analysis, the author chose 3 shapes which are most commonly used in the building industry, and most commonly analyses in previous research: Longitudinal shape; U-shape; Square shape (Figures 01, 02).

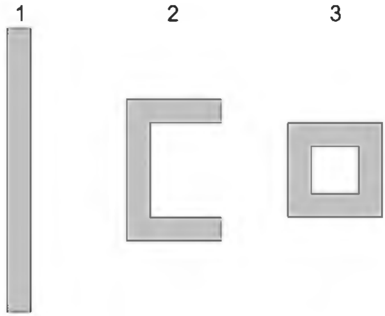

Figure 01. Building shapes (plans). 1. Longitudinal shape. 2. U-shape. 3. Square shape. Source: Author. 2017. Software: AutoCAD 2017

The Author did computer simulations for data collection by to following steps: - Analyzed different orientations (South, South-East 30°, 45°, South-West 30°, 45°); - Analyze different WWR (90%, 70%, 40%); - Analyzed impact of shading devises (Figure 03): horizontal (0.5m, 0.8 m, and 1 m long); - Analyzed the impact of natural ventilation (Natural ventilation mode of Sefaira software with following input data: cross-ventilation type; 40% of operable windows; city as a site terrain type).

Results of the research and discussion. Overall the obtained results indicate that the difference in energy consumptions between least energy-efficient option and most energy-efficient option is 13.9%, which supports the research aims and objectives in terms of finding the extent of increase of energy-efficiency by certain passive design means.

It has been emphasized that the least energy-efficient result is 130 kWh/m2. Author supposes that the reason for this is high cooling demand caused by solar radiation. While, the most energy-efficient result is 112 kWh/m2 (Figure 04). The author considers that the main reason for this is mitigation of cooling demand caused by solar radiation by low WWR (Window-to-wall ratio) (40%) and long (1m) shading device, which has been proven by computer simulations.

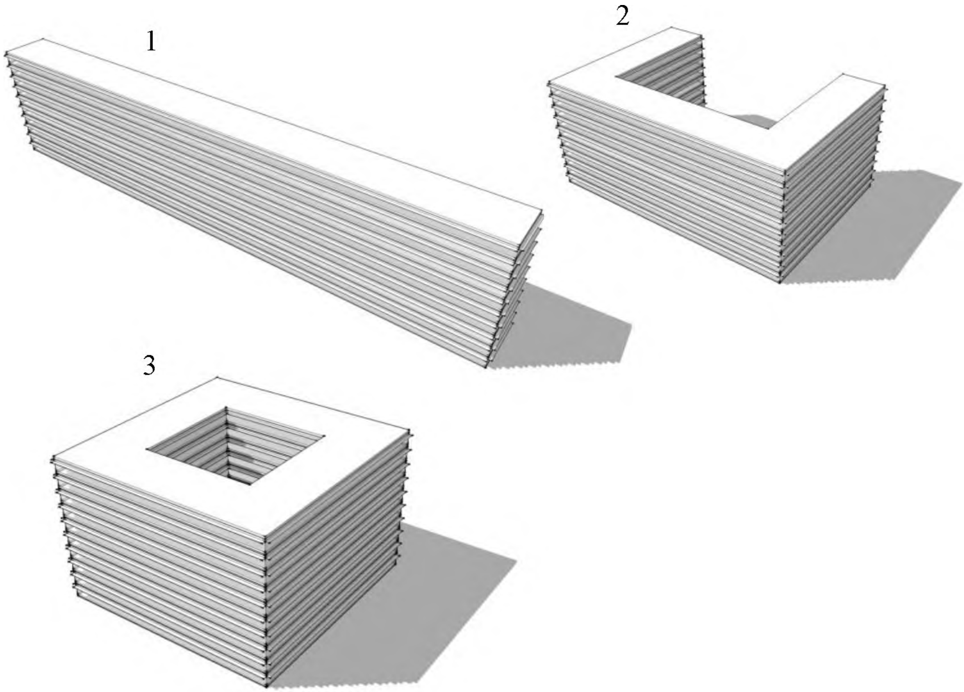

Figure 02. Building shapes. 1. Longitudinal shape. 2. U-shape. 3. Square shape. Source: Author. 2017. Software: SketchUP 2017.

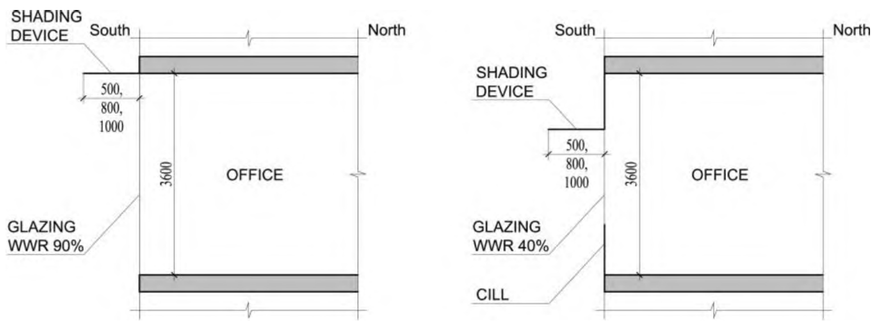

Figure 03. Schematic section of the model for analysis with horizontal shading device (conventional overhang). Source: Author. 2017. Software: AutoCAD 2017.

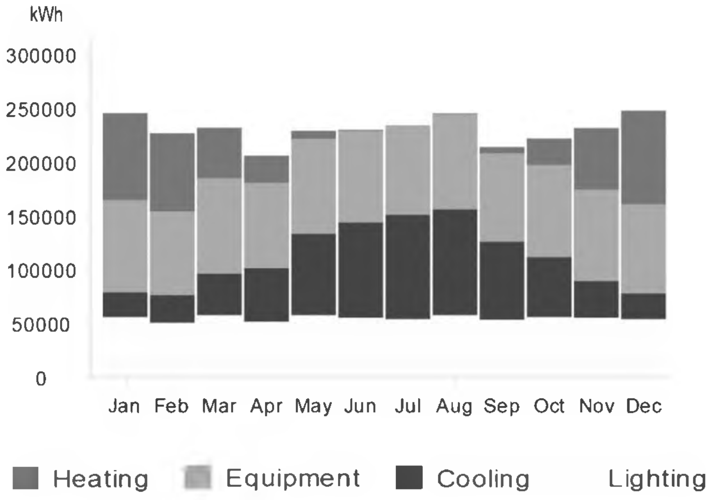

Figure 04. Annual energy footprint of most energy-efficient option. Source: Author. 2017. Software: Sefaira.

As for the obtained data of energy-efficiency for natural ventilation mode, it can be seen that it can increase the energy-efficiency in the range from 19-26%. It means that the difference in energy consumptions between least energy-efficient option (without natural ventilation) and most energy-efficient option when natural ventilation mode is applied can reach 30%.

As for day-lighting, author concludes that there is a strong correlation between WWR and day-lighting, correlation between orientation and day-lighting and correlation between shading device size and day-lighting. In addition to it, one more factor that significantly influences day-lighting is overshadowing of the analyzed building by itself.

In addition to it, one more factor that significantly influences day-lighting is overshadowing of the analyzed building by itself. This issue does not apply to Shape 1 (Longitudinal) of the analysis; however, it applies to Shape 2 (U-shape) and Shape 3 (square shape) in particular. It can be proven by shading masks simulated by VirVil software which provides evidence that there is significant difference between amount of sky visible from fifth floor of the center of North facade between Shape 1, Shape 2 and Shape 3 (Figure 157). Due to the overshadowing by itself these two shapes show lower day –lighting at WWR 70% and very low day-lighting on WWR 40% than Shape 1.

After analyzing the obtained results from the simulations, the authors can state that these results correspond to the results of the previously conducted studies that have been covered in the literature review, for instance, the idea of highest performance of the combined effect for energy-use reduction has been widely reflected (Stevanovic S. 2013). According to the author's results, the combined optimization of: building shape, building orientation, window-to-wall ratio and shading devices can lead up to 13.9% of energy use reduction and up to 30% when natural ventilation is applied. Furthermore, individually the strategies can reduce energy use up to: 5% by building shape; 1% by building orientation; 11% by WWR; 4% by shading devices; 26% by natural ventilation. That means that in this case the most efficient passive design strategy is natural ventilation and optimization of WWR, while building shape, shading devices sizes and building orientation optimization are less efficient. These figures correspond to the figures achieved by previous researchers, for example, (Manzan M. 2014), which are 19-30% when the strategy of shading devices is applied; and (Goia F. 2016), which are 5–25% when strategy of WWR is applied.

However, these indices are only applicable to the methodology proposed by the author: climatic data of London; design input data for simulations; Sefaira software used for simulations. It has to be mentioned that the author deliberately used already very energy-efficient building models for analysis in order to understand the further limits for energy-savings. That's why different methodology may lead to different results; notwithstanding, the main trend reflects the findings from the literature review of direct correlation between building shape, building orientation, WWR, shading devices and building energy-efficiency (Goncalves C., Umakosshi E. 2010), (Catalina T., Virgone J., Iordache V. 2011), (Manzan M. 2014), (Gonzalo R., Rainer V. 2014), (Goia F. 2016).

The simulations conducted by the author have also confirmed the idea of previous research (Premrov M., Leskovar V., Klara Mihalic K. 2015) that suggests the South and close to the South orientations for the purpose of passive heating in winter because vertical south glazing transmits the maximum solar radiation in winter and minimum in summer.

Furthermore, it has to be highlighted that since most energy-efficient results have been achieved by shapes 2 and 3 which have different Relative compactness, therefore RC does not really influence significantly on energy-efficiency; however, the fact that only two shapes with different RC have been tested, does not allow to generalize the results regarding the effect of RC on energy efficiency. Despite, it is evident that the main factors of influence on energy-efficiency are: natural ventilation, WWR, shading devices and orientation.

Another issue that has to be raised is the contradiction between an energy-efficiency and a day-lighting. The achieved result of the highest energy-efficiency show the lowest day-lighting results. That's why the authors considers that the compromised results have to be selected as the most appropriate ones in order to respond the both goals: high energy-efficiency and high day-lighting. In this case issues like overshadowing of the analyzed building by itself and WWR lower than 40% have to be avoided.

Moreover, it has to be mentioned that according to the conducted simulations annual wind directions do not affect natural ventilation efficiency. This issue remains obscure for the author and it needs further consideration. The author supposes that the results regarding the natural ventilation mode are not precise enough and cannot be trusted completely, therefore it can be treated as one of the limitations of Sefaira software; in order to obtain accurate result of natural ventilation, sophisticated fluid dynamic simulations have to be conducted, which are not what Sefaira software is capable of.

In addition to it, the author has discovered some other contradictions in the results of the software simulations, for instance, by using the response curves or processing the actual 3D model, slightly different results can be achieved, which can mislead the researcher.

However this contradictions only affect the accuracy of the simulations, but the main correlations remain consistent.

Furthermore, author revealed the fact that software does not link the percentage of day-lighting of the spaces to energy consumption of electric lighting, which may lead to substantial errors in the results. Theoretically, higher percentage of day-lighting leads to reduction of energy consumption for electric lighting, but according to the achieved results it remains the same for building model of WWR 90% and WWR 40%, which may be a sign of another inaccuracy of Sefaira software.

As for the other limitations, the author wants to emphasize that due to the time constrains only limited number of shapes, limited number of WWR and limited number of horizontal shading devices sizes have been analyzed. One more limitation of the study that has to be highlighted is the fact that author looks at the buildings without the urban context. The results of the same experiments in the urban context can vary significantly because of the overshadowing of the examined building by the surrounding buildings.

Conclusions. The authors concludes that the main aim of the research of determination the options to reduce energy demand for office groundscrapers in the temperate climate by architectural passive design means has been achieved, however the number of limitations of the methodology have to be taken into account. The key findings have been discovered by means of literature review and computer simulations (Sefaira software). The conducted literature review has revealed the main passive design strategies capable of influencing the building energy demand reduction, they are: building shape; building orientation; window-to-wall ratios; shading devices; day-lighting; natural ventilation. The author has analyzed these strategies and found out to what extent they can reduce building energy demand. Moreover, individually the strategies can reduce energy use up to: 5% by building shape; 1% by building orientation; 11% by WWR; 4% by shading devices; 26 % by natural ventilation. In addition to it, it has to be mentioned that the obtained results of energy-efficiency overcome significantly the existing benchmarks including: typical energy consumption in offices in Europe, CIBSE Good Practice for UK offices (191 kWh/m2) and correspond to the indices of good practice of energy consumption in offices (naturally ventilated cellular) in the UK.

Based on the all achieved data from the conducted simulations, the author as a part of the aims and objectives of the study has created an early design stage framework . The aim of the framework is to serve as guidance for architects and environmental designers in order to design energy-efficient ground-scrapers with sufficient percentage of day-lighting, by usage of the analyzed passive design strategies in temperate climate.

Author proposes architects and environmental designers to use this framework instead of doing time-consuming calculations themselves as a very first step for an energy-efficient design. The author divides the combinations of the analyzed passive design strategies into three categories (recommended, acceptable and not recommended) by color. Recommended states for highest energy-efficiency and high day-lighting; acceptable states for good energy-efficiency and good day-lighting; not recommended states for low energy-efficiency and low day-lighting.

According to the framework the most suitable combinations have WWR 70%-40% for longitudinal shape, while U-shape and square shape can be used on WWR 70%; in addition to it, author can assume that on the basis of interpolation, lower WWR (for instance, 60%, 50%) can also be acceptable for these shapes. Furthermore, in has to be pointed out that the building orientations of South, South West 30° and South East 30° show the best results in terms of energy-efficiency and day-lighting. The author concludes that the reason for WWR 90% being not recommended almost in all cases is a relatively low energy-efficiency. However, the reason for WWR 40% being not recommended almost in all cases is a low day-lighting caused by self overshadowing.

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Анотація

Дослідження присвячене оптимізації архітектурних проектів на ранній стадії проектування заходами енерго-ефективних стратегій пасивного-дизайну використовуваних для офісних комплексів (горизонтальної компоновки) в умовах помірного клімату, на прикладі Лондона, Великобританія. Як метод дослідження були використані, огляд літератури і комп'ютерні симуляції за допомогою програмного забезпечення Sefaira. Ефект від наступних стратегій пасивного-дизайну на енерго-ефективність будівель було проаналізовано: форма будівлі, орієнтація будівлі по сторонах світу, відношення площі вікон до площі стін

(ООС), горизонтальний сонцезахист, природне освітлення і природна вентиляція.

Ключові слова. Рання стадія проектування, енерго-ефективність, енергетична потреба, стратегії пасивного-дизайну, офісних комплексів (горизонтальної компоновки), форма будівлі, орієнтація будівлі по сторонах світу, відношення площі вікон до площі стін, горизонтальний сонцезахист, природне освітлення і природна вентиляція.

Аннотация

Исследование посвящено оптимизации архитектурных проектов на ранней стадии проектирования мерами энерго-эффективных стратегий пассивного-дизайна используемых для офисных комплексов (горизонтальной компоновки) в условиях умеренного климата, на примере Лондона, Великобритания. Как метод исследования были использованы, обзор литературы и компьютерные симуляции с помощью программного обеспечения Sefaira. Эффект от следующих стратегий пассивного-дизайна на енерго-эфективность зданий был проанализирован: форма здания, ориентация здания по сторонам света, отношения площади окон к площади стен (ООС), горизонтальная солнцезащита, естественное освещение и естественная вентиляция.

Ключевые слова. Ранняя стадия проектирования, энерго-эффективность, энергетическая потребность, офисные комплексы (горизонтальной компоновки), форма здания, ориентация здания по сторонам света, отношения площади окон к площади стен, горизонтальная солнцезащита, естественное освещение и естественная вентиляция.

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