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The energy savings potential of windows in the office buildings sector: State of the art

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Abstract

In recent years glazed envelop has gained popularity in modern building practice throughout the world. The need to energy conservation and sustainable development in buildings is causing a new interest towards such typical envelop building. The construction of appropriate windows is important for reducing the energy use for heating, cooling and lighting in building, especially in office ones where internal gains may exceed the transmission losses. In this paper, existing studies on the topic of window opening are highlighted. A general process driving to the effects of the window on energy consumptions is identified, based on studies presented in literature. This approach is used to highlight how fenestration system affects energy consumption, thermal and visual comfort in office buildings. Authors pinpointed the lack of researches on the performance of glazed facades in hot-summer and cold winter zones. Whereas, some studies elaborated in other climates reveal no similarities; therefore it is necessary to find a significant tool to help direct future research.

Keywords: Fenestration system, Window to Wall Ratio (WWR), Glazing, Energy efficiency.

1. Introduction

Nowadays, energy performance of the envelop building deserves great attention, especially the fenestration system, which is responsible for the most part of the heat gains/losses in the buildings. It is evident that appropriate design and construction of fenestration system can reduce the energy consumption and the environmental impact over its life cycle. Energy savings in buildings not only lead to financial savings and a reduction in the demand for electricity, but also to environmental preservation. To achieve this goal, shade, orientation, type, size and glasses must be correctly specified. According to Encyclopædia Britannica [1], a window is an opening that allows the passage of light and air. It is often arranged for the purposes of architectural decoration. A window is defined as consisting of:

1. Window glazing (single, double, triple, etc.)
2. Spacer
3. Cavity gas (air, argon, krypton, xenon)
4. Window frame

Glazing area is the most important component with regard to energy efficiency. It is defined by the window-to-wall ratio (WWR) which represents the percentage of net glazing area in the exterior building envelope. It has a significant influence on interior building conditions such as thermal, visual and acoustic comfort and energy consumption. Thus it is an important criterion for the design of an efficient building envelope, which should be determined based on the energy requirements for heating and cooling, air quality and daylight.

2. Methodology

In this paper, we present initially the report of window to wall ratio (WWR) with energy efficiency, then we will pass towards the daylithing parameter, we will try to isolate related parameters to the maximum, although they are difficult to dissociate. Some studies are described in more detail, hanging that others are briefly presented here.

3. Literature review

A number of experimental, numerical and theoretical investigations have contributed to a better defining the most efficient fenestration, and its thermal and visual behaviour. It is found in literature review that the presence of the window influences strongly the thermal comfort in three ways:

- Exchange of long-wave, electromagnetic radiation between building occupants and their environment.
- Absorption of solar radiation by the body.
- Convective effects from cooling or warming air currents.

Because of their transparency, glazed façades transmit solar radiation directly into the building. According to Manz and Menti [2], highly-glazed spaces can cause significant thermal energy gains or losses in buildings. On the other hand, window surface temperatures often fluctuate much more than those of other surfaces in a room [3]. Thus occupants can be adversely affected by the presence of large hot or cold surfaces [4], their thermal comfort will be strongly affected but presence of glazed surfaces in the space living. This is why numerous physical aspects need to be considered, when employing glazing in modern buildings, such as use of daylight, optimizing and controlling solar energy gains, minimizing thermal losses, minimizing glare, and optimizing thermal comfort [2]. Evidently their thermal behaviour is difficult to predict [5].

According to Bektas [6] and Kontoleon [7], orientation, glass type, and transparency ratio of the facades are important parameters which determine the energy requirements of buildings. In Jaber and Ajib research [8] authors confirmed that window design, especially glazing choices, is a critical factor for determining the effectiveness of passive solar design. According to Ochoa [4], apparent window size contradictions arise when optimizing simultaneously for low energy (small sizes) and visual comfort (large sizes). In terms of energy consumption, increased window area does not necessarily mean reduced electricity use for lighting [9].

According to Motuziene [10], for each orientation and glazing type, dependency of the total annual energy demand on fenestration is analogous: with the rise of the fenestration, energy demand and influence of the glazing characteristics rises as well. In addition to all these parameters, Ozkan [11] states the importance of thickness of insulation material in terms of energy consumption.

3.1. Effect of (WWR) on building energy efficiency

Glazing area influences building's heating, cooling, ventilation and lighting energy demand. In this context many studies analyzed the effect of the increase of (WWR) on energy efficiency. These studies are frequently based on simulations approaches, and starts from the need for analysis for the energy balance in order to reduce the energy needs, the use of renewable energies, and daylight. Among these studies, Bodart and Herde [12] analyzed, how width of the office space, (WWR), window position, orientation and light transmittance influence lighting energy demand and global primary energy (PE) demand of the office building. In 2006, Persson [13] performed a parametric study and investigated the energy consumption and maximum power needed to keep comfortable indoor temperature between (23-26 °C). The authors found that the size of the windows does not influence the peak power for heating noticeably. However, using a larger window area facing south would increase cooling loads during the summer, in the case of lack of ventilation and screening. Poirazis *et al.* [9] carried out energy simulation of single skin office buildings in Sweden climate in 2008. The purpose of the study was to determine the impact of glass on the energy use during the occupation stage. The main conclusion is that for highly glazed office buildings, careful design is needed to ensure low energy use.

In the latitude 32° (Amman city), Hassouneh *et al.* [14], examined the influence of windows on the energy balance of apartment buildings in 2010. Eight types of glazing are investigated. It has been found that a larger window facing south, east and west decrease energy use in winter, with use of certain types of glazing such clear glass. While decreasing the glazing window in north direction can save energy. In another study, Su and Zhang [15] explored the Environmental performance of different window type in a typical office building in hot summer and cold winter zone in China based on life cycle assessment. The results show that single glazing window has the greatest influence on the life cycle environmental burden of whole building, especially for north direction. They recommended (WWR) value from 40 to 50 % for the office building with clear glazing. On the other hand, the window with low-e has a little effect on the life cycle environment burden.

The study of Leskovar [16] evaluated the potential of different (WWR) with regard to energy-efficiency of prefabricated timber-frame, with the use of the PHPP software. The results indicated that the largest influence of increasing the (WWR) is observed for the south orientation. In contrary north is less expressive. In another paper, Pino *et al.* [17] evaluated thermal and lighting behaviour of office buildings in temperate climate of Santiago climate (33.44° latitude) in 2012**,** through computational simulations in dynamic conditions. The most influential factor on heating and cooling demand is the size of glazed surfaces. Later in 2013, Lee *et al.* [18] reported a study in which the annual heating, cooling and lighting energy consumption of different types and properties of window systems, is examined in five typical Asian climates: Seoul, Taipei, Manila, Shanghai, and Sapporo. The authors established a design guideline in optimizing window system for each climate. By means of a regression analysis, authors established simple charts for the relationship between window properties and building energy performance. In the same context, Kim *et al.* [19] tried to determine the effect of variation of the window elements on energy consumption by using the COMFEN4.0 simulation tool. Authors propose an actual energy analysis indicator in the Republic of Korea. For their part in 2015, Hee *et al.* [20] used a literature review to study the impacts of window glazing on the energy and daylighting performances of building. The glazing technologies and optimization techniques used in choosing a glazing were highlighted.

Many other researchers have tried to define the most efficient fenestration. Among these studies: Demirbilek *et al.* [21]; Ghisi and Tinker [22]; Li *et al.* [23]; Zemmouri and Schiler [24]; Eskin and Turkmen [25]; Binarti [26]; Singh and Garg [27]; Sabouri, and Mohd Zain [28], all the authors studied the influence of the (WWR) on the energy consumption of buildings. Each researcher has determined the best window size for a defined climate through his study, in order to achieve energy conservation. According to their results, we conclude that, there is a correlation between the glass area and energy consumption, however the best (WWR) is relative to each type of climate.

3.2. Effect of (WWR) on daylighting

The lighting has psychological and physiological effects on the occupants and several advantages on visual comfort. A big size of glazing allows increasing of the illumination level in the space. At the same time, the problem of overheating due to solar gains can arise. In cold zones, with overcast skies, diffuse light is a good source of space lighting. In contrast, daylighting is most challenging in hot and sunny climates due to the great amount of illumination received from the sun. Performance characteristics of glass, like light transmittance and solar heat gain coefficient, and size of glass affect the quantity and the quality of light which enters the building.

Many researchers have tried to define the most efficient fenestration in terms of lighting. Ghisi and Tinker [22] defined an ideal window-to-wall ratio (WWR), in terms of lighting energy demand. It varies between 10 and 37 %, depending on orientation and geometry of the room.

According to the study elaborated by Tzempelikos *et al.* [29], the availability of daylight is ensured by the largest (WWR). The use of large windows of clear glass allowed the maximization of use of daylight. The authors defined a sufficient (WWR =30 %) for typical perimeter office facing south. Manuel and Melendo [30] reported a study which investigated the impact of (WWR) on annual energy in HEED’s region. This study showed that increasing (WWR) produces a significant increase in annual energy demand, but there's glazing ratios for each direction in which the availability of natural lighting is stabilized. As a result, the reduction of (WWR) below these values can provide adequate lighting, with a significant reduction in energy consumption and low values of CO_2 emissions. According to the same study, a facade faces south with a (WWR) of 30% provides an illumination value of 500 lux on the work plan for 85.9% of working time per year. Furthermore, the increase of 30% (WWR) will not result in a significant increase in daylight. Saridar and Elkadi [31] examined the impact of the changes of the façade configuration on the levels of daylight in offices of Beirut (Lebanon), by using a method of calculation. (WWR) is regarded as a measurement to determine daylight levels through the various stages of the design evolution of the facade in Lebanon. The survey showed that in recent office buildings with large glazed areas in this country, the users use the curtains and artificial lighting because of glare. M.C. Singh and Garg, 2010 [27] report a study of the daylight potential in the reduction of the electric load, with daylight software (ADELINE 3.0) and the Perez model. The analysis is established for three different climatic conditions from India; composite climate (Delhi), heat and dryness (Jodhpur) and heat and wet (Mumbai). Results indicate that for a low value of the visible transmission of the window the energy saved by the use of daylight increase with the increase of the glazed sector of the window, however for a high transmission of the window even if a glazed surface is 20%, autonomy in daylight is carried out.

The simulations carried out by Tzempelikos *et al.* [29] investigated four types of windows and three climatic zones of India, and showed that a façade directed to the South, with a (WWR) of 30%, allows providing 500 lux of natural illumination on the work plan for 85.9% of working time in year. However Increasing (WWR) more than 30% will not have a significant increase in daylight.

For the Northern façade, increasing the sector of the glazing from 40% to 80%, results of increasing the availability of the daylight of 7.06 %. The two directions East and West reach stability conditions of daylight for (WWR) larger than 40 %. This work is of interest regarding energy saving in this country. According to Pino [17] a small window to wall ratio (WWR) with a solar protection can reach a better performance of daylight than the great ratio due to the prevention of the glare. Bülow - Hübe [32] reported another study in 2008, which investigated the effect of some façade alternatives on the availability of daylighting and visual comfort in office buildings. The programs Rayfront/Radiance and Daysim are employed in this work. Three cases are compared, where the windows present a (WWR) of 30, 60 and 100 %. The author found that venetian blinds and overhangs significantly reduce daylight factor. The comparison between the three sectors of window studied highlighted that the case with 30 % (WWR) inclined with 30° avoid the direct penetration of daylight, while preserving a visual relationship to outside. From this study also rises that it is difficult to find a powerful system of screening for the whole year.

A research carried out by Mazloomi [33] investigated the horizontal distribution of the daylight factor according to the variation of the window to the wall in the tropics. The case of the pendentive dome buildings is investigated in this work in Kuala Lumpur climate (Malaysia). Five various ratios (WWR) are considered (0.1 0.2, 0.3, 0.4 and 0.5). The results approve a direct relationship between the (WWR) and the daylight factor (DF). In general, any increase in (WWR) with a step of 0.5 results in increase from DF from 0, 5%. The objective of another study of Voll *et al.* [34] focused on daylithing availability in European zones of approximately 59 to 60° of Northern latitude. An ordinary window is compared with a daylight window. The last one is provided with an external screening and interior horizontal reflective panels.

The results show that the window known as daylight allows smoothing out the interior daylight distribution. It prevents consequently the glare caused by large glazing. The results show that daylight window allows the use of (WWR) = 50-90%, when an ordinary window allows a glazed surface of only 40-50 %, to avoid glare problems. Shi and Lin Chew [35] in their analysis of the renewable energy systems and the effectiveness of each one in the reduction of the energy consumption, concluded that the parameters relating to the system of daylight, such as the type of fenestration, material, size, form, orientation, position, ceiling and shade devices, must be conceived carefully to optimize the luminous environmental quality for occupants.

In order to determine the alternatives of building envelope to provide the optimal conditions in terms of visual, thermal, and acoustic comfort in the office rooms, a research project was carried out by Unver *et al.* [36]. Three rooms of different size, two various types of glass and two ratios of transparency are selected (20 and 50 %). simulations were carried out for the weather conditions of Istanbul. The results show that the orientation, the screening and the (WWR) are the most important parameters to maintain required daylight level, while the type of glass and the thickness of the wall do not affect significantly visual comfort. Energy simulations of the building were carried out by Lee and Tavil [37] with the Doe-2 program in order to determine control strategies which would allow electrochromes windows (EC) to improve visual comfort. Electrochromes windows were combined with overhangs in order to provide a protection of the direct solar radiation in a typical commercial building directed to the south in hot and cold climates such as Houston and Chicago. It results that EC windows, with overhangs can reduce considerably the average annual daylight glare index (DGI) and provide significant annual energy saving for large windows, for the examined cases. According to the research realized by Ghisi and Tinker [22] in the climate of Leeds and Florianópolis, the great sectors of window bring more daylighting in a space, but they can produce losses or excessive gains of heat which increase cooling and air-conditioning load of energy. Pino *et al.* [17], in another work which examined the buildings in Santiago (Chile), found that a small (WWR) with solar protection can reach a better performance of daylight than the large (WWR) due to occupant behavior prevention of glare. This result agrees well with the survey of Saridar and Elkadi [31], and Poirazis [9] mentioned above.

It is obvious that such behavior affects the energetic consumption. In their study Chirarattananon *et al.* [38] confirm that the increase in (WWR) allows an increasing penetration of lighting with a heat gain. This relative profit of light and heat by the glazing and the whole wall is related to the properties of each type of glass, as well as the properties of the wall.

4. Conclusion

Literatures review shows that before optimizing the overall performance of a building envelop, fenestration system must be controlled according to the solar azimuth and altitude. Glazing choices, shading devices and orientation are the main parameters needed to define the (WWR). Another finding is that there is a correlation between the glass area and energy consumption, however the best (WWR) is relative to each type of climate.

The above-mentioned studies reported in the literature of effect of (WWR) on daylighting comfort conditions and energy demand; show that the majority of researches are undertaken in cold, hot, moderate, and tropical climates. Only a few researches on the performance of glazed facades in hot-summer and cold winter zones have been undertaken. However, there is a scarcity of research in semi arid climate till now; the only study among the main sources of literature which were reviewed concerning office buildings in semi arid climate was investigated by Zemmouri and Schiler [5] in Batna climate in Algeria.

Considering the research tools, simulation and numerical models are the most used to define the best (WWR) in each climatic conditions.

Finally, we conclude that studies presented still cannot answer what (WWR) is optimal in terms of energy efficiency, when daylithing, cooling heating, and ventilation demands are considered in semi arid climate. A great work is still needed in semi arid climate, may be a significant tool to help future research.

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