PARAMETRIC ANALYSIS FOR DAYLIGHT AUTONOMY AND ENERGY CONSUMPTION IN HOT CLIMATES

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ABSTRACT

Significant contradiction arises in buildings in the hot climate regions when relating window sizes and shadings to achieve both reduced energy consumption (requiring minimum opening ratios and more shading) and sufficient daylighting (requiring maximum opening ratios and less shading). This paper is a part of an on-going Master Thesis research based on a Parametric Analysis to study the quantitative effect of window's ratio, glazing and shading techniques on Daylight Autonomy and Energy Consumption in a hot climate region. This study aims to aggregate two different parameters to achieve better daylight autonomy and less energy consumption, mentioning possible further criterions for assessing the buildings performance.

INTRODUCTION

Designing facades is one of the most complicated subjects that faces the architect throughout the design process, especially when the design intention is to reduce energy consumption and improve the occupants health and well-being (Rashid et al. 2008; Edwards and Torcellini, 2002; Boyce, 2003). Facade openings in buildings are important for several reasons; they provide daylight, which is considered the best source of light that matches human visual response and required colour. Thus, they have a substantial positive impact on the occupants (Li & Tsang, 2008). Natural lighting has two noticeable effects, Light and Heat. In hot climates, large windows can provide more daylight but higher cooling loads, while small windows can decrease energy consumption but do not offer sufficient daylight. Hence, hot climate is considered one of the most challenging climates when it comes to daylighting (Meleki, 2012). On designing daylit buildings, the most critical decisions come in the conceptual phase and the primary strategies (Leslie et al. 2011). Due to the exponential growth of cities, and the need for more residential building, it is important to provide a guideline for the architects and designers in order to achieve good results regarding daylighting.

Based on the Egyptian code of Energy Efficiency in Residential Buildings (EERB), different choices of glazing transmittance and interior reflections were proposed for the different window ratios and Projection Factor (PF). Research has been conducted to assess the effect of window to wall ratio (WWR) and shading types on both daylight autonomy and energy consumption or even daylighting alone (Mandalaki et al., 2012, David et al., 2011 and Li & Tsang 2008). Others that followed developed daylighting dashboards (Reinhart et al., 2010, Leslie et al., 2011) were based upon new simulation software attempted to combine more than one parameter in examining daylighting and energy consumption, e.g. DIVA for Rhino and AGi32. So an integrated design approach of daylighting and energy consumption was therefore highly recommended (Hampton, 1989).

The Authors present a new contribution in this paper, where the urban context is a considerable factor within the simulation process. Several window ratios were combined with different shading types to assess both daylight and energy consumption (heating & cooling). All these parameters have been parametrically analysed through a multiple simulation process. This research presents an important step towards a more inclusive and validated optimization process.

METHODOLOGY

This paper is a part of a Master Thesis, which aims at conducting a Parametric Analysis between two main parameters; Daylight Autonomy and Energy Consumption. It is a computer-based study of a single residential zone in Cairo.

This study is realized through four main steps. The first step is defining in detail the properties of the chosen climatic zone for the study. The second step is pin pointing the software used for the simulation, illustrating the process of using these tools. The third step entails a clear image on the variants and invariants that the parametric analysis was based on in addition to the urban context analysis. The fourth and last step defined the thermal and daylight parameters assumed in the simulation process giving the results. The sections followed explain in detail the steps undertaken.

Weather analysis

The location of the Case study is in Cairo, Latitude 30.1 and Longitude 31.4. The high temperatures in winter ranges from 19C to 29C, while at night it drops from 11C to 5C. High temperatures in summer can reach 40C by maximum, and drops to 20C at night. In Egypt, there is more demand on cooling since the hot arid climate is predominating and overheat period lasts for about 7 months. (Attia et al., 2012) According to the Weather tool supported by Ecotect 2011 Software, the extreme sun altitudes are 36.4 degrees in winter and 83.2 degrees in summer at 12:00 noon for a south façade.

Simulation

Two simulation tools were used in this study. First: Design Builder simulation software for the thermal analysis and energy consumption – only heating and cooling loads –. Second: DIVA for Rhino is used for the Daylight Autonomy simulation and calculation in accordance with the energy consumption of the electric lighting used to compensate the luminance needed for the areas that did not meet the targeted luminance.

DIVA for Rhino performs a simulation for the single thermal zone. However, thermal model built in Design Builder since it covers more materials that applied for the assessment of the case in Cairo. As for the electricity loads consumed by lighting, it will be calculated precisely according to Daylight Autonomy by DIVA, as Design Builder does not provide this integration yet.

Variants and Invariants

Many factors affect the assessment of Energy Consumption and the Daylighting inside the buildings. This is shown as follows:

Parameters Group 1

- Geographical location (Fixed)
- Sky condition (Fixed)
- Area / volume (Fixed)
- Function / Activity (Fixed)
- Urban context and Orientation (Fixed)
- Vertical Sky Component (VSC): The height of the window above the ground (Variant)

Parameters Group 2

- Window Design & Ratio (Variant)
- HVAC, Lighting and Equipment (Fixed)
- Building Envelope (Fixed)
- Glazing properties: Transmittance, Reflectance, Secularity, SHGC (Variant)
- Shading Types and devices (Variant)

Due to time constrains, research scope and limitations, the parameters were not all handled at the same time. As illustrated above the Geographical location, sky condition, Area, Function, VSC, Urban context and orientation were all fixed. The Authors gathered them under a group of parameters whereas the architect or the engineer does not have any possibility to change or modify. The second group of parameters is WWR, HVAC, Building Envelope, Glazing properties and Shading types, where the architect may have the possibility to modify an existing condition. This study will handle the WWR, VSC and Shading Type as three variants, it must be noted that thermal and visual comforts are not included in this research.

Model parameters

The simulation examines an experimental Shoebox representing a sample of a single residential zone. The shoebox parameters are as follows: 4m x 5m x 3m (Width x Length x Height). The total area is $20m^2$, with $60m^3$ Volume. Window to Wall Ratio varies from 20% to 40% and 60% on the South Façade, with different designs. The simulation examines seven different Shading cases. (1)The first case has no Shade. (2) The second case has a tinted double layer glaze with Total solar transmission (SHGC) 0.427 and U-value 3.1 W/m^2K. (3) Horizontal blinds parallel to the window with 180-degree angle. (4) Perforated screen with 80% perforation ratio and 1:1 depth ratio as an optimized parameters of a solar screen (Sherif et al. 2012) (5) An overhang and side fins with 50cm long over the window. (6) Fixed shading overhang and side fins with tinted glaze. (7) Fixed shading overhand and side fins with horizontal blinds. (8) The last shading type is Horizontal blinds with tinted glass.

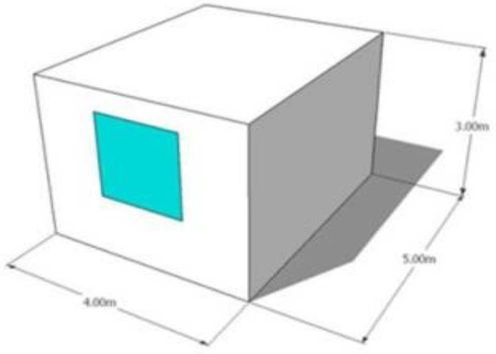


Figure 1 Shoebox Model

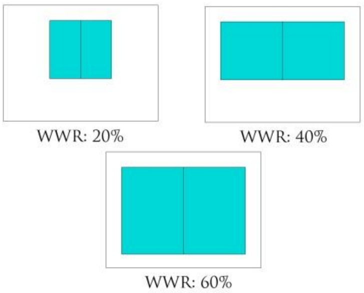


Figure 2 Proposed Window ratios

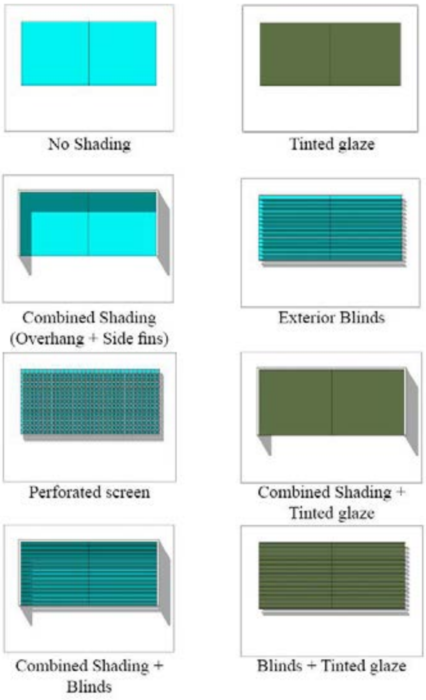
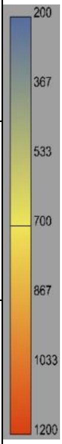
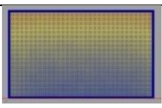
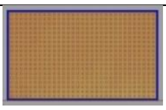
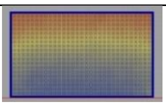
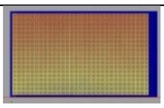
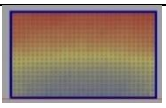


Figure 3 Window different shading types

Urban context definition

Since the assessment process is based on simulation, the urban context should be simulated before assessing the single zone. The Egyptian unified code for construction (2008), states that the minimum street width for an urbanized neighbourhood is 10 meters and the height of the building should not exceed one and half of the street width. This gives several possibilities for the formation of an urban context. The Author conducted an earlier study to illustrate the possible effects of the urban context on the amount of solar radiation exposed by the building's façade. The dimensions of a prototype with 6 stories residential building are18 meter height and 22m width (Attia et al., 2012) was built in a three virtual urban contexts according to the Egyptian unified construction law. Simulations were carried out with DIVA for Rhino. The following results showed up (see table 1).

Table 1: Radiation map on different facades according to different context

	12m width street	24m width street	No neighboured building	kWh/m 2
North Façade	 mean radiation: 290kWh/m^2	 mean radiation: 355kWh/m^2	 mean radiation: 430kWh/m^2	
East Façade	 mean radiation: 514kWh/m^2	 mean radiation: 677kWh/m^2	 mean radiation: 856kWh/m^2	
West Façade	 mean radiation: 575kWh/m^2	 mean radiation: 785kWh/m^2	 mean radiation: 1010kWh/m^2	
South Façade	 mean radiation: 714kWh/m^2	 mean radiation: 975kWh/m^2	 mean radiation: 1192kWh/m^2	

The study is focuses on the south orientation with 12m width Street. Two levels are examined; higher (12m) above the ground, and lower level (5m) above the ground.

Thermal model parameters (Design Builder)

The wall section for the thermal model was selected according to an optimized case for the Egyptian typical wall section for the residential sector. However, in this case interior walls, Ceiling and Floor are set adiabatic, only the exterior wall has the properties that will affect the thermal analysis. The total U-value of the exterior wall is 0.32 W/m^2.K according to the following wall section.

Table 2 Exterior Wall Section

Material	**Width (mm)**	**Conductivity (W/m.K)**	**Density (Kg/m^3)**
Mortar	20	0.88	2800
Inner Brick leaf	120	0.62	1700
Insulation	100	0.04	15
Inner Brick leaf	120	0.62	1700
Mortar	20	0.88	2800

The designed density of the occupants is 0.2person/m^2, which has a mean of four persons per the zone. Metabolic rate is 0.9 for a general manual work and light activities. No internal gains from any equipment or lighting are calculated. The model was designed without holidays. Heating Setpoint temperature is 20C while cooling Setpoint is 28 and the ventilation setpoint is 22C. The U-value of the double clear glazing is 3.15 W/m^2K. The window has a wooden frame of 4cm, and without any dividers.

Daylight model parameters (DIVA for Rhino)

According to the Egyptian code of Energy Efficiency in Residential Buildings (EERB) the mean target illuminance for the single residential zone is 300 lux. Ceiling reflectance is 80%, Floor and Ground reflectance are 20%, Interior walls reflectance 50%, Outer facades with reflectance 35%.

According to the Illuminating Engineering society of North America (IESNA) Daylight Availability refers to the amount of daylight available from the sun and the sky at a specific location, time, and date and sky condition. In order to calculate this, the annual amount of daylight should be quantified. Climate-based Daylight Modeling approaches (CBDM) (Mardaljevic, 2000; Reinhart and Walkenhorst, 2001) are approaches that handle long periodic analysis. However, there is no consensus in identifying the important information generated by these methods. This stage uses the Dynamic Daylight Performance Metrics (DDPMs): Daylight Autonomy (DA) (Reinhart and Walkenhorst, 2001) and Useful Daylight Illuminance (UDI). Those metrics use annual simulations to find the percentage of useful daylight availability at a given sensor point according to a given required illumination level. In order to calculate the Daylight Autonomy or Useful Daylight Illuminance, the designer should use advanced daylighting simulation tools such as Daysim using Radiance simulation engine.

Adequacy of the daylighting levels are defined according to the most common approaches used which is (DA) and (UDI). As defined by the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylit alone. The target illuminance is used as the metric for the space according to (IESNA). The (UDI) distribution uses upper and lower thresholds (Nabil and Mardaljevic, 2005 & 2006) times that represent excessive daylight that can lead to thermal and visual discomfort is the upper threshold (UDI>2000lux) and the times with too little daylight is the lower threshold (UDI<100lux) and the intermediate level is (UDI 100-2000lux)

Until now, several subcommittees under the (IESNA) and the (CIE) attempt to define and make authoritative practice of DDPM criteria to evaluate the performance of Daylighting (Mardaljevic , 2009). According to the Daylight Rule of Thumb (DRT) where an interior area is considered to be daylit if it receives at least half the time sufficient daylit compared to an outside point, which means more than 48% (Reinhart 2005). Since this is an on-going development to assess the minimum threshold for Daylight Autonomy in the different types of buildings (Sherif et al.) 2012, assessment criteria adopted in this paper were assumed as follows:

– Due to the possible difference in results that usually occur between the simulation model and reality, a margin of 5% variance in Daylight Autonomy between the different designs is considered. In addition, more than 50 Kwh/yr. is considered a “significant’ in the annual energy consumption.

– The percentage of the space with a Daylight Autonomy larger than or equal to 50% is considered the moderate threshold for a well Daylit living area for a residential zone. The type of uses that need 300lux level of illumination were not expected to occupy more than 50% of the space, and other uses at the back area of the room do not need higher daylighting levels.

On the other hand, 300Kwh/yr. is defined as the threshold for the total energy consumption in which it resembles the criteria of passive house designs that consumes no more than 15Kwh/m^2/yr. Occupancy schedule were set from 8:00 to 18:00. This same duration will be used for assessment duration for the Daylight availability with a reference to the Energy Consumption.

DIVA calculates the electricity needed for lighting. According to the available daylight, light bulbs switch on/off manually when daylighting threshold is under 250 lux (Reinhart, 2004). There is one group of lighting sensors is set in the first third are of the room. According to the Egyptian code of Energy Efficiency in Residential Buildings (EERB), the mean amount of electric density needed to illuminate a living room is 19W/m^2. If we use energy saving bulbs, therefore 80 W is needed to light up the room when there is no sufficient daylight.

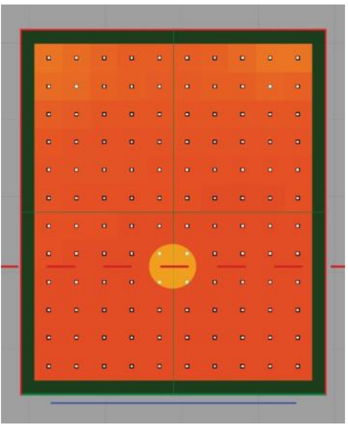


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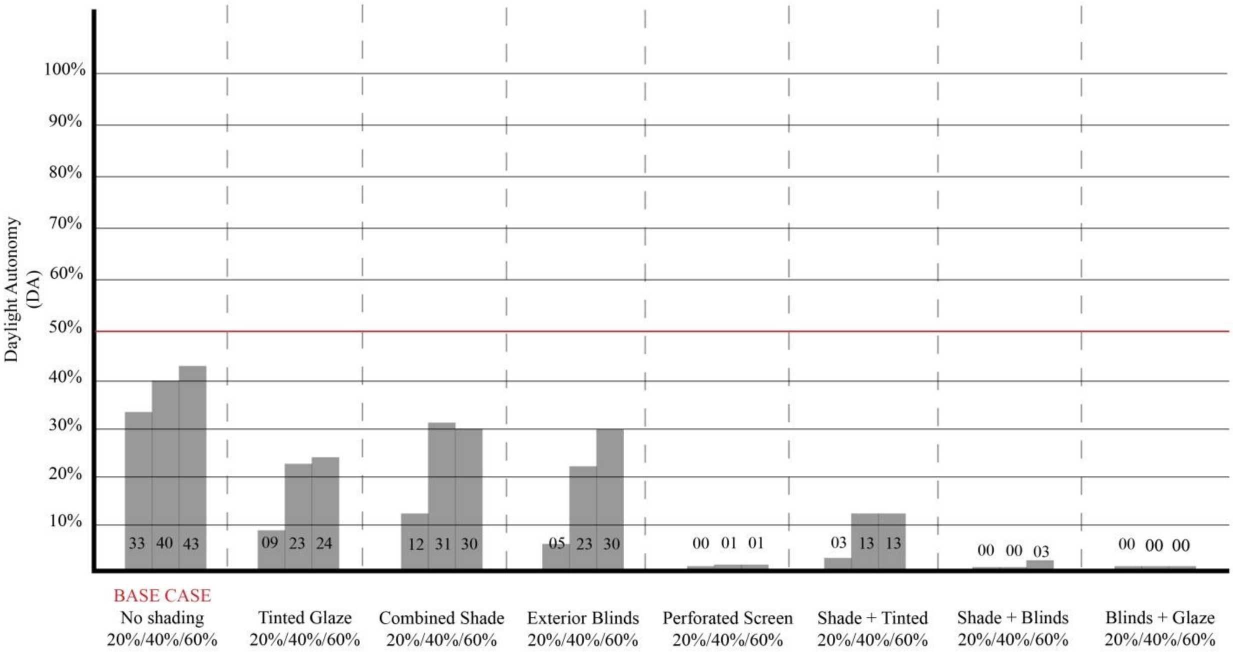
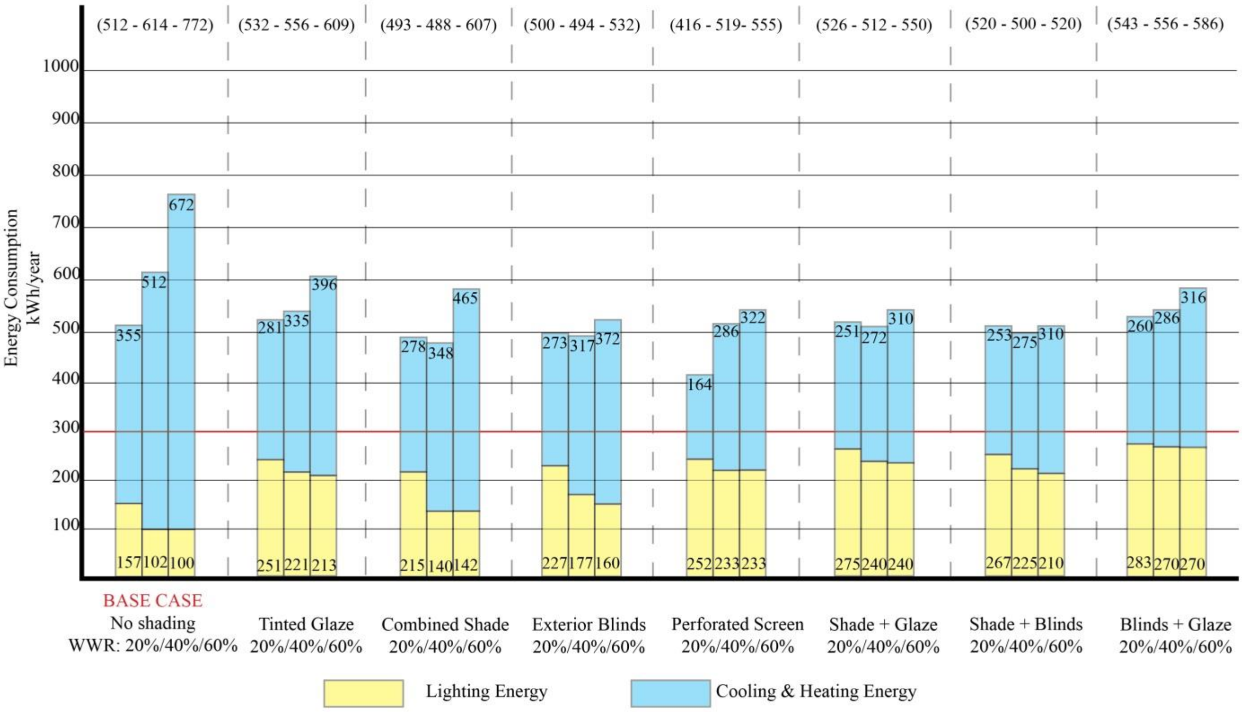
Figure 4 The placement of the lighting sensor

RESULTS

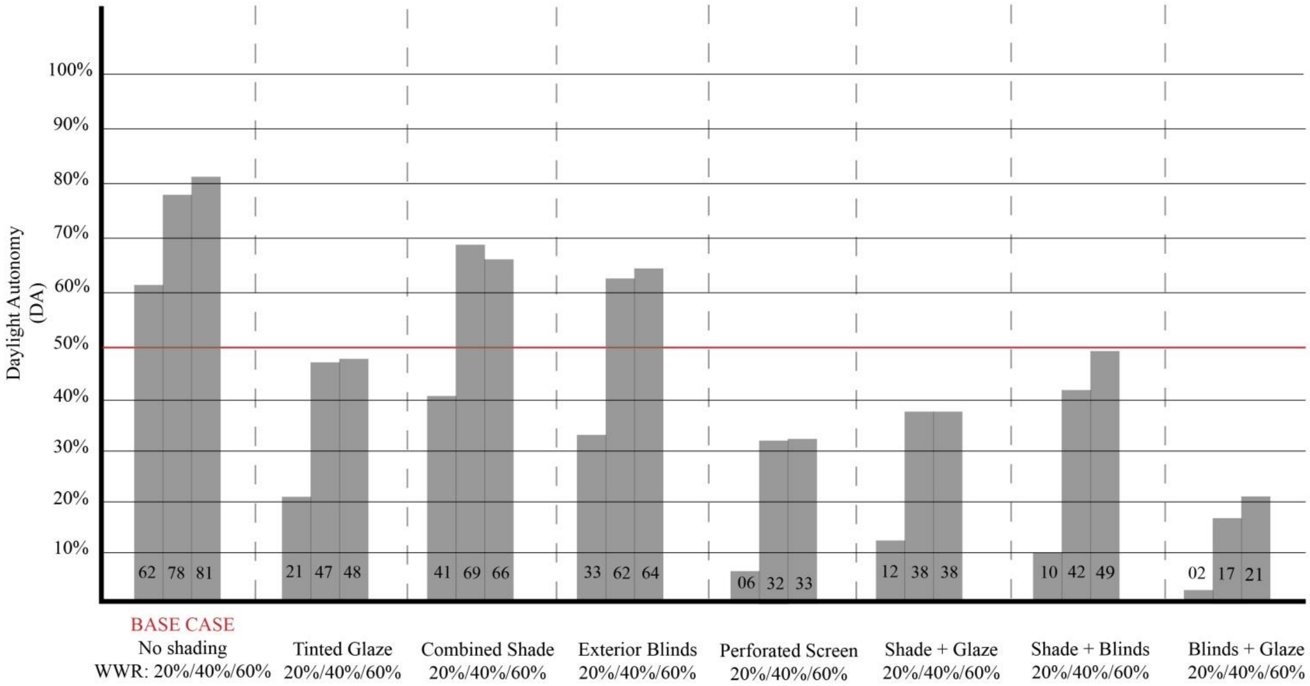
Lower Floor Daylight Autonomy (DA)



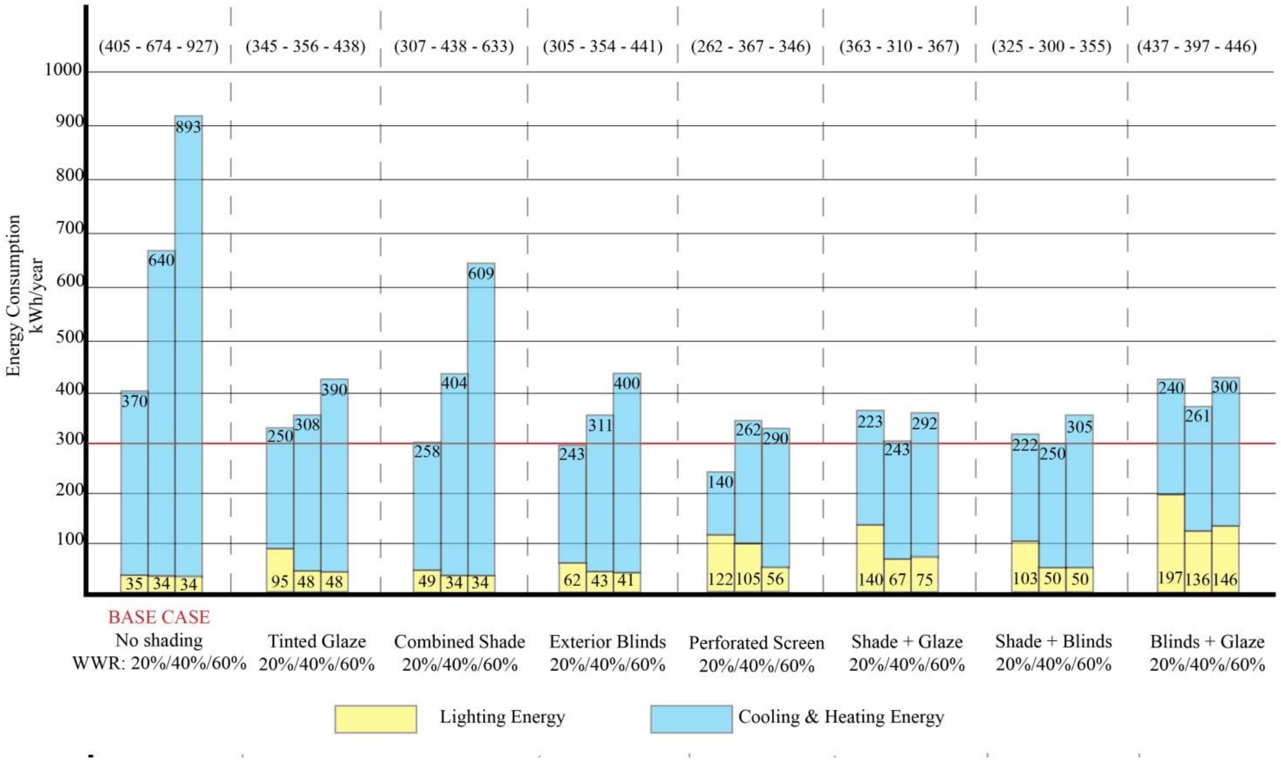
Lower Floor Energy Consumption



Higher Floor Daylight Autonomy (DA)



Higher Floor Energy Consumption



DISCUSSION

This study has showed 96 simulation; 48 for each of daylighting performance and energy consumption. It is obvious now that the assessment strategy for different window designs will differ intensely according to the urban context. Lower floors need more lighting energy than the upper floor, which approximate the total energy consumption results with the upper floors that consume more heating and cooling energy.

The lighting energy is calculated using DIVA for Rhino, in which the resulted schedules are integrated with the energy model through EnergyPlus simulation engine. The integration between the two simulation tools was important. Heat loads generated by the lighting energy were calculated in the total heating and cooling loads giving results that are more valid.

However, the Egyptian code of Energy Efficiency in Residential Buildings (EERB) has proposed optimum window ratios, it was important in this research to study the integration of various window ratios with different shading devices and glazing. The study has proven that different window ratios effects change dramatically according to the type of shading and glazing. Trade-offs between different solutions can be made according to the resulted performance. The overall target of this paper is to aggregate two different parameters to achieve better daylight autonomy and less energy consumption.

In this research, the Daylight Autonomy is given the priority in the assessment process and then energy consumption comes in the second stage. This is because there are many strategies that control the total energy consumption, such as the HVAC system, insulation materials and internal loads, which are fixed in this case.

CONCLUSION

In the lower floor, there is a significant shortage of daylighting in all types of fenestration designs with even with the maximum window ratios. Some design options failed to achieve at least the target illuminance which is 300 lux, such as perforated screens, combined shade with blinds or tinted glaze and blinds with tinted glaze, in all window ratios.

The second, third and fourth options seem to have the same results; with WWR 20% tinted glaze gives DA 9%, combined shade gives DA 12% and blinds gives DA 5%. With WWR 40%, tinted glaze and blinds have the same result of DA 23%, but combined shade have higher DA with 31%. Only with 60%, combined shade and blinds give higher DA 30% than the tinted glaze that gives DA 24%.

The base case without any shading device or tinted glazing has better performance in daylighting. The difference in daylight autonomy between WWR 40% and 60% in the base case is 3%, which has no significant effect. On the other hand, 60% window ratio consumes much energy than 40% in the base case. Therefor a window with 40% WWR has the better performance; however, it may have other disadvantages due to privacy concerns (Hegazy et al. 2013).

In the energy consumption chart, most of the design options, except the base case, with the different window ratios have the same energy consumptions with approximately equal 500 Kwh/yr. with 30 Kwh/yr. more or less. It is also significant that in many cases the lighting loads are nearly equal to or higher than the heating and cooling loads.

In some design options, WWR 40% consumes more energy that WWR 20%, such as combined shade, exterior blinds, combined shade with tinted glaze and combined shade with blinds, which is unexpected by the community of architects or designers. Yet, it is important to know that these cases are according to the designed parameters and simulation conditions.

In the upper floor, only the perforated screen, combined shade with tinted glaze and blinds with tinted glaze, failed to achieve the DA 50% threshold. Tinted glaze did not reach the DA threshold, however with WWR 40% and 60% it was very near to reach it. The base case have the higher DA % in all window ratios, nevertheless it consumes much more energy for cooling.

The third and fourth options of combined shade and exterior blinds have high DA. WWR 40% and 60% give only 2% or 3% of difference; however, WWR 60% consumes more energy than WWR 40% with almost 200 Kwh/yr. with the combined shade option, and 90 Kwh/yr. with the exterior blinds option. WWR 20% of both options did not reach DA 50% and consume almost the same energy.

The debate can be run between the second and the seventh option with WWR 60%. The DA difference is only 2% that is considered not significant, but it is significant with energy consumption in which tinted glaze with WWR 60% consumed more 83 Kwh/yr. than combined shade with glaze. The best choice between the different designs will be the seventh option of combined shade with blinds.

Similar to the previous chart of the energy consumption, some design options with WWR 40% consumes more energy that WWR 20%, such as combined shade with tinted glaze or blinds and blinds with tinted glaze. Only with perforated screens, the WWR 60% consumes less energy than

WWR 40% due to the significant reduction in lighting loads.

This study resembles an important step to define results that are more compatible with the onsite conditions. The Authors are suggesting conducting further research to examine the wide range of parameters of each shading type including examining the performance of the four facades under multiple urban contexts.

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