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IMPACT OF FENESTRATION ON BUILDING ENERGY CONSUMPTION, A CASE STUDY TOWARDS ACHIEVING NZEBs IN EGYPT

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Abstract

This Research paper mainly focuses on the impact of fenestration design alternatives on the building energy consumption through an extensive simulation process using OpenStudio interface of EnergyPlus program. A medium size office building model was created as a case study. A variety of different scenarios for window to wall ratio "WWR", the use of appropriate shading systems of different designs and their impact on the building energy consumption were analyzed. 51 cases for different WWR and shading system Design-alternative combinations were studied in 3 Egyptian cities "Cairo, Alexandria and Aswan" located in 3 different climate zones. Cooling loads were reduced in some cases by more than 40% while total Building energy dropped by around 26% in some cases. This research can help designers optimize the energy performance of the building by making few changes to the building architectural envelope and its shading system.

Keywords

Fenestration, Shading, Simulation, Zero Energy Buildings.

1. Introduction

Although there have been many studies done on fenestration design properties in energy-efficient buildings, the application of these studies on the Egyptian situation is much less. Egypt is located in a hot arid climate region with a very high solar radiation intensity. The thermal performance of the building envelope is one of the most important determinants of the building's energy consumption, as facade configurations are predicted to be responsible for up to 45% of the building's cooling loads (Mohamed.M et al 2013). Thus, Designing fenestration and using optimized shading plays a significant role in reducing the solar radiation effect on Buildings which will reduce cooling demands and enhance indoor thermal comfort. This helps to control the indoor temperature, improve thermal comfort and reduce cooling Loads, as fully shaded openings during hot weather can reduce solar heat gains by as much as 80% Mohamed. M et al (2013). Nowadays new buildings must be designed, built up and managed in order to achieve (or approach) the Net Zero Energy Buildings (NZEBs) goal. In this regard, innovative energy saving strategies have to be taken into consideration (Adolfo. P et al 2015).

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A zero energy building can be defined in several ways, depending on the boundary and the metric. USA Department of Energy DOE had set four definitions for ZEBs
(A)Net Zero Site Energy. (B)Net Zero Source Energy. (C)Net Zero Energy Costs. (D)Net Zero Energy Emissions. (P. Torcellini et al 2006)
Net Zero site energy can be more suitable for the situation in the 3 cities since off-site renewable energy is not easily accessible in these areas as most of the available renewable energy power plants are located quite far from main cities. Up until now Egypt doesn't have any ZEB and since the whole world now is moving towards ZEB, this research aims at reducing the energy consumption of Egyptian office buildings as a necessary step towards achieving the ZEB targets.

2. Methodology

Egypt is situated between latitude 31.33° and 22 °N, and Longitude 26 and 35 °E. It consists mainly of desert (≅ 94% of Egypt land) except for Northern and Eastern coast and Nile valley (George B 2013.). Egypt is divided into eight climate zones: Northern Coast zone, Cairo and Delta zone, Northern Upper Egypt zone, Southern Upper Egypt zone, East Coast zone, Highland's zone, Desert zone and Southern Egypt zone. This paper will focus on the main three climatic zones (shown in Fig. 1) defined in EREC (H.a.B.N.R.2008). These three climatic zones are: (1) Cairo and Delta zone (Cairo governorate), (2) North coast zone (Alexandria governorate) and (3) the Southern Egypt zone (Aswan governorate). About 50% of the construction projects carried out in Egypt are located in Cairo and Alexandria governorates (L.B. Joe 2003), while Aswan governorate is considered a very different zone in terms of the climatic aspects compared to the other zones (M.S. Shafaq2012).

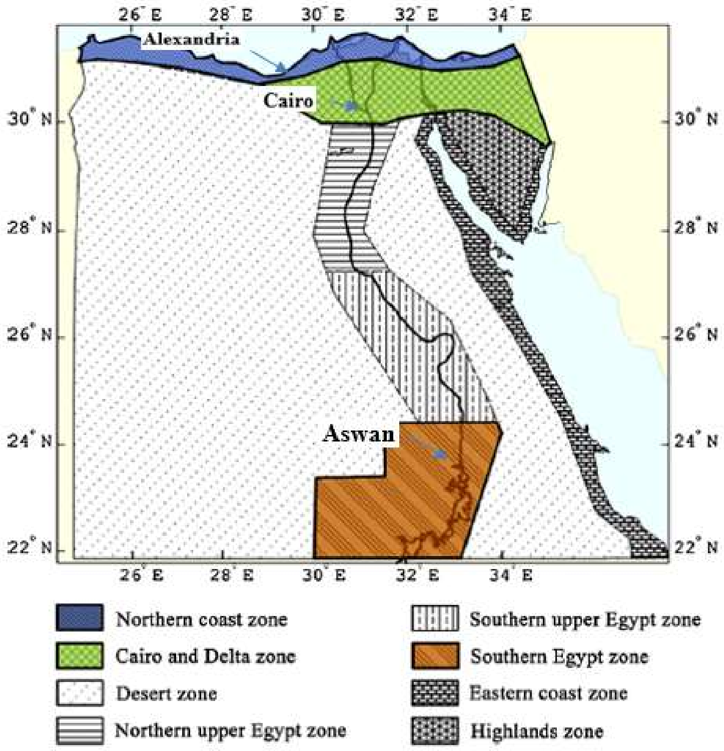


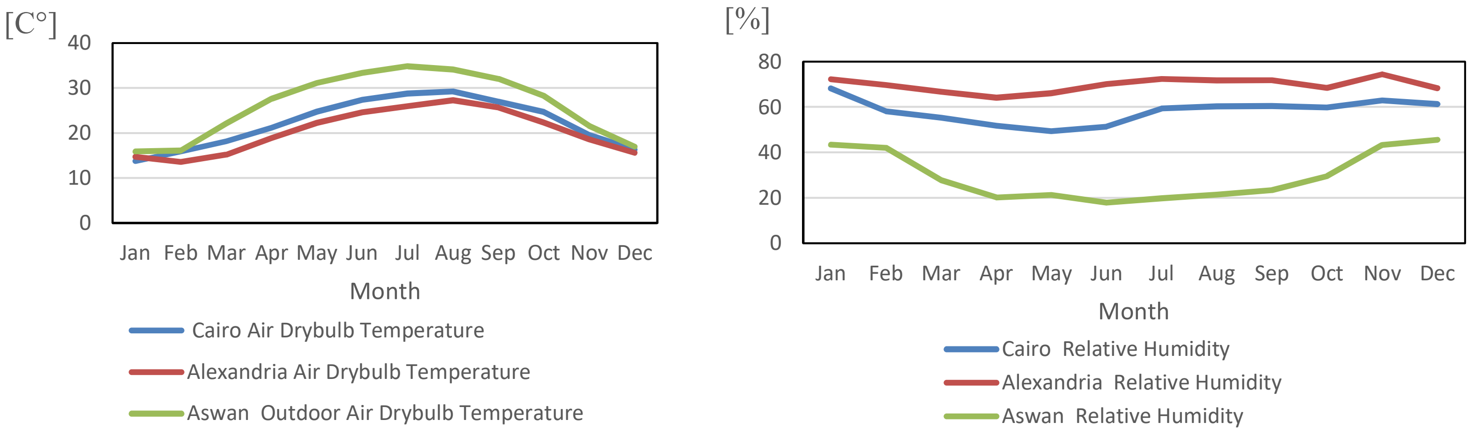
Fig. 1. Egypt's climatic zones classification map according to EREC [1].

The main objective of this research was to optimize the energy performance of the building through proposed fenestration and shading system design combinations.

Configurations of the case Study.

2.1. Weather Data Files.

Weather Data (EPW) Files for the three cities were downloaded from the official EnergyPlus website of the US Department of Energy DOE (U.S.D.o.E 2012).
Average temperature and relative humidity for the three cities are shown in the following graph (Fig.2).



(a) Average Temperature C°

(b) Relative Humidity %

Fig. 2. Average Temperature and relative humidity for the 3 cities studied in this research.

2.2. Building Model.

A sketchup model for a typical Egyptian Office building was created to run the simulations required for this research. Model details are shown in table. 1, table. 2 and table. 3.

***Table 1.** Research Model characteristics*

Building Area	Total Floor area	Floor Height	Number of Floors	Number of Thermal Zones	Main Use
200 M2	1000 M2	3 M	5 Floors	5 Thermal Zones	Office Building

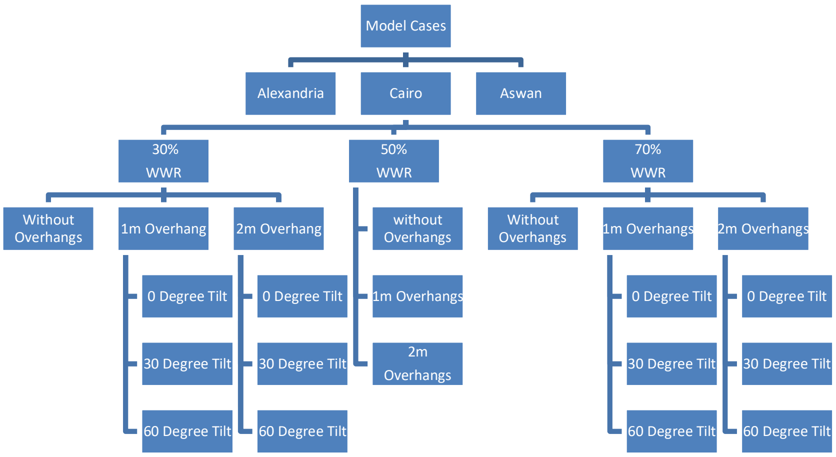


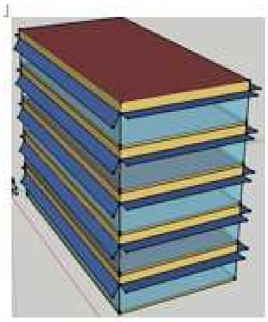
Fig. 3. Case studies implemented in this research.

Table 2 .*Used Glass Specifications*

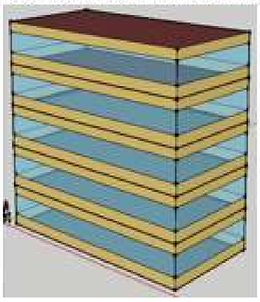
Window Type	Window thickness	$SHGC^a$	VT^b	U-Value	Tint
Single	6mm	0.62	0.57	5.778 W/m2.K	Blue

$SHGC^a$: Solar Heat Gain Coefficient.

VT^b: Visible transmittance.



70% WWR, 1m 60° Tilted Overhang



50% WWR, without Overhang.

Fig. 4. Typical elevation of Modelled Building.

Table 3.*External walls main characteristics.*

External Walls	Thick (mm)	U-Value (W/m^2k)
½ in Gypsum+1 in Stucco+8in CONCRETE HW+ Mass wall Insulation R-4.23IP	274	0.18

Window and wall configurations are according to ASHRAE 90.1-2010 requirements.

2.3. Activities and HVAC systems.

A fixed schedule for heating and cooling was used in all the different simulations. The schedule was defined through a fixed activity template, heating and cooling setpoints were assumed as given in Table. 4 based on the common lifestyles for the office occupants in Egypt (holidays, work hours, Setpoint temperatures etc.).

Table 4.*setpoint temperatures assumed for Heating and cooling in this research.*

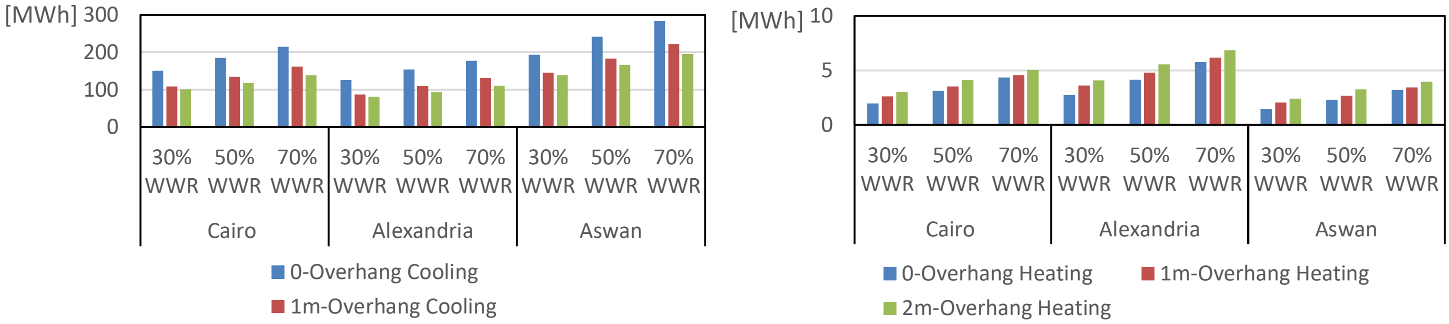
Heating Setpoint	21° C
Cooling Setpoint	24° C

For each case that has been tested, a simulation has been conducted to evaluate thermal loads “Heating, Cooling, Lighting “and to obtain the total energy consumption in **[GJ]** total energy required for Cooling, Heating and Lighting. OpenStudio default Ideal Air Loads system was used for this research model HVAC system and was fixed for all cases, it included a central air conditioning system which is generally used for Commercial Buildings in Egypt.

3. Results and discussion.

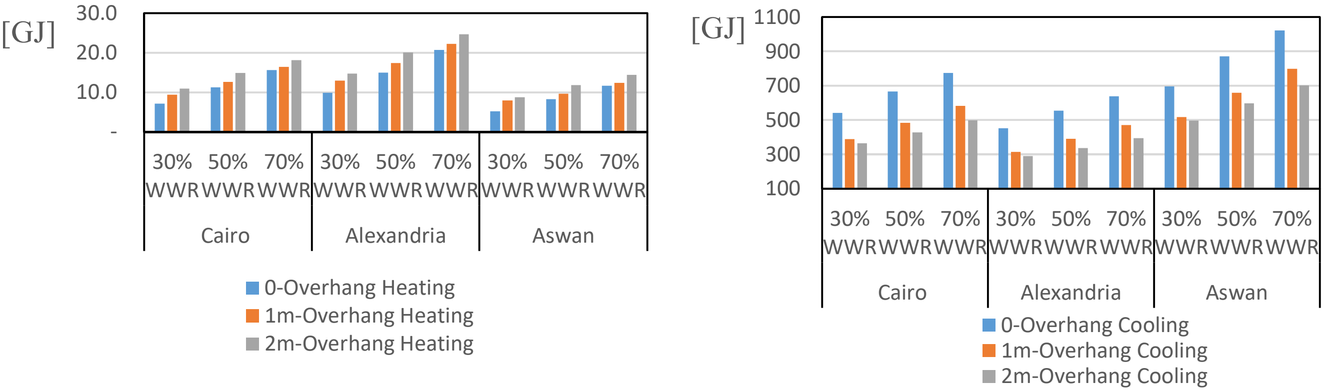
3.1. Effect of Window to wall ratio. 2.3.

Window to wall ratio percentage has a huge impact on the building Cooling/Heating thermal loads, thus the total energy required for both Heating/ cooling loads is greatly affected by WWR%. Although WWR is not only designed according to the building thermal loads but there are other factors to be considered like views, Daylighting and Natural ventilation. This research mainly focused on the WWR% impact on thermal performance regardless of these other factors. The following Graph (Fig. 4) shows Heating/Cooling loads in the 3 cities for “30%, 50%, and 70%” WWR cases. As shown in the graph heating loads decreased with increasing WWR% while total loads have increased in the 3 cities cases since they are located in cooling dominated climate. Fig. 5 Shows Cooling and heating Energy for different WWRs.



(a) Cooling loads Comaprisons **(b) Heating loads Comaprisons**

Fig. 5.Effect of WWR on Thermal Loads.



(a) Heating Energy Comaprisons (b) Cooling Energy Comaprisons

Fig. 6.Effect of WWR on Energy consumption.

3.2. Effect of overhang length.

Using optimized shading systems plays a significant role in reducing the solar radiation effect on Buildings which will reduce cooling demands and enhance indoor thermal comfort. In this research 3 shading scenarios were studied “without-Overhangs, 1m-Overhangs, 2m-Overhangs”, cooling loads dropped down more than 25% when applying 1m-overhangs while increasing the overhang length was less effective in 30% WWR”5%” case than the other two cases 50% WWR “8%” and 70% WWR “11%”**.** Thus, it’s highly recommended to use longer overhangs for 50% and 70% WWR cases. The following graph (Fig. 6) shows the impact of changing overhang length on Energy consumption for cooling, heating and lighting.

3.3. Effect of Overhang Tilt Angle.

Overhang tilt angle can influence the amount of Cooling load deductions and thus reduce the amount of Energy required for Cooling in the building. The following Graphs (Fig. 7, Fig. 8) show potential thermal load deductions due to applying two different scenarios of overhang tilts “30° and 60° “ for both cases 30% and 70% WWR.

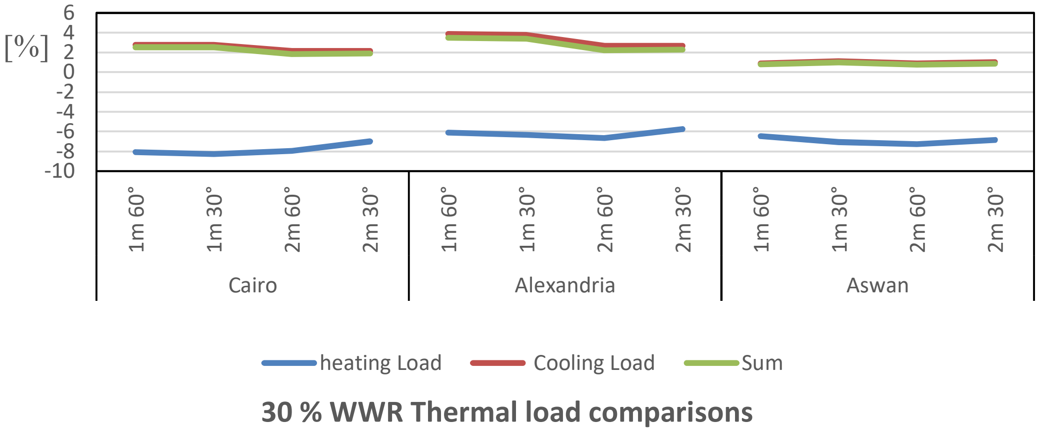
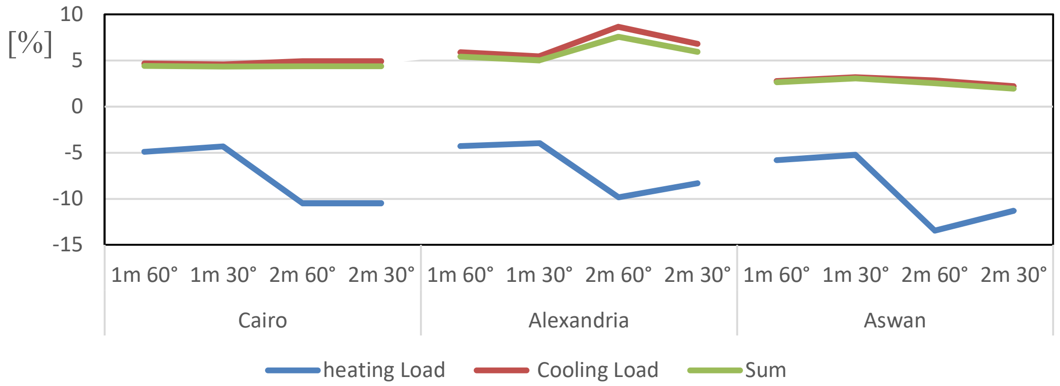


Fig. 7. Effect of Overhang-Tilt angle on thermal Loads, 30% WWR case.



70 % WWR Thermal load comparisons

Fig. 8.Effect of Overhang-Tilt angle on thermal Loads, 70% WWR case.

Applying the tilt technique had better effect on the 2m-Overhang than the 1m-Overhang for 70% WWR case while the contrary happened for 30% WWR case. There was not much thermal load deductions achieved through applying 60° tilted overhangs compared to the 30° tilted case. Thus, 30° overhangs can be more applicable if we would take the use of Daylighting and better view factors into consideration. While this technique could reduce thermal loads by 9% in some cases like in 2m-Overhang Alexandria 70% WWR case, its effect was almost negligible "1%" for 2m-Overhang Aswan 30% WWR case.

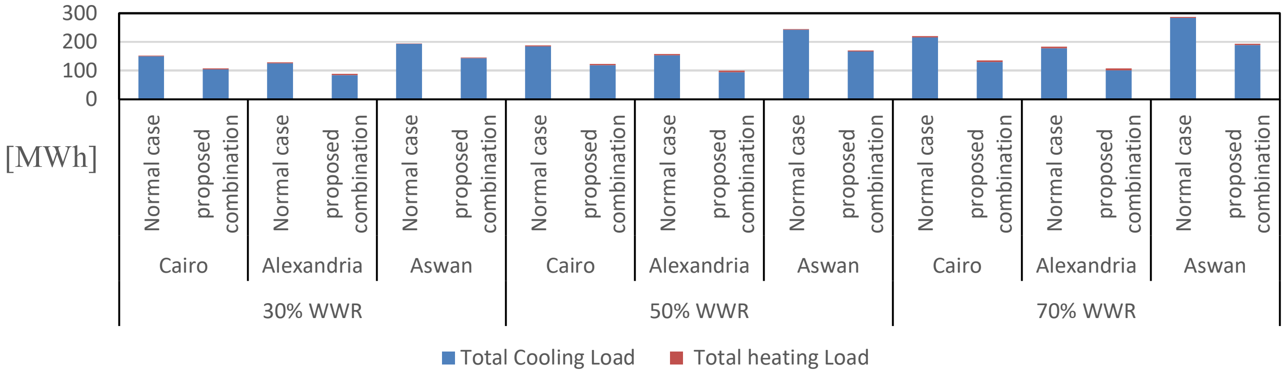
3.4. Effect of climate conditions.

Buildings should be designed to adapt to the environment they shall be built in and also passive techniques shall be uniquely optimized according to the building situation and climatic conditions. In this research we studied three case scenarios for 3 Egyptian cities located in different climate zones. (1) Heating loads were 24 ~27% Higher in Alexandria than Cairo cases while being 25~35% higher in Aswan case. (2) Cooling loads were 20~25% lower in Alexandria and 25~28% higher in Aswan case compared to Cairo case.(3) Total "Heating+Cooling" loads were 15-20% lower in Alexandria compared to Cairo and 25-30% Higher in Aswan compared to Cairo case.

4. Conclusion.

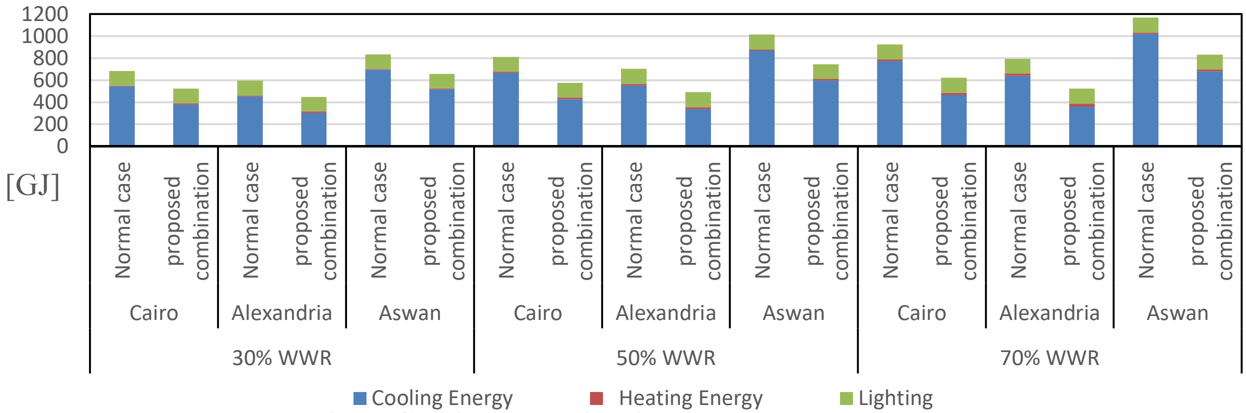
In this paper, the impact of various fenestration factors have been evaluated, such as WWR, Overhang Length, Overhang-Tilt Angle on Cooling and Heating thermal loads in 3 different Climatic zones in Egypt. Different combinations of WWR "30%, 50%, 70%", Overhang lengths" without, 1m Overhangs, 2m Overhangs" and Different Overhang-tilt Angle "perpendicular on the wall, 30° and 60° Tilts" were analyzed in in 3 cities " Cairo, Alexandria, Aswan" Located in Egypt. Simulation results showed different Performances for each combination across the three different climatic zones when using different WWR, Overhang length and Overhang Tilt. However, in general, the results recommend using (A) 1m Overhang with 30° tilt Angle for 30% WWR case since the benefit achieved from increasing the overhang length to 2m doesn't have a big effect on thermal loads " less than 5%" while adding 1m overhang with 30° tilt Angle reduces cooling loads by 30-35%.(B) 2m Overhangs for 50% WWR case since it has a big effect on cooling loads by 35-40% and total thermal loads " Heating+Cooling" by about 30-35%.

(C) 2m Overhang with 60° tilt Angle for 70% WWR case to achieve less total loads of around 40%. The following graphs (Fig. 9, Fig. 10) show the potential drop in thermal loads and energy consumption according to the above proposed models. The combinations recommended in this research has the biggest effect on reducing thermal loads in Alexandria City while being least effective in Aswan city “around 10% difference in the total thermal load deduction percentage”. The fenestration and shading Combinations provided in this research can help designers optimize the energy performance of the building, improve thermal comfort and reduce energy consumption as a necessary step towards achieving the ZEB targets in Egypt.



Total Heating and Cooling Thermal Loads

Fig.9.Proposed Combinations Vs Normal case Thermal Loads.



Heating , Cooling and Lighting energy

Fig.10.Proposed Combinations Vs Normal case Energy consumption.

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