SIMULATION-BASED STUDIES TO REACH THE NET ZERO ENERGY TARGET FOR A HOUSING PROTOTYPE IN ALEXANDRIA, EGYPT

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Abstract- The residential sector has become the main consumer of electricity. A grid-connected Net Zero Energy Building (NZEB), an approach for the mitigation of the energy usage can be achieved by the synthesis of passive strategies, efficient building systems, and renewable energy technologies. The main scope of this paper is to present a net zero energy single family two-storey housing prototype which is assessed using energy performance simulation tools to evaluate the environmental impacts of a variety of building envelope thermal characteristics that can be decided during the early-design stage to help developing a design that is capable of meeting our economic, environmental and social challenges in the climatic region of Alexandria, Egypt. To achieve this aim, two simulation software 'DesignBuilder' and 'Diva-for-Rhino' were used to conduct a series of sensitivity analysis on a set of design parameters which influence the building performance to examine the actual impact of each factor on cooling and heating loads to help with the design decision making with respect to the net zero energy goal for Egypt's climate and how to offset the building's annual energy need through building integrated photovoltaic units.

Index terms- Energy, Net Zero Energy Buildings (NZEB), Energy Simulation, Housing Prototype, DesignBuilder, Annual Site Energy, Daylighting Performance, Glare.

I. INTRODUCTION

a. Energy consumption in Egypt

Egypt is currently facing a rapidly growing energy demand and has recently been suffering from occasional power outages when demand exceeds the grid capacity; due to its aging infrastructure, growing population, economic expansion combined with lack of renewable energy production technologies. According to the Ministry of Electricity and Energy in Egypt [1] 2012/2013, the main consumer of electricity is the residential sector which accounts for 42% of the total nationally generated electricity due to the expansion of residential communities.

New residential building envelope designs are developed without much concern to the local climate and with no objective to conserve energy. As a result, this have contributed to an overall poor thermal performance of the buildings, which became more dependent on artificial means to provide omfortable thermal environment at high-energy consumption [2]. However, the building sector still have the highest potential to reduce energy use at the lowest cost by improving the energy-efficiency of new constructed residential buildings to contribute to the sustainable development [3].

b. Net Zero Energy Approach

A radical approach for the mitigation of the energy usage in the building sector is the concept of Net Zero Energy Building (NZEB) [4] which can be achieved by the synthesis of passive strategies, efficient building systems, and renewable energy technologies [5].

The European Parliament defines a NZEB as "A building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site"[6] as illustrated in Figure (1). The period for measuring the performance is one year of operation, to include all season variations [5].

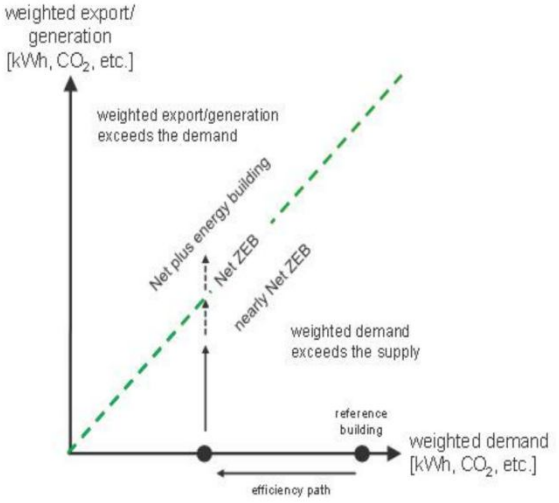


Figure 1: Pathway to the Net Zero Energy Target.

The term "net" is used in grid-connected buildings to define the energy balance between energy used and energy sold [5].

Twenty percent of the design decisions taken during early design phases subsequently influence 80% of all design decisions. In order to design and construct such buildings it is important to insure informed decision-making during the early design phases of NZEB [7].

c. Energy Simulation Tools

Building performance simulation tools can be used at the earliest design stage to asses various design options. Methodologies for calculating annual energy use of buildings and assessing the building performance have developed to complex dynamic energy performance simulation tools which are flexible and accurate tools for indicating relative changes in energy use, and comparisons between design options which can be used to determine whether the project as a whole is meeting the established energy target [8].

II. SIMULATION-BASED APPROACH

a. Research Objective

The main scope of this paper is to present a moderate economic single-family net-zero energy housing prototype designed for the warm climate of Alexandria, where energy modeling programs are used throughout the process, as both a design-decision making tool and an assessment tool for the building envelope with respect to the net zero energy target.

b. Simulation Tools

Simulation is carried out using:

- Energy Simulation: DesignBuilder graphical user interface (GUI), incorporating the EnergyPlus calculation engine which has been validated under the Evaluation of Building Energy Analysis Computer Programs test BESTTEST/ASHARE STD 14.
- Daylighting Simulation: DIVA (Design Iterate Validate Adapt) an environmental analysis plugin for the Rhinoceros used to interface Radiance and Daysim for annual simulation and illuminance computation.

c. Simulation Methodology

In order to achieve the stipulated aim, the simulation-study traces the following steps:

- The location of Alexandria, Egypt (Climate Region 4A) and the associated weather files are loaded for accurate results.
- A baseline model is created to estimate the annual energy consumption of conventional construction for the prototype followed by post-decision trial and error approach where simulation parameters are tested. Then, results are compared to the baseline value.
- Experimentation is conducted for a year round daylighting performance using the Dynamic Daylight Performance Metrics (DDPM) [9] and the possibility of glare occurrence is studied.
- A new proposed building with the highest efficient values is simulated to calculate its annual total energy consumption.
- PV-roof mounting solutions is used to offset the building's annual consumption to determine the possibility of reaching the zero energy target in Alexandria's climate.

III. BASELINE-CASE

a. Alexandria's Climate

Alexandria has a hot desert climate (Köppen climate classification: BWh), The city's climate is influenced by the Mediterranean Sea, moderating its temperatures, causing variable rainy winters and moderately hot summers that, at times, can be very humid.

With the aid of a computer program (Climate Consultant 5) and the Department of Energy (DOE 2011d) weather files for Alexandria. Psychometric charts were produced, as shown in Figure (2) to help determine the passive approaches which are applicable for this climate.

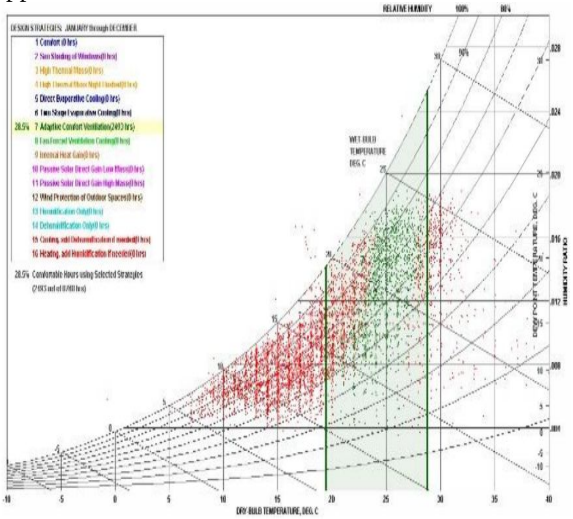


Figure 2: Psychometric Chart, Alexandria, Climate Consultant.

b. Climatic Design Response

As recommended by Climate Consultant and passive approach in hot climates design guidelines:

- Long narrow building floor plan can help maximize cross ventilation in temperate and hot humid climates.
- Building has to be exposed to cooling breezes, and design to exclude adverse winds while allowing for cross-ventilation.
- Provide enough north glazing to balance daylighting. However, minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain. Size south-facing overhangs to shade windows in summer and allow solar gain.

c. Proposed Prototype

The proposed plan in Figure (3) for the prototype is designed to maximize these passive approaches. Moreover, the space zoning is affected by the traditional Egyptian privacy principles.

The plan has a rectangular form of an aspect ratio of 1:3 [4] oriented along east/west axis which can perform well in hot climates.

The east and west sides of the building receive the most intense heat from the sun, minimizing the plan dimensions and openings in these facades, which can reduce solar heat gain significantly. In addition, admitting diffused light from the north in a narrow floor can provide sufficient natural light, reducing the need for artificial lighting.

Orientation of windows to the prevailing winds can facilitate cross-ventilation [10].



Figure 3: Floor plans for the single family housing prototype.

d. Baseline-case Description

For accurate results, the proposed plan is classified in DesignBuilder into zones according to its activity. A schedule for the occupancy as indicated in (table 1) has also been selected to calculate the internal heat gain from occupants of each zone and its impact on heating and cooling loads.

Table.1 Building Description Inputs

Parameter	Inputs
Location	Alexandria, Egypt
Climate	Warm, Mediterranean climate
Total Area	131.5 m²
Occupancy	Family weekday (Sat.-Thu.) 6:00 – 8:30 & 15:00 – 23:00 / Family weekends (Friday) 8:00 – 24:00 Taking into consideration July and August (School Summer Holiday)
Target Illuminance	300 Lux [11]
Wall construction	Single Red Brick Wall 125mm
Roof Construction	Concrete Slab without Insulation
Floor Construction	Concrete Floor 200mm
Glazing Type	Single Clear 3mm
Lighting	Fluorescent
HVAC	Split / No Fresh Air

e. Baseline-case Results

Simulations are carried out for the baseline model throughout the year to study the effect of seasonal variations on air temperature and total annual fuel breakdowns.

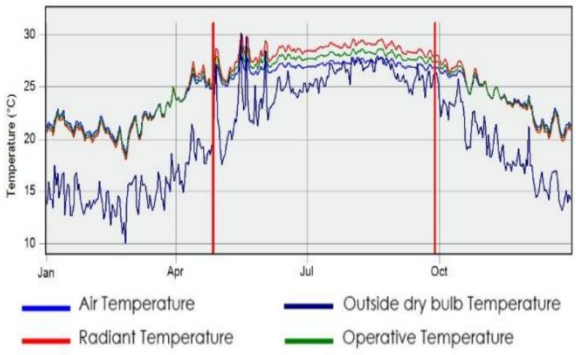


Figure 4: Annual Temperature calculations for the baseline case – DesignBuilder Simulation.

It can be observed from Figure (4) that the interior air temperature rises over 27.51C˚ in summer and 18.59C˚ in winter, as an impact of internal loads and occupancy.

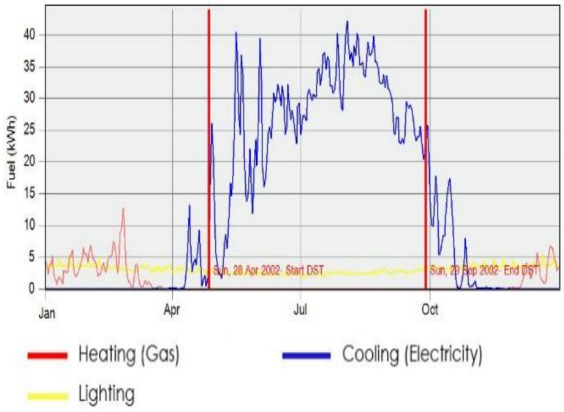


Figure 5: Annual Fuel Breakdown calculations for the baseline case – DesignBuilder Simulation.

The baseline case is mainly depending on electricity from the grid as a source of heating and cooling. It can be observed from Figure (5) that cooling loads are maximized in summer months.

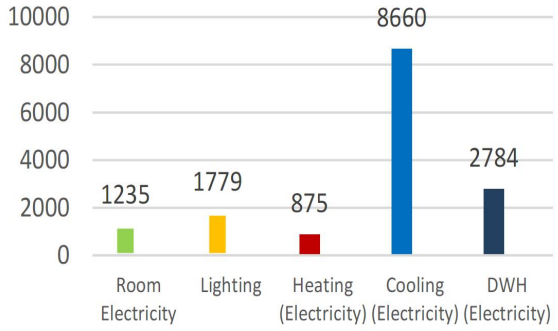


Figure 6: Annual Net Site Energy Calculations (KWh) for the Baseline case – DesignBuilder Simulation.

Annual Net-Site-Energy per total building area simulation results for the baseline case were calculated as 116.27 kWh/m², as shown in Figure (6).

It can be concluded that lighting and cooling loads are dominant in this case and should be reduced.
Calculations for reduction of energy used in Domestic hot water (DHW) and Room Appliances will not be covered in this paper.

IV. PARAMETRIC RANGES SIMULATION

Parametric analysis is performed to investigate the impact of varying the parameter values on design decision making for a less energy consumption design. Each parameter is studied separately to examine the actual impact of each factor on cooling and heating loads.

Design-Decision Impact

a. Building Orientation

The results of simulation of the rectangular prototype indicates the best orientation along the east-west axis as suggested in the baseline case. As shown in Table (2), the energy consumption could have increased by 12.5% if the building was wrongly oriented.

Table.2 Building Orientation Simulation Results

Case/Angle		Orientation	Net site energy
Baseline	0°	N	116.27 kWh/m²
Case(1)	45°	N	120.11 kWh/m²
Case (2)	-45°	N	126.63 kWh/m²
Case (3)	90°	N	130.76 kWh/m²
Case (4)	-90°	N	124.23 kWh/m²

b. Openings/ Daylighting Simulation

Daylighting performance year round is studied for the baseline-case. Table (3) illustrates the parameters and the properties of the internal surfaces. Where, no external obstruction was assumed and an external ground reflectivity of 20% is used.

Table.3 Baseline space parameters

Case Parameters		
Reflectivity Ratios	Wall	50%
	Ceiling	80%
	Floor	20%
Window parameters	WWR	20%
	Material	Double glazed 80%

Experimentations is conducted using "Daylight-Availability" as a dynamic daylight performance metric (DDPM) [9]. Where, three daylight availability evaluation levels are used: "daylit", "partially daylit" and "over lit" areas. The Daylight Availability criteria adopted in this paper considers that acceptable performance is achieved when the "daylit" areas reaches >40% of the space area.
"Daylight glare probability" (DGP) [12] is chosen as a qualitative daylight metric to evaluate the visual comfort and glare aspects. "Imperceptible glare" (DGP <35%) is considered an acceptable case.
According to the Egyptian code for energy efficiency in residential buildings (EERB) [11], the target illuminance for the single residential zone is 300 lux. The reference plane, on which daylighting performance is simulated, is a grid of 0.4m*0.4m. A 0.85m height reference plane is selected in this study and the occupancy schedule is considered to be from 8:00 AM until sunset.

- **Daylight Availability analysis**

The baseline-case simulation results are carried out using Diva-for-Rhino software. As shown in Figure (7), all the spaces are considered acceptable (Daylit >40%) except for 3 spaces; the "Kitchen", "Master Bedroom" and "Bedroom 2". Therefore, openings for the three spaces has to be modified to reach the acceptable percentage.

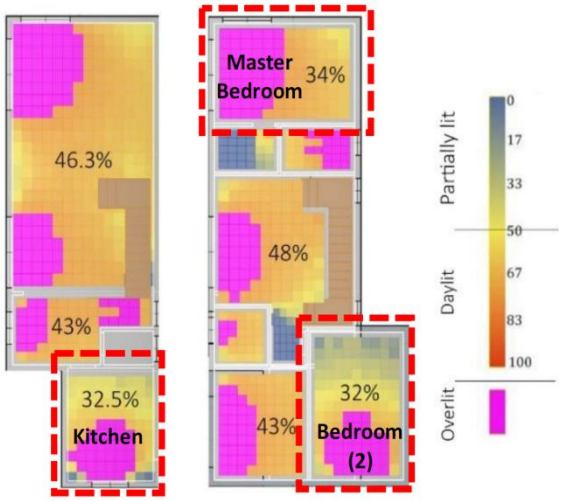
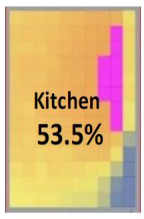
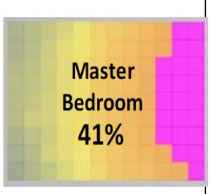
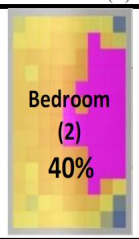


Figure 7: Daylighting Availability Analysis for the baseline-case.

West oriented windows in the "Kitchen" and "Bedroom 2" shows an inefficient daylighting performance for the spaces. Therefore, windows are suggested to be opened towards South orientation instead, and to be further shaded by means of windows shading devices which can improve daylighting and energy performance in hot climates.
Simulations are carried out to study the effect of changing the design-decision for the orientation of the openings to from West to South.

Table 4. Daylight Availability modification results.

Kitchen	Master Bedroom	Bedroom (2)
		

It can be observed from Table (4) that orienting the windows towards the south façade can increase the daylighting performance and reduce the total energy consumption to 116.27 kWh/m² by 2.6% compared to the baseline-case.

- **Daylight glare probability analysis**

"Bedroom 2" is selected for glare analysis, as the probability of glare phenomena is more likely to occur in south orientation. The camera is located in two positions as shown in Figure (8).

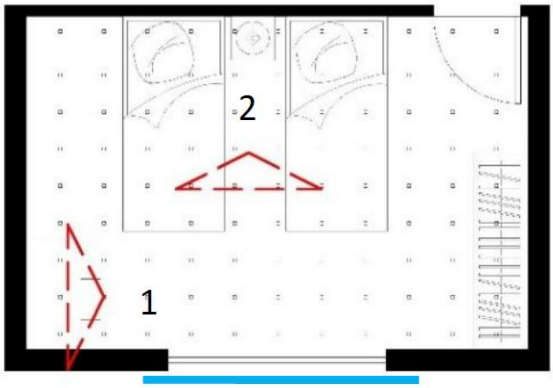
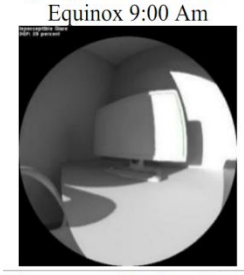
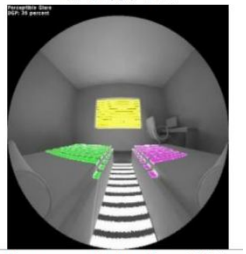


Figure 8: Camera position for DGP analysis.

"Imperceptible glare" can occur in the simulated cases if solar screen are used to provide smooth daylighting distribution as illustrated in Table (5).

Table 5. Daylight Glare Probability Analysis.

Camera 1	Camera 2
Spring/Autumn Equinox Equinox 9:00 Am	Winter Solstice at 12:00 PM
	
Imperceptible glare 28%	Imperceptible glare 34%

c. Cooling Reduction Simulations

- **Shading Devices**

Exterior shadings for windows are considered as an effective option for passive cooling in hot climates. Energy consumption simulations are carried out in DesignBuilder to examine the impact of using fins, overhangs, and louvers.

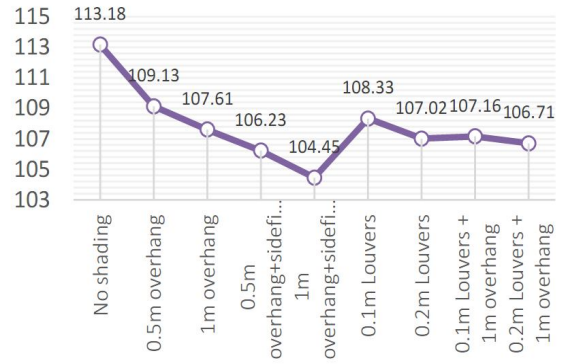


Figure 9: Annual total heating and cooling loads (KWh) for the shading devices parameters.

According to the simulation results shown in Figure (9), 1m overhang+1m side fins has much higher reduction impact on total energy consumption by 7.7% and can be considered for the design.

- **Natural Ventilation**

For hot climates, natural ventilation can help meet a building's cooling loads without using mechanical air conditioning systems. Simulations were carried out to determine the reduction of energy if natural ventilation is the main design cooling strategy. The results shows a reduction of 6.7% of the total annual net energy which can be reduced to 105.56 kWh/m².

d. Energy Simulation (Building Envelope)

Minimizing heat transfer through the building envelope is crucial for reducing the need for space heating and cooling. The inputs to Envelope-Related Energy Demand are areas of envelope elements (external walls, roofs and windows glazing types). Simulations were run to test the construction materials that are mostly used in the Egyptian residential building sector.

- **External Wall Material**

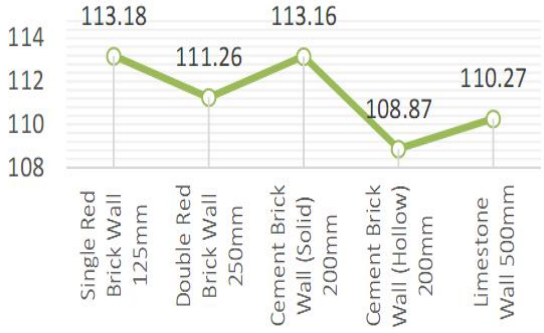


Figure 10: Annual total heating and cooling loads (KWh) for the wall construction material parameters.

Simulation results as shown in Figure (10) indicates that a Hollow cement block 200mm gives better energy saving of about 3.8% with respect to other wall materials.

- **Roof Insulation**

Figure (11) illustrates the effect of increasing the Expanded Polystyrene (EPS) roof insulation thickness for the roof of the building compared to the baseline case using no insulation for the roof.

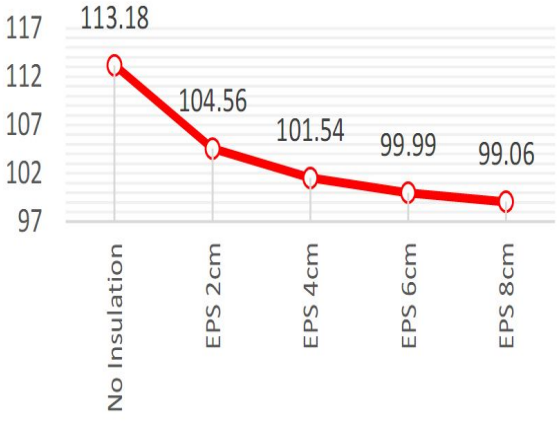


Figure 11: Annual total heating and cooling loads (KWh) for the roof insulation thickness parameters.

It is concluded that increasing the thickness of EPS insulation to 8cm can reduce the total loads to 99.06 kWh/m² saving about 12.5% for the proposed prototype.

- **Glazing Type**

Different glazing systems ranging from single glazed clear 3mm to Double blue-tinted glazed 3mm/13 mm air, has been analyzed in terms of their impact on the total energy consumption.

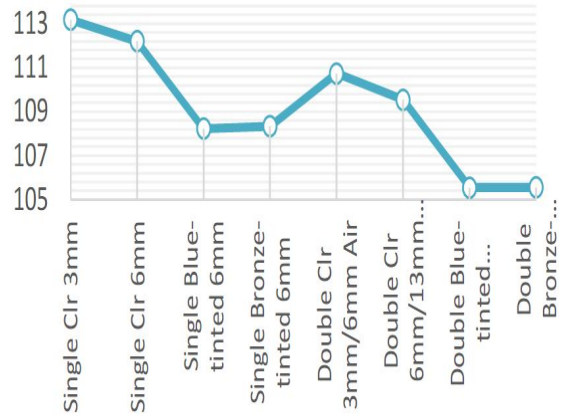


Figure 12: Annual total heating and cooling loads (KWh) for the glazing type parameters.

Figure (12) illustrates that a blue-tinted double glazing 6mm/13mm air gives better energy saving of about 6.9% with respect to other glazing types.

V. RESULTS AND FINDINGS

a. Annual Simulation Results

After, applying the highest energy efficient tested parameters to the model. Annual net site energy simulation results were calculated 71.85 kWh/m², as shown in Figure (13).

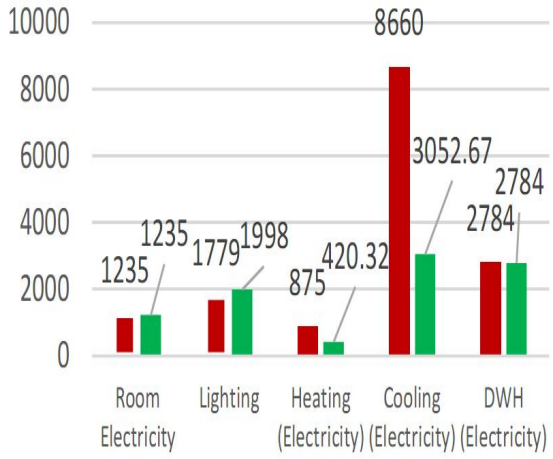


Figure 13: Annual Net Site Energy Calculations (KWh) comparison between the baseline case and the new proposed building – DesignBuilder Simulation.

b. Photovoltaic-mounting integration

DesignBuilder does not yet support the integration of PV panels. Therefore, plugin "Skelion" has been used for Sketchup 2014. Photovoltaic panels with 230W power were mounted on the available roof area of the building (70m²) tilted by 30°towards south. The PV panels produced 14594 KWh, however the building total energy needs is 9450.25 kWh. Therefore the building can reach the net zero energy target and can also be considered as a plus energy building.

CONCLUSIONS

- A reduction of 38.2% in the total site energy consumption can be achieved on changing design decisions and parameters; building orientation, location of windows, roof insulation, wall construction materials, glazing types, and shading devices.
- Decisions made in the early design stages while it's more flexible often have a direct influence on energy use, and indoor environment.
- Daylight affects visual, thermal comfort as well as energy efficiency in buildings. As a result, various design alternatives shall be studied in the early design stages.
- Energy simulation and evaluation tools cannot make appropriate design decisions on behalf of the designer. Therefore, building evaluation studies should empower the designer rather than supplement his rule.
- The success of a building also depends largely on the people who use it. If occupants are not committed to reducing their personal energy consumption by shutting windows and turning off appliances, a net-zero structure can easily lose its status, becoming just an "efficient" building.

ACKNOWLEDGMENT

This paper is based on two master's thesis carried out in the Architectural Department at The Faculty of Engineering, Alexandria University, Egypt. We thank the professors who monitored and evaluated it.

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