Achieving Zero Energy & Zero Carbon Buildings through Design Treatments Residential Buildings Using PV Panels

Marwa Ahmed Mostafa, Prof. Dr. Ehab Mahmoud Okba, Dr. Rabab Salah Mohammed
Architecture Department, Fayoum University/ Faculty of Engineering, Egypt

***Abstract*—Green architecture, sustainable buildings, environmentally friendly, and other terms have recently become popular in the construction fields among both professionals and non-professionals. Although it is mostly needed and highly feasible, the application of these ideas is not yet at the same level of popularity in Egypt.**

The aim of this research is to propose a method to be used in solving the energy problem and carbon emissions in the building sector in Egypt. Since it is concerned with the existing building stock, the methodology will be addressing retrofitting strategies not new design strategies. The research utilizes energy and carbon simulation to validate its initial assumptions and to test the feasibility of the proposed guideline. The final outcome of the research is a method that combines both design treatments and renewable energy strategies that suit the Egyptian context and potential to convert existing buildings to ZEB & ZCB buildings.

The study starts with the defining ZEB, ZCB, concept to familiarize the reader with its different aspects. The empirical part of the study utilizes simulation to validate the proposed guideline by applying it on an already existing residential building. The detailed steps of converting an already existing residential building to zero-energy & zero-carbon building are the final outcome of the research.

***Keywords*— Zero-energy buildings, Zero-carbon building, Renewable Energy, Solar Panel, Optimal design, Thermal insulation**

I. INTRODUCTION

Many countries around the world are facing the global problems such as problem of energy consumption and the problem of running-out of fossil fuels and their increasing global demand, It is the gap between the uses of fossil fuels and the exponential rise in the demand of energy harmful to the environment and humans which already resulting in the energy insecurity that will be a hallmark of life and in all countries in the next decades. Another one is the emissions of greenhouse gases arising from burning of fossil fuels to generate energy that leads to climate change and global warming. Egypt is one of the countries, in the hot arid region, that face these environmental problems. [1]

Sustainable urban development is essential to enhance the quality of life of the citizens, protect human health and to decrease the impact of cities upon resources outside the urban context. Thus, there is a need for zero energy and zero carbon buildings which are urban areas powered by renewable energy techniques and technologies. This research aims to achieve the criteria of designing zero energy and carbon and maximizing the benefits of sustainable technologies through an integrated planning and design approach. [2]

II. LITERATURE REVIEW

2.1 Greenhouse Gas Effects:

Atmospheric scientists first used the term 'greenhouse effect' in the early 1800s. At that time, it was used to describe the naturally occurring functions of trace gases in the atmosphere and did not have any negative connotations. It was not until the mid-1950s that the term greenhouse effect was coupled with concern over climate change. In recent decades, the greenhouse effect in somewhat negative terms. The negative concerns are related to the possible impacts of an enhanced greenhouse effect. On the other hand, Life on earth would not be possible without the greenhouse effect. [3] figure (1)

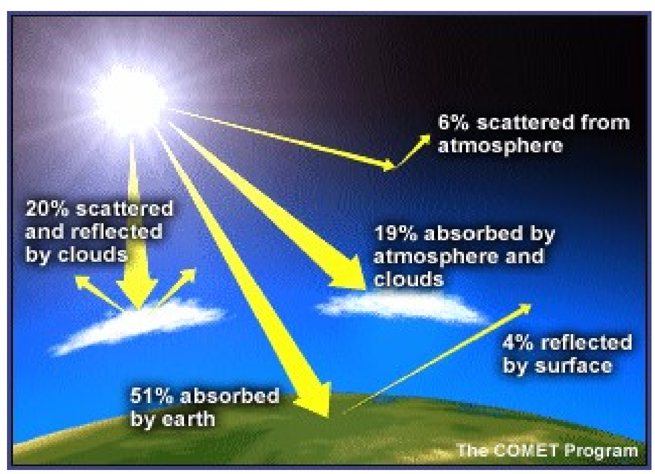


Fig. 1 Greenhouse Effects

Source :(http://www.ucar.edu/learn/images/radiate.gif)

2.2 Energy Performance of Buildings in Egypt:

The only official source of energy consumption data in Egypt is the ministry of electricity and renewable energy. This body gives an annual report that provides statistics of the electricity generated and distributed throughout the given year. In its latest published report for the year 2017/2018, it stated that 51.3% of the overall electricity consumed goes to the residential buildings as seen in figure (2). [4]

The study revealed that 74% of the electricity used is consumed towards reaching thermal comfort, where 65% goes to cooling purposes while 9% goes to heating ones. [5] This shows the importance of solving the thermal comfort aspects and proves that if the building insulation efficiency was enhanced, the energy saving will be significant. [6]

Purpose of Usage	Quantity (GWh)
Industry	17303
Agriculture	5528
Government & Public Utilities	13622
Residential	61962
Commercial Shops	5003
Public lighting	5692
Others	11716
Total	**120826**

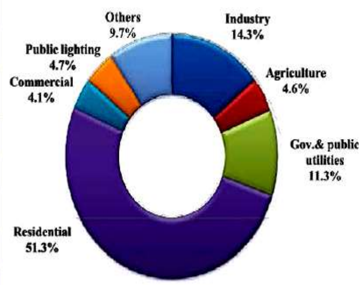


Fig. 2 Amount and percentages of energy sold according to purpose of usage

Source: (Eehc, 2018)

2.3 Definitions of Zero Energy Building:

Zero energy building can be defined as a building that produces as much energy on-site as it consumes on an annual basis. Provided four definitions of zero energy building: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. A classification system based on renewable energy supply options is also used to distinguish different types of zero energy building. [7]

2.4 Definition of Zero Carbon Building:

Zero carbon building is defined as an energy efficient building with a near zero, or very low energy demand. Energy from renewable sources and renewable energy produced on-site or nearby, should cover as much as possible of the required energy. [8] In comparison, the definition of zero carbon building, according to the Norwegian Research Centre on Zero Emission Buildings, is based on greenhouse gas emissions during the lifetime of the building. [9]

2.5 Extraction of the most efficient design treatments for zero energy and carbon buildings:

The following variables can be used as a basis for measuring and modeling the zero energy and carbon buildings suitable for the local environment:

2.5.1 Zero Energy strategy:

A. Optimal design: (windows shading, reflective color surfaces, landscaping). [10]
B. Thermal insulation: (multi-layered glazing, high insulation materials, Wall Insulation, green roof, Eco-Material). [11]
C. Heating and cooling systems: (natural ventilation, Day lighting Strategy). [12]
D. Energy production: (Renewable energy resources). [13]

2.5.2 Zero carbon strategy:

A. Renewable Energy Resources: (solar panels, Wind energy, Biomass…. etc.). [14]
B. Water Management: (Grey Water Systems, water capture technology). [15]
C. Eco-Materials (Green Material): (Recycled Materials, Renewable Materials, Material for Efficiency, Materials for waste treatment). [16]
D. Indoor Environmental Quality: (Thermal comfort, Day lighting, Natural ventilation). [17]

III. METHODOLOGY APPLICATION

The research is aimed at supporting buildings designed to be zero-energy and emissions buildings. It calls on architects to shift their designs from local buildings (designs and properties of traditional materials) to zero buildings or near to zero buildings.

Implementation of the theoretical study on an existing project gives the chance to the study to develop from being an analytical research to a hands-on experiment. This research will utilize an actual residential building in BeniSuef governorate as its case study. The building has certain energy performance level and needs a certain amount of electricity to perform. If the energy performance could be enhanced and the electricity could be generated through PV panels and reducing carbon emissions, then the building can be a zero-energy& carbon building.

The research method can be summarized in order to determine the zero energy building and carbon emissions by:

1- Determining the characteristics of the building with the traditional characteristics and measuring the amount of its operational capacity (as an annual total).
2- Apply the environmental design treatments identified in the theoretical framework and measure the availability of energy consumed in the building compared to the energy consumed in the building with the traditional characteristics. By increasing the number of design treatments employed in the building, the building's need for energy will be reduced to as little as possible.

3- Alternative energy: After reaching the minimum energy required to operate the building, the designer is trying to try the availability of this energy from renewable sources of energy, especially solar systems integrated with the design of the building.

3.1 Approved software (Design Builder program):

The thermal calculations associated with the subject of research require many complex calculations of temperature and solar radiation and the properties of insulation and lighting, and calculations of operating devices and the amount of energy produced from solar panels.

Thermal measurements and the calculation of the electrical energies required to operate the building will be carried out through ready-made software (among which is the Design Builder program whose reliability can be trusted) (Figure 3).

3.1.1 Overview about the program:

The design builder program calculates cooling and heating systems, by integration of mechanical and natural system. The program also calculates the amount of artificial light needed by the building to achieve visual comfort, by incorporating artificial lighting gradually as natural as needed during daylight hours. This program contains all the Egyptian climate data for the regions (city climate of each region), and gives results each hour which gives the user a detailed picture of the way of building performance.

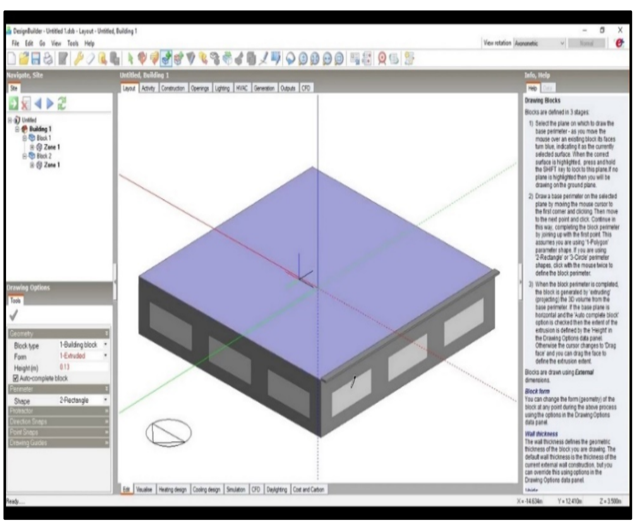


Fig .3Shows the interface of Design Builder software

3.2 First Stage:

3.2.1 Determining the characteristics of the building with the traditional characteristics: Building data:

A) Location of the building (case study): The building is located within the social housing project in BeniSuef Governorate in the Bayad Al Arab in East BeniSuef.

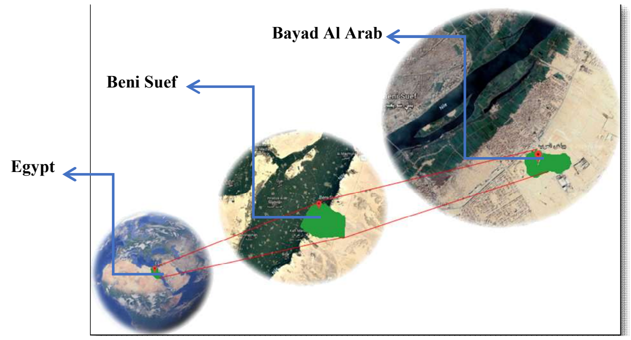


Fig .4 The building location

Source: google earth

*B) Description of the building(case study):*The case study building is a 5 storey residential building with four apartments per floor each of an approximate area of 80 m^2 and total surface area of the building is 335 m^2. The building has one staircase acting as the core vertical circulation. The typical floor plan and front elevation for the prototype are as seen in figures (5) and (6) respectively.

C) Construction materials of the building (case study): The building's vertical envelope is a single wall of 25 cm thick bricks, having aluminum framed windows. No insulation is installed in the outside or the inside of the envelope. The roof layering is the finishing tiles, the waterproofing membrane, the thermal insulation, and then the concrete slab that is covered by pilaster from inside.

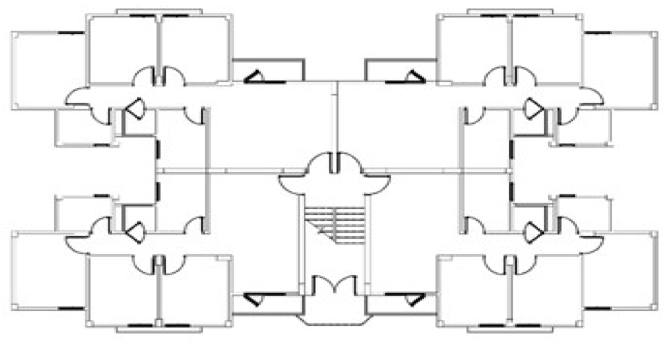


Fig .5 Typical floor plan for case study building

Fig .6 Front Elevation for case study building

3.2.2 Building data analysis:

The most important data to be considered in this case is the energy consumption data because it has a direct impact on the amount of energy to be saved either through design treatments or to be generated by the renewable energy system. Average consumption monthly rates were detected as seen in fig (7) from the actual electricity bills of the case study building.

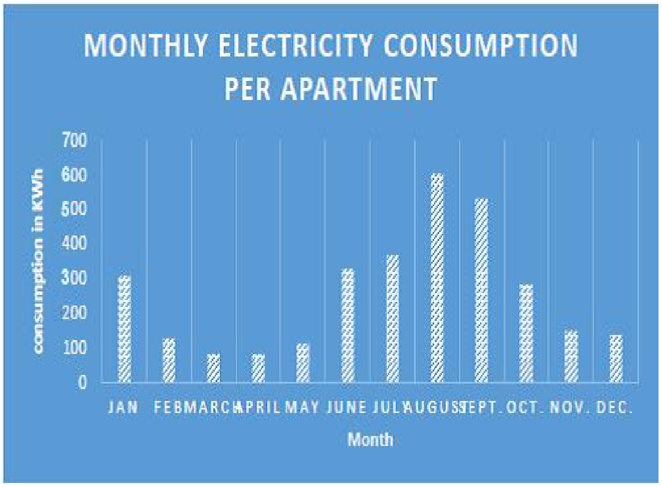


Fig .7 Monthly electricity consumption per apartment in the case study building – 2018

The total average electricity consumption per apartment is **3204** kWh/ year. In order to calculate the electricity consumption for the whole building, then the 20 apartments have to be considered: **64080** kWh/ year approximately **64000** kWh/ year.

3.2.3 Simulation:

For environmental design treatments effect to be verified, energy simulation needs to be performed. Using Design Builder software, the electricity consumption of the existing building with its current situation is done. The building after environmental design treatments is then simulated in order to be able to measure the difference in electricity consumption between the two cases.

3.2.3.1 Current Situation Simulation of consumed energy:

The daily simulation of the current status of the building in fig (8) showed great resemblance to the actual electricity consumption of the building that is provided by the actual electricity bills. It is also clear that the maximum air temperature and outside dry bulb temperature lie between July and September, and this is where the maximum electricity consumption is found.

• *Annual simulation:*

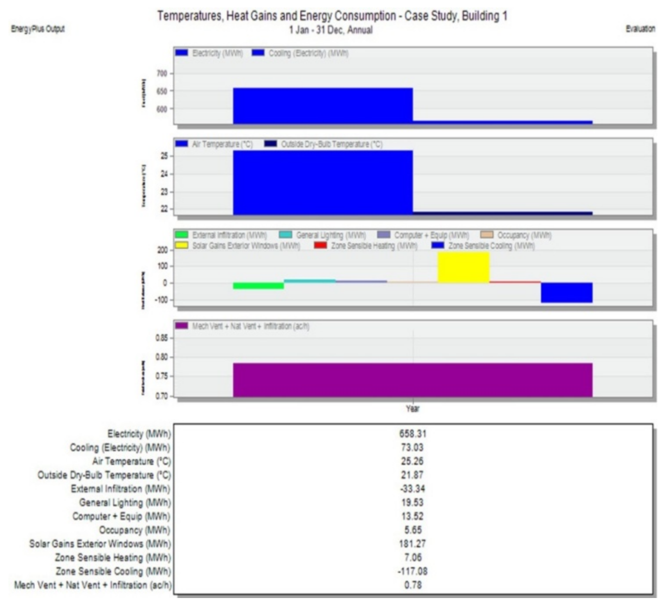


Fig. 8 Annual simulation of consumed energy

By comparing the annual electricity consumption as seen in fig (7) **66000** kWh to the actually calculated number from the actual electricity bills **64000** kWh it is found to be almost 3% of variance. The annual electricity consumption has to be highlighted because it is the value that will be compared to the simulated case in order to show the effectiveness of the proposed environmental design treatments.

3.2.3.2 Current Situation Simulation of Carbon Emissions:

A simulation of the Design builder program for the amount of carbon emissions in the case study was done in the case study before adding any design treatment to reduce carbon emissions. Annual carbon emissions from the case study **66819 kg.**

• *Annual simulation:*

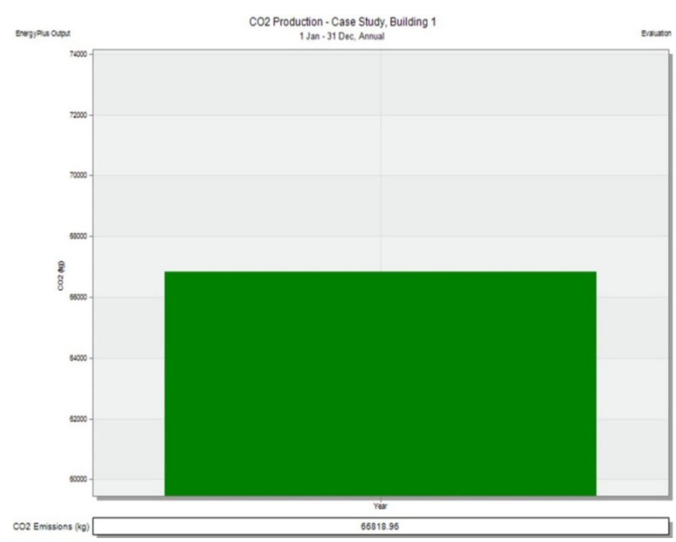


Fig. 9 Annual simulation of carbon emissions

3.3 Second Stage:

Testing of Environmental Design treatments on the Building (Case Study):

Table 1 shows the environmental treatments to be used on an existing building. The efficiency of these treatments will be measured by applying them to the building (case study) and comparing the amount of energy consumed annually in the building before the inclusion of the design treatments and after their inclusion.

Table. 1 the main design treatments to be used in the existing building

Design Treatments		
Zero Energy	Optimal Design	Window shading
		Exterior building paints
	Thermal insulation	insulating materials
		Insulating walls
		Insulating roof
		green roofs
	Autonomous cooling systems	Cooling by natural ventilation
	Renewable Energy Resources	Solar Panels
Zero Carbon	Solar Panels/ Wind energy	Solar Panels/ Wind energy
	Water Management	Grey Water Systems
		water capture technology
	Eco-Materials	Recycled Materials
		Renewable Materials
		Material for Efficiency
		Materials for waste treatment
	Indoor Environmental Quality	Thermal comfort
		Day lighting
		Natural ventilation

3.3.1Case study after adding design treatments of zero energy strategy:

• *Annual simulation of consumed energy:*

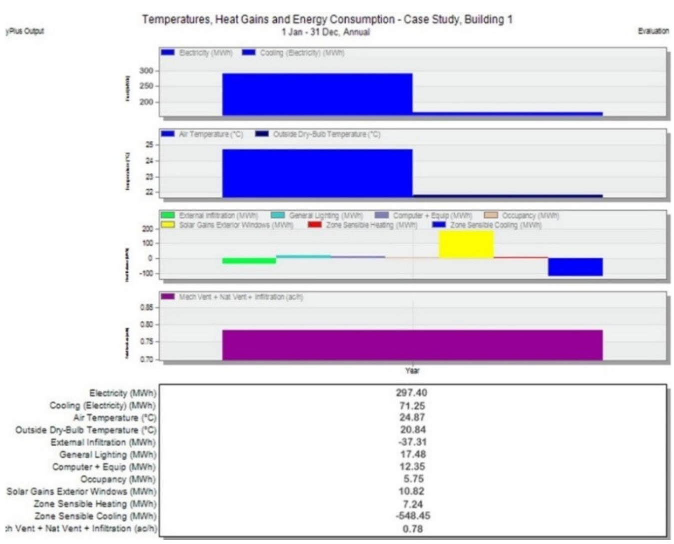


Fig .10 design treatments annual simulation

The two values that are significantly important from the annual simulation results are: the annual electricity consumption and the solar gains from exterior windows. The annual electricity consumption has decreased from **66000** kWh to **29740** kWh which is equivalent to half.

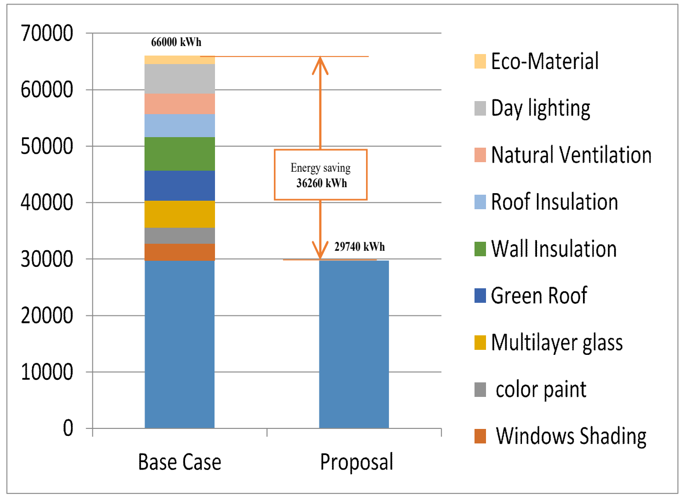


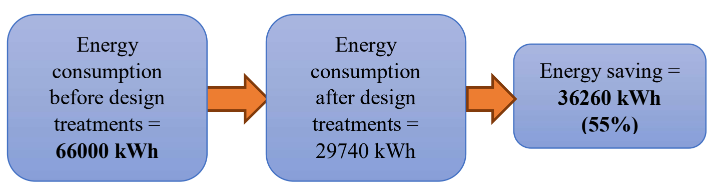
Fig .11 The comparison between the existing building's consumption and the design proposal (by Researcher, 2019)

3.3.2 Simulation Conclusion of Energy Consumption:

After considering the environmental design treatments, the annual electricity consumption is decreased to **29740** kWh instead of **66000** kWh in the current existing case. This shows the impact of the environmental design treatments technologies used and gives a base for solar panel system design to work on.

Energy consumption in Base-Case = 66000 kWh

Windows Shading = 62740 kWh	3260 kWh (5%) Saving
Light color paint = 63190 kWh	2810 kWh (4%) Saving
Multilayer glass = 61315 kWh	4685 kWh (7%) Saving
Green Roof = 60705 kWh	5295 kWh (8%) Saving
Wall Insulation = 60070 kWh	5930 kWh (9%) Saving
Roof Insulation = 61890 kWh	4110 kWh (6%) Saving
Natural Ventilation =62480 kWh	3520 kWh (5%) Saving
Day lighting = 60650 kWh	5350 kWh (8%) Saving
Eco-Material = 64700 kWh	300 kWh (2%) Saving



3.3.3 Renewable Energy Production:

Solar panels: Solar panels have been adopted because they are the most efficient in Egypt. Based on calculations of the solar panels and the energy produced, the amount of energy produced from the area of solar panels **335** m^2 produced energy **67918.7** kWh and each square meter produces **202.7** kWh. As the actual building needs of energy is **29740** kWh. As explained previously the area of solar panels will be as follows:

The area of the solar panels required for the case study to reach the zero building = 29740 / 202.7 = 147 m^2

3.3.4 Case study after adding design treatments of zero carbon strategy:

• *Annual simulation of carbon emissions:*

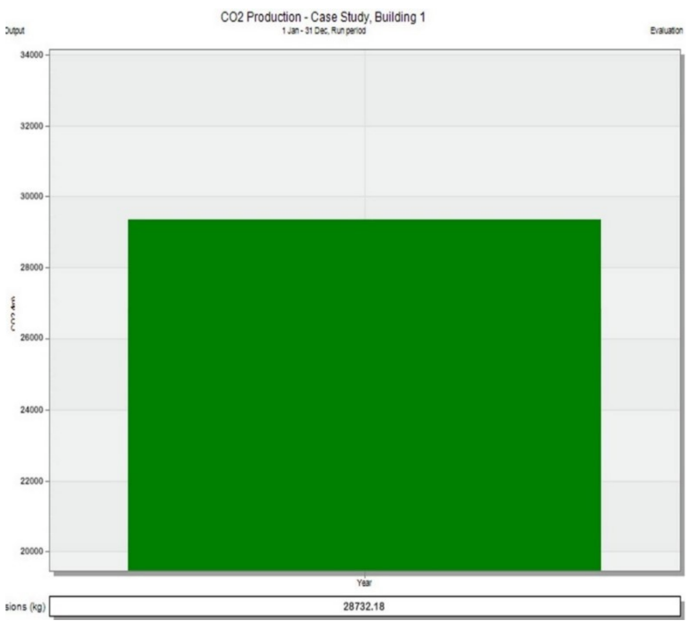


Fig .12 Design treatments annual simulation

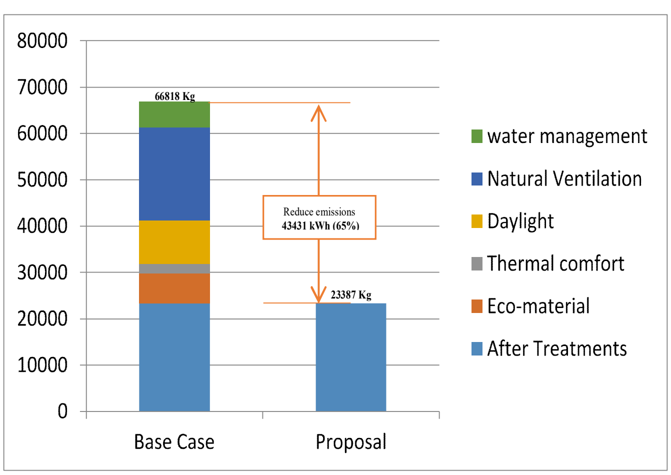


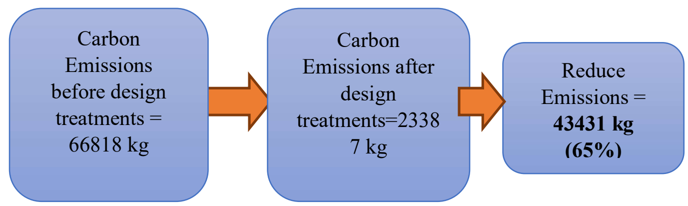
Fig .13 The comparison between the existing building's carbon emissions and the design proposal (by Researcher, 2019)

3.3.5 Simulation Conclusion of Carbon Emissions:

After considering the environmental design treatments, the annual Carbon Emissions is decreased to **23387 kg** instead of **66818 kg** in the current existing case.

Carbon Emissions in Base-Case=66818 kg

Eco-Material Strategy= 60136 kg	6682 kg (10%) Reduce
Thermal Comfort=64813 kg	2005 kg (3%) Reduce
Day lighting Strategy= 57464 kg	9354 kg (14%) Reduce
Natural Ventilation = 46773 kg	20045 kg (14%) Reduce
Water Management =61473 kg	5345 kg (8%) Reduce



Thus, we conclude from the previous calculations that it is possible to achieve zero building energy and carbon emissions in Egypt based on environmental design treatments, the building's energy needs were compensated from solar panels to reach the zero building.

IV. CONCLUSIONS

Existing residential buildings in Egypt suffer from low insulation levels from which increases the energy consumed to reach the thermal comfort inside the building. A possible solution for this problem is to convert existing buildings to zero-energy buildings. The study proposed a guideline to be followed to reach this result and implemented the guideline on a case study building in BeniSuef. The results of the study reveal that an existing residential building can be converted to zero-energy & zero-carbon building using the design treatments. The study analysis implemented in the case study reveals using materials existing in the market- and the PV panels' installation and it was found to be affordable.

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