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Converting Egyptian Commercial Building to NZEB using Low-Carbon Measures

Ayman Mohameda[1], Moataz O. El-Sherif[1], Mohamed Fatouh[1,2]

[1] Mech. Power Eng. Dep., Fac. of Eng. @ El-Mattaria, Helwan Uni., Masaken El-Helmia, Egypt.
[2]High Institute for Eng. & Tech. - Obour, k21 Cairo/Belbies Rd, Cairo, Egypt ,
.
Corresponding Author Email: ayman.a.m.mohamed@m-eng.helwan.edu.eg

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Abstract **– The present work aims at analyzing the energy savings of the low-carbon retrofitting measures in an existing administration building as well as their economic feasibility. Atstarting, energy consumption analysis of an exemplary existing commercial building inCairo (Egypt) is carried out. Then, low-carbon measures in the considered building areapplied and evaluated. The low-carbon measures include both passive and active measuresto reach Net Zero Energy Building (NZEB). The exiting building energy consumption ofheating, cooling, ventilation, lighting, and appliances are analyzed using building simulationpackage, which consists of Sketchup, Open Studio and Energy Plus software under Cairoclimatic conditions. The simulated results are validated with the real energy consumption ofthe existing building. The yearly average deviation between the simulated results and thereal existing case is less than 1%. The economic feasibility of all implemented low carbonmeasures are conducted using the payback period. The reported results confirm thatconverting the existing administration buildings to NZEB is applicable under the Egyptiancircumstances using low-carbon retrofitting measures implementation and renewable energy (PV panel) systems installation.**

Keywords – commercial building; net zero energy building; low-carbon measures; cooling demand, building energy modeling and simulation.

I. INTRODUCTION

Decreasing energy consumption, carbon emissions and water usage are main keys toward better environmental sustainability. The increasing energy consumption and the accompanied greenhouse gas emissions are considered one of the greatest concerns recently.The total electricity demand in Egypt for the year 2018 reached 131.15 TWh with an annualaverage growth rate of 4.12%. The building sector alone contributes with 68% of totalelectricity demand in 2018 (EEHC, 2018).

In MENA region, the proposed energy saving strategies were applied on cases to develop the building regulations and energy codes (Hanna, 2010; Hanna and Physicist, 2006; Shamseldin, 2017). The National Energy Efficiency Action Plan (NEEAP) in Egypt targetsto apply 3 steps to reduce electrical energy consumption: efficient lamps (LED), efficientappliances and the encouragement to use solar water heaters (Elrefaei and Khalifa, 2014).Green pyramid rating system (GPRS) was developed for Egypt as a national environmentalrating system for buildings but it is not certified yet (Hanna, 2015). Using a model buildingsimulation tool and making sensitivity analysis to reduce the electric power consumption onpeak hours was carried by (Elharidi et al., 2013). The effect of implementing passive low-carbon measures on new buildings was studied theoretically in several studied. The shading,window glazing, air tightness and insulation can reduce energy consumption of an average of 33% (El-Darwish and Gomaa, 2017). Regarding active low-carbon measures, the high investment in the solar panels could be achieve a negative final energy balance and thefeasibility of applying nearly zero energy building (nZEB) as a proposed solution for theenergy problem in New Borg El Arab City, Egypt (Reda et al., 2015). Solar panels could be used also in a hybrid renewable energy system to achieve a net zero energy village in Alexandria (Diab et al., 2015).

Accordingly, the national trend and the target of this phase is going to reduce the energy consumption in the buildings sector by applying the NZEB strategies to the newbuildings and refurbishment the already existing buildings to reduce the demand and applyon-site generation to reach NZEB target. By 2030, the sustainable development strategy (Egypt vision 2030 – Second Pillar) aims at reducing the energy consumption and greenhouse gas emissions by 14% and 10%, respectively.

The objective of the present research is to evaluate of applying energy efficiency measures on existing administration building under Cairo climatic conditions to reduce both energy consumption and greenhouse gas emission.

II. RESEARCH METHODOLOGY

The research methodology includes selected building profiles and simulation tools as well as models of existing and retrofitted buildings. All architectural and performance data are obtained from the designer and the operator. Thereafter, the model is created on a certified building simulation tool. The simulation results are verified with the actual energy performance. The proposed passive and active low carbon measures are implemented on a simulation model to examine the techno-economic performance of the building.

Selected Building Overview

The selected building includes a basement, ground level and four typical floor plans, as shown in Figure 1. The building locates in Maadi smart village (29º58’19” N, 31º17’00” E), Cairo, Egypt. The building covers an area of 4000 m^2 and the parking lot is 2,107 m^2. The total building area and height of the building are 25,000 m^2 and 28.5 m, respectively. The area with air conditioning is 19,342 m^2 (77.4%), while the area without air conditioning is 5,658 m^2 (22.6%).

Building Simulation Tool and model

Open Studio V.2.3, Sketchup V.17.0 and Energy Plus V.8.8 is used as an integrated package to simulate selected buildings. This package is an open-source platform that has been used in several published investigations (Guglielmetti et al., 2011; Raslan and Mavrogianni, 2013).

2.2.1 Existing building (reference case)

The existing building envelope thermal properties are obtained from the design package (ECG, 2012). Its external walls consist of sandstone (hashma stone), air gap, insulation board, vapor barrier, and hollow block masonry. The overall heat transfer coefficient (U-Value) of the wall is 0.28 W/m^{2}K. The solar heat gain coefficient (SHGC), the heat transfer coefficient (U-value, and the window-to-wall ratio of the building window are 0.3, 1.44 W/m^{2}K and 25%, respectively. The design year and weather file for Cairo, Egypt is used (Energy Plus, 2021).

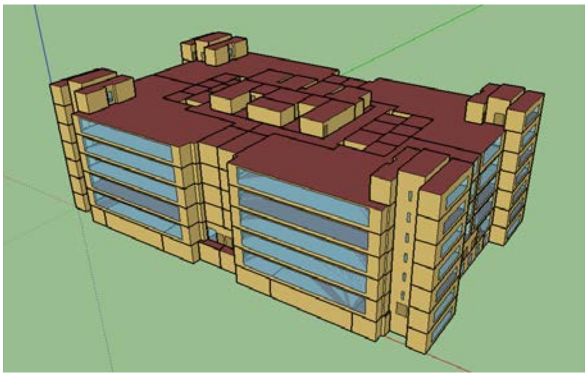


Figure 1 Case Study Building Model

The existing building consists of 251 spaces that can be classified into certain types based on activity usage reported in the literature (Brackney et al., 2018). Air-conditioned space types are call centers, training rooms, rest areas, lockers, corridors, and IT rooms. Other space types are only ventilated, such as storage rooms, electrical rooms, and toilets. The building is operating for 24 hours on three consecutive work shifts (each, 8 h). With 3,093 building occupants per shift, there are no temporary staff, visitors, or residents in the building. Each space type has an occupancy schedule based on building operations work shifts starting at 8am, 4pm and 12pm each day, as shown in Figure 2. As shown, these schedules are being changed to half on weekends and official holidays. According to the design, the peak occupancy load is 8.22 m^2/person. Table 1 gives the peak lighting power densities according to the literature (Schwedler et al., 2010) and the design package (ECG, 2012). The electrical equipment load is obtained from the distribution of equipment in all spaces in the building considering the capacity and quantity of each equipment. The ventilation system brings fresh air into the building, with an average of 0.3 L/s m^2 according to the design package.

The existing building uses a variable refrigerant flow (VRF) air-conditioning system with cooling capacity of 1050 TR. The VRF air-conditioning system has various advantages such as sustainable, cost effective, lower maintenance costs and quiet operation. As important, VRF technology offers the ability to capture a significant number of points toward LEED certification. The VRF air conditioning system in the existing building uses R410a as the working fluid and has a rated cooling COP of 3.3 and a rated heating COP of 3.5.

2.2.2 Modified building using low-carbon measures

Existing buildings are retrofitted with low-carbon measures, which can be divided into passive and active measures. Passive measures include increasing external wall insulation, window shading, and choosing window types with low solar transmittance. To replace high-power lamps, energy-saving lighting lamps (fluorescent lamps, LED lamps, etc.) are used as active measures. The effect of implementing these measures on the existing building are investigated and compared with a reference model (existing building). Also, the impact of applying all measures to the base case model is studied and compared with the reference case.

The existing type of glazing in the existing building is double glazing with air space. It has a U value of 1.44 kW/m2K, good reflectivity, moderate light transmittance and moderate solar heat gain. Other window glazing types are proposed to investigate their effect on annual thermal demand. Table 2 lists thermal and optical characteristic of the proposed glazing types.

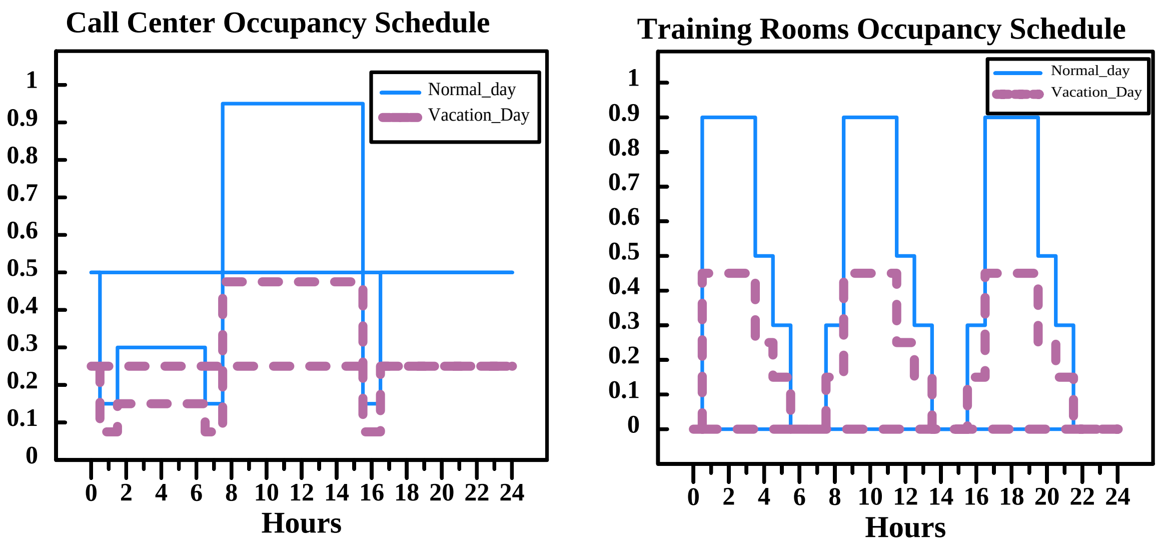


Figure 2: Occupancy Schedules

Table 1 Base Model Lighting Intensity (ECG, 2012)

Space type	Base Model lighting intensity (W/m^2)	Space type	Base Model lighting intensity (W/m^2)
Break Area	6.69	Stairs	6
Call Center Room	12	Storages	9
Corridors	5	Training Rooms	12.78
IT & Server Rooms	13.83		

Table 2 Thermal and optical characteristic of glazing types (Hanna, 2010; HBRC, 2006)

Types	**Name**	**U**	**SC**	**SHGC**	τ_{vis}
00	Base Model	1.44	0.42	0.3	0.45
01	Single Glazing (Blue)	6.17	0.71	0.61	0.57
02	Single Glazing (Grey)	6.17	0.69	0.59	0.43
03	Single Reflective (Class A) 1 Clear High Emissivity	5.41	0.36	0.31	0.2
04	Single Reflective (A) Tint Medium Emissivity	5.11	0.29	0.25	0.09
05	Double Glazing Tint Low Emissivity	1.78	0.37	0.28	0.44
06	Double Glazing, Reflective (A) Clear Medium Emissivity (IG)	2.35	0.2	0.17	0.13
07	Double Glazing, Reflective (A)Tint, Medium Emissivity (IG)	2.35	0.18	0.15	0.08

Where U is the U-value [kW/m^2 K], SC is the shading coefficient [-], SHGC is the solar heat gain coefficient [-] and τ_{vis} is the visible transmittance [-].

The most popular passive method of controlling sunlight and unwanted solar heat is external shading. The unwanted solar rays can cause occupant discomfort and increase cooling loads. The projection factor is a way of characterizing the effect of horizontal shading on facade windows. The projection factor (PF) is defined as the ratio between the length of the horizontal shadow and the height of the window. In the base model, the façade windows are exposed to sunlight. The projection factors of 0.4, 0.6, 0.8, and 1.0 are used in each direction separately as well as in all directions together.

Based on the existing lighting system data, the lighting lux of the space type is estimated according to HBRC (2006). The present work includes 4 types of lighting fixtures. It may be noted that fluorescent lamps are considered as the base model lighting fixtures. Alternative lighting fixtures include incandescent, compact fluorescent (CFL), and light-emitting diode (LED) lamps. These alternative lighting fixtures are investigated with the design lighting lux level remaining constant as in the base case.

Lighting efficacy of incandescent and CFL is 17.4 and 78.9 lm/W, respectively, based on the reported data in literature (HBRC, 2006) while that of fluorescent lamps and the alternative LED lamp is 60 lm/W and 106.67 lm/W, respectively, according to manufacturer catalogue (Philps, 2019). The lighting intensity of each alternative lighting fixture is calculated by maintaining the same light intensity (lux/ m2) in all spaces.

2.2.3 Adding photovoltaic panels to the Modified building

The photovoltaic panels are proposed to be fixed on the existing building, with a total available surface area of 5,615 m^2 for the installation of photovoltaic panels. The total surface area includes 3,508 m^2 of roof plan area (about 90% of the roof area, which is reserved for maintenance purposes) and 2,107 m^2 of off-building parking. The efficiency of the photovoltaic panel and the inverter is 18% and 95%, respectively, according to the manufacturer data (ABB, 2019; Jinko, 2019).

2.2.4 Economic analysis of low-carbon measures

The economic analysis of low-carbon measures is carried out using the payback period method. The payback period is the ratio of the increase in the total investment cost of the retrofit (i.e., from a less efficient design to a more efficient design) to the reduction in annual operating costs. This type of calculation is known as a “simple” payback period because it does not consider changes in operating expenses over time. As noted in literature (Shouman et al., 2016), projects with short payback periods are less risky. The payback period is calculated in two steps using the above definition. The first step is to estimate the payback period for each energy efficiency measure, and the second step is to calculate the payback period for PV panel installation.

The input data to the program are the weather file and design days, the building operation schedules, the building construction and used materials, the building loads (people, lighting, equipment, etc.), the space types, thermal zones, HVAC systems, OpenStudio measures, PV data and economic parameters. Output data from the program includes Open Studio reports that include net site energy, annual and monthly energy consumption, total facility building electricity consumption, photovoltaic panel output, and payback period.

III. RESULTS AND DISCUSSION

In this section, the results of the base case model are reported, discussed, and validated against the actual energy consumption obtained from the building database. The impact of proposed low-carbon measures and photovoltaic panels is predicted, followed by their economic performance.

3.1. Base Case Results

Hourly space cooling and heating demand is shown in Figure 3. Based on a total floor area of 25,000 m^2, the peak space cooling and heating requirements are 1.25 MW and 30 kW, respectively. Figure 4 shows the monthly demands. The annual space cooling and heating requirements are 171.2 kWh/m^2 and 1.1 kWh/m^2, respectively. The peak monthly space cooling demand occurred in August at 21.16 kWh/m^2. The annual electricity consumption is 107.71 kWh/m^2, of which the annual equipment load is 78.6 kWh/m^2, and the annual lighting load is 29.11 kWh/m^2.

3.2 Building Model Validation

To validate the model using the actual energy consumption of the building, the space heating and cooling demands must be converted into electricity delivery demands, resulting in the air conditioning system described earlier in Section 2.2.1. The simulated total annual electricity consumption including the air-conditioning system, equipment and lighting loads is 200 kWh/m^2. According to the building's meter reading, the existing building consumes 198.6 kWh/m^2 of electricity per year. The monthly average deviation between the simulation model and the actual building for the whole year is 1.36%. The deviation is due to inaccurate weather files, human error in meter reading, and unmeasured changes in actual occupancy rates, and the data obtained are monthly data. The simulated and real monthly energy demands are shown in Figure 5. It can be concluded that the simulation model is reliable and suitable for predicting the effect of implementing the proposed low carbon measures.

3.3 Results of the Modified building

External shading of windows and changing window types are considered as passive low-carbon measures, and high-efficiency lighting (fluorescent lamps, LEDs, etc.) are used as active low-carbon measures to retrofit buildings. Moreover, photovoltaic panels are installed to reduce electricity demand and achieve NZEB balance. The impact of implementing low-carbon measures on the base model is investigated and compared with a reference case.

1) Effect of the Shading

Figure 6 illustrates the cooling and heating requirements for the use of external shading on windows. Since the building's orientation and sun position face the building's south façade most of the year, adding shading to the south can significantly reduce cooling requirements. Similar results were found by Elhadad et al. (2018). Vice versa, north-facing shades have the lowest cooling demand reductions. When the shade is installed in all direction, the cooling load is reduced by 5.3% and the heating load is increased by 0.77%.

2) Effect of the Glazing Type

Figure 7 shows the annual cooling and heating demands due to the installation of the proposed glazing types. The lowest cooling load is achieved with glazing type 07. The highest cooling loads occur when using type 01 glass. Type 04 glass, on the other hand, produces the highest heating load, and solar radiation easily passes through the glass due to its high solar coefficient (SC) and high visible light transmittance (τ_{vis}). Due to the very low visible light transmission (τ_{vis}), the heating load is the lowest when using type 01 glass.

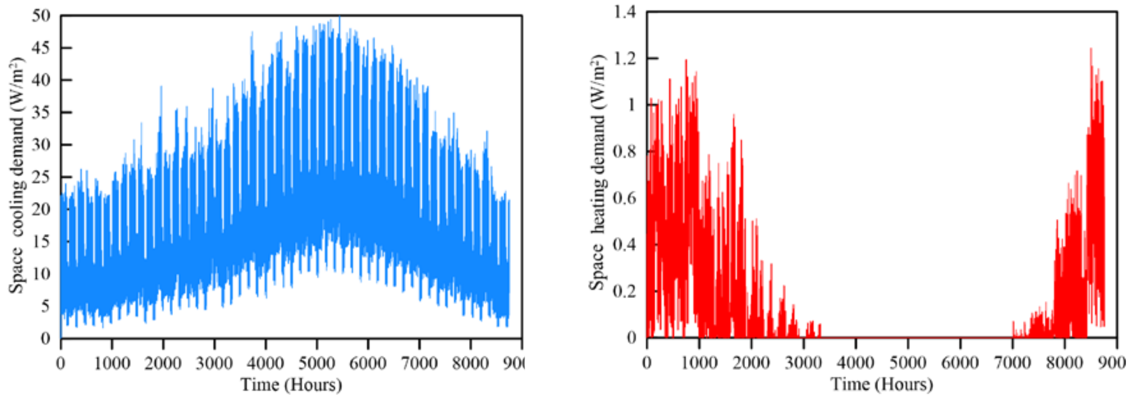


Figure 3 Base case annual space cooling (left) and heating (right) demand

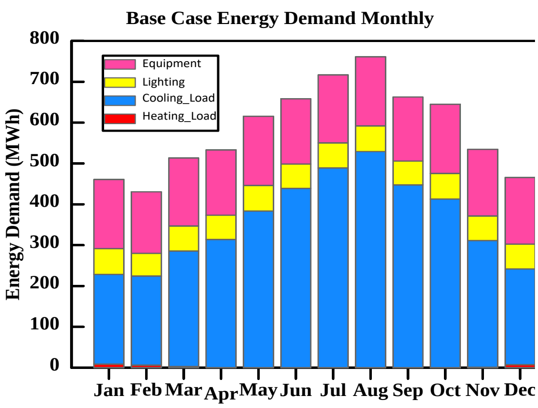


Figure 4 Base case monthly demand

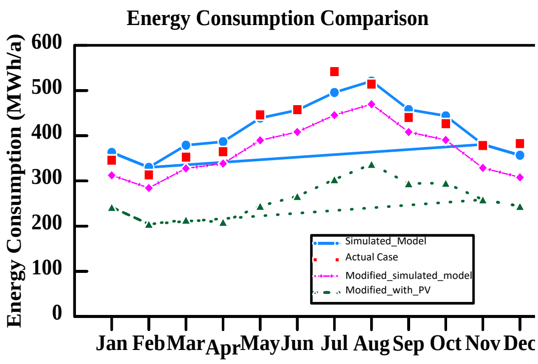


Figure 5 Monthly Energy Demand of basic model and modifications

3) Effect of the Lighting fixtures

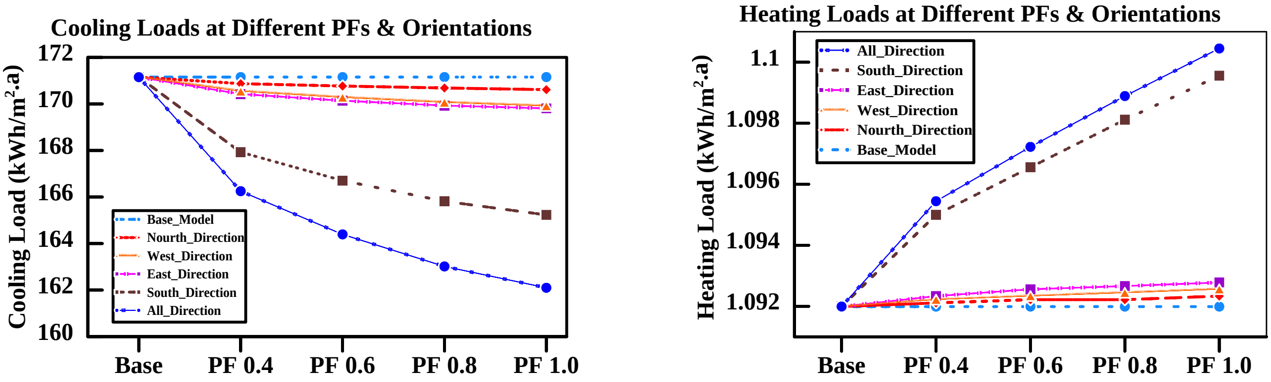
Figure 8 presents the space cooling, heating, and electric demand using different lighting types. LED lighting has the lowest cooling demand while the incandescent lighting has the highest cooling demand. On the other hand, the lowest heating requirement is achieved with incandescent lamps, as their low efficacy of 17.4

lm/W results in high internal heat gain. The highest heating demand is achieved with LED lighting, as its high efficacy of 106.67 lm/W results in the lowest internal heat gain. Compared to the base case, using LED lights reduces cooling requirements by 7.9%, increases heat load by 5.5%, and saves 43.8% in primary electrical lighting requirements. Regarding the total electricity demand delivered, implementing LED lighting achieves a total energy savings of 9.4% compared to the base case.

4) Effect of Photovoltaic panels

The suggested locations for these photovoltaic panels are the roof and the parking lot outside the building. The available areas of the roof and the parking lot are 3,508 m^2 and 2,107 m^2, respectively. The simulation results show that the photovoltaic panels generate 1.3 GWh/a in a total area of 5,615 m^2 (that is, each square meter of photovoltaic panels produces 230.8 kWh/m^2 per year). The efficiency of photovoltaic panels commonly used in the local market is assumed to be 18%. The active area accounts for 90% of the total photovoltaic area. The inverter efficiency is assumed to be 95%.

Figure 5 shows the monthly electricity demand for the base (actual) case and the modified model without and with PV panels. The modified model includes integrated glass type 07 glazing (double glazing, reflective (A) tint, medium emissivity (IG)), LED lighting type, and south shading with a projection factor of 1.0. The simulated annual electricity demand of the modified model is 176.4 kWh/m^2. After applying photovoltaic panels, the annual electricity demand is reduced to 124.5 kWh/m^2 (about 29.45% reduction). However, the annual energy consumption of the building implementing all the proposed modifications is reduced by 37.86% compared to the actual building electricity bill. To be clear, to achieve NZEB, the required photovoltaic panel area must be equal to 13,489 m^2. It is about 3.37 times the footprint area of the building. This is quite unachievable due to whether the land availability in the existing building location is limited, or the land cost is very expensive.



(a) Cooling Load (b) Heating Load

Figure 6 Cooling and heating Loads at Different PFs and Orientations

5) Payback period results

The initial cost of energy efficiency measures (glazing, shading, LED lighting) and photovoltaic panels is estimated based on local market research. Operation and maintenance costs are estimated based on the life and maintenance schedule of each measure. Glass and shades have a long lifespan of about 20 years. This means there is no cost to change it throughout its lifetime. Based on the manufacturer's recommendations, change of both LED lighting and photovoltaic panels is taken into consideration throughout the life of the project.

The simulation results confirm that the total glazing (Type 07) area that had to be supplied and installed is 2487 m^2 (≈ 2500 m^2). According to the local market prices, it is found that the cost to supply and install (cladding and frame) of this glazing type (Type 07) with shading has an average price of 1,000 LE per m^2. Hence, the glazing replacement and shading installation cost is 2,500,000 LE.

The main types of lighting fixtures are 18W compact, 14W 600mm tube fluorescent and 28W 1200mm tube fluorescent. These types will be replaced by 9W LED bulbs, 8W LED 600 mm tubes and 14.5W LED 1200 mm tubes. Each space in the building has its lighting operating hours. This helps to calculate how many times each lighting fixture allocated in each space will be replaced. The 8W 600mm LED tube and 14.5W 1200mm LED tube only need to be replaced once in the 20-year project period. The 9W LED bulb will be replaced three times. Hence, the total cost of the lighting equipment is 1,794,800 LE.

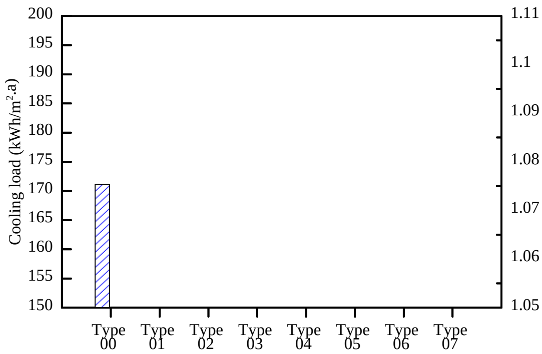


Figure 7 Annual Cooling and Heating Loads at different Glazing Types

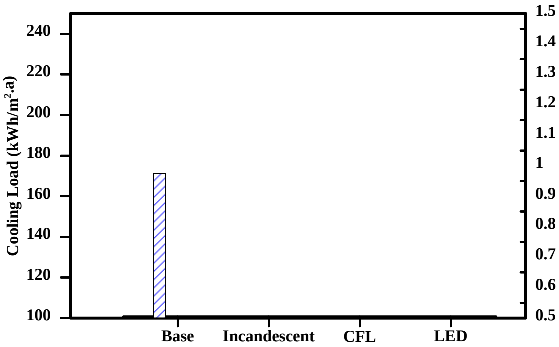


Figure 8 Cooling & Heating Loads at different Lighting Intensity

Existing lighting fixtures have lifetimes of 6,000, 20,000 and 20,000 hours. The replacement cost of the base model lighting fixture is 1,253,924 LE. Therefore, the net cost of implementing efficient lighting measures is 509,924 LE.

According to the simulation results, the solar panels produce 1,296,191 kWh/a. According to local market research, the average cost of 10 m^2 of solar panels is 17,000 LE. Maintenance costs are assumed to be 1.5% of capital cost per year. Therefore, the total initial and maintenance cost of the PV is 10,355,516 LE.

The simulation results revealed that the total initial and replacement cost is 13,365,440 LE for all low carbon measures and photovoltaic solar panels, and the operating cost saving is 3,035,046.4 LE. Consequently, the payback period for the retrofit of the building is 4.4 years.

IV. CONCLUSION

The present work aims at analyzing the energy savings of the low-carbon retrofitting measures in an existing administration building as well as their economic feasibility. The simulated results of an existing administration building showed that the annual delivered electricity is 279.955 kWh/m^2. The effects of implementing low-carbon measures can be summarized as follows:

- Replacing the base case glass type with a double-glazed, reflective (A) Tint, Medium Emissivity (IG) (type 07) provides a 4% reduction in energy compared to the base case.
- The percentage of energy savings due to the addition of shading to the south-facing façade windows is 2.11%.
- After applying 3 lighting fixtures; LED, CFL and incandescent lamps, LED lighting provides a saving of 43.8% in electricity demand for lighting and 9.4% in total electricity demand.
- The modified model integrating all low-carbon measures (except photovoltaic systems) achieved 11.9% savings in annual electricity demand relative to the base model.
- By installing a photovoltaic panel system on the modified model, the delivered energy demand is reduced by 29.45% compared to the base case.
- Achieving a net-zero energy building requires 3.37 times the building footprint.
- The payback period of the modified case without the PV system is 3.15 years. Adding a photovoltaic system to the modified model extends the payback period to 4.4 years.

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