

Energy Analysis for New Office Buildings in Egypt

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Abstract: This paper summarizes the results of energy analysis to determine the effectiveness of building characteristics in reducing electrical energy consumption for office buildings in Egypt. Specifically, the impact of building envelope performance is investigated of window size, building construction, and glazing type for two geographical locations in Egypt. It was determined that a window to wall area ratio of 0.20 minimizes the total annual electricity use for office buildings in two Egyptian locations, Cairo and Alexandria.

Keywords: Energy analysis; office; Insulation; WWR; PF; EIR; LPD

1. Introduction

In Egypt, over 55% of the total electricity consumption is attributed to residential, commercial, and institutional buildings. Artificial lighting is estimated to account for 36% of the electricity used in the commercial sector during 2013 and 2014. A significant increase in electricity demand is expected over the next few years with a growth rate of 6.8%. To improve the energy efficiency of buildings, an energy code is being proposed for new commercial buildings in Egypt [1]. As part of the development of the energy code, an extensive simulation analysis has been carried to determine the most cost-effective energy efficiency measures suitable for Egyptian buildings.

Building Envelope and window components are considered one of the fundamental design features of energy-efficient buildings. Unfortunately, incorporation of daylighting in commercial buildings is almost never considered in Egypt. In addition to costs, the lack of any extensive analyses to assess the cost-effectiveness of daylighting control strategies in Egyptian buildings may explain the reluctance of architects to incorporate daylighting in their designs.

This paper summarizes results of a detailed simulation analysis on the impact of building and window designs on the energy use for commercial buildings in Egypt DOE-2.IE, a whole building simulation tool, is used to determine the effects of building parameters on the total electricity use for typical office buildings. In addition, the paper provides a simplified relationship between building perimeter, floor area, glazing, window area, daylighting control strategy, and their effects on artificial lighting energy use for three locations in Egypt.

2. Climate of Egypt

Egypt is situated between latitude 31.33 °N and 22 °N and Longitude 26 & 35 °E. It consists mainly of desert ($\cong 94\%$ of Egypt land) except for Northern and Eastern coast and Nile valley. Deserts are mainly plain except for the East mountain chain and Sinai Mountains. The hot arid climate predominates, since

the impact of water surface is restricted to small area on the Nile sides. In this region, the over heating period is about 7 months duration and the peak shade temperatures reaches

about 40 °C. Solar Factors and the Orientation Factors were calculated for eight orientations for Cairo and Alexandria [2]. Two bin weather files were used for this study. The Outdoor Design temperature for Cairo (30.13 °N and 31.0 °E) and Alexandria (31.2°N, 29.95 °E) are respectively as follows; 38.5 °C & 32 °C.

3. Energy in Egypt

The main sources of energy in Egypt include natural gas, petroleum products, and electricity. The electricity is generated mainly from power plants fueled from primary energy sources. The increase in the overall energy demands has reached to about 140.2 Billion kWh with an annual increase of 7.5% [3], where the industry takes about 28.4%, Residential 42.6%, commercial buildings 10.4% and street lighting 4.4% while Agriculture have only 4.4%. The two major consumers of electricity are households and industry, followed by Government and public utilities.

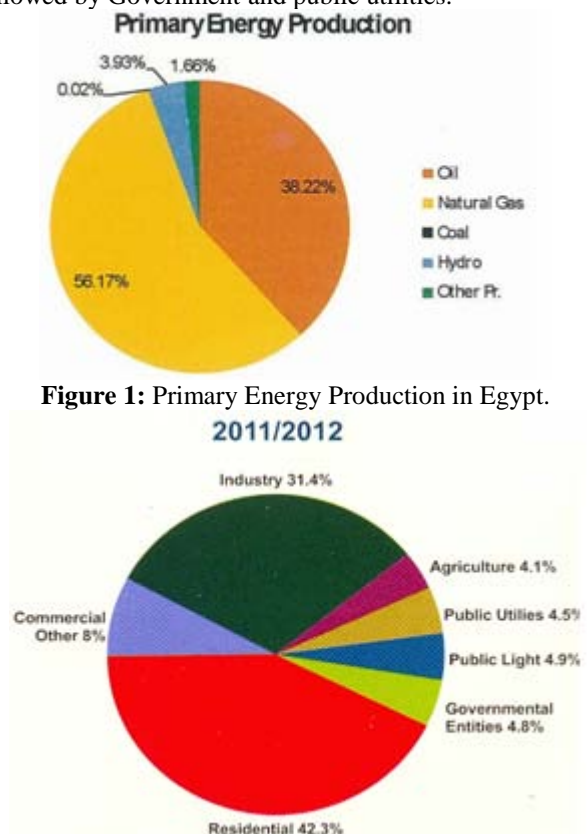


Figure 1: Primary Energy Production in Egypt.

Figure 2: Energy Sold by Purpose (GWh), [3]

4. Egyptian Energy Commercial Building Code

The final draft of the commercial energy code that has been developed is very innovative, for it specifies minimum building requirements to improve both thermal and visual comfort in non-conditioned buildings as well as minimum energy efficiency requirements in conditioned buildings. This Code gives minimum performance standards for building windows and openings, natural ventilation, ventilating and air conditioning equipment, natural and artificial lighting and electric power. A great effort has been made to ensure its applicability in our buildings in Egypt.

The New Egyptian Commercial Energy Code contains the following format shown below:

1. Scope and Compliance
2. General Requirements
3. Building Envelope

4. Natural Ventilation and Thermal Comfort
5. Heating Ventilation and Air Conditioning
6. Service Water Heating System
7. Day Lighting
8. Lighting
9. Electrical Power
10. Whole Building Performance
11. Definitions, Abbreviations And Acronyms

5. Modeling Description

The analysis is based on a prototypical Large office (LOF) building in Egypt (EG). The base case EG_LOF building used for this study is a twenty story building with a typical floor area of rectangular shape ($A_f = 900\text{m}^2$). The number of floors for the office buildings can vary from 2 to 25 stories.

Table 1: Recommended Thermal Resistance and U-values for Different countries ($\text{W/m}^2 \cdot ^\circ\text{C}$) [7].

Country	Roof		Walls		Floors	
	R	U	R	U	R	U
Austria	3.3	0.303	1.4-2.0	0.5-0.7	1.6-2.3	0.43-0.63
Belgium	1.3-2.4	0.42-0.77	1.0-1.5	0.67-1.0	-	---
Canada	4.9-7.0	0.14-0.20	2.1-3.3	0.30-0.48	4.9	0.204
Denmark	5.0	0.2	2.5	0.4	3.3	0.303
Egypt	1.67	0.6	1.0	1.0	----	---
Finland	3.5-4.4	0.23-0.29	2.9-3.5	0.29	4.4	0.23
France	2.5-4.0	0.25-0.4	1.5-2.0	0.50-0.67	1.0-1.3	0.77-1.0
Jordon	1.0	1.0	0.56	1.8	--	--
Kuwait	2.5	0.40	1.75	0.57	--	--
Greece	2.0	0.5	0.9	1.1	0.3-2.0	3.3-0.5
Holland	1.9	0.53	1.5	0.67	1.5	0.67
Italy	2.6	0.38	1.7	0.59	--	--
New Zealand	1.5-3.0	0.33-0.67	0.6-1.7	0.59-1.67	0.9-1.7	1.67-1.1
Norway	4.4	0.23	2.9-4.0	0.25-0.34	3.3-4.4	0.23-0.303
Spain	0.7-1.4	0.71-1.43	0.6-0.7	1.43-1.67	1.0-1.4	0.71-1.0
Sweden	5.0	0.2	3.3	0.303	3.3	0.303
Switzerland	2.0	0.5	1.7	0.59	1.7	0.59
Turkey	2.63	0.38	1.7	1.0	--	--
U K	2.9	0.34	1.0	0.59	--	--
USA (various)	3.5-7.0	0.14-0.29	2.0-3.5	0.29-0.5	0.0-3.5	0.29
West Germany	2.2-3.3	0.303-0.45	0.7-1.2	0.83-1.43	0.8-1.8	0.56-1.25

The dimension of the building is 45m by 20m with a floor-to-floor height of 3.0m. Every facade has 10 modules of 3m wide that facilitate the definition of 10 windows on each orientation. To study the effect of orientation on the wall construction and WWR or roof insulation, the LOF_One façade is used for Mid_Floor and using HVAC system SUM. SUM is simply accumulates results from the loads program and only used when the envelope parameters are investigated. The characteristics of the office building were developed based on the results of a survey conducted as part of the efforts to develop an energy code for commercial buildings in Egypt. It should be noted that the study presented in this paper focuses on the impact of building envelope on the total electricity savings. The DOE2Parm simulation models [4] was used in this study for typical office buildings in Egypt.. Generally, a floor area of 900m^2 per story is considered in the analysis. The model considers is rectangular building. Figure 1.a provides an actual view of an office building in Egypt, which is the Electricity building in Abbassia. Figure 1.b shows typical floor plan of the

Office Building. Typical densities and schedules for office buildings are used to model occupancy, lighting, and equipment. For all the office building floors, recessed fluorescent luminaries were used to represent standard commercial installations. Lighting density was set at 15W/m^2 to meet the ASHRAE/IES standard for office buildings [5]. Typical Egyptian office building occupancy schedules are used to define the operation patterns for the electrical lighting system. All the perimeter areas (A_p) were considered open spaces with no or little interior partitions. The perimeter areas were assumed to have a depth of 6 m.

6. Parametric Analysis

The analysis presented in this paper encompasses various types of modern commercial buildings. The different geometries allow for the characterization of buildings with various perimeter areas and floor areas. Window to wall area ratio was set to vary from 0 (no openings) to 0.9 (glazed walls). Due to the vast selection of windows, five different

glazing types with varying light transmittance were selected and analyzed. The intent was to obtain a wide range of transmittance values to get a broad representation of available products in Egypt.

6.1 Large office parametric energy results

Parametric analyses have been conducted for key energy variables for the large office building, across typical ranges of values. The variables analyzed include:

- 1) Building Orientation
- 2) Roof insulation
- 3) Wall construction and insulation
- 4) Curtain wall, with rigid insulation
- 5) Mass wall, 12 cm brick, rigid insulation on 'outside' between brick and outside mortar layer
- 6) Window-to-Wall Ratio (WWR)
- 7) Glass Type, Solar Heat Gain Coefficient (SHGC)
- 8) Solar shading using overhangs and fins
- 9) Lighting power density
- 10) HVAC System type



Figure 3: Actual View of one façade of the Electricity Office Building in Cairo, Egypt

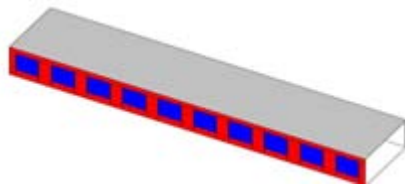


Figure 4: One Façade for Office Building-Isometric

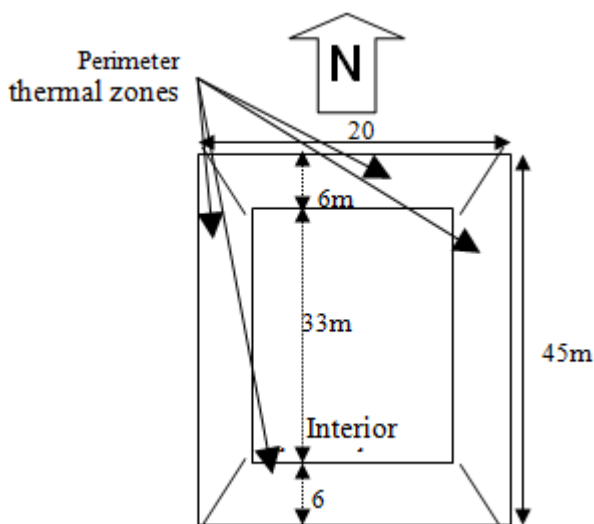


Figure 5: Typical Floor of Rectangular Plan of Large Office

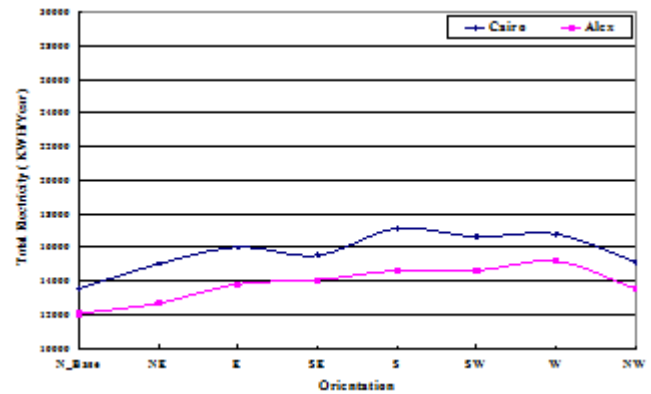


Figure (6.a): Effect of building orientation on the total electricity consumption (KWh), MID Floor- Rec. (7x 15 modules)

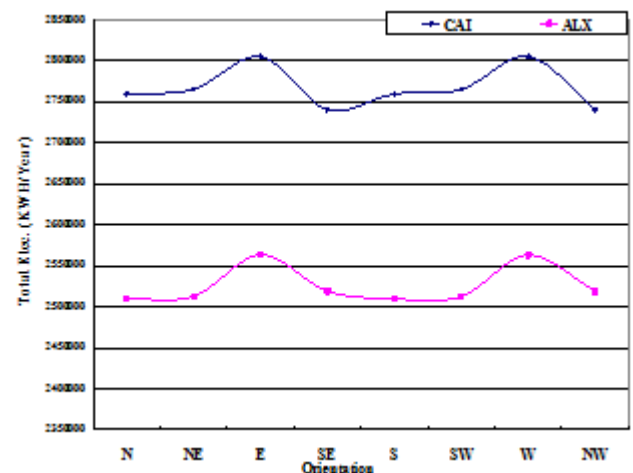


Figure (6.b): Effect of building orientation on the total electricity consumption (KWh), LOF 20-Rec. (15x7 Module).

The resulting annual energy analysis is shown in Figure 6. The analysis is done for one façade building in mid-floor, as shown figure 6.a and for the whole building as shown in figure 6.b. Figure 6.a indicates that office building with aspect ratio of 2:1 with a N/S orientation will use 22% less energy than the same building with long sides facing E/W. Figure 6.b shows the total Electricity/year for 8 orientation for the hollow building, and it save less energy by about 1.6% for Alexandria and 2.2% for Cairo.

6.2 Roof Insulation

A single roof construction was examined-120mm RC slab with cement tiles above it. The insulation is fixed above the RC slab and under the cement tiles. Four kinds of insulating materials were examined namely; Rigid Polystyrene (25, 50,75mm thick); Celton (100mm and 150mm); perlite (25 and 50mm) and Vermiculite (25 and 50mm thick),[8].

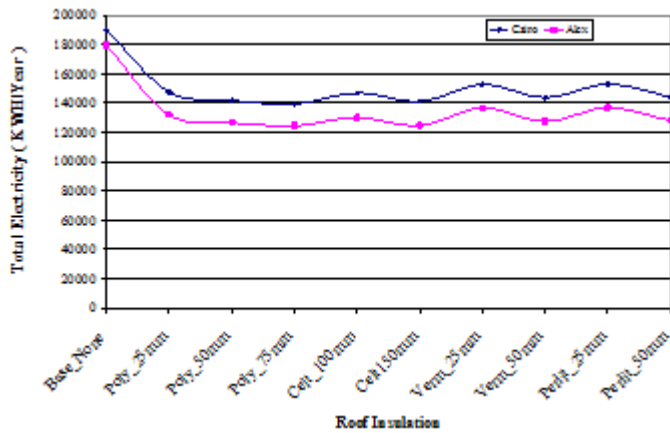


Figure 7: Effect of Roof insulation on the total electricity consumption (KWh), Top Floor - Rec. (7x15 module)

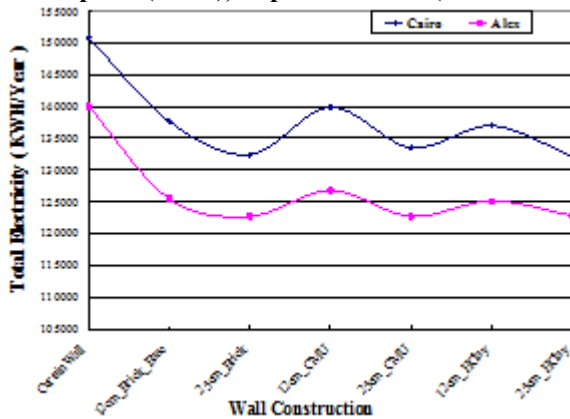


Figure 8: Effect of wall construction on the total electricity consumption (KWh), Mid. Floor - Rec. (7x 15 modules).

The resulting annual energy results are shown in Figure 7. The results indicate that the use of 75mm_Poly of roof insulation has the most impact, but the difference in the total Electricity (kWh/Year) between 75mm Poly and 50mm_Poly is not visible. The annual Electricity saving percent of 30% has been achieved for Cairo relative to 22% for Alexandria. The same saving in the total Electricity reduction could be reached, if we use 150mm_Celton, or 50mm_Perlit.

6.3 Wall Construction and Insulation

Three types of construction were examined with two insulation locations for one of the constructions. The first type consist of Curtain wall with aluminum or glass on the outside, then insulation, then air space, then a layer of gypsum board on the inside. The second type consists of 120mm hollow clay brick with mortar on both sides with rigid insulation on the inside between the brick and the mortar type. The third type contains 250mm hollow clay brick with mortar on both sides and rigid insulation in the middle between the two courses of clay. A wide range of wall construction were examined namely; 120mm_Brick (BC), 250mm_Brick, 120mm_CMU, 120 & 250mm_HClay. Five insulation systems and two locations (in & out) were tested i.e., none (BC), 10mm, 25mm, 50mm & 75mm thick. The energy results are shown in Figures 4 indicates that the use of 250mm thick Clay Brick or 250mm CMU has much saving than 120mm thick Brick or CMU. The annual saving in the total electricity reaches to 2.1% and 3.5% relative to

12cm brick and 12cm CMU. The change in the wall building materials in Cairo has much impact greater than Alexandria by about 7.2%. Increasing the wall insulation thickness greater than 25mm had diminishes.

6.4 Windows-to-Wall Ratio (WWR)

The window-to-wall ratio (WWR) is the ratio of the total glass area to the total building wall area (including the glass area) for all elevations of the building together. WWR directly affects the amount of solar heat gain entering the building, thus it has a great impact on energy consumption of the whole building. The Base Case (BC) for large office building in Egypt uses WWR=0.4. For the parametric analysis, single variable, has been changed across a wide range of values from 0.1 till 0.9.

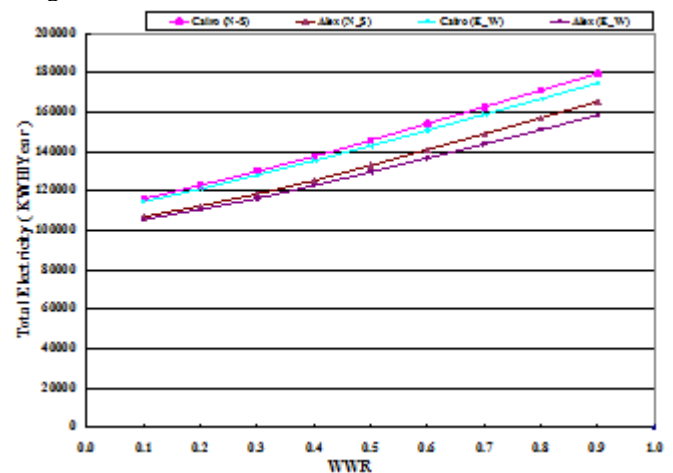


Figure 9: Effect of Window to Wall Ratio on the total electricity consumption (KWh), Mid. Floor -Rec. (7x 15 modules).

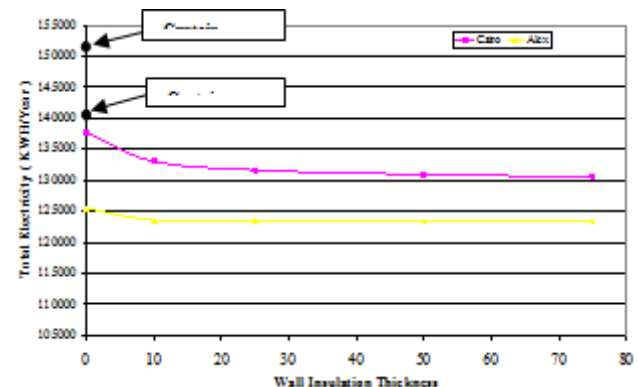


Figure 10: Effect of wall insulation on the total electricity consumption (KWh), Mid. Floor - Rec. (7x15 module)

6.5 Glass Type-Solar Heat Gain Coefficient (SHGC)

The Base Case for large office building in Egypt uses Glass Type 1P_SHGC_61. For the parametric analysis the SHGC, single variable, has been changed across a wide range. All nine fenestration options use regular aluminum frames, with no thermal breaks. Four of the nine options use a single pane of glass, while two options use double-pane, or two panes of glass. The double-pane options have a low emissivity coating on the inside pane of glass.

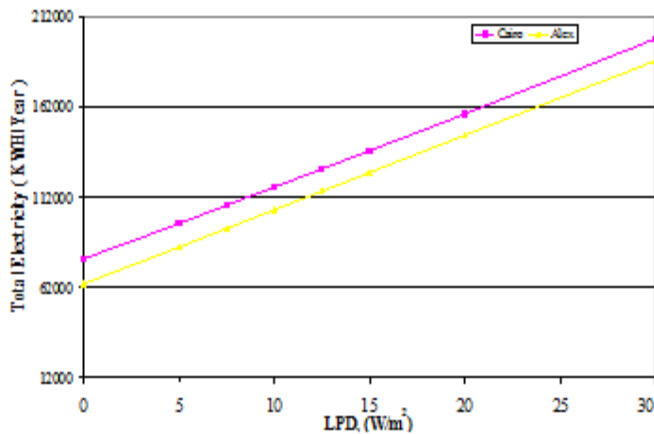


Figure 14: Effect of LPD on the total electricity Consumption (KWh), Mid Floor - Rec. (7x 15 modules).

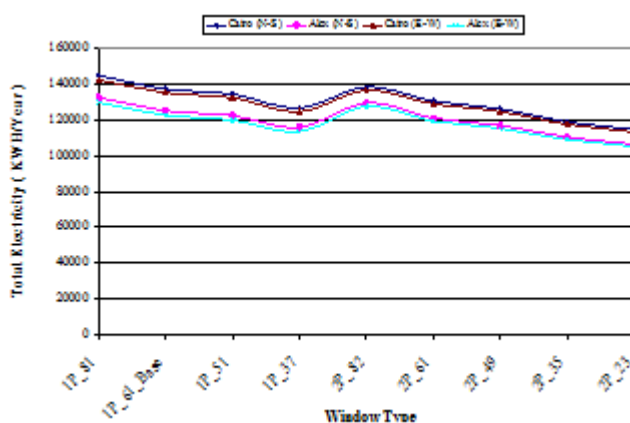


Figure 11: Effect of window type on the total electricity consumption (KWh), Mid. Floor- Rec. (7x 15 modules)

The resulting annual energy results are shown in Figure 11. The results indicate that the type of glass used in large office buildings is an important variable. The range of SHGC values examined resulted in change in the total building electricity use of about 20%. In Cairo, reducing the SHGC from 0.81 to 0.23 will reduce the total electricity use by 20% and 18% in Alexandria.

6.6 Solar Shading Using Overhangs and Fins (PF)

The Base Case for the large office building in Egypt uses the following percent: 0,0.25,0.5,0.75,1.0 for both overhang

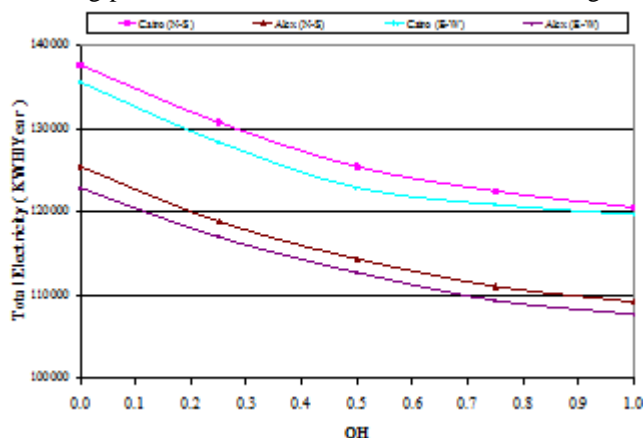


Figure 12: Effect of Over Hang (OH) on the total electricity consumption (KWh), Mid. Floor-Rec. (7x15) module.

The resulting annual energy results for overhangs and fins are shown in Figure 13. The results indicate that the projection factors of overhang and fin in a large office building are an important variable and can produce 6%-18% annual energy reduction depending on the building location, building orientation and the type of exterior shading used.

6.7 Installed lighting Power Density (LPD)

Lighting Power Density (LPD) is one of major part of energy consumption in office building. This section investigates the magnitude of influence of lighting power density on the building consumption. The Base Case of Large office building uses 15 W/m² where the variable being changed from 0 to 30 W/m².

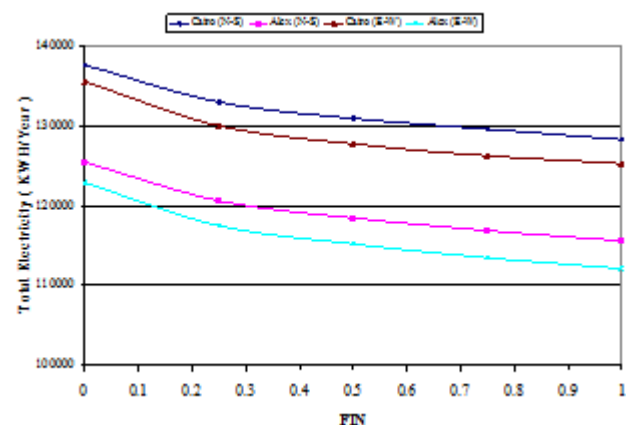


Figure13: Effect of FIN on the total electricity consumption (KWh), Mid. Floor - Rec. (7x15 module).

The annual energy results obtained are shown in Figure 9. The results indicate that the lighting power density level has a great impact on the annual energy use of office building. The energy consumption increased by about 80% when the light power level was increased from 5 to 25 W/m².

6.8 Air-Conditioning Systems (HVAC)

Five different HVAC system types are analyzed namely; **SUM**, **RESYS** (Residential System), **PSZ** (Package Single Zone), **TPFC** (Two Pipe Fan Coil), **VAV** (Variable Air Volume). Two typical systems in Egypt (**PSZ** and **TPFC**) were used.

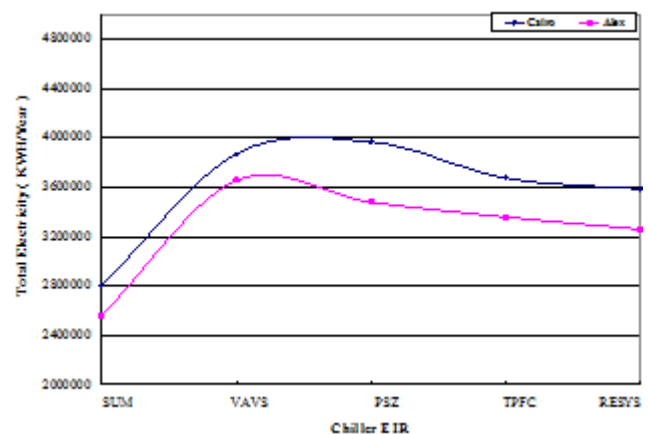


Figure 15: Effect of System Type on the total electricity consumption (KWh), LOF 20 - Rec. (7x15 module).

For the building loads analyses above (envelope and lighting), we have used the SUM system, which tallies the loads on the HVAC system but does not include any system efficiency consideration. HVAC system selection can have a significant impact on building energy use, often producing total annual energy use variations in the range of 30%, as shown in Figure 10.

6.9 Air-Conditioning Chiller Efficiency (EIR)

The Base Case Chiller EIR is 0.25 for large Office building. The parametric analysis is varied from 0.286 to 0.16 for Cairo and Alexandria.

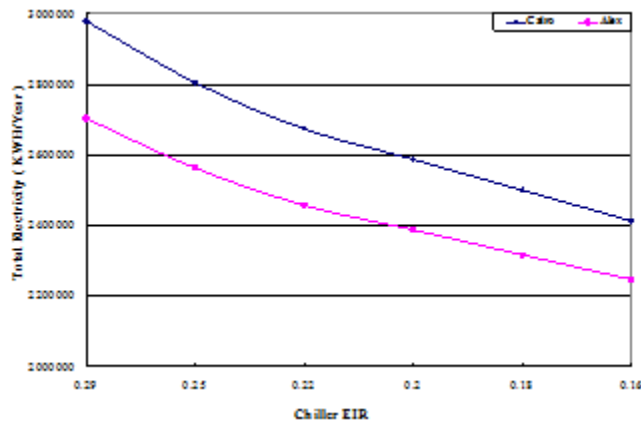


Figure 16: Effect of chiller EIR on the total electricity consumption (KWh), LOF 20 - Rec. (7x 15 modules).

6.10 Space Set-point Temperatures (SPT)

The Base Case for large office building in Egypt uses 23°C for the cooling set point during the occupied periods. The set point temperature is changed over the range of 18-29°C.

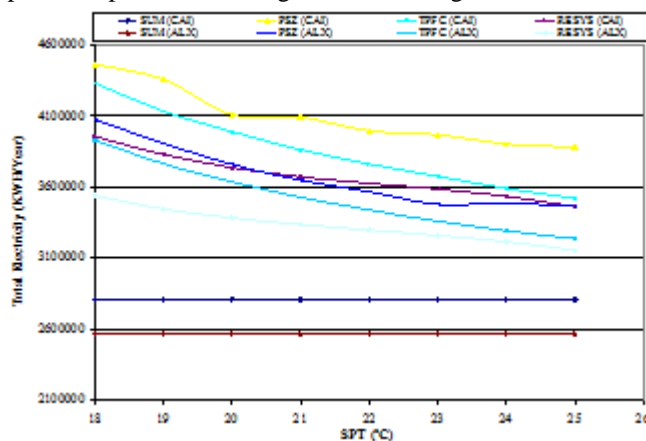


Figure 17: Effect of cooling SPT on the total electricity consumption (KWh), LOF 20 - Rec. (7x 15 modules) for Different HVAC Systems

The annual energy results are shown in Figure 12. The results indicate that total annual building energy consumption is reduced by about 10% when the cooling set temperature is increased from 18 to 29 °C. Thus for each degree C in set-point temperature there is 1% reduction in total building energy use and a 2% reduction in loads on the cooling system.

7. Conclusion

The energy consumption of large office buildings are major part of energy usage in Egypt, and this study reaches to significant findings results. A “Base Case” of Large Office “EG_LOF” was defined, and sets of potential energy saving measures are determined. The energy saving of each of these measures based on DOE2 parametric simulation, are shown in Table 5. The estimated results illustrates a considerable energy savings would reached by (1) starting with the Base Case Large Office that represents current practice, and then (2) changing the key energy-related features to comply with the requirements of the energy code, as shown in column 3. The items that we identified include: 1) Roof insulation; 2) Wall insulation; 3) Window-to-Wall Ratio (WWR); 4) Lighting Power Density; 5) Chiller EIR; 6) Glass Type (Solar Heat Gain Coefficient -SHGC)

The essence of this paper has illustrated how significant energy saving in office buildings can be achieved by judiciously selecting materials with appropriate design technique.

Table2: Large Office [2]

Parameter Studied	Current Practice	Energy Code	Energy Saving
Orientation	-	N-S	2%
WALL_CONSTRUCTION	12cm_Brick	25cm_HClay	2%
WALL_SURFACES	Mortar Both	Mortar Both	-
WALL_INSULATION	None	25mm_Out	2.5%
WINDOW_TYPE	1P_SHGC_61	1P_SHGC_37	6%
ROOF_INSULATION (Top Floor)	None	Poly_75mm	30%
WINDOW-TO-WALL-RATIO(WWR)	0.4	0.2	20%
SHADING USING OVERHANGS (OH) AND FINS (FINS)	-	N-S	10% 4%
OFFICE_LPD	15	15	-
OFFICE_EQPD	5	5	-
Set-Point Temperatures	22	24	2%
CHILLER_EIR	0.253	0.182	8%

Acknowledgment

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Author Profile



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