Assessing the Energy Efficiency and Environmental impact of an Egyptian Hospital Building

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Abstract. Energy consumption in Egypt’s buildings has increased considerably with the growing need to achieve thermal comfort conditions inside buildings. The continuing increases in both residential and commercial buildings require an increase in power generation meeting the new demand. Energy consumption in buildings increases yearly due to the increase in HVAC systems operating hours. It is desirable to minimize the energy consumption and to promote the use of renewable energy resources, saving the earth from global warming effects and the depletion of the ozone layer. In hot and humid climatic regions, high temperatures with high humidity levels results in humans’ discomfort leading to high HVAC energy consumption. In order to understand the energy performance in Egyptian hospitals as they have special requirements and massive energy consumption of HVAC equipment, medical equipment, lighting and infection control systems a hospital located in Alexandria, Egypt was chosen as a case study. The study aims to investigate the energy consumption in Egyptian hospitals and to evaluate the energy-saving efficiency of an existing building. A model for under construction hospital was created using DesignBuilder simulation tool. The initial model was validated based on the hospital construction and mechanical consultants’ data. The initial model was then retrofitted firstly to the latest outdoor design conditions and weather file data recommended by ASHRAE and NREL. Energy efficient techniques affecting annual HVAC energy consumption and whole building energy were investigated. The study provides information for energy efficiency improvements in Alexandria, Egypt hospitals helping designers managing energy in buildings reducing the energy consumption sufficiently. A new DOAS was implemented for temperature and humidity independent control of HVAC system showing significant energy saving in both HVAC and whole building energy consumption. This research recommends a new energy models for future hospitals in Alexandria, Egypt improving the energy efficiency in Egyptian buildings.

Keywords: Energy Efficient Buildings, Energy Saving, Dedicated Outdoor Air System, Environmental Impact
1. Introduction

Egypt's electrical installed capacity, as of 2016/2017, was 45.008 gigawatts (GW), higher than the expected installed capacity in 2015/2016 of 38.86 GW by an increase of 15.82%, according to the latest annual report of the Egyptian Electricity Holding Company [1]. Power generation which depending on burning petroleum-based fuels produces CO$_2$ emissions from combustion. The consumption of energy is increasing daily due to new electronics, more electrical need for daily life leading to an energy crisis. Due to the efficiency of power plant stations and transmission lines, 1 kWh consumption needs 3 kWh generation [2]. In the period from 2000 to 2015, energy consumption in the world led to an increase in carbon emission by 43.76% indexed to year 2000 [3]. Gas emissions is one of the most dangerous crises that increases the global warming and ozone depletion causing climate change in the whole world. Human activities are the main source for global warming and greenhouse gases as CO$_2$ that absorb infrared radiations leading to climatic changes and raised the world temperature [4]. Due to climate and temperature changes, large sizing Air Conditioning systems are required in hot zones [4]. The potential for electricity savings is probably greatest in commercial buildings where a significant portion of the energy demand is expended by the heating, ventilating and air-conditioning (HVAC) systems.

Many benefits can be achieved from energy efficient equipment such as:

1) Less need to build new power plants.
2) Reduction of greenhouse gas emissions since less energy will be produced which means less carbon dioxide emissions from power plants.
3) Reduction of electric bills, which increases the consumer purchasing power for other products helping the local businesses.
4) Avoid future energy deficit as power demand rises.

From the latest annual report of the Egyptian Electricity Holding Company, the energy consumption by commercial and utility sector reached about 16.8% of Egypt’s energy consumption [1]. In commercial buildings, Air Conditioning systems consume about 56% and lighting systems consume about 21% of total energy used in building [5]. Air conditioning systems take a large proportion in energy consumption in hospitals due to long operation times. According to these crises, designers and engineers began seeking for energy management systems for superior energy saving for the air conditioning systems of buildings to help saving the environment from global warming, Ozone layer depletion and degradation, and save more money. The computer simulation tools available nowadays can typically provide energy use by load type (i.e., energy used by HVAC, lighting, equipment, etc.) [6]. Simulation tools such as EnergyPlus, eQuest, DesignBuilder, etc. provide the energy use data.

2. Methodology

Based on the survey, a hospital building located in Alexandria, Egypt was chosen for the case study. To account for energy interactions between building subsystems, DesignBuilder V4.5 was used to build the initial model which was then validated based on the Egyptian construction and mechanical consultants. The energy performance of the initial and other models of the building were simulated to verify that energy savings are achievable. DesignBuilder was chosen as it is an interface to the EnergyPlus which is developed by U.S. Department of Energy’s (DOE) Building Technologies Office (BTO) as a detailed building simulation tool. DesignBuilder computes building energy use based on the interactions between climate, building envelope, internal gains, and HVAC systems. The following steps were used on DesignBuilder in the study:

1. Building the architectural characteristics of the hospital initial model, defining each space in the model.
2. Creating ASHRAE baseline energy model for Alexandria, Egypt using the latest recommended ASHRAE design conditions.
3. Applying latest standards (ASHRAE 62.1-2016, ASHRAE 170-2017, 90.1-2016, AIA healthcare, Green Guide for health care facilities) to the baseline model.
4. Simulating the initial, ASHRAE baseline and energy models to show that 50% (or greater in hot humid climates) energy savings are achieved when the energy design measures are applied to the ASHRAE baseline model.
5- Implementing Dedicated Outdoor Air System into the Modified Energy Model. Figure (1) graphically shows the steps to achieve energy savings.

![Diagram of the modelling process](image)

**Figure 1.** Flow diagram of the modelling process

### 3. Literature Review

As previous research by the Spanish Institute for Energy Diversification and Saving (IDAE), stated that CO$_2$ emissions are highly affected by building sector, especially, healthcare system that achieved the highest energy intensity, associated with the different activities it involves [7]. Alfonso et al. [8] stated that energy management and renewable energy globally reduce CO$_2$ emissions in both energy production processes and in actions involving the improvement of energy efficiency. Hoyt et al [9] found studied increasing the cooling setpoint from 22 to 25°C, approximately 29% energy savings were achieved. He also mentioned that in hot climates increasing cooling set points will be more efficient. Ahn et al. [10] found using simulation tools that LED lightings when used with control strategy reduces energy consumption 20–40% of the total energy consumption in buildings. Jenkins et al. [11] studied for a typical 6 office building, savings of lighting reached annual savings of 56–62% and a reduction in CO$_2$ emissions of nearly 3 tonnes are predicted by changing the lighting type. Sabry et al. [12] discussed using DesignBuilder simulation tool the effect of walls and roof insulation on
energy consumption and CO₂ reduction in residential buildings in Egypt. Reduction of about 40% of the energy consumed by the HVAC resulted when using thermal insulation in the walls and roofs, such savings represent a significant operating cost reduction. Karmany et al. [13] stated that countries sustainable development and green building assessment systems has a direct relationship. She also stated the benefits of sustainable design and construction through a green building assessment system have paybacks on three stages; (1) human level benefits, (2) Country-level benefits, and (3) global level benefits. Dutta et al. [14] study, shows the effect of different glazing types on reduction of both cooling load and energy. The paper gives an idea of the selection of window glazing from commercially available glasses, so that building managers can select the suitable type of glass from commercial market based on research outcome to reduce the energy consumption of building.

Elharidi et al. [15] discussed that different systems efficiencies (HVAC, lights, equipment) and occupant behavior (e.g. use of systems, temperatures) were also identified as significant factors in energy savings, each with the potential of around 30% saving compared to current typical offices. Possible policy measures to promote energy efficient systems and energy conscious behavior are proposed which together can reduce the energy demand of typical offices by 50%. Yusoff et al. [16] stated that buildings consume huge percentage of annual energy consumption such as in HVAC, lighting and electrical equipment. Wardah also mentioned the effect of efforts done by governmental and nongovernmental agencies which helps improving buildings energy efficiency through many strategies and technologies. AbdulRazek [17] developing tools for Energy Efficiency for Lebanese buildings to compare the current buildings performance with the local and international standards to set energy efficiency benchmarks that compares the consumption with the best practices. He also mentioned that the average annual consumption in hospitals according to ANSI/ASHRAE/USGBC/IES Standards 189.1 was 200.37 kWh/m². Carbonaria et al. [18], studied the hospitals and community clinics contribution to energy consumption and their negative environmental impact. Zhang et al. [19], studied the DOAS (dedicated outdoor air system) as it became one of the most recently used efficient systems. Kim et al. [20], is comparatively evaluating the energy performances of a dedicated outdoor air system (DOAS) as it is a decoupled system solution that independently controls sensible and latent air conditioning loads.

The review shows that energy consumption is a major study that governments invest in. Since a lack of research in Energy savings in hot humid climate regions, a hospital in Egypt was chosen as a case study.

4. Climatic Design

Climate and outdoor design conditions are the most effective parameters on building loads, HVAC equipment performance and building energy consumption. A building’s energy consumption is a direct result of the weather, building use and the building orientation. Maximum summer design conditions are not recommended for use with comfort applications where it is occasionally permissible to exceed the design condition as maximum conditions do not exceed more than 3 hours in a normal summer [21]. Since extremely hot events are mostly short duration, therefore sacrificing comfort under typical conditions to meet short occasional extremes is not recommended [22].

The outside design conditions in Alexandria, Egypt (DBT 40 °C, WBT 30 °C) as Table (1) which is estimated by most HVAC designers, leads to oversizing of HVAC systems eventually resulting in waste of energy. Retrofitting to the recommended ventilation rates and the ASHRAE Outside Design Conditions 2017 (DBT 33.2 °C, WBT 22.4 °C) shown in Table (1) [22] and weather file data of Alexandria, Egypt as Figure (2) provided by EnergyPlus [23], is recommended.
Table 1. Climatic design conditions of Alexandria

| Initial Model* | ASHRAE Baseline Model [22] |
|----------------|----------------------------|
| DBT °C | WBT °C | DBT °C | WBT °C |
| 40   | 30   | 33.2  | 22.4  |

*Value by most HVAC designers

Figure 2. Alexandria, Egypt weather file data [23]

5. Case Study Description

In this study a hospital in Alexandria, Egypt was chosen. The building consists of five floors with a total area of about 10,000 m² as shown in Figure (3). Spaces in the hospital were assigned to different space types shown in Table (2).

5.1 Building Envelope

In this section, building construction materials are mentioned.

Figure 3. Hospital Overview
Table 2. Conditioned Area Percentage

| Zone                        | Area (m²) | Area % |
|-----------------------------|-----------|--------|
| Trauma                      | 46        | 0.54%  |
| Triage                      | 16        | 0.19%  |
| Examination/ Treatment      | 301       | 3.55%  |
| Staff Lounge                | 131       | 1.54%  |
| Offices                     | 243       | 2.86%  |
| Imaging Diagnosing Rooms    | 228       | 2.68%  |
| IT Room                     | 50        | 0.60%  |
| Corridor/ Waiting Area      | 3,774     | 44.30% |
| Pharmacy                    | 68        | 0.80%  |
| Shop                        | 27        | 0.32%  |
| Clinics                     | 331       | 3.89%  |
| Conference room             | 130       | 1.53%  |
| Sampling/ Laboratories      | 48        | 0.57%  |
| Physical Therapy            | 133       | 1.56%  |
| Operating Rooms             | 351       | 4.12%  |
| Delivery Rooms              | 32        | 0.38%  |
| Recovery Rooms              | 83        | 0.98%  |
| Post-Surgery Rooms          | 37        | 0.44%  |
| NICU                        | 129       | 1.52%  |
| ICU                         | 226       | 2.66%  |
| Bedwards                    | 1,728     | 20.20% |
| Living Rooms                | 248       | 2.92%  |
| Isolation Rooms             | 58        | 0.69%  |
| Doctors Rooms               | 99        | 1.18%  |
| Total Conditioned Area      | 8,517     | 100%   |

5.1.1 Glazing Type
As mentioned in ASHRAE [24], the largest cooling load is the heat that comes through the glazing; windows, glass curtain walls and skylights. If the building is designed to reach the energy targets of ASHRAE standard 90.1 2010 or later, the glazing type will almost be at least double low-e glazing. Single glazing assumed by most HVAC designers is assumed as a factor of safety which leads to higher cooling loads leading to system oversizing. In this study, the single clear glazing of both initial and baseline model assumed by most HVAC designers in Egypt was replaced by the recommended double glazing from Saint-Gobain UK company catalogues (High Performance Glass Solutions) as Table (3).

Table 3. Glazing Specifications

| Model               | Initial & Baseline | Modified Model |
|---------------------|--------------------|----------------|
| Glazing Type        | 6 mm Single Clear Glass | 6 mm Double Reflective Low-e Colored Glass 6 mm Air gap |
| U-factor (W/m² °C)  | 5.778              | 2.235          |
| SHGC                | 0.819              | 0.15           |
5.1.2 Exterior Walls

A well-insulated building has lower cooling energy requirements [25]. The hospital initial model and ASHRAE baseline walls were constructed as Egyptian building market construction. The walls were then insulated using Polyurethane with the thickness recommended by Egyptian Housing and Building National Research Center [26] and the Guide for Energy Efficiency in Buildings [27]. The construction layers of initial, baseline and modified energy model are tabulated in Table (4) as the built-up model.

### Table 4. Building Construction Description

| Model                      | Initial & Baseline | Modified Energy Model |
|----------------------------|--------------------|-----------------------|
| Exterior walls             |                    |                       |
| Construction               | 200 mm Common Brick| 200 mm Common Brick + |
|                            | 50 mm Cement Plaster| 50 mm Cement Plaster +|
| U-factor (W/ m² °C)        | 1.924              | 0.708                 |
| Roof                       |                    |                       |
| Construction               | 20 mm Cement Plaster| 20 mm Cement Plaster +|
|                            | 180 mm Hurdy Block +| 180 mm Hurdy Block + |
|                            | 20 mm Moisture     | 20 mm Moisture         |
|                            | 25 mm Mortar Layer +| 25 mm Mortar Layer + |
|                            | 30 mm Tiles        | 30 mm Tiles           |
| U-factor (W/ m² °C)        | 2.27               | 0.75                  |

5.2 Ventilation Requirements

Ventilation rates were tabulated in Table (5) based on room type according to the *AIA Guidelines for Design and Construction of Health Care Facilities* [28]. ANSI/ASHRAE/ASHE Standard 62.1-2016 [29]. ANSI/ASHRAE/ASHE Standard 170-2017 [30].

### Table 5. Recommended Ventilation Rates for hospitals [28][29][30]

| Room Type                  | Ventilation per Person (L/s per person) | Ventilation per Area (L/s- m²) | Minimum Total ACH |
|----------------------------|----------------------------------------|-------------------------------|-------------------|
| Anesthesia gas storage     | -                                      | 0.61                          | 8                 |
| Examination/Treatment Rooms| 2.5                                    | 0.3                           | 6                 |
| Trauma                     | 2.5                                    | 0.3                           | 15                |
| Triage                     | -                                      | -                             | 12                |
| Operating Suite/Delivery Rooms | -                                    | -                             | 20                |
| Imaging Diagnosing         | 2.5                                    | 0.3                           | 6                 |
| Offices                    | 2.5                                    | 0.3                           | -                 |
| Bed wards                  | 2.5                                    | 0.3                           | 6                 |
5.3 Internal Loads

Internal loads are the loads generated inside the building envelope.

5.3.1 Lighting Loads

Lighting load appears twice in any building energy use. It appears first as lighting power. Then a part of this power appears again as heat load for the HVAC system. The HVAC system uses additional power to remove the heat generated by the lights [24]. HVAC load caused by lighting is closely related to electricity consumptions of lamps.

In this study, the old lamps of both initial and baseline model assumed by most HVAC designers in Egypt was replaced by the new LED lamps [31] as Table (6).

| Pharmacy       | 2.5 | 0.9 | 4 |
|----------------|-----|-----|---|
| Physical Therapy | 9.4 | 0.3 | 6 |
| Clinics        | 2.5 | 0.3 | 6 |
| Corridors/Waiting | -   | 0.3 | - |
| Recovery/ ICU  | -   | -   | 6 |
| Conference     | 2.5 | 0.3 | - |

5.3.2 Occupant Density

Occupancy density values by room type were defined according to AIA Guidelines for Design and Construction of Health Care Facilities [28], and ASHRAE Standard 62.1 - 2016 [29] in Table (7).

5.3.3 Plug Loads

Plug loads are energy used by equipment that is usually plugged into an outlet typically including office and general miscellaneous equipment, computers and others are tough to be estimated. Plug load densities tabulated in Table (7) were recommended by the Green Guide for Health Care: Best Practices for Creating High-Performance Healing Environments, Version 2.2 (GGHC) [32] and ASHRAE Standard 90.1-2016 [33] and they remain constant in all simulated models.

6. Initial Building Energy Use

In order to verify the accuracy of the energy saving potential models, the initial model was compared with results obtained from the consultant.

Building energy consumption evaluations are done by assessing the contribution of each element in the initial building on the annual energy consumption. The energy consumption of each of these elements is shown in Figure (4) and the monthly distribution energy consumption is shown in Figure (5).
6.1 Factors affecting HVAC equipment oversizing

Several common safety factors were applied in the initial model to create examples of how and where load calculations can be inflated leading to system oversizing.

The initial model load calculations were estimated for:

1. Extreme Outdoor Design Conditions
2. Uninsulated Building Envelope (Glazing type, Walls, Roof)
3. High Lighting power density
4. Worst Case Scenario (combining all safety factors).

To illustrate the effects on the load calculation of manipulating the outdoor/indoor design conditions, the indoor conditions were adjusted as ASHRAE 170-2017 recommendations, and the outdoor conditions were adjusted to the ASHRAE outside design conditions of Alexandria, Egypt [22] from the extreme temperatures used by most HVAC designers in Egypt as in Table (1). These changes are represented to designers wishing to bump the system size up for added cushion. Load reduction of about 30% was achieved by only adopting latest ASHRAE design conditions as shown in Figure (6).
### Table 7. Recommended occupant densities and plug loads of hospitals

| Zone                        | Occupant Density (# / 100 m²) [28] [29] | Plug Loads (W/m²) [32][33] |
|-----------------------------|----------------------------------------|-----------------------------|
| **Ground Floor**            |                                        |                             |
| Trauma                      | 5.38                                   | 43.06                       |
| Triage                      | 5.38                                   | 21.53                       |
| Examination/ Treatment      | 5.38                                   | 16.15                       |
| Staff Lounge                | 66.67                                  | 1.00                        |
| Offices                     | 7.53                                   | 11.84                       |
| Imaging Diagnosing Rooms    | 5.38                                   | 96.87                       |
| IT Room                     | 4                                      | 10.00                       |
| Corridor/ Waiting Area      | 32.29                                  | 1.08                        |
| Pharmacy                    | 10.76                                  | 10.80                       |
| Shop                        | 8                                      | 15.00                       |
| **1st Floor**               |                                        |                             |
| Clinics                     | 5.38                                   | 16.15                       |
| Conference room             | 50                                     | 10.00                       |
| Treatment Rooms             | 5.38                                   | 16.15                       |
| Sampling/ Laboratories      | 5.38                                   | 43.06                       |
| Offices                     | 7.53                                   | 11.84                       |
| IT Room                     | 4                                      | 10.00                       |
| Physical Therapy            | 10.76                                  | 10.80                       |
| Corridor/ Waiting Area      | 32.29                                  | 1.08                        |
| Imaging Diagnosing Rooms    | 5.38                                   | 96.87                       |
| **2nd Floor**               |                                        |                             |
| Operating Rooms             | 5.38                                   | 43.06                       |
| Delivery Rooms              | 5.38                                   | 43.06                       |
| Recovery Rooms              | 5.38                                   | 21.53                       |
| Post-Surgery Rooms          | 5.38                                   | 21.53                       |
| NICU                        | 5.38                                   | 21.53                       |
| ICU                         | 5.38                                   | 21.53                       |
| IT Room                     | 4                                      | 10.00                       |
| Offices                     | 7.53                                   | 11.84                       |
| Corridor/ Waiting Area      | 32.29                                  | 1.08                        |
| **3rd Floor**               |                                        |                             |
| Bedwards                    | 5.38                                   | 10.80                       |
| Living Rooms                | 5.38                                   | 10.80                       |
| Isolation Rooms             | 5.38                                   | 43.06                       |
| Doctors Rooms               | 5.38                                   | 10.80                       |
| Staff Lounge                | 66.67                                  | 1.00                        |
| IT Room                     | 4                                      | 10.00                       |
| Corridor/ Waiting Area      | 32.29                                  | 1.08                        |
| **4th Floor**               |                                        |                             |
| Bedwards                    | 5.38                                   | 10.80                       |
| Living Rooms                | 5.38                                   | 10.80                       |
| Isolation Rooms             | 5.38                                   | 43.06                       |
| Doctors Rooms               | 5.38                                   | 10.80                       |
| Staff Lounge                | 66.67                                  | 1.00                        |
| IT Room                     | 4                                      | 10.00                       |
| Corridor/ Waiting Area      | 32.29                                  | 1.08                        |
7. Results
The results of different parameters applied for energy saving will be discussed in order to evaluate the effect of each parameters on the energy performance. Each parameter was studied individually to show its impact on the power consumed. Parameters studied are listed below each with a graph showing its effect.

7.1 ASHRAE Recommendation Adoption (ASHRAE Baseline Model):  
Retrofitting the Outside design conditions (ODC) from most Egyptian designers and consultants’ data to the latest ASHRAE outside design conditions mentioned in Table (1) with the weather file data of Alexandria, Egypt provided by EnergyPlus [23], adjustment of the recommended ventilation requirements [28] [29] [30] and implementing a Variable Air Volume (VAV) showed a great reduction on HVAC energy use in the building. About 25% energy saving in HVAC energy consumption and about 12% in the whole building energy use was achieved.

7.2 Glazing Type:  
The use of Double Low-E glazing which has been treated using especially metallic oxide covering which produce heat reflective surface while permitting light to pass through it, a reduction of about 5% in HVAC Energy consumption and about 2% energy savings in Whole Building Energy use was achieved compared to the ASHRAE baseline model.

7.3 Thermal Insulation:  
Polyurethene insulations addition to both external walls and the roof resulted in reduction of about 16.5% in HVAC Energy consumption and about 7% savings in Whole Building Energy use.

7.4 Lighting Power Density (LED Model):  
In this study, the lighting bulbs power density in the hospital initial and baseline models which are estimated by most HVAC designers in Egypt (40 W/m²) were replaced by new LED lamps with about 7.5 W/m² [31]. Energy savings of about 21% in HVAC Energy consumption and about 41.5% energy savings in whole building energy use compared to the ASHRAE baseline model.
7.5 Modified Energy Model:

Combining the Double Low-E glazing, thermal insulation with LED techniques was named as Modified Energy Model resulted in about 55% savings in HVAC Energy consumption and about 59% energy savings in Whole Building Energy use compared to ASHRAE baseline model.

7.6 Dedicated Outdoor Air System Model (DOAS):

Implementing a Dedicated outdoor air system (DOAS) to the Modified Energy Model achieved savings of about 63.5% in HVAC Energy use and about 62% energy savings in Whole Building Energy use compared to the ASHRAE baseline model.

Figure (7) represents the effect of different models on HVAC energy use.

![Figure 7. HVAC Energy Use of Different models](image1)

Figure (8) shows the effect of the different models on Whole building energy use.

![Figure 8. Building Energy Use of Different models](image2)
Figure (9) illustrates the annual whole building energy use of the Initial model, ASHRAE baseline model, Modified Energy model and the (DOAS) model.

Table 8. CO\textsubscript{2} emissions reduction compared to Initial model

|          | Initial model | ASHRAE Baseline model | Modified Energy model | DOAS Model |
|----------|---------------|------------------------|-----------------------|------------|
| Tons of CO\textsubscript{2} | 4,212         | 3,718                  | 1,536                 | 1,409      |
| Reduction | -             | 12%                    | 63%                   | 67%        |

Figure 9. Whole Building Energy Performance of Different Models

7.7 Carbon Dioxide Emission Reduction:

Electricity reduction helps reducing CO\textsubscript{2} emissions, global warming and air pollution saving the environment. The U.S Environmental Protection Agency [35] stated that 1 kWh of consumption produces 0.707 kg of CO\textsubscript{2} which equals 0.000707 tons CO\textsubscript{2}. Table (8) shows the reduction in CO\textsubscript{2} emissions by different models compared to Initial model.
8. Conclusion:

The study revealed that applying the energy saving techniques on the hospital buildings improves the performance of lighting systems, HVAC system, and the whole building energy use. In addition, leads to reduction CO₂ emissions. The conclusion can be summarized as:

1- Adopting ASHRAE Outdoor Design Conditions (Alexandria, Egypt) results in 30% less cooling load compared to most Egyptian market designing conditions which leads to right sizing avoiding the over sizing of HVAC systems.

2- ASHRAE Recommendations (Outside design conditions, Ventilation, HVAC System, etc.) must be applied in the Egyptian market as investigated in this study showing 25% reduction in HVAC energy use and about 12% in whole building energy use compared to the Initial Model.

3- Double Glazing should be considered as an important parameter in commercial buildings as the study shows about 5% savings in HVAC energy use and about 2% energy savings in whole building energy use.

4- Building construction codes are recommended to be applied to all commercial buildings such as adding insulation materials to construction as it showed about 16.5% energy savings in HVAC energy use and about 7% energy saving in whole building energy use compared to ASHRAE Baseline Model.

5- Lighting Emitting Diodes (LED) available nowadays are efficient in energy saving as it showed about 21% in HVAC energy use and about 42% in whole building energy use compared to ASHRAE Baseline Model.

6- The Modified Energy Model showed significant energy savings of about 55% in HVAC energy use and approximately 59% of the whole building energy use with 217 kWh/m² compared to 525 kWh/m² in ASHRAE Baseline Model and 596 kWh/m² in Initial Model when applying the energy saving techniques.

7- By implementing Dedicated Outdoor Air System to the Modified Energy Model, a reduction of 67% in Whole Building energy use can be achieved compared to the built-up Initial Model.

8- Dedicated Outdoor Air System Model energy use is 199 kWh/m² compared to 200 kWh/m² recommended by ASHRAE 189.1-2009 [17].

9- Energy saving techniques helps reducing CO₂ emissions which helps saving the environment.

Commercial buildings energy saving techniques, have huge impact on energy consumption in Egypt. So, the Egyptian government must start applying the energy saving codes to establish minimum levels of energy performance for unconstructed buildings and auditing for constructed buildings which will lead in decreasing energy and fuel consumption.
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