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ORIGINAL ARTICLE

Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt

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Abstract Egypt has large energy production but due to the huge increase in domestic consumption and decrease of investment in energy sector, Egypt has become dependent on hydrocarbon imports. This problem had a negative impact on economical trade balance and the country budget. Therefore, Egyptian government stimulates the energy saving research. Air conditioning system in buildings consumed 56% of total energy consumed in buildings (Fink, 2011, Aldossary et al., 2013) [17,18]. In Future HVAC energy consumption will rise further due to increase in growing population, rapid expansion and call for new residential and commercial buildings, and rising global warming due to climate change. A hospital in Alexandria, Egypt, was chosen as a case study as the hospital considered a huge energy consumption building due to 24 h 7 days availability, medical equipments, and requirements for clean air and disease control. In this study an efficient energy saving technique that decreases the energy consumption and reduces HVAC system sizing in buildings was developed. This will provide specific methodologies and information, for energy efficiency improvements in hospital at Alexandria, Egypt, to help hospital designers and managers in getting started on an energy managing program and creating some "energy winnings" in order to save more energy for other purpose.

The new system that was selected according to the new hospital cooling loads was compared against the existing system and significant energy saving (7,068,178 kW h/year) was found.

1. Introduction

The argument about energy usage has increased recently in the Egyptian society. Egypt was exposed to repeated electricity failure because of expanding demand, natural gas supply

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Nomenclature

A	area (m^2)
CFM	cubic feet per meter
CLF	cooling load factor
CLTD	cooling load temperature difference (°C)
ppm	parts per million
Q_l	latent load (W)
q_{rad}	cooling load caused by solar radiation (W)
Q_s	sensible load (W)
Q_t	cooling load (W)
Q_{VL}	latent cooling load due to outdoor air (W)
Q_{VS}	sensible cooling load due to outdoor air (W)
SC	the shading coefficient of fenestration component
SCL	solar cooling load (W/m^2)
T_i	indoor air temperature (°C)
T_o	outdoor air temperature (°C)
U	heat transmission coefficient of envelope component (W/m^2 °C)
Vo	outdoor air flow rate (l/s)
W_i	indoor air humidity ratio (kg_w/kg_a)
W_o	outdoor air humidity ratio (kg_w/kg_a)

Abbreviations

AC	air conditioning
ASHARE	American Society of Heating, Refrigeration and Air Conditioning Engineers
AHU	air handling unit
AIA	American Institute of Architects
CADDET	Centre for Analysis and Dissemination of Demonstrated Energy Technologies
CAV	constant air volume
CO_2	carbon di-oxide
DB	dry bulb temperature
DCV	demand control ventilation
GGHC	green guide for health care
HAP	hourly analysis program
HVAC	heating, ventilation and air conditioning
Low-E	low emissivity glass
LPD	light emitting diodes
NERL	National Renewable Energy Laboratory.
OA	outside air
ORs	operating rooms
USDOE	United States Department of Energy
Vac	ventilation and air conditioning.
VAV	variable air volume
WB	wet bulb temperature
WWR	window to wall ratio

shortages, old infrastructure, and insufficient generation and conduction capability. Commercial buildings consume large amounts of energy; especially hospitals have higher energy consumption than any other activity in the commercial and institutional sector. This is due to 24 h and 7 days availability, medical equipment, and requirements for clean air and disease control.

As shown in Fig. 1, commercial and governmental sectors consume about 20% of the total energy consumption. For that energy saving studies have a great importance nowadays. In fact it needs nearly 3 kW h of electricity energy to and distribute 1 kW h to the consumers as the electrical energy has approximately 33% efficiency [1]. So saving any little portion of electricity will save a large amount of energy consumed.

The previous studies investigated many sides of energy saving such as in the Energy Analysis Department at Lawrence Berkeley National Lab Roberson et al. [3] compared residential ventilation strategies in four climates. They recommended that multi-port supply ventilation had to be balanced by a single-port exhaust ventilation fan, and that builders would offer balanced heat recovery ventilation to buyers as an optional upgrade. Bizzarri and Morini [4] developed a theoretical analysis which focused on the environmental benefits achieved through a shift from the conventional systems, normally operating in hospitals, to various hybrid plants. Then Balaras et al. [5] reviewed published standards and guidelines on design, installation, commissioning, operation, and preservation of HVAC mounting in hospital ORs, internal thermal surroundings. They also summarized measured data from short observing of internal thermal surroundings along with audit outcomes and main features of 20 ORs in 10 major Hellenic hospitals. Ho et al. [6] found that a total improved performance could be achieved by placing the air supply grilles nearer to the vertical centerline of the wall while the location of the air exhaust grilles is somewhat unimportant. After that Fasiuddin and Budaiwi [7] found that energy savings up to 30% could be obtained while maintaining acceptable level of thermal comfort when HVAC systems were properly selected and operated. Also Saidur et al. [8] tried different energy saving technique for electrical motors used in a hospital. A good review was reported by Vakiloroaya et al. [9] discussing the influence of integrated control of shading blinds and natural ventilation on HVAC system performance in terms of energy savings and human comfort. Also Attia et al. [10] aimed to develop representative simulation building energy data sets and benchmark models for the Egyptian residential sector. In the same time, Samali et al. [11] investigated theoretically the energy saving problem of air-cooled central cooling plant systems using the model-based gradient projection optimization method. However, Implementing the Berkeley Retrofitted

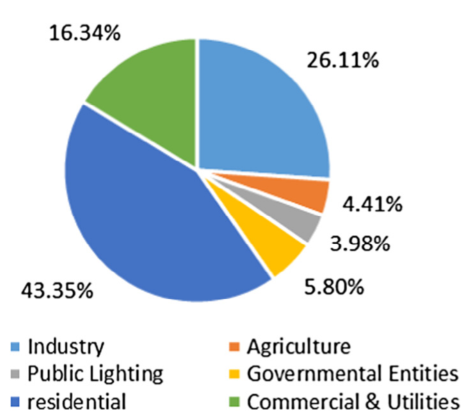

Figure 1 Energy consumption in Egypt [2].

and Inexpensive HVAC test bed for Energy Efficiency (BRITE) platform allowed Aswani et al. [12] to actuate an AC unit that controls the room temperature of a computer laboratory on the Berkeley campus that is actively used by students, while sensors record room temperature and AC energy consumption. Ascionea et al. [13] investigated the healthcare facilities as a critical application in the field of energy demand for air-conditioning. Regarding DCV, Dougan and Damiano [14] stated that concept of using CO_2 input for DCV makes sense and could save money on building operating costs under specific circumstances. Then Metelskiy [15] studied CO_2 based demand controlled ventilation system to control the quantity of supply outside fresh air in a building reliant on a sum of persons and their action.

1.1. Aim of work

- To study and explain the problems and important aspects of building energy performance.
- To apply building energy standards and distill useful experience and information.
- To examine the effects of climate on building thermal design and to analyze the major characteristics of Alexandria-Egypt weather.
- To explain energy saving model that can be applied in Egypt for retrofitting buildings.

2. Cooling load

Calculating cooling and heating loads on a construction or any area are the first step in designing the AC system. Choosing and sizing the cooling or heating devices necessary to maintain comfortable interior air conditions depend on the this step [16]. Some of the features that effect results are as follows:

- Conduction/convection of heat through walls, ceilings, grounds, doors and windows.
- Radiation through windows and heating effects on wall and ceiling surface temperatures.
- Heat generated by lights, persons and equipment.
- Movement level, occupancy patterns.
- Satisfactory comfort and air quality levels of occupiers.
- Heat gained/lost with ventilation air wanted to keep air quality.
- Climate conditions (temperature, humidity, wind speed, latitude, elevation, solar radiation, etc.).

A lot of cooling and heating loads calculation methods were used. In this paper the CLTD/SCL/CLF method was used to calculate the required cooling loads to be removed [16]. No alterations to the original method, including the values of all coefficients, were made.

3. Methodology

The following figure illustrates the methodology which is followed in this study is illustrated in Fig. 2.

This study will be started by analyzing the building model knowing all the parameters which effect the energy consumption specially the changeable parameters. After that, a new building design model will be generated to develop the new energy saving model. Then using a computer simulation program a report for the new energy consumption will be generated to compare it with the old energy consumption.

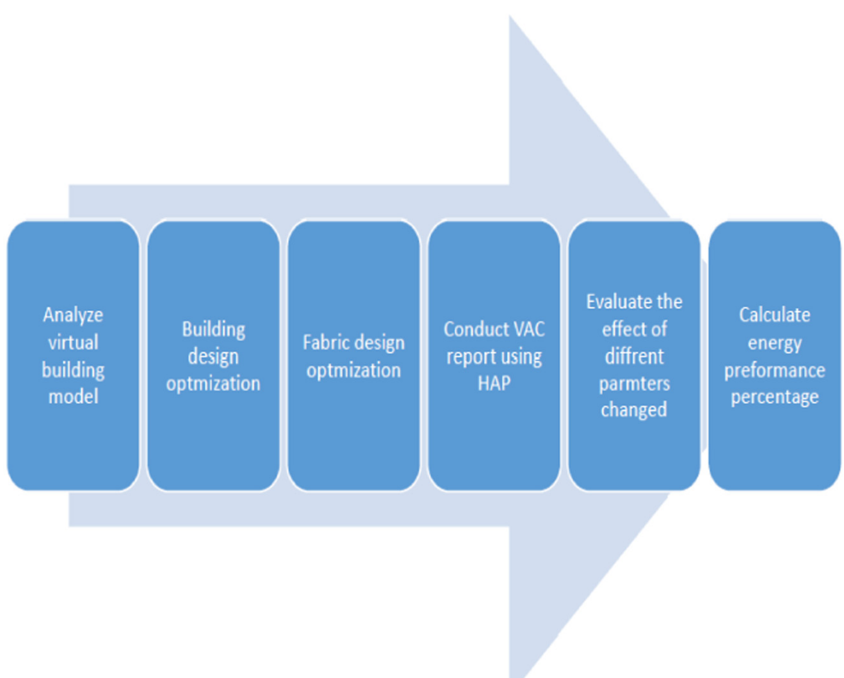

Figure 2 Methodology.

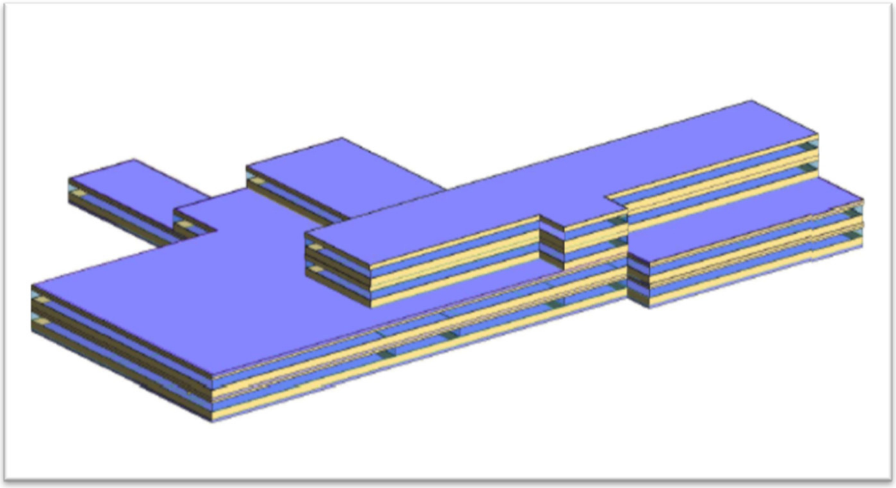

Figure 3 Hospital layout.

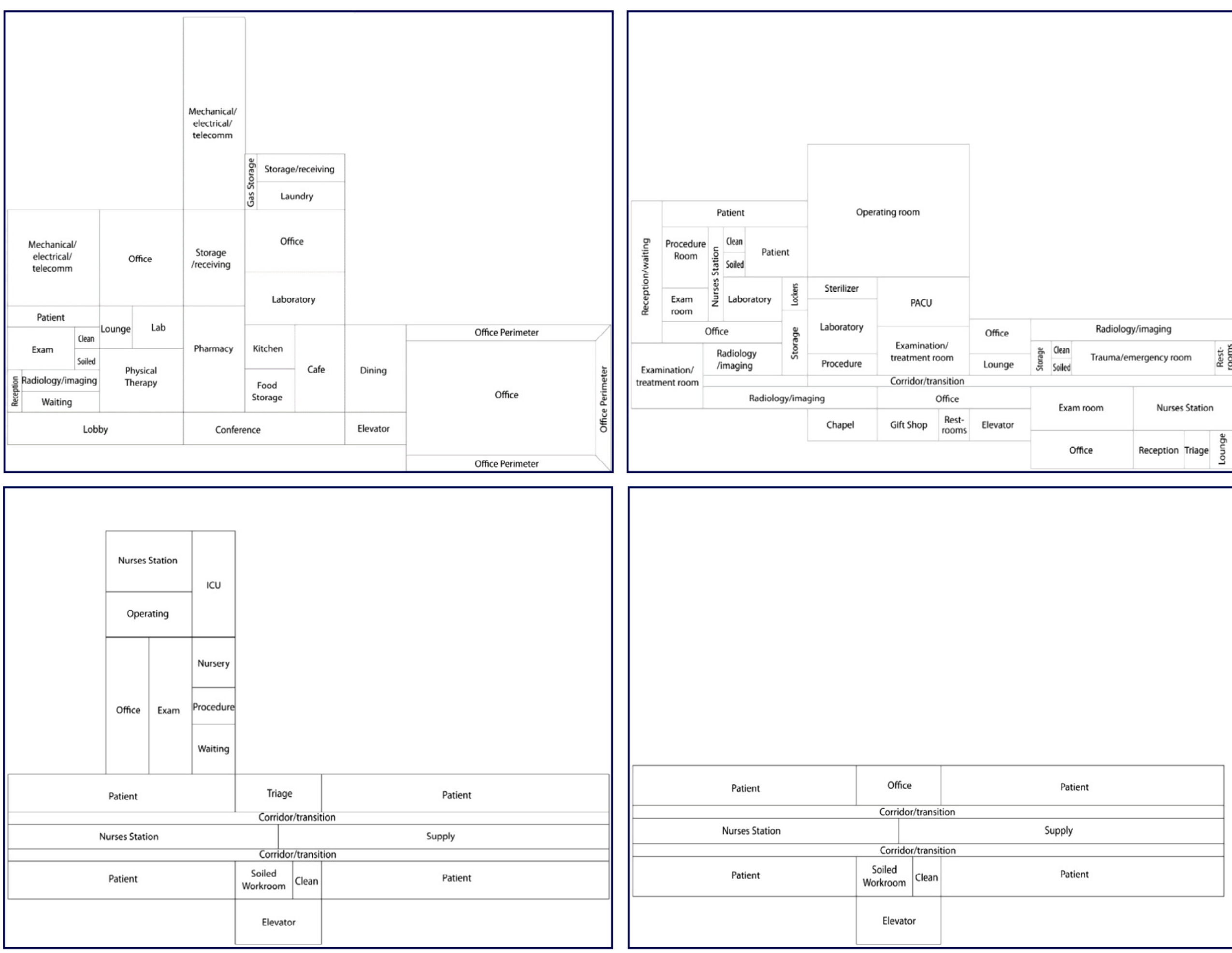

Figure 4 Hospital schmidt diagram.

4. Case study

4.1. Description of case study

In this study a hospital located in Alexandria, Egypt, is taken as a case study. It consists of four floors with a total area of 31019.2 m^2 as shown in Fig. 3. From Fig. 4, it is considered that this hospital is a large hospital with different departments. To understand facility management in energy conservation, different parameters that affect the energy problem specially lighting and VAC were studied.

Every room in the hospital model was assigned to 1 of 32 space types. These rooms correspond to rooms mentioned in Standard 62.1-2004 [19]. Table 1 gives an example of different spaces.

4.2. Fabric

4.2.1. Exterior walls

All the walls in the hospital were made with the basic concept of building in Egypt. The basic layers and the suggested wall layers are shown in Table 2.

4.2.2. Roofs

The current and energy saving models' roof constructions were like the wall construction. The roof saving model with protecting insulation completely above surface, where the assembly consisted of three layers: a roof membrane, RSI-1.9 batt insulation, metal decking and 13 mm gypsum board was used.

4.2.3. Glazing

Table 3 shows the old and the new window design. The energy saving model reduced the overall heat transfer coefficient by half.

4.3. Internal load densities

Interior loads include the heat produced by persons, lights and equipment (plug and process loads).

4.3.1. Occupancy density

Occupancy density values by space type were defined according to Standard 62.1-2004 [19] (see Table 4).

Table 1 Different hospital rooms.

Room type	Floor area (m^2)	% of total
Anesthesia gas storage	59.4	0.19
Examination/treatment room	1905.3	6.15
Nurse station	1462.6	4.7
Nursery	97	0.3
Operating suite	2153.2	7
Radiology/imaging	1252	4
Patient room	4415.8	14.5
Pharmacy	609.9	2
Physical therapy	502.1	1.6
Procedure room	530.4	1.7
Reception/waiting	494.7	1.59
Trauma	451.5	1.4

Table 2 Exterior wall design.

Baseline model	Energy saving model
203 mm common brick	203 mm common brick
13 mm plaster gypsum	13 mm plaster gypsum
	RSI-1.9 batt insulation
Overall U 1.941	Overall U 0.401

Table 3 Window design.

Baseline model	Energy saving model
Aluminum frame without thermal breaks	Aluminum frame with thermal breaks
3 mm clear glass	Double 6 mm low-E clear glass with an air gap 6 mm
Overall U6.975	Overall U 3.138

Table 4 Occupancy density.

Room type	Density (#/100 m^2)	Room type	Density (#/100 m^2)
Anesthesia gas storage	0.00	Patient room	5.38
Examination/treatment room	5.38	Pharmacy	10.76
Nurse station	5.38	Physical therapy	10.76
Nursery	5.38	Procedure room	5.38
Operating suite	5.38	Reception/waiting	32.29
Radiology/imaging	5.38	Trauma	5.38

4.3.2. Plug and process load

Plug and process loads are extremely hard to estimate. When available, plug and process load densities were taken from the Green Guide for Health Care: Best Practices for Creating High Performance Healing Environments, Version 2.2 (GGHC) [21] (see Table 5).

4.3.2.1. Interior lighting. The current internal LPDs for each room type were derived using the space-by-space method described in ASHRAE [20].

The energy saving model internal LPDs for each room type are provided in Table 6. The LPDs used were based on Bonnema et al's [22] study.

4.4. Ventilation and Air conditioning systems

4.4.1. Ventilation

Ventilation rates by room were defined according to the *2006 Guidelines for Design and Construction of Health Care Facilities* [23], ASHRAE/ASHE Standard 170-2008 (ASHRAE, 2008), and Standard 62.1-2004 [19], based on room type. Hospitals are exceptional among commercial buildings in that they have

Table 5 Plug and process load example.

Room type	Electric plug load (W/m^2)	Electric process load (W/m^2)	Room type	Electric plug load (W/m^2)	Electric process load (W/m^2)
Anesthesia gas storage	10.8	0	Patient room	10.8	0
Examination/treatment room	10.8	0	Pharmacy	10.8	0
Nurse station	2.7	5.4	Physical therapy	10.8	0
Nursery	10.8	0	Procedure room	10.8	32.3
Operating suite	10.8	32.3	Reception/waiting	1.08	0
Radiology/imaging	10.8	86.1	Trauma	10.8	32.3

Table 6 Some values of internal lighting.

Room type	Old LPD (W/m^2)	New LPD (W/m^2)	Type	Old LPD (W/m^2)	New LPD (W/m^2)
Anesthesia gas storage	9.69	8.61	Patient room	7.53	7.53
Examination/treatment room	16.15	11.84	Pharmacy	12.92	12.92
Nurse station	10.76	10.76	Physical therapy	9.69	9.69
Nursery	6.46	6.46	Procedure room	29.06	21.53
Operating suite	23.68	21.53	Reception/waiting	13.99	9.69
Radiology/imaging	4.31	4.31	Trauma	29.06	21.53

Table 7 Ventilation rates.

Room type	Ventilation per person (L/s per person)	Ventilation per area (L/s m^2)	Required total air change	Room type	Ventilation per person (L/s per person)	Ventilation per area (L/s m^2)	Required total air change
Anesthesia gas storage	–	0.61	8	Patient room	–	–	6
Examination/treatment room	2.4	0.31	6	Pharmacy	2.4	0.91	4
Nurse station	2.4	0.31	–	Physical therapy	9.4	0.31	6
Nursery	–	–	6	Procedure room	–	–	15
Operating suite	–	–	20	Reception/waiting	2.4	0.31	–
Radiology/imaging	2.4	0.31	6	Recovery room	–	–	6

total airflow necessities as well as ventilation airflow necessities (see Table 7).

4.4.2. Air conditioning system

The current HVAC system was chosen as a CAV system with hot water reheat at the zone terminal. Four AHUs served the hospital one for every floor. This air handler configuration was selected to simplify the energy model, merging each floor as a single zone on which the energy saving model design was based. The design deck air temperature was 12.8 °C for AHU's.

The energy saving model used DCV system. DCV was designed for zones in which the OA requirement was a function of occupancy. In these zones, the terminal unit damper position was allowed to sway as the occupancy in each zone changed, so that these zones were not over ventilated. CO_2-based DCV system controls the quantity of supply OA in a building depending on the number of persons and their activity. People are the main source of CO_2 in a building (If a number of people in a room are doubled, the CO_2 level will automatically double) the CO_2 sensor measures the difference between the value of CO_2 in the atmosphere comparing it with the CO_2 level in the room and then calibrates the change and decides whether the room needs fresh air or not based on preset difference levels which are listed below (see Table 8).

Table 8 CO_2 differential level.

Outdoor CO_2 level	400
Minimum CO_2 differential level	100
Maximum CO_2 differential level	500

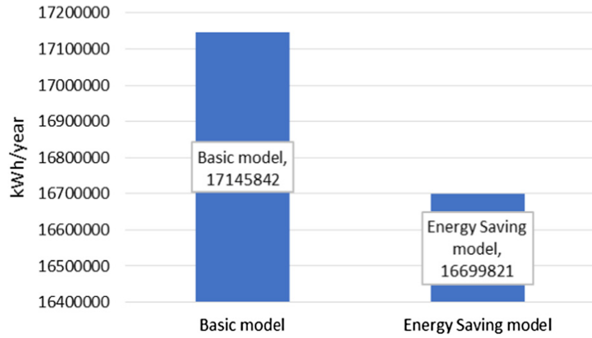

Figure 5 Effect of lighting on power consumed.

DCV (CO_2 based) is better to use because of the following:

- The hospital is a buildings where the number of people varies always during the entire day (24-h period).
- Cooling and ventilation for most spaces are required in all times through the year.
- DCV is applied in the areas with high utility rates, high energy needs and energy costs.

The AHUs connected in these zones use VAV fans, so as the dampers closed, the fans turned down, saving primary fan energy in addition to the energy that would otherwise have been essential to condition the supplementary OA.

5. Simulation program

Once the hospital was defined, the current model and the energy saving model using Carrier's Hourly Analysis Program (HAP 4.9) were generated. This simulation was taken in two separate ways: (1) using Standard 90.1-2004 in creating the current model; and (2) applying energy saving standers to construct the lower-energy model. These two models were used to generate percent energy savings comparisons.

6. Results

Different parameters were studied in order to evaluate the effect of each parameters on the energy saving process, each was studied individually to show its impact on the power consumed. Parameters studied are listed below each with a graph showing its effect.

6.1. Lighting effect

Fig. 5 shows the importance of Switching from LPDS listed in ASHARE [20] to the low-energy interior LPDs based on Bonnema et al's [22] study.

From Fig. 5 the importance of decreasing lighting intensity revealed a reduction of 2.6% from the total power consumed per year. The LPD values mentioned before take in account

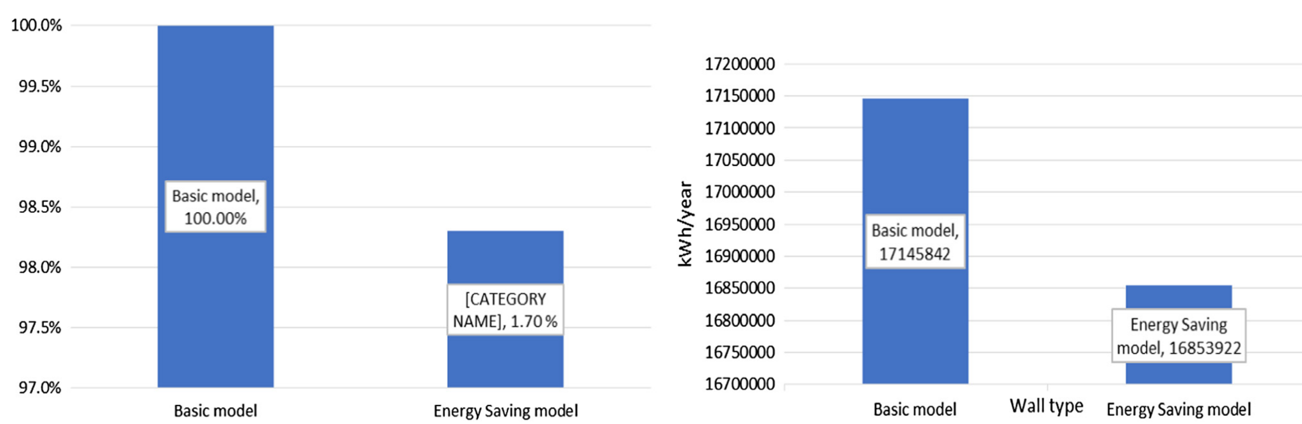

Figure 6 Percentage of adding insulation on power consumption.

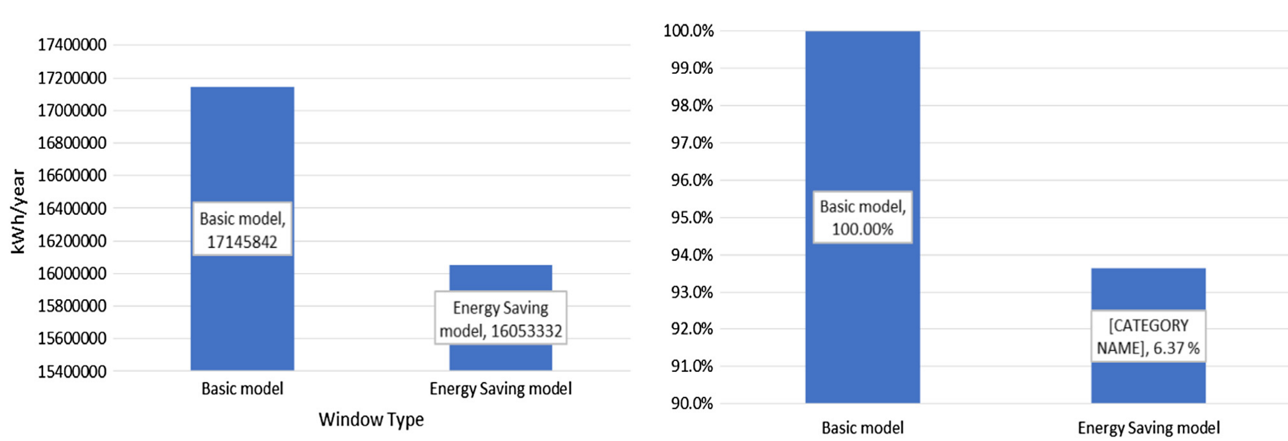

Figure 7 Power consumption with changing window type.

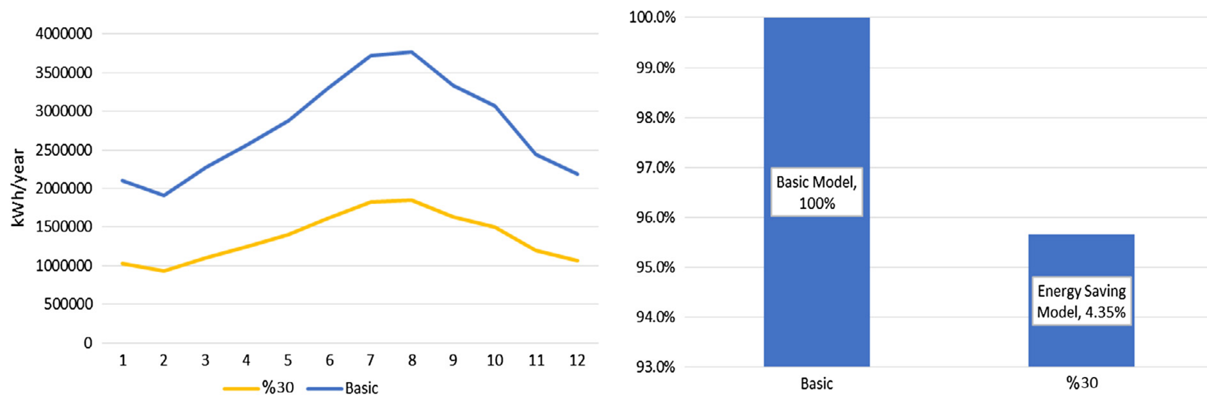

Figure 8 Power consumed with WWR.

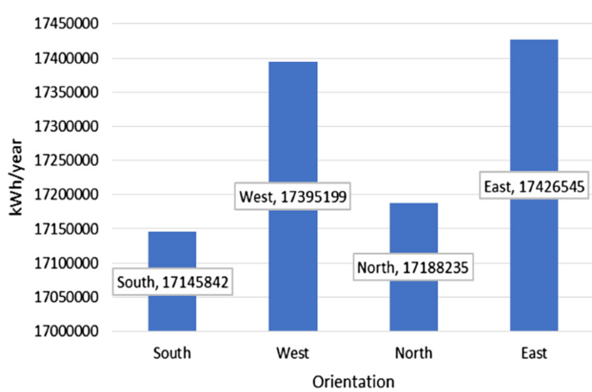

Figure 9 Consumed power in different directions.

an additional 10% reduction for certain spaces where occupancy sensors must be added.

6.2. The impact of adding insulation to the walls

Fig. 6 shows the importance of adding insulation to the exterior walls. Adding the 1.9 batt-insulation resulted in saving about 2% from the basic wall. A lot of the energy we use to heat or cool our buildings can basically escape out without insulation. Insulation helps to do the following:

- Save cash from your energy bills.
- Reduce your energy use and decrease greenhouse effect.
- Reduce loads on cooling systems.

6.3. Glazing

6.3.1. Window type changing effect

Low emissivity (Low-E) glass is window glass that has been treated with a special metal or metallic oxide covering, producing a surface that reflects heat, while permitting light to pass through. In Fig. 7 using the low-E glass resulted in 6.3% reduction due to the decrease in the amount of ultraviolet and infrared light that can pass through glass without conceding the amount of visible light that is transferred.

6.3.2. Glass percentage to wall (basic (40%), 30%)

As shown in Fig. 8 Window area or window-to-wall ratio (WWR) is changed by 10% affecting energy performance in a building to decrease by 4.3% which will have influences on the building's heating and cooling. The WWR is the measure

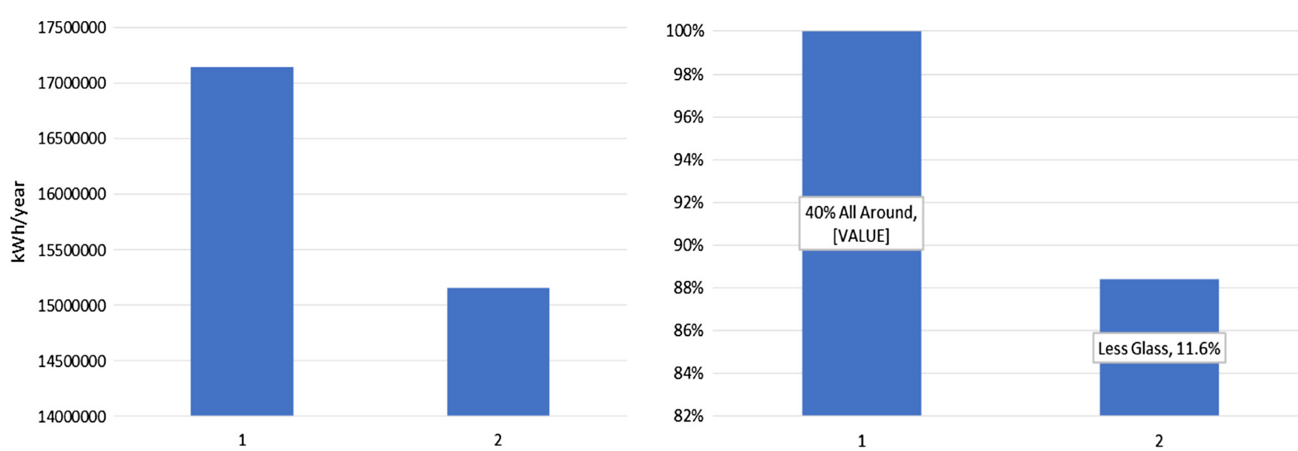

Figure 10 Effect of reducing glass in west and east directions.

of the proportion area determined by dividing the building's total glazed area by its external envelope wall area.

6.4. Building orientation

The current has the largest side in the south side (188 m), to study the change of orientation, rotate the building by 90° to face a different directions (once to face west, east and north), and the following graph shows the result.

Building orientation refers to the way a building is located on a site and the arranging of windows, rooflines, and other structures, the relative position of the Sun is a main factor in heat gain in buildings, which makes the correct orientation of the building a essential concern in passive solar construction. In Fig. 9 placement of building elements will have a significant role because of the impact of solar radiation on the building and the prevailing breezes. Just like natural air, natural ventilation through inflow of air and compatible lighting is necessary in every building which must be carefully pondered upon during orientation.

Reducing the glass percentage in west and east direction will result in 11% reduction as shown in Fig. 10, and west and east direction has the bigger SHGC so we recommend increasing glass percentage in north and south directions (e.g. North and south directions contain 40% glass compared to 20% glass in west and east directions).

6.5. Different AC systems (CAV, VAV, DCV)

In DCV the ventilation airflow rate is continuously matched with the actual demand. By this, it offers an obvious advantage compared to CAV and VAV. Due to decreased average airflow rates, less energy is needed for fan operation and for heating and cooling of the supply air.

Figs. 11 and 12 show the reduction percentage due to system changing, and DCV system reduced energy consumption due to the following:

- DCV saves energy consumption by avoiding the cooling, and dehumidification of additional ventilation air than it is required.
- The impact of CO_2-based DCV will appear in higher density rooms, where people density always varies.
- Real control of ventilation system will offer the chance to control interior air quality.

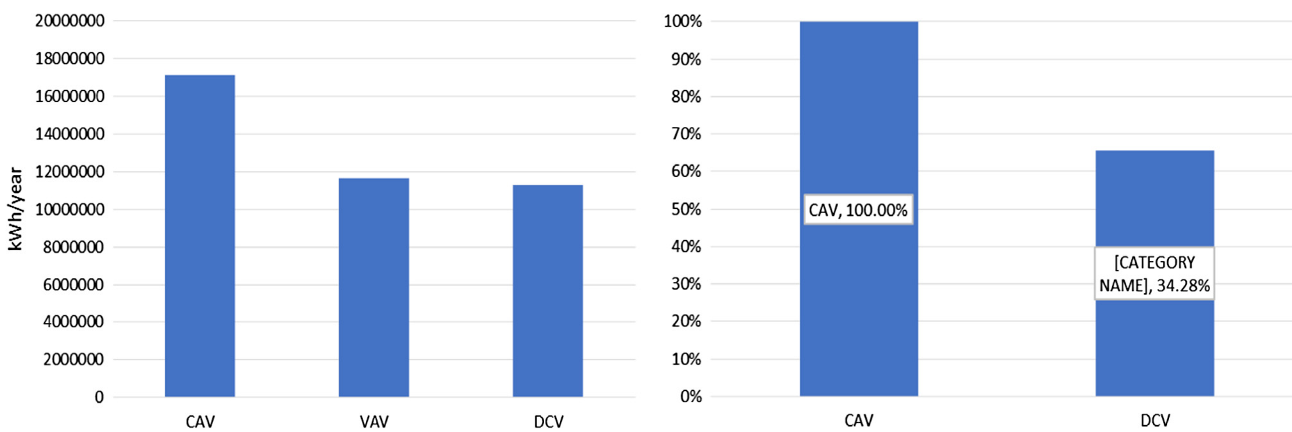

Figure 11 The effect of changing systems with power consumed.

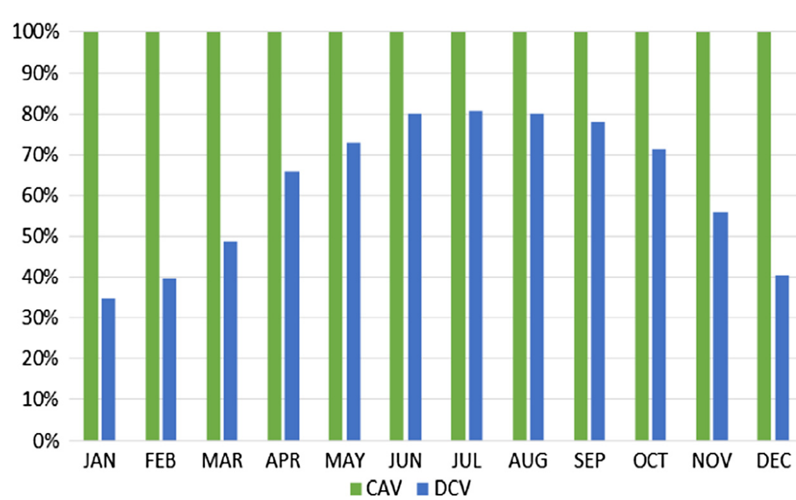

Figure 12 DCV reduction to CAV in a year.

6.5.1. Simulating both The base model with and the energy saving model

Fig. 13 illustrates that, the total energy consumption is 17,145,842 kW h/year of the basic model and a total consumption of energy saving model is 10,077,664 kW h/year, with reduction of 41% as a result of combining each energy saving parameter discussed above. Reducing 7,068,178 kW h/year will result in saving cash and power for other uses (see Table 9).

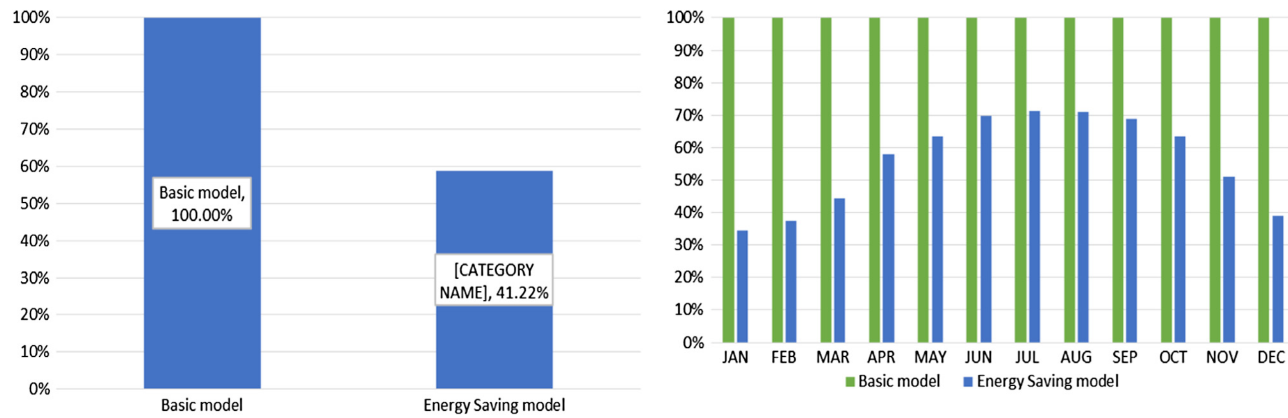

Figure 13 Basic model vs. energy saving model.

Table 9 Energy consumption per months.

Month	Base model (kW h/year)				Energy saving model (kW h/year)			
	Floor 1	Floor 2	Floor 3	Floor 4	Floor 1	Floor 2	Floor 3	Floor 4
January	509,491	353,321	117,122	100,276	116,372	199,155	39,039	16,190
February	460,471	319,385	109,546	91,689	122,840	185,320	39,511	18,714
March	544,959	377,524	134,284	107,458	197,552	233,896	54,785	29,520
April	618,571	413,959	157,666	120,173	352,741	280,583	77,081	48,436
May	699,729	458,679	179,540	134,753	455,566	322,360	94,084	62,467
June	811,465	513,055	207,686	153,043	600,691	377,015	119,275	81,374
July	914,787	570,767	234,666	172,752	689,308	425,661	139,755	94,276
August	926,859	577,449	238,447	175,670	696,318	430,465	142,487	95,220
September	816,156	517,224	210,444	155,303	590,328	377,806	120,749	79,885
October	746,244	484,702	191,423	143,592	489,017	339,267	101,677	63,808
November	590,925	399,928	146,425	114,720	282,191	257,136	65,458	35,982
December	529,642	365,458	124,414	104,000	157,002	213,177	45,332	20,790
Total	8,169,298	5,351,451	2,051,662	1,573,427	4,749,926	3,641,840	1,039,235	646,663

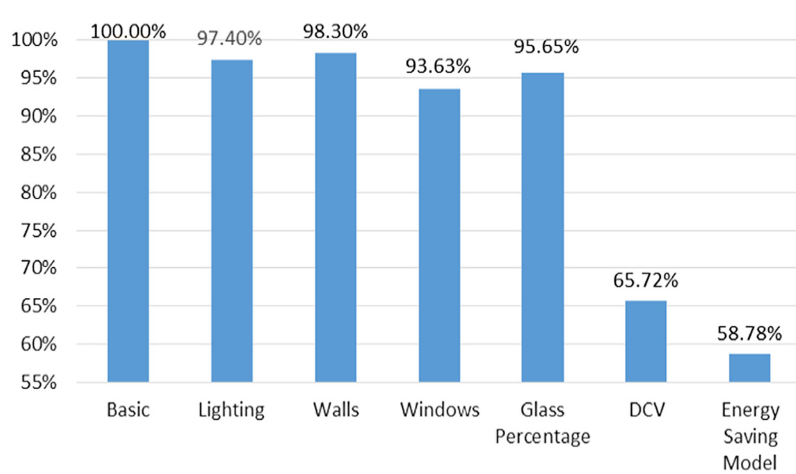

Figure 14 Parameters comparison.

6.6. A comparison between different parameters changed

Fig. 14 shows the effect of saving energy in each parameter alone.

7. Conclusion

- The simulation showed potential annual electricity savings of 41% over the base case when applied DCV system to control the quantity of outdoor fresh air supply, relying on the amount of CO_2 in a building compared to outside door reading. DCV makes it easy to get the required ventilation and improve indoor air quality while saving energy. Such methods will reduce energy consumed by a great percentage.
- Building construction regulations must be applied to all governmental buildings and private sector considering Building construction materials (insulation in walls and glass quality decreased energy consumption by about 8%), in order to decrease energy consumption.
- Building orientation must be selected carefully Before deciding its position the orientation, things have to be chosen according to weather or climatic implications of the area because such can affect the building badly. Building must be designed by determining few factors with respect to natural air, natural light and energy saving approach. Glass Exposure is vital to choose so as to make way for natural air and light. Natural air work as food for people in making them feel healthy, peaceful and good.
- Applying energy saving techniques and methods to commercial buildings would have a great impact on energy usage and carbon emissions in Egypt. So the Energy Performance of Buildings requires certain rules to establish minimum levels of energy performance for new buildings and buildings undergoing major renovation, which will lead to decreasing fuel consumption.
- According to the latest price variation by the Egyptian government, the consumption of more than 1,000 kilowatts will cost about 50 piasters per kW h. So saving 7,068,178 kW h/year will result in saving about 3,500,000 L.E./year.

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