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Improving Energy Performance of Existing Office Buildings

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Abstract

Egypt, as a developing country, suffers an energy crisis manifested by limited energy resources and increasing demand. This crisis is anticipated to worse in next few years due to the fast developments in major sectors of the country, including the building sector. The existing building stock in Egypt consumes more than 60% of the electrical energy. Improving the energy performance in buildings can be done by retrofitting the building envelope, using more efficient energy-using equipment such as lighting and air conditioners, using renewable energy sources, and altering the occupants' behavior concerning energy usage. In this paper, a quick, easy-to-implement procedure is proposed for implementation in existing office buildings. The procedure combines both economic and environmental aspects of energy conservation methods and prioritize them, along with the solution economics, energy saving and environmental benefits. An office building in Alexandria, Egypt, is taken as a case study to illustrate the effectiveness of the procedure. The results are easily presented to the decision makers. The procedure can be applied to most non-residential buildings. A national action plan is required immediately to be implemented in Egypt seeking for energy conservation actions in the existing building sector, which can save energy, decrease fuel imports to operate power plants, decrease the need to build new power plants, decrease the associated carbon dioxide emissions and improve the overall economic situation of the country.

Keywords

Energy Conservation, Energy Efficiency, Office Buildings, Retrofitting, CO_2 Emissions

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1. Introduction

Energy is a key issue for development of any nation. However, using energy consumes finite fossil fuels; causes air pollution, environmental damage, global warming and costs money. Let us assume that we have a certain amount of natural gas (or methane CH_4). A common way to convert its chemical energy into work is to combine it with oxygen from the atmosphere and burn it to release its chemical energy in the form of heat. Accordingly, methane and oxygen undergo a chemical reaction and produce water and carbon dioxide, as shown in eq. (1):

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + heat \tag{1}$$

The amount of CO_2 released in order to generate 1 kWh of electric energy is shown in Table 1 [1].

Table 1. CO_2 emissions (kg/kWh).

Fuel	Coal	Oil	Nat. Gas
CO_2	0.95 ~ 1	0.75 ~ 0.8	0.55

According to the United Nations Environment Programme (UNEP), buildings consume about 40% of global energy, 25% of global water, and 60% of global electricity. Buildings also emit more than 30% of global greenhouse gas (GHG)

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emissions. Under the business-as-usual projection accompanied by rapid urbanization, emissions caused by the buildings sector may more than double by 2050 [2].

According to the United Nations Development Programme (UNDP), the buildings sector can play a critical role in mitigating climate change by reducing energy consumption and GHG emissions. The buildings sector has the most cost-effective and proven solutions for reducing energy consumption and GHG emissions [3].

Retrofitting may involve improving or replacing lighting fixtures, ventilation systems, or windows and doors, or adding insulation where it makes economic sense. Retrofitting existing buildings has the potential to reduce energy usage by 30–40 % [4].

1.1. Building Energy-Retrofits Worldwide

A number of studies had been carried out worldwide to analyze the effectiveness of retrofit methods in different building types.

In USA, the US Department of Energy (DOE) conducted the market in an effort to save 50% of energy use in its office buildings [5]. The Environmental Protection Agency (EPA) in USA launched an Energy Star program for rating and certifying buildings. To be certified, a building must earn a score of 75 or higher on a 1-100 scoring system set by EPA for different types of buildings [6]. In Europe, a Public Private Partnership (PPP) was established to achieve the goals of the European Union to limit its CO_2 emissions by 80% in 2050, compared to 1990 figures [7]. Besides, the European Union aims to transform existing buildings to Near-Zero Energy Buildings (nZEB) by minimizing the building need for energy and supplying this energy from renewable sources [8]. It is worth noting that the USA aims at cost saving whereas the European Union aims at CO_2 reductions. Similar efforts are carried out in Japan [9]. The new-growing economies, such as China [10] and India [11], with its increasing demand on energy, and its potential on the CO_2 emissions, are also aware of the importance of energy conservation measures in office buildings and set national action plans for reducing energy consumption in office buildings. It is worth noting that energy conservation in office buildings attracts even the rich gulf countries, like Kingdom of Saudi Arabia [12].

1.2. Energy Consumption in Egypt

According to the Egyptian Electricity Holding Company (EEHC), the energy mix (2014-2015) is shown in Figure 1. About 91% from the total energy generated is from fossil fuel, 8% from hydropower and 1% from renewables (wind and solar) [13].

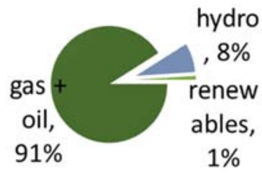

Figure 1. Energy mix in Egypt (2014-2015).

Applying the figures of table 1 to the Egyptian energy mix will yield 105 Million tons (Mt) of CO_2 emissions because of power production, about 47% of Egypt's total emissions of 225 $MtCO_2$ in 2014, with an emission rate of 0.6 kg CO_2 / kWh. This means that for every 1 kWh of energy saved, an equivalent 0.6 kg of CO_2 will be reduced.

The electricity consumption in buildings in Egypt exceeds 60% of the total electricity consumption in the fiscal year 2014-2015. Residential buildings accounted for approximately 44% while governmental, commercial and other buildings accounted for approximately 17% of the total consumption, as shown in Figure 2 [13].

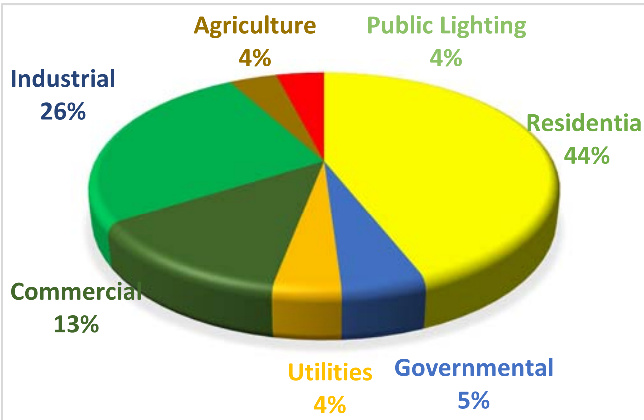

Figure 2. Electricity consumption in Egypt by sector (2014-2015).

1.3. Buildings in Egypt

In 2015, Egypt declared its 2030 vision comprising economic, environmental and social dimensions, in context with the United Nations (UN) 17 Sustainable Development Goals (SDG's) [14].

Improving the energy performance in buildings can be a key player for Egypt's action plan to achieve its 2030 goals. According to the latest census report in Egypt, there was approximately 11.5 Million building in Egypt (2006), of which about 0.5 Million buildings are regarded as office buildings [15].

Three building energy codes were introduced in Egypt for residential buildings (2005), commercial buildings (2007) and governmental buildings (2010). The codes are not mandatory and the government was unable to adopt and enforce the new codes until now. Adding to that, there were no guidelines provided in the code with regard to retrofit existing buildings [16].

Some research studies conducted in Egypt had shown that there are potential opportunities to reduce the energy consumption of non-residential buildings including governmental, hospital, corporate, educational institute and other commercial buildings.

Ayyad and Gabr showed how environmentally conscious architecture and planning are crucial for future national development plans, as the country experiences a considerable challenge in economic, social and environmental terms. They focused on how to have a "green" national development plan [17].

Sarhan et al. highlighted that several factors could reduce the energy consumption in offices; such as passive design, energy conservation plans, water management systems, controlled lighting systems, use of renewable energy, limited use of active air conditioning system and building envelope improvements. An office building (the Petroleum Complex) in Alexandria, Egypt is taken as a case-study to verify their assumption [18].

Nayera et al. studied the energy performance in two administrative office buildings (Petrojet Company) in Cairo. One building is a traditional classic building while in the other building the designer considers energy efficiency and solar energy generated power contribution to the power required. The study concluded that energy efficient lighting and HVAC systems used in the new building save 19% and 64% of the energy used respectively and will save about 46% from the source energy used. In addition the GHG emissions / m^2 in the new building is half that of the existing one [19].

Radwan et al. studied the energy performance of a hospital in Alexandria, Egypt. The hospital is considered a huge energy consumption building due to 24 h, 7 days availability, medical equipment, and requirements for clean air and disease control. The study focused on proper HVAC system sizing for energy efficiency improvement. The new system was compared to the existing system and significant energy saving (41%) was found [20].

Aboulnaga and Mostafa studied the energy performance in a higher education building (Department of Architecture, Faculty of Engineering, Cairo University). Energy consumption in education buildings depends, mainly on the building's activities, time of use and influx of visitors and students and academic staff as well as the academic terms (Fall, Spring & Summer). The study concluded that retrofitting measures are important to reduce energy consumption in higher educational buildings and cooling requirements in hot climate. The most important measures in the retrofitting process of the building envelop are glazing and walls' thermal insulation. Results show that applying retrofitting measures; energy use has been reduced by 15% from the baseline energy use [21].

2. The Proposed Procedure

The proposed procedure can be outlined as follows:

I. Data Collection

Data of interest include building type (bank –administrative building – etc.), number of employees, working hours, building area, electricity and water bills for at least 12 months, number and size of loads including lighting fixtures, air conditioning system, electric water heaters, elevators, computers, printers, copiers, and other office equipment. Other data of importance when installing solar panels include available area of the roof, maximum-recorded temperature during the year, etc.

II. Energy Audit & Saving Opportunities

Assign an audit team (internal or external). An external auditor may have a new look. Auditors should be experienced and perform their audit according to an audit plan. The audit report should conclude with energy saving opportunities.

III. Evaluation of the Opportunities

Each opportunity will be evaluated in terms of energy saving and its equivalent CO_2 reduction. Each opportunity will be assigned a score within the rating system with high scores given to projects with high energy saving. This will be column I in the final decision matrix.

IV. Financial Analysis

Each opportunity will be financially evaluated using Pay Back Time (PBT) and Net Present Value (NPV) methods. Opportunities with shorter PBT's and higher NPV's will be assigned high scores in the rating system. This will be column II in the final decision matrix.

V. Apply Organization's Constraints

Each organization may have certain constraints such as funding problems (limit the application of high investment projects), need to comply with laws (prefer environmental projects even if not economically feasible), time zone limit (prefer projects with short implementation period), etc. Within these constrains some opportunities may be ignored even if technically and/or economically attractive.

VI. Prioritize Opportunities

The project with highest energy & environmental benefits will be assigned a score of 100 in column I, and all other projects will take a score represents its energy savings relative to this project. On the other side, the project with highest financial benefits will be assigned a score of 100 in column II, and all other projects will take a score represents its cost savings relative to this project.

The first column I is multiplied by a factor ($0 < \alpha < 1$) representing the attitude of the organization towards energy and environment, whereas the second column II is multiplied by a complementary factor β ($\alpha + \beta = 1$) representing the attitude of the organization towards money saving. Note that if it is required to maximize energy saving and environmental benefits, then put $\alpha = 1$ and therefore $\beta = 0$ and the priority list of column I will be generated after eliminating any projects subject to the organization constraints. If it is required to maximize the financial benefits then put $\alpha = 0$ and therefore $\beta = 1$ and the priority list of column II will be generated after eliminating any projects subject to the organization constraints. If there is equal preference then $\alpha = \beta = 50\%$.

3. Case Study

3.1. Data Collection

Alexandria National Refining & Petrochemicals Co. (ANRPC) is a refinery based in El-Max, Alexandria, Egypt. The company has an administrative building comprising of the following:

- Ground floor (Meeting Room – Reception)
- 1st floor (Chairman + Managerial Board)
- 2nd floor (Engineering Departments)
- 3rd floor (Human Resources Departments)
- 4th floor (Financial Departments)

The building collected power data is shown in Table 2. Figure 4 shows the electricity consumption trend during 2015 & 2016. The distribution of the consumed energy on various types of loads is shown in Figure 5.

Figure 3. Building under study.

Table 2. Energy Data for the building.

Year of construction	**2005**	
Normal operating hours	7.30 am: 3.30 pm From Sunday to Thursday	
No. of Employees	180	
Base Area	800 m^2	
Air conditioners	Number	Power
Split Units	76	230 kW
Lighting Fixtures	Number	Power
Fluorescent 4*20W	675	54 kW
Spot CFL 2*13W	325	8.5 kW
Office Equipment	Number	Power
Computers	80	80 kW
Printers	20	40 kW
Copiers	8	32 kW
Water Heaters	Number 40	Power 80 kW
Elevators	Number 2	Power 36 kW
Water Pumps	Number 4	Power 10 kW

Figure 4. Electricity consumption pattern.

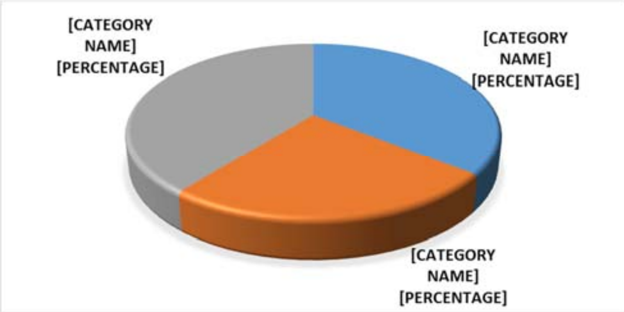

Figure 5. Energy consumed by type.

3.2. Energy Saving Opportunities

3.2.1. Building Envelope

Replace the glazing system with new glass that allows sunlight to enter and blocks heat energy. This will decrease both the lighting load and the air-conditioning load.

3.2.2. Lighting System

Replace lighting fixtures with LED. LED consumes 50% of energy consumed by fluorescent. Moreover, there will be no heat emitted from conventional lights, and hence, the air-conditioner loads will decrease.

3.2.3. Air-Conditioning

Use central air-conditioning systems instead of individual split units.

3.2.4. Office Equipment & Electric Appliances

Replace appliances with newer ones with energy label A, with lowest consumption and highest efficiency.

3.2.5. Elevators

Use motors with variable speed drives instead of two-speed motors.

3.2.6. Heating Water

Use solar water heaters instead of electric heaters.

3.2.7. Photo-Voltaic (PV) Solar Systems

Photo-Voltaic (PV) solar systems can supply part of the building loads during the shining envelope, which coincides with the working time. The panels may serve as shading plates for the roof and hence, decrease the air-conditioner loads.

3.2.8. Personal Behavior

This is the most important, yet frequently overlooked, energy saving opportunity.

3.3. Financial Analysis

- The current tariff for electricity in Egypt (Mar. 2017) is around 1 Egyptian Pound or Livre Egyptien (L.E.) / 1 kWh. This is equivalent to approximately 0.05 $/kWh.

- Several financial indicators can be used for analyzing the financial benefits of a certain project. The most familiar methods are [22]:

I. Payback time (PBT)

The PBT represents the time during which a project will recover its initial cost, as shown in equation (2). The project with the shortest PBT is preferred.

$$\text{PBT (year)} = \frac{\text{Project Total Cost}}{\text{Annual Saving}} \tag{2}$$

II. Net present value (NPV)

The NPV of a project takes into consideration the present value of money, which will be obtained throughout the project lifetime. Projects with a positive NPV are accepted, since the revenues are enough to pay the interest and recover the initial capital cost before the end of the life of investment. Projects with the largest positive NPV should be chosen. The NPV can be calculated from equation (3):

$$\text{NPV} = -\text{Co} + \sum_{t=1}^{N} \frac{R_t}{(1+r)^t} \tag{3}$$

Where Co is the initial investment, N is the lifetime of the project, t is the year counter, R_t is the net Revenue in the year t and r is the discount (interest) rate.

3.4. Company Response/Constraints

Out of the discussed opportunities, three opportunities sound attractive to the company. These are replacing lighting fixtures with LED, installing PV solar panels and replacing the air conditioning system with a central one.

3.5. Evaluating Opportunities

3.5.1. Replacing Lighting Fixtures with LED

- 675 fluorescent lighting fixtures (80W) will be replaced with LED panels (40W)

Annual energy saving = 675 * (80-40) * 8 hours per day * 250 working days per year / 1000 = 54,000 kWh

- 325 CFL Spots (26W) will be replaced with LED Spots (15W)

Annual energy saving = 325 * (26-15) * 8 hours per day * 250 working days per year / 1000 ≈ 6,000 kWh

Total Annual Energy Saving from LED Lighting = 60,000 kWh (43% saving)

Annual CO_2 reductions = 0.6 * 60,000

= 36,000 kg CO_2

- Cost of 1 LED panel = 600 LE

- Cost of new LED panels = 675 * 600 = 405,000 LE

- Cost of 1 LED spot = 200 LE

- Cost of new LED spots = 325 * 200 = 65,000 LE

Total Cost of Project = 470,000 LE

- Annual energy savings = 60,000 LE

- Note that the lifetime of LED = 30,000 hours (15 years, based on 250 working days, 8 hours daily) compared to a lifetime of 2 years for fluorescent. This means that the conventional lamps ought to be replaced 7 times.

- Saving cost of not-purchased lamps =

7 * 4 * 675 * 10 LE + 7 * 2 * 325 * 20 LE

= 189,000 + 91,000 = 280,000 LE

- Annual saving of not-purchased lamps =

280,000 / 15 ≈ 20,000 LE

Total Annual Savings = 60,000 + 20,000 = 80,000 LE (14% saving)

PBT = 470,000 / 80,000 = 6 years

- Considering interest rate = 10%, and assuming that the energy prices and the re-lamping costs will increase by 10% annually

NPV = -470,000 + 15 years * 80,000 LE = 730,000 LE

3.5.2. Installing PV Solar System

- The rooftop of the building (after subtracting the areas occupied by services) has a net area of about 200 m^2. For generating 1 kWh of solar energy, we need 10 m^2. Therefore, the available area can host a 20 kW solar station.

Annual energy saving = 20 kW * 6 hours per day * 300 sunny days per year = 36,000 kWh (6% of total load)

Annual CO_2 reductions = 0.6 * 36,000 = 21,600 kg CO_2

- The cost of the 20 kW system (panels, inverter (converts dc solar power into ac power, wires, distribution panel, installation, etc. (without batteries) = 300,000 LE.

Annual savings = 36,000 LE (6 % saving)

PBT = 300,000 / 36,000 = 8.3 years

NPV = -300,000 + 20 years * 36,000 LE = 420,000 LE

3.5.3. Replacing Split Air Conditioners (A/C)

- 76 split type A/Cs with total power 230 kW will be replaced with a central air conditioner with an equivalent ton refrigerant but consuming only 150 kW (65%).

Annual energy saving = 35% * 200,000 kWh = 70,000 kWh (35%)

Annual CO_2 reductions = 0.6 * 70,000 = 42,000 kg CO_2

Cost of new air-conditioning system (including installation) = 850,000 LE

- The old air conditioning (installed at 2005), are considered as scrap. Note that the useful lifetime of the air conditioner is between 10-15 years. In our analysis, we will consider its life to be 15 years.

Annual money saving = 70,000 LE

PBT = 850,000 / 70,000 = 12 years

NPV = -850,000 + 15 * 70,000 LE = 300,000 LE

- It should also be noted that this project may benefit from the two previously discussed projects. For example, replacing normal lighting with LED will minimize the thermal heat emitted from normal lights, and thus will decrease the thermal load. Also, installing PV panels will work as a shed for the roof and therefore will decrease the thermal load.

3.6. Prioritizing the Opportunities

- The central A/C comes in the first place from energy saving (70,000 kWh) and CO_2 reductions. It will be assigned a score of 100.

- The LED project score = 60,000 / 70,000 * 100 = 86

- The PV project score = 36,000 / 70,000 * 100 = 52

Table 3 summarizes the results.

Table 3. Energy saving Scoring.

Project	kWh saving	Kg CO_2 saving	Score
A/C	70,000	42,000	100
LED	60,000	36,000	86
PV	36,000	21,600	52

- From the financial perspective, the LED project has the lowest PBT and the highest NPV value (730,000 L.E.). It will be assigned a score of 100.

- The PV project score = 420,000 / 730,000 * 100 = 58

- The A/C project score = 300,000 / 730,000 * 100 = 41

Table 4 summarizes the results.

Table 4. Financial Scoring.

Project	Cost (L.E.)	PBT (yrs)	NPV (L.E.)	Score
LED	470,000	6	730,000	100
PV	300,000	8.3	420,000	58
A/C	850,000	12	300,000	41

Based on the company policy, a factor α is addressed to the preference of energy saving, and a complementary factor β is addressed to the financial preference. The results are summarized in Table 5.

Table 5. Decision making matrix.

A	β	LED score	Solar score	A/C score
0	1	100	58	41
¼	¾	96.5	56.5	56
½	½	93	55	70.5
¾	¼	89.5	53.5	85
1	0	86	52	100

4. Discussion

Egypt is facing energy and economic challenges that can render its vision for development by 2030. Buildings in Egypt consume more than 60% of electricity, and this figure seems to increase each year. This imposes a huge burden on the electricity sector to build new power plants each year to match the rising demand. With limited natural resources of fuel, the government has to import these fuels (which increases the foreign currency crisis) or rely on coal, which will worsen the environmental situation.

Some energy efficiency codes are introduced by the government that concentrates on design of new buildings, and unfortunately lacks any implementation mechanism. Also, the existing building block is ignored totally in these codes.

Energy prices are rising each year and this will impose another burden on building owners. Several energy saving opportunities are available especially for older buildings, which are not designed according to modern energy-efficient technologies.

5. Conclusions

In this paper, the authors showed that several opportunities are available to improve the energy performance in existing buildings. A procedure is proposed that combines both economic and environmental aspects of energy conservation methods and prioritize them, along with the solution economics, energy saving and environmental benefits. An office building in Alexandria, Egypt, is taken as a case study to examine the effectiveness of the procedure. The results are easily presented to the decision makers with both economic and environmental indices. The procedure can be applied to most non-residential buildings, which consumes about 17% of the total energy consumption in Egypt. Applying LED light replacement can save about 43% of the total lighting loads. Installing PV solar system can save 6 % of the electrical energy demand. Replacing old split air conditioning units with central one can reduce 35% of the air conditioning loads. More energy saving values can be achieved if these projects are implemented together. Similar percentage of the emitted CO_2 can be saved. Applying the proposed procedure in the existing governmental, corporate, and other office building can highly improve the energy performance in Egypt, decrease its need to build new power plants, save foreign currency needed to import fuels, can cut CO_2 reductions and can reduce energy bills to the individual buildings.

References

[1] International Energy Agency (IEA), “Energy, Climate Change and Environment: 2016 Insights”, IEA Publications, France, November 2016.

[2] United Nations Environment Programme (UNEP), “Buildings and Climate Change”, Sustainable Buildings & Climate Initiative (SBCI).

[3] United Nations Development Programme (UNDP) & Global Environment Facility (GEF), “Promoting Energy efficiency in buildings”, 2010.

[4] Z. Ma et al., “Existing building retrofits: methodology and state-of-the-art”, Energy and Buildings, vol. (55), pp. 889–902, 2012.

[5] U.S. Department of Energy (DOE), “Strategies for 50% Energy Savings in Large Office Buildings”, National Renewable Energy Laboratory (NREL), 2010.

[6] U.S. Department of Energy (DOE), “Advanced Energy Retrofit Guide: Office Buildings”, Pacific Northwest National Laboratory (PNLL), 2011.

[7] European Commission, “Energy-Efficient Buildings: Multi-annual roadmap for the contractual Public Private Partnership (PPP) under Horizon 2020”, Luxemburg, Publications Office of the European Union, 2013.

[8] Hans Erhorn and Heike Erhorn-Kluttig, “Selected examples of Nearly Zero-Energy Buildings”, Energy Performance of Buildings, September 2014.

[9] The Energy Conservation Center, Japan, “Energy Conservation for Office Buildings”, 2010.

[10] Peng Xu et al., “Assessment of energy-saving technologies retrofitted to existing public buildings in China”, Energy Efficiency, vol. (9), pp. 67–94, (2016).

[11] The Energy and Resources Institute (TERI), “Roadmap for Incorporating Energy Efficiency Retrofits in Existing Buildings in India”, 2013.

[12] Sarah A. Al-Ghamdi et al., “Energy Conservation by Retrofitting: An Overview of Office Buildings in Saudi Arabia”, International Conference on IT, Architecture and Mechanical Engineering, May 22-23, 2015 Dubai (UAE).

[13] Egyptian Electricity Holding Company (EEHC), “Electricity Annual Report: 2014-2015”, 2015.

[14] Ministry of Planning, Cairo, Egypt, “Sustainable Development Strategy: Egypt’s Vision 2030”, 2015.

[15] Egyptian Central Agency for Public Mobilization and Statistics (CAPMAS), “Egypt Census: 2006”, 2006.

[16] G. Hanna, “Energy efficiency building codes and Green Pyramid Rating System”, International Journal of Science and Research, vol. 4(5), pp. 3055-3060, 2015.

[17] K. Ayyad and M. Gabr, "Role of Environmentally Conscious Architecture and Planning as Components of Future National Development Plans in Egypt", Buildings, vol. (3), pp. 713-727, 2013.

[18] A. Sarhan et al., "Thermal envelope retrofit: an assessment framework", WIT Transactions on Ecology and The Environment, vol. 2, pp. 803-813, 2013.

[19] N. Abd-Allah et al., "Energy Conservation in Existing Office Building: Case study Petrojet Company Head Office Buildings in Cairo, Egypt", World SB 2014, Barcelona, Spain, 28-30 Oct. 2014.

[20] A. Radwan et al., "Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt", Alexandria Engineering Journal, vol. 55, pp. 3061-3071, 2016.

[21] M. Aboulnaga and M. Moustafa, "Sustainability of higher educational buildings retrofitting approach to improve energy performance and mitigate CO_2 emissions in hot climates", Renewable Energy and Environmental Sustainability, 1, 28 (2016).

[22] D. White, "Evaluating the Economics of Energy Saving Projects", American Institute of Chemical Engineers (AIChE), December 2011.