International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-1, Issue-8, October 2013

Energy Efficient Air Conditioning System in Gaza Strip

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Abstract—This study aims to design buildings to be energy efficient in terms of air conditioning. The design of air conditioning (AC) system that concentrates on cooling load depends on three approaches: optimal thermostat calibration in summer, building envelope insulation, and variable speed derive (VSD) interval compressor. Energy audits and analysis were particularly conducted on Irada building at the Islamic University of Gaza (IUG). Significance savings were achieved using optimal thermostat calibration, building envelope insulation technique, and VSD technique. Finally it can be concluded that the process of designing energy efficient buildings is the best method to improve the efficiency of electricity sector in Gaza Strip.

***Index Terms*—Energy efficiency, air conditioning, thermostat calibration, building envelope.**

I. Introduction

Gaza Strip is located in the south-west area of Palestine. It expands along the Mediterranean Sea with 40 km long and between 6 and 12 km wide. The total area of the Gaza strip is estimated at 365 km^2. Its height above sea level reaches 50 m in some locations. It is located on Longitude 34^o 26' east and Latitude 31^o 10' north [1]. Gaza Strip depends on three main sources of electricity suppliers including Israel Electricity Company, Egyptian Electricity Company, and the local Gaza Power Plant. It also imports the fossil fuels by two ways either directly from Israel or indirectly (by tunnels) from Egypt.

Fig. (1) shows the electricity load demands for the Gaza Strip from 2001 to 2010. It's clear that electricity needs increased by about 10-15 MW annually, as a result of the natural population growth and the expansion in the different sectors requiring electricity supply [2]. Unfortunately, the main problem of energy in the Gaza Strip is that it has almost no conventional energy sources. This problem becomes worse by the high density pollution of the Gaza Strip and the difficult political status caused by the Israeli occupation. According to Kandeel [12], Gaza Strip needs (360) MW of electricity while the available supply is (197) MW. The large share of this supply about (60%) with an average load of 120 MW is provided by the Israeli Electricity Company. Locally, about (32%) with an average load of 60 MW is provided by Gaza Power Plant.

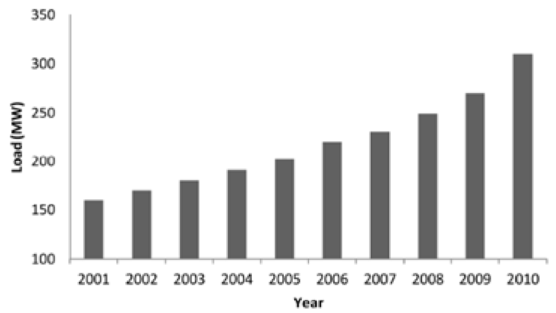

Fig.(1) The electricity load required for Gaza Strip from 2001 to 2010

In addition, about (8%) with an average load of 21 MW is provided by Egyptian Electric Company. In the light of previous statistics, the Gaza Strip has been suffering from a real shortage in electricity supply estimated between 30% to 50%. This led to scheduled cuts of electricity supply for several hours per day which has negative effects on all aspects of the Palestinians life and make it very hard to go about normal life. This shortage rate of electricity supply will increase by the time if other options are not found. Considerable options to solve this problem available in the Gaza Strip are renewable energy sources such as solar and wind energy and energy saving measures.

This paper proposes a scheme for energy saving measures of air conditioning systems and uses Irada Building at IUG as a case study to show the effectiveness of the proposed method. This research represents three methods to achieved this ultimate objective, the first method is optimal thermostat calibration during summer time with no cost attached, the second method is building envelope insulation and runs at low cost, and the third method is VSD and runs at high cost.

This paper is organized such: chapter 2 talks about general structure about buildings in Gaza Strip, chapter 3 covers energy efficient methods for ac systems and presents the results with achieved savings, finally chapter 4 concludes this paper.

II. CASE STUDY BUILDING SPECIFICATIONs

The most common construction system in the residential buildings of Gaza is the structural system (reinforced concrete foundations, columns, and ceilings). In this study, building materials are defined to match the most common ones in Gaza especially in Irada building at IUG. This is intended to explore thermal performance of the reference building, and decide whether it needs some improvement or not. The

Manuscript received October 01, 2013.
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following is a description of several materials used in the reference modeling case:

A. External Walls

Most commonly, walls in Gaza are made of hollow concrete blocks and thin layers of cement plastering applied to the internal and external walls as shown in Fig. (2). A typical section of external walls shows 20 cm hollow concrete blocks, with 1-1.5 cm of internal plaster and 2-3 cm of external plaster. Thermal properties of this element are as follows: U-value, 2.3 W/m^{2}K; admittance, 4.4 W/m^{2}K; decrement factor, 0.3; and time lag, 7.4 hrs [3].

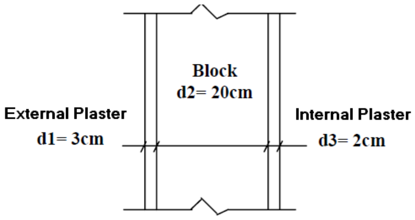

Fig. (2) External Wall of Gaza Building

B. Ceilings

The typical ceiling section shows three parts: 8 cm layer of reinforce concrete, 17cm layer of hollow concrete blocks, and 2 cm layer of plastering as shown in Fig. (3). Thermal properties of this element are as follows: U-value, 2.6 W/m^{2}K; admittance, 4.9 W/m^{2}K; decrement factor, 0.4; and time lag, 6.8 hrs [3].

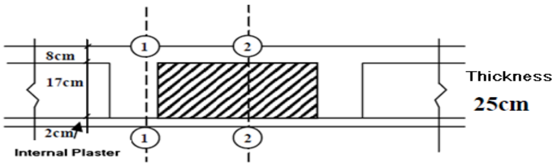

Fig. (3) Ceiling of Gaza Building

C. Glazing

Windows are important parts of the building envelope since they provide both lighting and ventilation. A typical single-glazed window with aluminum frame is assumed here. Thermal properties of this element are as follows: U-value, 5.5 W/m^{2}K; admittance, 5.5 W/m^{2}K; solar heat gain coefficient, 0.9 [3]. According to our site visit to Irada building at IUG, we noted that there are two air conditioning machine each of them 18.2KW; these air conditions serve only six rooms in ground floor with room descriptions are shown in Table I.

III. AC SYSTEM EFFICIENT ENERGY METHODS

Air conditioning system is one of the most expensive operating costs that a business faces today. For this reason, we concentrate our study in this paper on three methods that can be used to reduced the energy consumed by air condition machine as follows:

A. Optimal Thermostat Adjustment Method

People can reduce their electric bills by raising their thermostat setting during summer and reducing it during winter [4]. It is claimed that an increase of 1°C in thermostat setting can achieve as much as 6% reduction in the load [4].

TABEL I: AIR CONDITIONING ROOM DESCRIPTIONS

No.	Room Name	Room Area (m^2)	Ext. Wall Area (m^2)	Windows Number	Win. Area (m^2)
1	Multimedia Laboratory	6× 8	19.20	2	1.92
2	Pyrography Workshop	6× 8	19.20	2	1.92
3	Staff (A)	4.15× 6	13.28	1	3.00
4	Staff (B)	3.85× 6	12.32	1	3.00
5	Staff (C)	3 × 5.45	17.44	1	2.16
6	PC, Mobile &S. Devices	6× 8	19.20	2	1.92

B. Optimal Thermostat Adjustment Method

People can reduce their electric bills by raising their thermostat setting during summer and reducing it during winter [4]. It is claimed that an increase of 1°C in thermostat setting can achieve as much as 6% reduction in the load [4]. The majority of people feel comfortable at a room temperature (T) of 21-26°C depending on the relative humidity (RH) and other factors [5, 6]. The optimal set point of thermostats (TSP) to achieve saving cost in summer seasonal is 24°C for cooling distribution load. At T = 24°C and RH = 50%, almost all people feel comfortable at rest or doing light work. Adjust the air conditioner thermostat set point temperature percentage of saving in cooling system in summer can be calculated by equation (1) [6]:

$$\textit{Energy Saving } \% = \frac{[(T_{exist} - T_{out}) - (T_{suggested} - T_{out})]}{[(T_{exist} - T_{out})]} \quad (1)$$

where T_{exist} is the current temperature inside the room and equal 21ºC in all rooms, T_{out} is temperature before cooling the space and $T_{suggeted}$ is the suggested room temperature. As an example, the energy saving at readjust the temperature from 22 ºC to 24 ºC at library building can be calculated by equation (2)

$$\textit{Energy Saving } \% = \frac{[(21-32)-(24-32)]}{[(21-32)]} = 27\% \quad (2)$$

This procedure is applied to all areas in Irada building. This method is based upon the number of air conditions and their set point temperatures. The measure is used to control the set point temperature of the air condition to suit the indoor climate, depending upon the ambient temperature, and the seasonal operation hours which we assumed in our calculations to be 640 hours. Table II presents the electrical consumption of the AC system and annual energy saving after readjusting the thermostat to optimal temperature. The determinant factors that affect the calculation of the percentage saving energy are the indoor and outdoor temperature. Indoor temperature expresses the performance of AC system and the losses inside the required cooling area include the thermostat set point by human. Outdoor temperature is not controlled due to the variation in ambient temperature and humidity in the weather. The optimal thermostat set point is 24ºC and this set point laying in comfortable temperature for human.

TABEL II: INCREASE THE AIR CONDITIONER TSP TEMPERATURE

N	Room name	T out	Rate	Using	Saving	Power Saving	Energy Saving
		°C	Kw	KWh/yr	%	KW	KWh/Yr
1	Multimedia laboratory	36	7.6	4864	20%	1.52	972.8
2	Pyrography workshop	37	7.6	4864	18%	1.37	875.5
3	Staff (A)	36	4.9	3136	20%	0.98	627.2
4	Staff (B)	34	4.5	2880	23%	1.04	662.4
5	Staff (C)	34	4.2	2688	23%	0.97	618.2
6	Pc, Mobile &S.devices	32	7.6	4864	27%	2.05	1313.2
Total				23296			5069.4

C. Building Envelope Insulation Method

The building envelope and its components determine the amount of heat gain, heat loss and wind that enter inside the building. We will focus our study in external wall, ceiling and windows. Fig. (4) below explains the modification on Fig. (2) which clarifies the new suggested external walls insulation of Irada building at IUG [7]. Fig. (5) below explains the modification on Fig. (3) which clarifies the new suggested ceiling of Irada building at IUG with insulation [7].

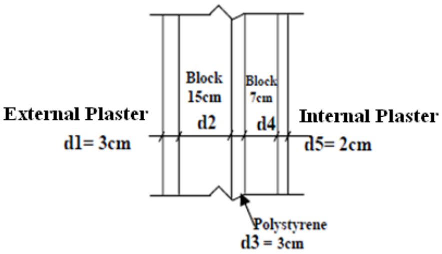

Fig. (4) New suggestion external wall with insulation

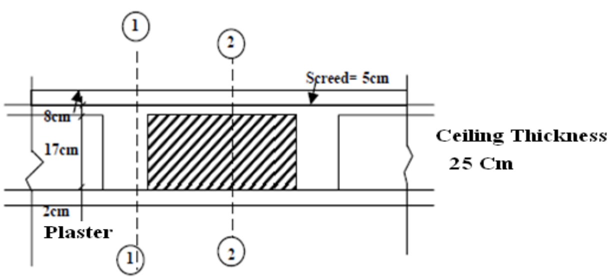

Fig. (5) New suggestion ceiling with insulation

For windows we will replace single glass windows which have thermal transmittance 5.6 W/m^2.k by double glass windows which have lower thermal transmittance reach about 2.8 W/m^2.k. To calculate cooling load we can use the following equations (3) [8]

$$U = \frac{\sum U_d A_d + \sum U_w A_w + \sum U_{win} A_{win}}{A_t} \quad (3)$$

Where; U is total thermal transmittance (W/m^2.k), U_d is external door thermal transmittance(W/m^2.k), U_w is external wall thermal transmittance (W/m^2.k), U_{win} is external window thermal transmittance(W/m^2.k), A_d is external door area (m^2), A_w is external wall area (m^2), A_{win} is external window area (m^2) and A_t is total area of external wall including all opening (m^2). We can calculate U_w from equation (4)

$$U_w = \frac{1}{0.18 + \frac{d_1}{k_1} + \cdots + \frac{d_i}{k_i}} \quad (4)$$

Where; 1/k_i is the thermal resistivity (W/m.k) and d_i is thickness (m).

First Step: Using Fig. (2) to calculate thermal transmittance for current status wall of Irada building without insulation

A_t = Area of wall = 19.2 m^2

A_{win} = External window area = 3.84 m^2

A_w = Clear wall area = 19.2 − 3.84 = 15.36 m^2

Then,

$$U_w = \frac{1}{0.18 + \frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3}}$$

$$= \frac{1}{0.18 + \frac{0.03}{1.2} + \frac{0.2}{0.8} + \frac{0.02}{1.2}} = 2.12\ W/m^2.k$$

$U_{win} = \frac{5.6W}{m^2}.k$ for single glass aluminum window

$$U = \frac{U_{win} \times A_{win} + U_w \times A_w}{A_t}$$

$$U = \frac{5.6 \times 3.84 + 2.12 \times 15.36}{19.2} = 2.82\ W/m^2.k$$

Second Step: Calculate thermal transmittance for recommended wall with insulation as per Fig. (4).

$$U_w = \frac{1}{0.18 + \frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \frac{d_4}{k_4} + \frac{d_5}{k_5}}$$

$$= \frac{1}{0.18 + \frac{0.03}{1.2} + \frac{0.15}{0.8} + \frac{0.03}{0.04} + \frac{0.07}{0.8} + \frac{0.02}{1.2}} = 0.8\ W/m^2.k$$

$U_{win} = 2.8 \left(\frac{W}{m^2}.k\right)$, for double glass aluminum window.

$$U = \frac{U_{win} \times A_{win} + U_w \times A_w}{A_t} = \frac{2.8 \times 3.84 + 0.8 \times 15.36}{19.2} = 1.2\ W/m^2.k$$

Third Step: Cooling load calculation of Irada building

$t_i = 20C^\circ$, $t_o = 32C^\circ$ $\Delta t = 32 - 20 = 12C^\circ$

$$Q_t = -(Q_c + Q_s + Q_v + Q_i) \quad (5)$$

where; Q_s = gain/solar

$t_s = t_o + \frac{I \times a}{h_o}$ where; I = intensity of radiation = 645

a = absorption coefficient of outer wall surface = 0.58

$f_o = \frac{1}{R_o}$, $h_o = \frac{1}{R_o}$

$t_s = 32 + \frac{645 \times 0.58}{16.6} = 54.5C^{\circ}$, $\Delta t_s = 54.5 - 20 = 34.5C^{\circ}$

Fourth Step: Calculate cooling load for current wall using Equ. (5)

$$Q_c = Q_{win} + Q_w = U_{win} \times A_{win} \times \Delta t + U_w \times A_w \times \Delta t_s \quad (6)$$

$= 5.6 \times 3.84 \times 12 + 2.12 \times 15.36 \times 34.5 = 1373.48\ W$

$Q_s = A_{win} \times I \times \theta$ where; θ = solar gain factor

= 0.75 (single glass window)

$Q_s = 3.84 \times \times 645 \times 0.75 = 1857.6\ W$

$$Q_v = \frac{\rho.C.V.n.\Delta t}{3600} = \frac{1.25 \times 1000 \times (6 \times 8 \times 3.2)12}{3600} = 640\ W$$

Where; air change one time per hour

$Q_i = 6 \times 140 = 840\ W$ where; No light on and there is six persons in the room

$Q_t = -(1373.48 + 1857.6 + 640 + 840) = -4711.08\ W$

Calculate cooling load for recommended wall using Equ. (6)

$$Q_c = Q_{win} + Q_w = U_{win} \times A_{win} \times \Delta t + U_w \times A_w \times \Delta t_s$$

$= 2.8 \times 3.84 \times 12 + 0.8 \times 15.36 \times 34.5 = 552.96\ W$

$Q_s = A_{win} \times I \times \theta$

where; θ = solar gain factor = 0.65 (double glass window)

$Q_s = 3.84 \times 645 \times 0.65 = 1609.92\ W$

$$Q_v = \frac{\rho.C.V.n.\Delta t}{3600} = \frac{1.25 \times 1000 \times (6 \times 8 \times 3.2)12}{3600} = 640\ W$$

Where; air change one time per hour

$Q_i = 6 \times 140 = 840\ W$ where;No light on and there is six persons in the room

$Q_t = -(552.96 + 1609.92 + 640 + 840) = -3642.88\ W$

% of energy saving in heating load =

$$\frac{3642.88 - 4711.08}{4711.08} \times 100\%$$

=22.7%

Table III shows comparison for heating and cooling load calculation before and after making insulation and it shows also the percentage energy saving in each room with AC system in Irada building at IUG.

TABEL III

COOLINGLOADCALCULATION

N	Room name	U Exist W/m².k	U Rec. W/m².k	Q_t Exist W	Q_t Rec. W	Energy saving %
1	Multimedia laboratory	2.8	1.2	4711.8	3642.8	22.7
2	Pyrography workshop	2.8	1.2	4711.8	3642.8	22.7
3	Staff (A)	2.9	1.25	3305.7	2534.3	23.3
4	Staff (B)	2.9	1.29	3062.5	2343.8	23.5
5	Staff (C)	2.5	1.1	2817.8	1982.6	29.6
6	PC, Mobile & S. devices	2.8	1.2	4711.8	3642.8	22.7

D. AC System Using VSD Inverter

Most fixed-speed compressors in traditional AC systems only operate at 0% and 100%; in other words, fixed-speed compressors are either off or on, wasting energy when partial-load conditions prevail. And even if you have a traditional system with 2 or 3 stages, it doesn't compare to the full-range variable capacity of the inverter-driven system that fully supports part-load operation. In comparison, VSD inverter compressors ramp up quickly, providing the energy necessary to achieve the cooling or heating demand of the zone. Then, working in tandem with system controls and sensors, the VSD inverter compressor varies its speed to maintain the desired comfort level. Fig (6) clarifies the basic existing technology of VSD. The system performs at only the minimum energy levels necessary and does not waste electricity when partial-load conditions are present, which is 97% of the time in most locations [9].

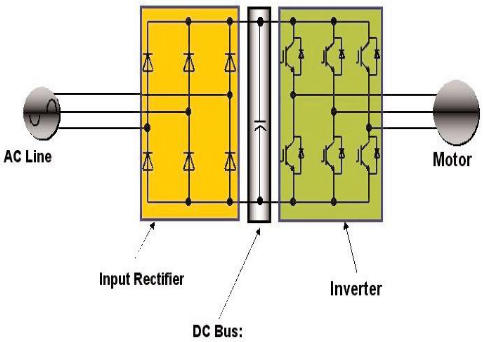

Fig. (6) VSD basics existing technology

As VSD usage in AC system applications has increased, fans, pumps, air handlers, and chillers can benefit from speed control. Variable frequency drives provide the many advantages such as energy savings, low motor starting current, reduction of thermal and mechanical stresses, simple installation, high power factor and lower KVA. When using the air condition included the inverter, the saving energy reaches up to 30 % [10]. Table IV, shows energy saving for using the AC with VSD inverter in Irada based on the measurements of power and energy consumption for air conditioners. For this calculation, we assume that the annual operating hours for AC machine is equal to 640 hours.

TABEL IV

ANNUAL ENERGYSAVINGFORUSINGTHEACWITH VSD

N	Room Name	Pwr W	Energy used kWh/year	Saving %	Power saving W	Energy saving kWh/year
1	Multimedia laboratory	7.6	4864	30%	2.28	1459.2
2	Pyrography workshop	7.6	4864	30%	2.28	1459.2
3	Staff (A)	4.9	3136	30%	1.47	940.8
4	Staff (B)	4.5	2880	30%	1.35	864.0
5	Staff (C)	4.2	2688	30%	1.26	806.4
6	PC, Mobile &S.devices	7.6	4864	30%	2.28	1459.2
Total			23296			6988.8

IV. Conclusion

Energy efficient system is very much essential in order to save energy, money and reduce in global warming. The objective of this study was to reduce the electrical rate of deficit in Gaza Strip due to limited electrical power resources in order to make available the saved energy for other uses. This paper presented a study of AC system to Irada building at IUG as a case study. The proposed scheme requires zero investment to boost optimal thermostat adjustment conservation programs, low cost to boost building envelope insulation conservation program and high cost to boost AC system using VSD inverter conservation program. The scheme of all methods were performed at six rooms inside Irada building. The proposed no cost energy saving actions achieved annual average energy saving of 21.7% with 5069.4 kWh and equivalent to $681.08 with immediate return. The proposed low cost energy saving actions achieved annual average energy saving around 23.7%. The proposed high cost energy saving actions achieved annual average energy saving of 30% with 6988.8 kWh and equivalent to $944.4. Assuming this percentage is the average saving of electrical energy that could be achieved by adopting the no cost, low cost and high cost electrical energy actions, then the rate of electrical deficit decreases by 3.3 % in Gaza Strip.

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