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# Energy Audit and Potential Energy Saving in an Office Building in Riyadh, Saudi Arabia

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**Abstract.** Energy audit is used in this paper as an efficient method/tool to assess and study the energy profile of a large office building in Riyadh City. The various components of the building are analyzed, such as specifications of the walls, the roofs, the windows, the lighting fixtures, the office equipments, the chillers, HVAC, the additional air conditioning units known as split types and the other equipments in the building. It has been found that air conditioning system represents 50% of the total installed power. The energy audit study has helped to diagnose and then define certain solutions and modifications for increasing energy efficiency in the building. The potential energy saving and the pay-back period of the proposed modifications are also calculated and analyzed for different solutions. After the implementation of the proposed modifications, the pay-back period is estimated to be 29 months. Recommendations are suggested according to the optimum solution.

## 1. Introducation

Energy audit is an essential activity for any organization wishing to control energy and utility costs. Energy audit is a tool for energy management, and not an aim in itself. It is a tool to determine and analyze the energy consumption of consumers units in order to determine energy saving options. The unit of consumers can be small or large; it can be a utility building, a workshop, a factory, a household, a village, etc. The analyses will give an indication of which areas/sectors most energy is consumed, indicating also where the highest savings can be obtained. The analyses will also reveal the sort of energy consumed and at what costs. In addition, an energy audit will pinpoint the places where energy losses occur. A more detailed analysis of the-high energy consuming-section(s) will give an indication if energy savings are possible and how (Al-Ajlan *et al.*, 1998; Surapong *et al.*, 2003). Often some measurements have to be taken, monitoring of consumption and studying energy bills are required and some calculations have to be made (Surapong *et al.*, 2003). However, even a rapid preliminary audit will reveal saving options. The energy audit study ultimately aimed to achieve maximum saving of electrical energy, minimum investment, and minimum pay-back period for the proposed modifications (Jane *et al.*, 2000).

The energy audit in this study was conducted by both walk-through audit and measurement audit. In other words, the energy audit includes preliminary energy audit and detailed one. Preliminary audit focused on obvious energy savings, improvement of the energy management, and cutting down of losses. Also, it does not indicate improvements for which relatively large investments are required. The preliminary audit aimed to record and analyze energy consumption by sector/department at minimum costs, identification of obvious energy wastes, rough calculation of energy/money losses and rough calculation on saving potentials, thorough analysis of electricity bills, visual inspection of energy saving opportunities, and determine areas/sectors that need more detailed analysis.

The detailed energy audit (5-7 weeks) aimed to perform detailed recording and analysis of energy consumption by sector/department during a longer and representative time span. Specialized devices for measuring equipment efficiency, thermal energy, electrical power pollution, de-rating of power transformer, and heat transfer have been used. Calculations of energy/money losses and possible savings have been done. The 5-7 weeks as an average are sufficient to perform detailed energy audit provided that a reliable measurement equipments with experienced engineers and technicians are available. The period of detailed energy audit depends on the size of the building and project.

## 2. Previous Studies

In the last three decades, electrical energy consumption in Saudi Arabia has increased rapidly from 3.7 million MWh in 1975 to 163.1 million MWh in 2006. Annual electricity consumption is expected to grow 6.4% on average. Saudi Arabia had a total generating capacity of 34.439 MW in 2006 (SEC, 2006). The ministry of Industry and Electricity (MIE, 1998) estimates that the demand for electricity will de 59,000 MW by 2020 (Watts, 1998). This requires a huge investment either for building new power plants or for upgrading the existing electric power systems, i.e. the investment required from the year 2007-2015 is estimated to be 190 billion SR (SEC, 2007), (1 US Dollar = 3.75 SR). The electric utilities in the country face problems of peak hours, generally believed due to the high demand for air conditioning in summer.

Said *et al*. (1996) reported the monthly average temperature in Saudi Arabia during the months of April through October is above $27^0$C ($80^0$F) for 76% of the time and below $21^0$C ($70^0$F) only 1% of the time. Similarly, during the months of November through March, the monthly average temperature is above $21^0$C for 24% of the time, and above $18^0$C ($65^0$F) 4% of time. They concluded that space cooling is required during the period from April to October in most areas of the country. For the Riyadh area (hot-arid climate), as an example, annual cooling and heating degree-days at $18^0$C base temperature are reported as 5535 and 506, respectively. More or less the same findings were presented by Al-Homoud (1997). These two studies show that two main seasons are dominant in most parts of Saudi Arabia. These seasons may be distinguished as summer and winter. The summer is very long and lasts for seven months (April through October) of the year.

In Saudi Arabia, buildings use the majority (more than 70%) of the total electric energy consumption in the country. Electricity consumption usually soars during summer, and about 70% of the total building energy consumption in the country goes toward air-conditioning buildings/facilities (Hasnain, 1998). Several simulation studies were conducted for Saudi residential buildings. Most of the researchers used DOE-2 to simulate the energy consumption in different houses. Among those simulation studies, Said and Al-Hammad (1993) showed potential for reducing energy consumption in residential buildings that are properly designed and operated. As much as a 40% reduction in the total annual energy consumption was reported from the study, considering the combined effect of the analyzed parameters. Al-Hamoud (1997) found annual energy savings of 37% and 28%, respectively, in the optimization of a small, two-story residential building in the city of Riyadh (a hot-arid climate) and in the city of Jeddah (a hot–humid climate).

Al-Hamoud and Mohammad (1997) showed that 15%, 19% and 40% annual energy can be saved in large, medium and small office buildings through envelope thermal optimization in the Riyadh area. Similarly, for Jeddah, annual energy savings of 8%, 12% and 24% can be obtained for large, medium, and small offices, respectively. Ahmad *et al.* (1994) reported an analysis of electric energy consumption for a supermarket in the city of Dhahran (a hot–humid climate). They concluded that 38% of energy in the commercial building studied is used for air–conditioning, 42% is used for appliances, and the remaining 20% is used by lighting.

Saeed (1997) conducted a study on two types of elementary school buildings in the Riyadh area. He found a drop of electric energy consumption in both buildings during the months of June through August, as schools were closed for summer vacation. Rabghi *et al*. (1999) showed electric power consumption by an air–conditioning system in a small department of a university. They examined a two–floor building in Jeddah. The spaces at the ground and first floor of the building are unconditioned and conditioned and conditioned, respectively. As electric energy consumption for the months of June through August was not measured, these two studies do not show the electrical energy consumption during the most crucial period of the year, when most of the energy consumed for air-conditioning systems occurs and increases peak electric load on the grid.

Al–Ajlan *et al*. (1998) and Hasnain (1998) reported that the electric demand is very high during summer, mainly due to air-conditioning consumption, which is high due to the lack of thermal insulation in most of the buildings, as well as the absence of other energy efficiency measures and load management strategies. Consequently, energy conservation has become an important target for the country. Several efforts have been made. But, they have not met expectations. And, not more than 3% to 4% total reduction at the country level has been achieved (Al-Tuwajiri, 1998). One of the essential goals of the the Ministry of Water and Electricity (MOWE), the former MIE, is the reduction of peak load by (at least) 20% during summer as well as reducing energy consumption by 30% (Al-Tuwajiri, 1998). Therefore, MOWE started advising customers to reduce their electric loads by implementing energy efficiency methods. At the same time, electric utilities guide their customers and follow up their efforts to achieve established goals. Additional benefits of reducing energy consumption are a clean environment and less investment in new power plants. It is worth mentioning that electricity is highly subsidized by the Saudi Arabian government, but no time of use electric tariffs and demand charges are used in the country.

Hasnain and Al-Abbadi (2000) estimated 15% to 20% of electric utility peak load is consumed by central air conditioning in office buildings and large facilities in Saudi Arabia. Therefore, the first step toward achieving the MIE goals for energy conservation and peak load reduction is to conduct an energy audit in an office building to find opportunities for energy efficiency and then to propose the proper techniques for increasing efficiency. The above-referenced studies covered electrical energy consumption in a supermarket. Schools and university buildings, but comprehensive building energy efficiency assessments were not conducted and efficiency improvement opportunities were not reported. To the best knowledge of the authors, measured experimental values of actual electrical energy consumption by specific equipment, such as chillers, air-handling units (AHUs), different lighting systems, office equipment, and other associated electric appliances, in an office building in Saudi climates are not available in the literature.

Hasnain and others (2000) found that daily air-conditioning energy represents 74% of an office building's total electric load during the summer peak period. Within the air-conditioning system, 74% of electrical energy is consumed by chillers, 21% by AHUs, and 5% by pumps. The other major measured electric loads are 11.4% for interior lights and 11% for office equipments. The paper also identified areas for energy and power saving in the building.

To the best of the author's knowledge, the pay-back period analyses are not available in the literature and the emphasis in the previous studies were on identifying areas for energy saving by audits without analyzing the pay-back period of the investments needed for the changes and modifications. The pay-back period is essential to be determined for the investors; otherwise, the energy audit would be incomplete and not useful. Identifying areas of energy saving might required a lot of investment and long pay-back period in which implementing the recommended modifications and changes become economically infeasible.

This paper presents measured values of actual electrical energy consumption by chillers, AHUs, different lighting systems, office equipments, and other associated electric appliances used in a multi-story Saudi office building in order to identify the major areas of electrical energy consumption, and to recommend practical methods for energy and power savings. The data analyzed in this paper are based on the measured values of actual electrical energy consumption by different equipments. The pay-back period for the required investment has also been analyzed and determined.

## 3. Building Envelope

The building is rectangular in shape with the front side elevation facing north, rear side elevation facing south, left side elevation facing east, and right side elevation facing west. There are no high-rise buildings located nearby or adjacent to it. The building had 12 floors, reinforced concrete building with a rooftop rooms for the control of chillers. In addition, the building has 2 basements; Basements 1 and 2 generally used as parking area, each basement has the same surface area as the floor. Table 1 gives a summary of the building specifications.

**Table 1. Summary of building specifications**

| Item | Description | Unit |
|---|---|---|
| 1 | Total interior space (volume) | 79,531 $m^3$ |
| 2 | Total exterior walls area | 10,818 $m^2$ |
| 3 | Total roof area | 2,693 $m^2$ |
| 4 | Total glass/windows/facade area | 4,380 $m^2$ |
| 5 | Total power of lighting fixtures | 698 kW |
| 6 | Total power of office equipment | 1,786 kW |
| 7 | Total power of chiller, HVAC system and split units | 2,788 kW |
| 8 | Other loads | 280 kW |
| 9 | Total estimated number of employees/staff (estimated) | 900-1000 |
| 10 | Total estimated number of visitors per day (estimated) | 300-400 |

The building envelope is made of reinforced concrete and prefabricated concrete blocks with a combination of tempered glass house in aluminum frame panel with window for each floor. The type of glass material used in the building is 12 mm tempered plate glass with 4 aluminum connectors per panel. The glasses are installed with explosion proof thermal film insulation and also to protect

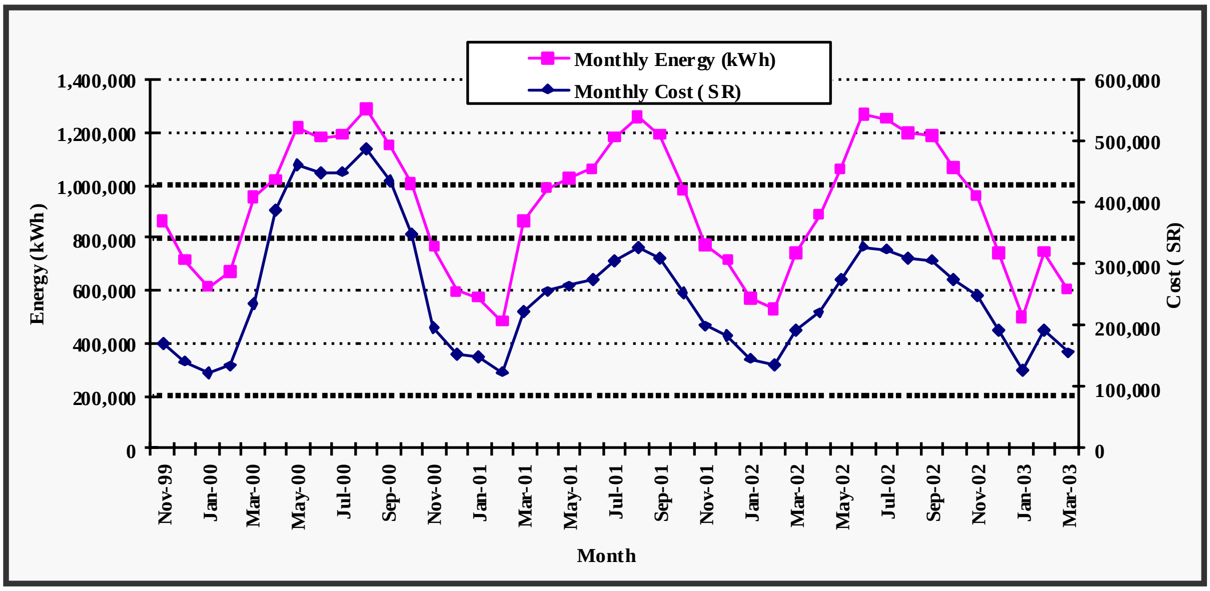


**Fig. 1. Monthly electricity energy consumption and electricity bill in Saudi Riyals (SR).**

from the sun's radiation. This explosion proof thermal films are replaced completely in recent days, i.e. in the month of September 2004 and its technical specifications is also enclosed in this paper. The exterior wall material is composed of prefabricated concrete block, while the interior wall material is a gypsum board with an aluminum foil inside fix in metal channels/framings. There are no thermal insulations in between the prefabricated concrete wall and the gypsum board interior wall. The roof top has insulation material and is made up of concrete slab with ordinary concrete tiles fixed by cement on top of it.

## 4. Building Occupancy

The building is mainly used for office functions of the whole company operations. All the operating departments are housed in the building. The work is five (5) days a week, eight (8) hours per day. The office hours starts at 8:00 AM up to 4:00 PM. The security in the building is 24 hours work. The number of personnel working in the building is estimated to be 900 to 1000. The estimated number of visitors coming in and out is roughly estimated to be 300 to 400 per day.

## 5. Building Data Collection and Measurements

The energy audit study was planned to start with (a) the building data collection which includes the specifications of walls, roofs, windows glass and frames, and (b) the measurements which include solar radiation and ambient temperature, chillers and Heating Ventilation Air Condition (HVAC) system, lighting system, office equipments and other electrical equipments in the building. The gathered data includes but not limited to the following:

1. Building elevation plans and internal distribution such as rooms, offices, etc.
2. Building specification for walls, windows, glass insulation, etc.
3. Electrical equipment such as lighting fixtures, types of air conditions, etc.
4. Office equipment, such as photocopying machines, PCs, printers, and others.
5. Measurement of lighting intensity (Lux).
6. Measurement of temperature profile inside the building.
7. Measurement of solar radiation and ambient temperature.
8. Relative humidity.

## 6. Data Analysis

The data analysis includes the various items and components of the building such as power, walls and glass and efficiency of the air condition system. Also, the monthly energy and the electrical bill are studied. Figure 1 shows the variation of monthly electrical energy (kWh) and the monthly electrical bill in Saudi Riyals (SR), (the conversion rate is 1 US Dollar = 3.75 SR). It is clear from Fig. 1 that the change of the electricity tariff (after the month of January 2001) has changed the cost of the monthly electricity bills, therefore for the same monthly energy consumption the electricity bill is reduced.

### 6.1. Power analysis

Table 2 shows the total power and its percentage for various types of electrical equipments. It is clear from the table that the air conditioning system and the office equipments represent respectively 50% and 32% of the total installed power. During the initial design of the building, before 25 years, the power of office equipment was estimated to represent low value as compared to the power required for the lighting fixtures. During the previous years, the power of office equipments has increased to around 250% of the power of the lighting fixtures. Also, due to the degradation of the coefficient of performance of chillers after 20 years of operation, the chillers system is not capable to reach the inside comfort temperature of the building. Therefore, the building has a dual problem, on one hand the demand for power has increased due to the addition of new electrical office equipment such as personnel computers and photocopy machines, so more cooling demand is needed, and on the other hand the efficiency of the chiller is decreased, as a result the cooling capacity is reduced. The management of the building proposed a fast solution to install additional split units, mainly on the rooms of the western side of the building to assist the central chiller system. The proposed solution has added the power demand to the highest available capacity of the power transformers that are supplying the building.

**Table 2. Total equipment ratings (kW)**

| Item | Power (kW) | % Power |
|---|---|---|
| Total power of lighting fixtures | 698 | 13 |
| Total power of office equipments | 1,786 | 32 |
| Total power of chillers, split units and HVAC | 2,788 | 50 |
| Total power of other loads (elevator & pumps) | 280 | 5 |
| **Total installed power** | **5,552** | **100** |

### 6.2. Indoor room temperature analysis

The building walls are not thermally insulated; the roof was insulated only 4 years ago. The glass in the exterior sides of the building was thermally insulated with insulation film before 3 years. All the previous factors have contributed to difficult situation where the power bill is high and the average comfort temperature of 25˚C is not reached during many days when the ambient temperature reaches more than 47˚C. Figure 2 shows the measured temperature on floor No. 10 of the building. The profile of measured temperature in the other floors was similar to the 10th floor. Figure 3 shows a plot of samples of measured temperature as compared to various temperature zones. It is clear from the drawing that the measured temperatures are in the hot zone which indicates that the walls need to be properly insulated.

### 6.3. Air-conditioning (A/C) system analysis

The building air conditioning is a fully centralized system from ground floor to 10th floor and it is controlled by Digital Control System (DCS). The chillers are all located at the rooftop of the building including the control systems, which is housed in a separate air-conditioned room (see Fig. 4). split/window type air-conditioning units have been added in some rooms due to insufficient cooling capacity of the centralized system.

The total peak cooling load at maximum average monthly ambient temperature of 46˚C, as per the condition of the building without wall insulation is 1124.82 Ton Refrigeration (TR). The air conditioning (AC) system of the building is composed of 11 chillers; each has 125 nominal TR. The actual performance of the AC system is decreased due to the aging problem (after more than 20 years of operation), as an example the efficiency of chiller number 8 is reduced to 63.81%. The present condition of AC system is not capable to supply the cooling demand; that was due to the aging of the AC equipment and many new electrical office equipments have been added in the building such as personnel computers and its peripherals, which means that the cooling capacity needs to be increased. Table 3 shows the actual performance of chiller number 8. It is clear from Table 3 that the average efficiency of the chiller has decreased by 36.19%. It has been noticed during the time of the measurement that the number of the compressors in operation varies between 12 and 14 during the time from 11:30 to 13:30 Hrs. respectively. This drop in the chiller efficiency refers to the following:

1. Control components efficiency drop and/or failure of some components.
2. Condenser coils efficiency drop.
3. Evaporator shell and tube heat exchanger efficiency drop due to scale and fouling.
4. Compressors liability and increasing shut down time for repair.

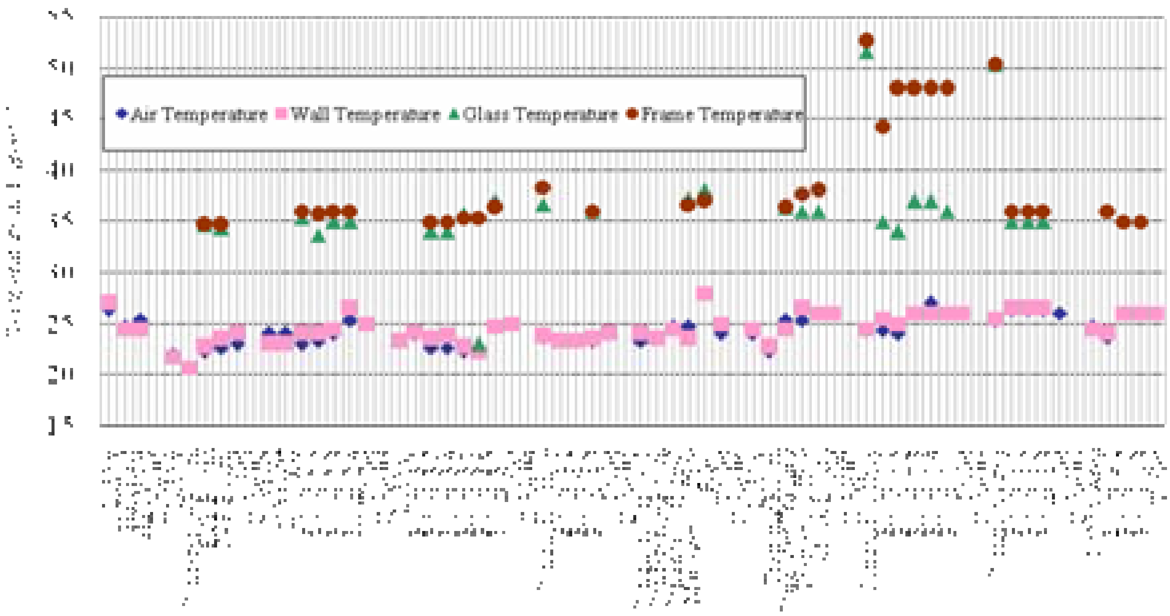


**Fig. 2. Temperature measurements for floor No. 10.**

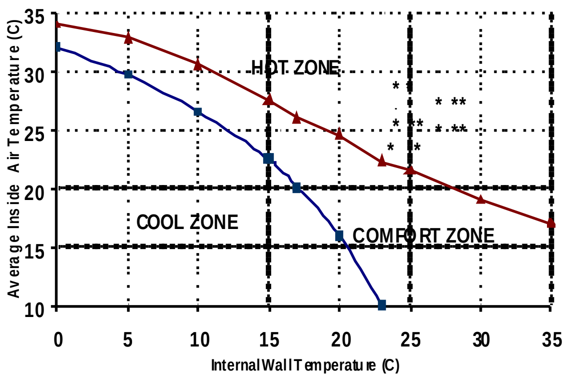


**Fig. 3. Plot of measured temperature at floor 10 and the comfort zone temperature profile.**

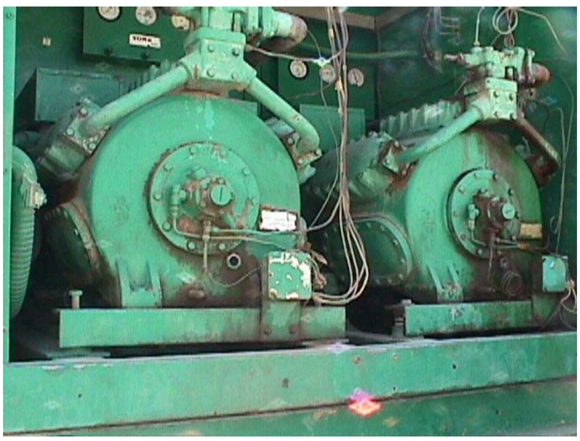

**Fig. 4. Chiller No. 4 with two compressors.**

### 6.4. Lighting analysis

The types of lighting fixtures used in the building are shown in Table 4. According to Table 4, the fluorescent lighting fixtures represents the highest percentage 89.8%. The measurement of lighting intensity (Lux) in various rooms shows that the average values of Lux are higher than the normal which is used for office building. Figure 5 shows the measured lighting values in floor 10 of the building. The normal Lux values for office building can vary from 300 to 500 Lux (Alex, 2000). This problem of high Lux is mainly due to the change in the partition walls in various floors in the building. To reduce the monthly electricity bill and to decrease the contribution of heat generated from lighting fixtures in the cooling load, it is recommended to adjust the lighting intensity to an average value of 450 Lux.

## 7. Proposed Modifications

The proposed solution deals with a number of options including the AC system, lighting, and walls insulation. From the audit analysis, the following summary is concluded:

a) High variation of lighting intensity (Lux=lumen /m$^2$).
b) High variation of air temperature.
c) High variation of supply air due to modification of repartition walls in each floor.

**Table 3. Performance summary of chiller No. 8**

| Ambient | Time | m | Cp | T in – T out | Q | Q | CH load as per design | Load ratio | Drop |
|---|---|---|---|---|---|---|---|---|---|
| °C | (Hrs) | kg/s | kJ /(°C * kg) | °C | kW | TR | TR | % | % |
| 38.3 | 11:15 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 131.00 | 63.13 | 36.87 |
| 38.6 | 11:30 | 16.20 | 4.18 | 4.20 | 284.41 | 80.77 | 131.00 | 61.66 | 38.34 |
| 38.7 | 11:45 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 131.00 | 63.13 | 36.87 |
| 38.7 | 12:00 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 130.50 | 63.37 | 36.63 |
| 39.8 | 12:15 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 129.00 | 64.11 | 35.89 |
| 39.7 | 12:30 | 16.20 | 4.18 | 4.40 | 297.95 | 84.62 | 129.00 | 65.60 | 34.40 |
| 40.0 | 12:45 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 129.00 | 64.11 | 35.89 |
| 40.3 | 13:00 | 16.20 | 4.18 | 4.00 | 270.86 | 76.93 | 127.50 | 60.34 | 39.66 |
| 40.8 | 13:15 | 16.20 | 4.18 | 4.10 | 277.64 | 78.85 | 129.00 | 61.13 | 38.87 |
| 39.6 | 13:30 | 16.20 | 4.18 | 4.00 | 270.86 | 76.93 | 131.00 | 58.72 | 41.28 |
| 40.4 | 13:45 | 16.20 | 4.18 | 4.10 | 277.64 | 78.85 | 129.00 | 61.13 | 38.87 |
| 40.5 | 14:00 | 16.20 | 4.18 | 4.20 | 284.41 | 80.77 | 130.00 | 62.13 | 37.87 |
| 40.0 | 14:15 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 131.00 | 63.13 | 36.87 |
| 39.0 | 14:30 | 16.20 | 4.18 | 4.30 | 291.18 | 82.70 | 132.00 | 62.65 | 37.35 |
| **Chiller average load values %** | | | | | | | | **63.81** | **36.19** |

**Table 4. Summary of lighting fixtures in the building**

| Location/Type | Fluorescent | Compact | Incandescent | Total (W) |
|---|---|---|---|---|
| Total Lighting Load (W) | 626,840 | 24,956 | 46,360 | 698,156 |
| % of Total contribution | 89.80 | 3.50 | 6.70 | 100 |

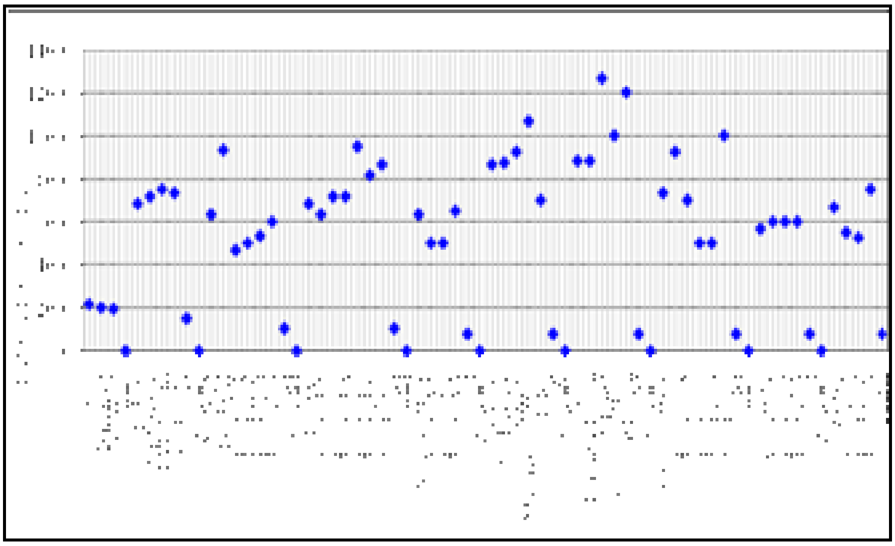

**Fig. 5. The measured lighting intensity at floor No. 10.**

d) Chillers and A/C System findings: Room temperature is not efficiently adjusted.

- Chillers are old (more than 20 years).
- No complete shading of chiller units.
- Inefficient chillers.
- Frequent periodic maintenance.
- High maintenance cost.

The solutions proposed are explained in the following section.

## 7.1. Building insulation

A reliable computer program developed by the author and others (Al-Ajlan *et al.*, 2006) based on a finite-volume, time-dependent implicit procedure was used to compute the yearly cooling and heating transmission loads through the building walls for different insulation thickness and materials. The variations of yearly transmission loads with insulation thickness, calculated under steady periodic conditions using the climatic data of Riyadh and for a west-facing wall, were fed into an economic model in

**Table 5. Chillers improvement options and cost**

| Options | A/C Chillers System Options | Materials Cost (SR) |
|---|---|---|
| 1 | Replacing Chillers Control System, each | 90,000 |
| 2 | Replacing Chillers Condenser Coils, each | 160,000 |
| 3 | Replacing Evaporator Shell and Tube, each | 80,000 |
| 4 | Replacing the Two (2) Compressors of each Chillers | 160,000 |
| Total (1-4) | Total Chiller's Rehabilitations, each | 490,000 |
| 5 | Replacing with New Chillers (Nominal 125TR) from International Manufacturers, each | 220,000 |
| 6 | Replacing with New Chillers (Nominal 125TR) from Local Manufacturers, each | 175,000 |

order to calculate the minimum total cost. The optimum insulation thickness was determined for seven insulation materials used in seven different wall configurations. By plotting the sum of the cost of insulation material, its installation and the present value of energy consumption (of air-conditioning equipment to remove the transmission load) over the lifetime of the building versus the insulation thickness, the optimum insulation thickness was determined at the point of minimum total cost. The discount and inflation rates as well as the performance parameters of the air-conditioning system were considered in the economic model.

Results under optimal conditions show that the yearly transmission loads and R-values are most affected by the type of insulation material used and least affected by the wall configuration.

For the values of the economic parameters used, molded polystyrene is found to be the most cost effective under optimum conditions with an optimum insulation thickness, averaged for all wall configurations, of 7.8 cm. The nominal R-value for walls with molded polystyrene under optimum insulation thickness is averaged at about 2.8 $m^2.k/W$ (Al-Ajlan *et al.*, 2006; Al-Sanea *et al.*, 2003). The corresponding thermal quantities averaged for all walls are calculated as follows: the yearly cooling and heating transmission loads are 13 and 5 $kWh/m^2.yr$ respectively, the yearly averaged time lag is 6.64 h, the yearly averaged decrement factor is 0.0132, and the peak cooling and heating transmission loads are 4.80 and 3.38 $W/m^2$ in August and January, respectively (Al-Sanea *et al.*, 2003).

It is proposed then to add molded polystyrene with the gypsum board on the internal side of the wall with an optimum thickness of 7.5 cm (Al-Ajlan *et al.*, 2006). As far as the glass windows and roof insulation is concerned, they have been insulated prior to this study.

### 7.2. AC system

The existing chillers have a life time of more than 20 years. The replacement of AC system was studied taking into consideration two options. First is partial replacement of AC system which includes the use of new efficient chillers and their controllers. Second is full replacement of AC system including pipes for water circuits, air handling units and controlled dampers. Table 5 shows these options including the cost needed for each one. It is clear that the cost of rehabilitation for each chiller (490,000 SR) is greater than the cost of its replacement (220,000 SR) and that based on the prices of international manufacturer. Hence, the replacement of chillers is selected in this study.

### 7.3. Lighting

Following are the various methods to adjust the lighting intensity in the rooms and to reduce electricity consumption for the building where one or more of the following methods can be implemented:

- Remove between 40 and 50% of the fluorescent tubes in each fixture, and measure the lighting intensity to be in the range of 400 to 500 Lux (Alex, 2000; Kasaboy, 1979). The tubes can be stored and used in future maintenance to replace the faulty tubes.
- Replace the opaque cover of the lighting fixture by a clear prismatic cover. The opaque cover reduces the lighting intensity by a factor of 15 to 25% depending on aging and frequency maintenance of cleaning. The estimated cost of clear cover depends on the quality and quantity of covers. It is advisable to purchase the total estimated quantity for all fixtures to be installed in all the rooms, which have high Lux. The replacement of the clear cover can be done for all the fixtures in steps to have a uniform look for all the rooms. After the replacement of the clear cover, a measurement of the Lux is made to adjust the lighting intensity.

**Table 6. Breakdown summary of energy saving and cost**

| | | | | |
|---|---|---|---|---|
| Building | | Annual Total Energy Cost (SR) for current Condition | | 2,951,700 |
| | | Annual Energy Cost for existing Chiller (SR) | | 1,481,892 |

| COST OF NEW INVESTMENT (SR) | | ENERGY SAVING COST (SR) / YEAR | | |
|---|---|---|---|---|
| Item | Total Cost (SR) | Item | Savings | %of Saving |
| Chiller (1000TR) | *1,400,000 | Cost of saved Energy of Chiller*** | 118,551 | 4 |
| Chiller Installation cost | * 600,000 | Cost of Maintenance of Existing Chiller | 240,000 | 8 |
| Glass film (m2) (Zero cost)** | 0 | Glass Insulation | 0 | 0 |
| Wall insulation (m2) | 703,170 | Wall isolation | 370,473 | .13 |
| Shading (m2), 11 Chillers | 4,200 | Shading of chiller | 29,638 | 1 |
| Lighting Fixture Clear Cover | 50,000 | Lighting Adjustment | 108,000 | 4 |
| Equipment for PQ of 10 Floors | 50,000 | PQ Equipment | 236,136 | 8 (13) |
| Total of new investment (SR) | 2,807,370 | Total Cost of Saving of Energy (SR) | 1,176,798 | 40% |

* Based on Local Manufacturer
** The Glass Insulation Film is already installed by the bank
***The difference in energy consumption is between the old and new chillers

**Table 7. Saving and pay-back period**

| | | |
|---|---|---|
| Pay-back period | Investment (*) (**) / Saving (Yr) | Months |
| | 2,807,370 / 1,176,798 = 2.39 | 29 |

*: The Investment cost includes the installation
**: The prices are subject to change (+,-) due to local and international market variations

- Rewiring of the fixtures to divide them into more controllable circuits by adding more control switches. This option needs the high cooperation of the user in that room, because without such cooperation, there will be no effect on reducing the lighting intensity.
- Install occupancy lighting sensors (motion sensors) to switch off the lighting in case there are no users in the rooms. This can be installed in meeting rooms and common zones.
- Install electronic dimmer switch to replace the existing normal switch, to adjust the lighting intensity, in the case of high ambient light during the day.

Note that the optimum options suitable for the adjustment of lighting intensity in the building are given in the above first two methods. The cost of these two methods is already considered in the investment and pay-back period in Table 6.

### 7.4. Power quality

The majority of the modern equipment in the building are known as non-linear equipment such as computers, printers, photocopying machines and adjustable speed drives. The non-linear equipments are characterized by the continuous voltage and current variations. These variations lead to more energy consumption in the equipment, increase the energy losses and increase the cooling load in the building. Many electrical types of equipment are available in the market to reduce the energy consumed in non-linear loads. From the measurement of power quality in each floor, it is found that the improvement of power quality will lead to an average of 8% in energy saving as shown in Table 6.

## 8. Analysis of Pay-back Period

The following options summarize the improvement methods for this study:

- To replace the chillers.
- To add insulation material to the exterior walls and insulation film to the exterior glass.
- To adjust the lighting intensity as per the recommended standards for office buildings (300–500 Lux).
- To adjust thermostat setting of A/C.
- To replace the faulty lighting fixtures by energy efficient lamps when conducting periodic maintenance.

The breakdown for the saving and cost are shown in Table 6. The table shows that the percentage saving from the annual total energy reaches high average values, such as 13% and 8% respectively for wall insulation and power quality improvement.

The pay-back period is linked to the number of modifications. If the suggested modifications are carried out, the pay-back period considering the saving after the modifications will be about 2 years and 5 months (29 months). Table 7 shows the pay-back period.

## 9. Conclusion

The energy audit is an effective tool to evaluate, analyze, diagnose the energy consumption of the building as well as help in proposing the solutions and modifications required and evaluating the pay-back period. This paper has analyzed the energy consumption in an office building and has proposed solutions and modifications which are believed to be very optimistic.

Based on the study findings, the pay-back period is very attractive for the implementations of the proposed modifications. The saving and pay-back period mentioned are subject to proper implementation of the suggested modifications and using appropriate materials, equipments, contractors and supervisions.

The prices mentioned in the pay-back period are based on the prices at the time of conducting the study. The actual prices are subject to variation at the time of the implementation of the recommendations.

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# تدفيق الطاقة والتوفـ ا مكن بـ مكتـ مدينة الرياض، ا ملكة العربية السعودية

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**كلمات ا فتا حية:** تدقيق الطاقة، توفير الطاقة، فترة الاسترجاع، مبنى مكتبي، الرياض.

**ملخص البحث.** استخدمت وسيلة تدقيق الطاقة في هذه الورقة كوسيلة فاعلة لتقويم ودراسة جوانب وصورة استخدام الطاقة في مبنى مكتبي في مدينة الرياض. لقد تم تحليل عدة مكونات وعناصر للمبنى، مثل مواصفات الجدران والأسقف والنوافذ، والإضاءة، وأجهزة المكاتب، وأجهزة التكييف والتبريد، بالإضافة إلى الوحدات الإضافية لأجهزة التكييف من النوع المنفصل، وجميع الأجهزة الأخرى المركبة في المبنى. لقد تبين من خلال هذه الدراسة أن نظام التكييف للمبنى يمثل ٥٠ ٪ من كامل الطاقة المركبة. إن القيام بتدقيق الطاقة قد ساعد على تشخيص حالة المبنى من ناحية استهلاكه للطاقة ومن ثم تحديد الحلول والتغيرات لزيادة كفاءة الطاقة في المبنى. إن الطاقة الممكن توفيرها وفترة استرجاع المبالغ المترتبة على تلك الحلول والتغييرات قد تم حسابها وتحليلها حيث تبين أن فترة استرجاع المبالغ المترتبة على تلك الحلول والتغييرات بعد تنفيذها تبلغ ٢٩ شهرًا فقط، وقد اقترحت الورقة عدد من التوصيات بناء على الحل والتغييرات المثالية.