IMPROVING OPERATIONAL STRATEGIES OF AN INSTITUTIONAL BUILDING IN KUWAIT

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ABSTRACT

The Building and Energy Technologies Department (BET) of the Kuwait Institute for Scientific Research has pledged to achieve 10% reduction in buildings energy consumption by the year 2005. Working in line with the Kuwaiti government that highly recognizes the national and international concerns to reduce global warming gases, BET formulated its 5-year strategic goal. Efforts were concentrated on buildings with partial occupancy, namely office buildings, where it was found that inefficient operation strategies were undertaken by building operators. Generally, office buildings were operated without taking the occupancy schedules into consideration. This actually created a great opportunity to reform common operation strategies and increase buildings energy efficiency, which is a step forward to achieve the set goal. This paper demonstrates the findings of a pilot study of an office/institutional building, located in Kuwait that targeted mainly reducing its energy consumption by modifying its operation strategies. The study focused on the major end user systems of the building main source of energy that is electricity, namely the air-conditioning, and lighting systems. It was estimated that for the base year, which was selected to be year 1999, the recommended operation strategies would save 21% of the annual energy consumption. The annual savings in electrical energy totaled over 2800 kWhr, which is equivalent to $18,400 (O&MS). Reflecting the savings on the national level and for buildings of similar type and occupancy pattern, it is estimated that the nation would save over $70 million due to the heavy government subsidy. In addition, the power plants emissions of CO_2 will be reduced by 749 millions kg.

Keywords: *Energy auditing, energy conservation and energy efficiency*

INTRODUCTION

Electricity in Kuwait has a single flat rate that is 2 fils/kWh (0.6 cents/kWh) for residential and office buildings. This rate has been fixed for the past 35 years (Kuwait, 1983). The rate is low since it is highly subsidized by the Government, while the actual cost reaches up to 15 fils/kWh (4.8 cents/kWh) depending on the price of oil barrel, the consumer only pays 2 fils/kWh (0.6 cents/kWh). The government subsidizes almost 85% of the electricity price in order to provide higher living standard for most of the local community. On the other hand, the weather in Kuwait is also very hot and dry. In fact the cooling degree days (CDD) to the base 20^{o}C (68^{o}F) are 2732.3, for a typical metrological year.

The cheap price of electrical unit and the very hot and dry climate formulated a special behavior with regards to energy consumption within buildings specifically in office buildings. The operation strategies are usually the same throughout the day, they differ only according to seasonal weather fluctuations between winter and summer months. This energy ignorant energy consumption behavior created a huge opportunity to save energy by reforming operation strategies of buildings and linking building energy utilization to the its working hours.

The Kuwait Institute for Scientific Research (KISR) building management has realized the importance of reforming the energy utilization behavior within office buildings. Starting with its main building, KISR's management aimed at increasing its energy efficiency. Thus, an energy audit was performed by the Building and Energy Technologies department (BET) of KISR.

BUILDING DESCRIPTION

The building comprises of private offices, partitioned offices, a library, an auditorium, a cafeteria, meeting rooms and labs. The building has a 23470 m^2 of air-conditioned area. A huge area of the building is dedicated to laboratory spaces. Almost 54% of the air-conditioned area is dedicated to the labs excluding the basement area. The building is a two-story building with a basement that includes emergency shelters, tunnels and enclosure of electrical cabling and connections. The architectural plans of the building are shown in Figures 1 and 2. The building incorporates a building automation system (BAS) that is utilized as an alarm-monitoring station (Mirza and Al-Ragom, 2001). Furthermore, it is used to monitor the air-conditioning system operation, mainly the inlet and outlet temperatures of the chillers and air-handling units (AHUs). The BAS is also used to monitor the fire alarm system.

To meet the building air-conditioning (A/C) requirements, the A/C system consists of 10 air-cooled chillers, each of 373 kW rated capacity. Two are on standby. The A/C system included 4 chilled water pumps to circulate the chilled water, one of which is a standby. The chilled water pumps require 75 kW each. The building was regularly utilizing three chilled water pumps all year round, as well as a minimum of one chiller during the winter season to a maximum of six chillers at the peak of the summer season (Maheshwari et. al., 2001).

The building lighting system mainly consists of fluorescent lamps. Other types of lamps were utilized including incandescent, parlamps and spotlights. In addition special task lights were utilized such as the emergency lights (Al-Nakib and Al-Ragom, 2001).

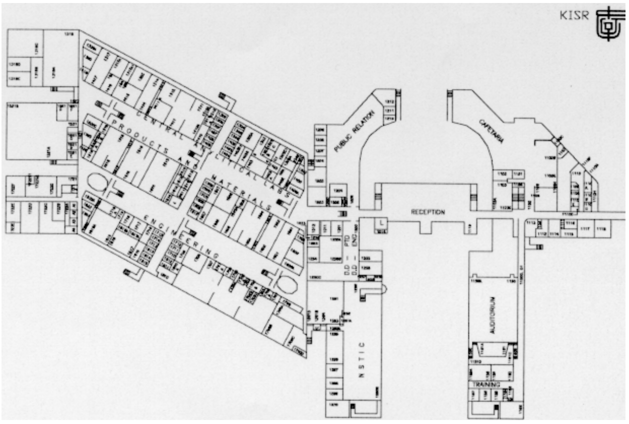

Fig. 1 Main facility architectural plan, ground floor

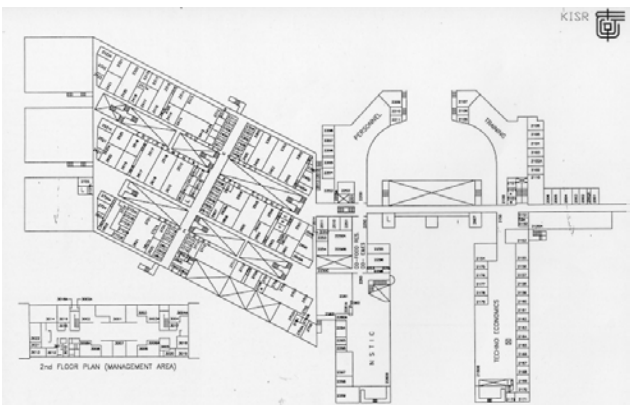

Fig. 2 Main facility architectural plan, first floor

APPROACH

The energy audit study of the building was on going for the period starting from March 2000 untill April 2001. During the study period all three levels of energy auditing were carried out. The focus of this paper will be limited to the first two levels of energy audits.

The building monthly energy consumption data were collected from the facilities management and services department, which is in charge of keeping the manually logged records of the building. The data for two consecutive years were used for the audit analysis namely for 1998 and 1999. The consumption data were corrected and correlated with the weather conditions for the same energy consumption logging periods, as it will be explained later in this section (Fig. 1).

In the first level of energy auditing, a walk-through was conducted to visually inspect the building and determine the areas of energy misuse and the building condition. The major energy end user systems were determined at this stage. Following the walk-through audit that covered 23,470 m^2, which is the building air-conditioned area. Following the first level of the audit, the standard audit was carried out. It involved a detailed survey to investigate the possible operation and maintenance strategies (O&MS) by inspecting the A/C and lighting systems equipment and their operation strategies. The third level of the audit involved developing a simplified simulation model utilizing DOE-2 building simulation program (Alghimlas, 2002).

The monthly consumption data collected were from the meter readings. The readings were not taken exactly on the same date of each month. This made the meter readings inconsistent. Thus the meter readings were corrected to reflect the consumption readings of the calendar month. To correct for the meter reading inconsistency, a daily average power consumption data were calculated. Then, the monthly consumption was determined by exploiting the daily average power consumption calculated from equation (1).

$$\text{Daily average power consumption (kWh/day)} = \frac{\text{Meter reading (kWh/month)}}{\text{Time period (days/month)}} \quad \ldots(1)$$

$$\text{Month}_i \text{ consumption (kWh/month)} = \text{DPC}_i \text{ (days/month)} \times \text{ND}_i \quad \ldots (2)$$

where,

Time period = number of days between two consecutive monthly meter readings

DPCi = daily average power consumption for a specific month i

ND_i = Number of days in Month_i

i = Specific month from January to December

Weather parameters, including the dry bulb temperature and the relative humidity, were also gathered. The data were monthly averaged to represent the weather characteristics for the same period of the meter readings.

BASE LINE ANALYSIS

Base load analysis is very essential in the verification of the savings attained by implementing energy conservation programs within buildings. In addition, base line analysis is very important for building management. Its importance resides in the fact that, once it is determined, it will provide building operation manger with a mean to check for any abnormalities in energy consumption.

The building base load that is the minimum constant amount of energy consumed in a building throughout the year was estimated using historical monthly power consumption data for two consecutive years (98-99). The data was plotted against the monthly averaged outside temperature as it's shown in Fig. 3. The historical data provided an indication regarding the major building energy consumers. Since the base load is the minimum load regularly consumed throughout the year. A horizontal line that coincides with the minimum consumption in Fig. 3 represents it.

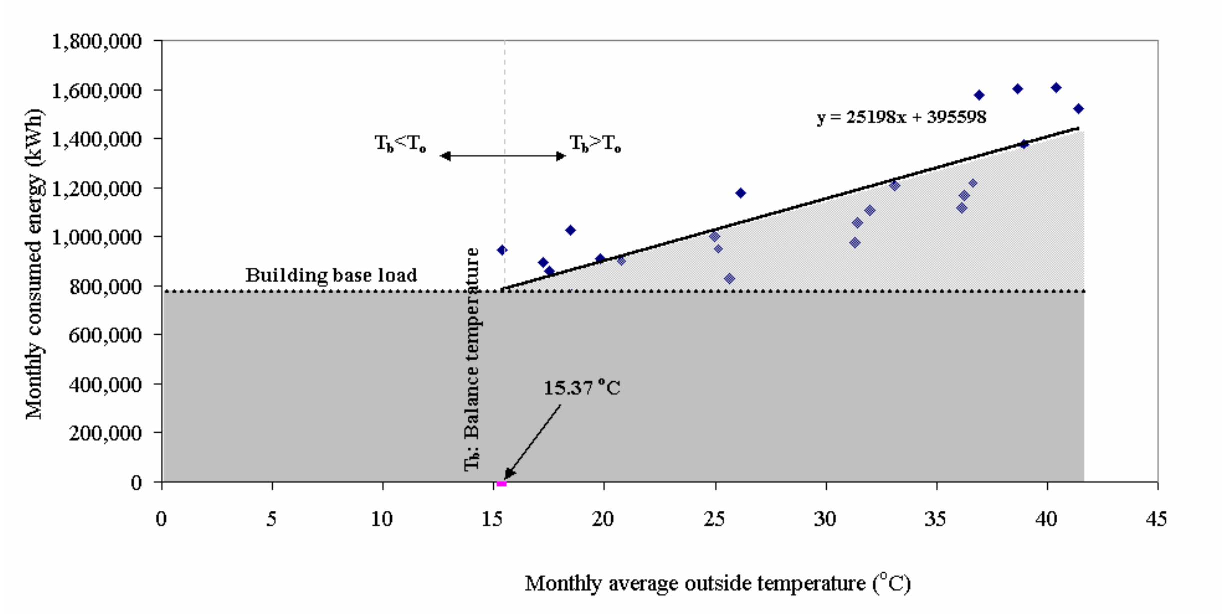

Fig.3 Main facility building base load

From the walk through audit, it was determined that, the major energy consumers are the A/C system, the lighting system and lab/office equipment. The base consumption of the building was found to be 800 MWh per month. This amount was being consumed regularly throughout the year, and it represented the minimum consumption of the winter months. By inspecting the building operation strategies and energy end users it was found that during winter season one chiller is always in operation as well as three chilled water pumps and the air handling units' fans and motors. In addition, the lighting system and office/lab equipment were utilizing the rest of the consumed power. This means that the base load of 800 MWh, actually represented not only the lighting system and office/lab equipment consumption but also the energy requirements for minimum air-conditioning required throughout the year.

Further analysis of the base load revealed more findings with regards to building energy consumption as shown in Fig.3. The area on the right side of the curve (i.e. the triangular area) represents the energy consumed by the air conditioning system in the summer season (seasonal energy consumption) that is weather dependant (Al-Ragom, 2001). The outside weather temperature and the monthly power consumption required for the building air-conditioning were correlated.

It is clearly shown that the maximum monthly-consumed energy in the summer months reached a value of 1600 MWh on July 1999, this consumption is double the base load. Out of this maximum consumption, the A/C system consumed 1155 MWh, which represented 72% of peak month total consumption.

The building balance temperature that is the outside temperature at which no cooling or heating is required for the building was found to be 15.37°C (58.67°F). In spite of that, the building operators were running one chiller throughout the year.

Another important analysis is baselining. Baselining, refers to the selection of a specific year on which the energy savings will be based. As it has been explained by Reddy T. et. al. (Reddy et. al., 1997), is crucial for determining progress toward a preset energy efficiency goals. In this study, the base line energy consumption was selected to be that of year 1999. The annual energy consumption for that year was 13,563MWh (Al-Ragom et. al., 2002).

ENERGY CONSUMPTION PROFILE

Since at least some energy consumption data are available for most existing buildings, a great deal of information can be obtained from an analysis of whatever data exist. The quantity and type of data available depend upon the type of metering that is installed in the building (Meckler, 1984). In KISR's main facility building, four substations were installed to provide the electrical requirements. The Ministry of Electricity and Water (MEW) has installed twelve energy consumption meters in the main facility building. The meters continuously display the building power consumption. The readings of the meters are collected manually every week and logged by FM&SD personnel to estimate the weekly and monthly power consumption.

The building power consumption for consecutive three years from 1998 to 2000 is plotted in Fig. 4, as well as few months of year 2001 (i.e. the end of study duration). The consumption was recorded and corrected as it was explained in the methodology section. The corrected data

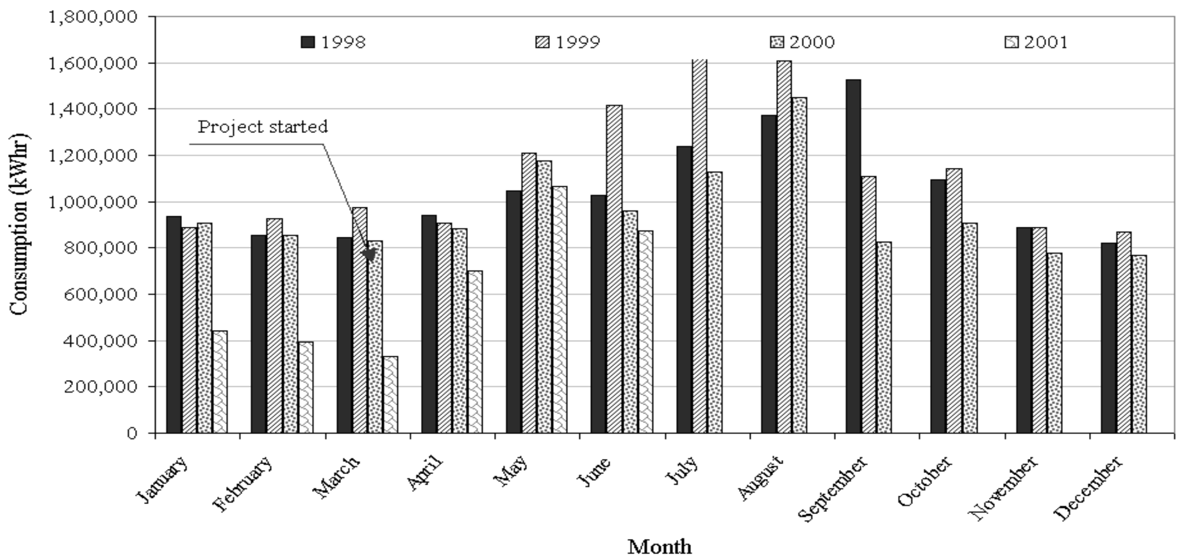

Fig. 4 Corrected KISR's main facility building power consumption

for years 1998 till 2000 that are shown in Fig. 4 describe the consumption pattern for the past three years.

The minimum consumption was just over 800 MWh for 1998 and 1999. The consumption of 1999 in general was more than that of 1998. This is linked greatly to the higher outside temperature (refer to Fig. 5). Although the outside temperature in 1998 was one degree higher than that of 1999, there is a large increase in the power consumption in September 1998 as compared to that in 1999. This is attributed to a poor building operation strategy. In general the building electricity intensity, which is the annual consumed electricity normalized against building air-conditioned area was found to be 533 kWh/m^2. Since no available national or regional benchmarks for buildings electricity consumption were available, the building electricity intensity was compared to that defined by the Chartered Institution of Buildings Services Engineers (CIBSE). It was found that the building intensity is very high as compared to good practice benchmark intensity of 234 kWh/m^2 for prestigious air-conditioned office buildings specified of the CIBCE (CIBSE, 1998).

MODIFICATIONS OF BUILDING OPERATION STRATEGIES

The base load analysis and the historical annual energy consumption profiles indicated that building electricity consumption was enormous, and that inefficient operation strategies were utilized particularly for the air-conditioning system. Opportunities of efficient building operation were investigated. After that several operation strategies were recommended out of which some were adapted and implemented by the facility operators. The recommended operation strategies are listed in tables 1 and 2. The details of the recommended operation strategies of the lighting and air-conditioning systems are discussed separately in the following sections:

Lighting System

The building architectural design permits the utilization of daylight through skylights and large efficient glazing areas. In spite of that, the light system is utilized primarily to provide the required luminosity. The main reason behind this misuse of the lighting system is the design of the lighting control switches. Each switch controls multi fixtures of different task areas. For example, in the library, the reading desks area which is located near the windows have the lights on all the time as the switch for this area controls the lights of the reception area which is located further away from the glazed surface. Similar situations occurred at other areas within the building. In view of this, delamping strategy was investigated, and implemented in several areas of the building. The luminosity level was measured after implementing this strategy and it was found that it matches the recommended levels by MEW (Al-Nakib and Al-Ragom, 2001).

Another strategy was recommended which involved modifications to lighting utilization periods. After conducting night-time light luminosity measurements, it was found that the luminosity exceeded the recommended values. For example, the MEW standard recommends a value of 5 lux for corridors during night-time while the measured was 62 lux. In view of this it was recommended to switch on only 20% of the lights in the main entrance area to maintain the recommended lux level and achieve energy savings.

During the walk through audit, it was noticed that some employees were using side lamps to provide adequate light level in their offices. They've opted to switch off the fixed florescent lights and use the incandescent side lamps. Moreover, some employees that have access to daylight, did not utilize it, instead artificial lighting was used. All these inefficient practices were adapted to avoid the light reflection and glare on the computer monitor that was due to improper office

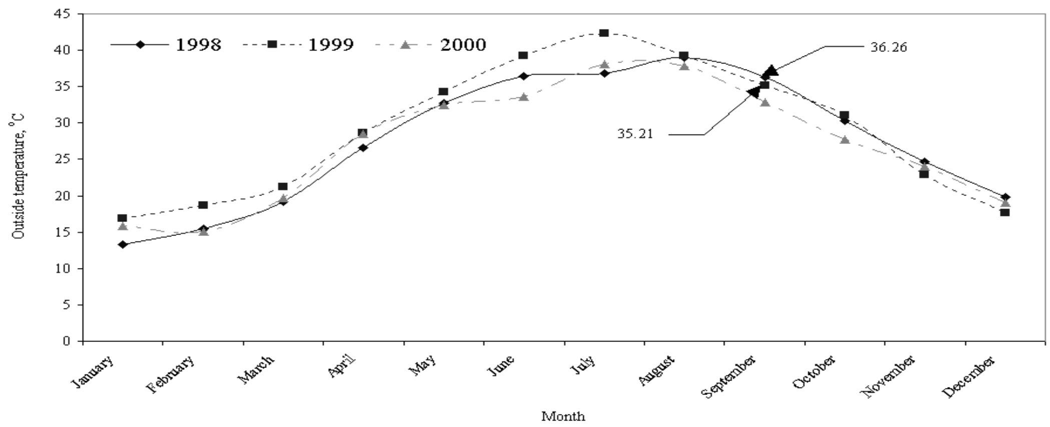

Fig. 5. Outside temperature profile 1998-2000

furniture arrangement. For that reason a survey was prepared and distributed to the employees. The survey aimed at determining the utilization habits of the building employees and their requirements. The results of the survey indicated that out of 263 employees that are located in the building, 113 have access to natural daylight in their offices. Out of the 113 employees, only 8 utilize natural light. In addition, 94 employees have side lamps in their offices. The estimated annual consumption of the side lamps assuming an average lamp rating of 60W and that they are used 5 days a week for 7.5 hours per day will be 11 MWh/year. To change the employees habits with regards to utilization of lighting system, the third strategy was recommended. This strategy suggested rearranging the office furniture in accordance with the light angle. This would motivate the employees to utilize day lighting and prevent them from using side lamps that will further reduce the consumption.

Strategy	Notes	Savings MWh/year
1. Delamping	Cafeteria, corridors, workshops, labs and offices	144
2. Modifications to lighting utilization schedules (during non-working hours)	*Working hours* 23% turned off *Non-working hours* 50-70% turned off	55
3. Reorganization of office furniture	Eliminate the need to utilize side lamps and promote the use of daylight	11

Table 1. Recommended operation strategies for the lighting system

AIR-CONDITIONING SYSTEM

The building air-conditioning system was operating almost under a fixed strategy. Six chillers are utilized during the peak summer (i.e. July through August) and a minimum of one chiller is always in operation during throughout the year as well as the three chilled water pumps. The indoor temperature of the building is usually maintained at 18-22^{o}C. The occupants mostly complain from the over cooled working environment. A detailed study for the chilled water distribution system and the air-conditioning system revealed that the air-conditioning system is oversized (Maheshwari et. el., 2001). Moreover, it was found that the chilled water could be circulated with only one pump.

This over sizing was intentional as it was assumed that there would be future expansion of the building, which did not take place. Moreover, the operation of the A/C system had a huge opportunity for energy consumption savings. The two chilled water pumps were not needed for the year round operation. For that reason it was logical to recommend closing them all year round. This strategy contributed greatly to the savings.

The daily operation of the A/C system was found to be fixed within the season. The A/C system was running continuously throughout occupancy and non-occupancy periods even during weekends and holidays. In view of this, different operation schedules are recommended for the A/C systems components. The supply air (SA) fans and return air (RA) fans that were continuously running, are going to have a certain operation schedules that are weather and occupancy dependant as shown in Table 2. In addition, the corridors are usually very cold; their temperature was maintained at 18-19^{o}C during occupancy period that dropped down to 11-12^{o}C at night. To overcome this uncomfortable situation, the closure of the corridors supply and return air fans was recommended during non-occupancy period through out the year.

The operation strategies for the A/C system included an assertive operation strategy that is recommended for winter season. In this strategy, the closure of the chiller and the chilled water pump throughout the season as well as the closure of SA and RA fans for all AHUs during non-occupancy period is recommended. Basically only free cooling is utilized during the winter season, by supplying 100% fresh air to the building during working hours.

Strategy	Implementation schedule	Savings MWh/year
1. Closure of third chilled water pump	Year round (168 h/week)	822.5
2. Closure of SA and RA fans of corridors AHUs during non-occupancy period	Year round (128 h/week)	404.2
3. Closure of second chilled water pump	Year round (168 h/week)	822.5
4. Closure of RA fans of all AHUs during occupancy period	Winter and mild season (30 weeks – 168h/week)	598.5
5. Closure of chiller and pump	Winter (9 weeks – 168h/Week)	347.8
6. Closure of SA fans of corridors AHUs during occupancy period	Winter (9 weeks – 168h/Week)	11.9
7. Closure of SA and RA fans of all AHUs during non-occupancy period	Winter, SA (9 weeks – 128h/week) Summer, RA (22 weeks-128 h/week)	494.9

Note: RA (return air), SA (supply air), AHUs (air handling units)

Table 2. Recommended operation strategies for the air-conditioning system

ESTIMATED SAVINGS

Since, the aim for the energy audit is to reduce the energy consumption. For that purpose, the recommended operation strategies energy savings were determined. The savings are listed in Tables 1 and 2. The estimated savings that can be achieved when implementing the recommended strategies for the lighting system would be 210 MWh/year. Out of which, 144 MWh/year was estimated for delamping only.

Additional savings are estimated when energy efficient operation schedules are utilized while adhering to the recommended luminosity levels during nighttime. This strategy would save up to 55 MWh/year.

Since energy auditing aims also at increasing the building energy efficiency, recommended procedures should not affect the occupants comfort. Actually, increasing comfort level whether thermal or visual is considered one of the targets for energy auditing. From this view point, the third recommended strategy aimed firstly at lowering the electrical consumption by diverting the occupants from using side lamps and encouraging them to use natural daylight. Keeping in mind that rearranging the office furniture was suggested to eliminate the glare on computer screens. Furthermore, this strategy would improve the working environment thus achieving additional benefit that is increased productivity.

In view of the A/C system, the savings that can be realized from adapting the recommended operation strategies for the A/C are substantial. The overdesign of the A/C system and the energy ignorant operation of the system by the building operators amplified the opportunity for energy savings. The total estimated savings that can be achieved by improving the operation of A/C system are 3502 MWh/year this represents 26% of the annual consumed energy by the building.

The major savings were achieved by switching off the chilled water pumps. The achieved savings by the closure of the two pumps represented 47% of the total achieved savings by modifying operation strategies for the A/C system. The modifications of the winter and mid season operation of the A/C system estimated savings are 42% of the total saved by implementing the A/C system O&MS. In addition the estimated savings that can be achieved by adapting energy conscious operation strategy during non-occupancy period are 26%.

The total achieved savings estimated for the implementation of the O&MS system when reflected on the base year consumption represented 20% and 1.09% for the HVAC and the lighting systems respectively. These savings when compared to those of the A/C system are considered trivial. But any savings that can be achieved; especially when they're free will be beneficial from environmental perspective if not from monitory one.

ENERGY AUDITING NATIONAL BENEFITS

Though the energy audit discussed in this paper was actually conducted on one office building, the savings were reflected on 800 (Almudhaf and Al-Ragom, 1999) similar buildings to estimate the national benefits, if similar practices were adapted throughout the country.

The savings were estimated based on the total cost of electricity, which is 0.015KD/kWh (0.05$/kWh) not the subsidized cost of 0.002KD/kWh (0.006$/kWh). In addition, a conservative figure of 15% savings of the buildings annual consumption achieved by modifications of their O&MS is assumed. The predicted annual savings for 800 buildings are 22 million KD (70 million $). From another perspective, the foreseen electricity savings will reduce the power plant emissions by 749 million kg of CO_2. The CO_2 emissions are estimated using a conversion factor of 0.52 kg CO_2/kWh for electricity production at

1997 figure (CIBSE, 1998) as there is no available data regarding the national fuel mix.

CONCLUSIONS

Considerable savings can be achieved by simply modifying the operation strategies of the building systems. At least 15% savings can be promised when adapting energy conscious operation strategies. In Kuwait, in spite of the fact that buildings are designed efficiently with respect to the building envelope, the building operation is habitually energy ignorant. This behavior is generally associated with the enforcement of energy conservation code by MEW (MEW, 1983) that controls the peak load requirements but not the consumption of the buildings. Another factor that is seriously contributing to the overuse of electricity is the government subsidy of electricity prices. The government covers over 85% of the total price.

The energy audit procedure followed in this study focused only on the operation of the building. Thus achieved savings are costless. The total savings achieved represented 21% of the total annually consumed energy. In view of the base load, implementation of the recommended O&MS will drop it by 10% and 65% during peak summer and winter respectively. The modified building operation not only will reduce the energy consumption but it will also enhance the indoor environment thus the employees productivity is expected to improve.

This paper anticipated the national benefits that can be realized when all office buildings operation strategies are modified and turned into energy conscious O&MS. The realized monitory savings would be 22 million KD (70 million $). Moreover, emissions by the power plants will be reduced by 749 million kg of CO_2. The foreseen benefits of energy auditing on the national level, outweighs those on the individual level. In view of that, it is recommended that the government should adapt an energy efficient building operation campaign especially for the governmental buildings.

This study utilized energy index defined by CIBSE benchmarks as a guideline for best practice for comparison purposes, as national indices are not available. Therefore, is recommended to establish such indices on national and regional levels. Moreover, although half of the building air-conditioned area is dedicated to labs, energy savings opportunities from lab ventilation were not studied in details and its recommended to be investigated in future audits as the project team faced some difficulties with building operators and labs management to change labs operational conditions.

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