ENERGY AUDIT IN THE KACST BUILDING

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Abstract

A six storey office administration building of KACST was selected to conduct an energy audit. This new building is in use since 1996 and having well-insulated walls and roofs and different types of lighting lamps. Building air conditioning system is comprised of three air cooled reciprocating chillers, three pumps and four air handling units (AHUs). This paper presents measured values of actual electrical energy consumed by individual chillers, AHUs, different lighting systems, office equipment and other associated electric appliances used in the building. The results show that daily air conditioning load comprises 75% of the building load during peak summer period. Whereas the other major measured loads are 11.2% and 10% for interior lights and office equipment respectively. Nevertheless, the uses of programmable thermostat and ice thermal storage are suggested to be incorporated in the building for energy and power savings.

1. Introduction

In the last two decades, electrical energy consumption in the Kingdom of Saudi Arabia has increased rapidly. This is mainly due to the rapid development and heavily subsidy of electricity costs (tariff ranges between 5 to 20 Halalas/kWh) [1]. This requires a huge investment either for building new power plants or upgrading the existing electric power systems. The electric utilities in the Kingdom face problems of peaking hours. The demand is very high during summer, mainly due to air conditioning consumption, lack of thermal insulation usage in most of the buildings as well as the implementing of the proper methods of energy conservation and the appropriate techniques for load management [2]. As a result, energy conservation became an important target for the Kingdom. Several efforts have been accomplished, however, they are not at the expectation and not more than 3-4 % at the country level has been achieved [3]. One of the essential goals of the Ministry of Industry and Electricity (MIE) is the reduction of peak load by 20% (at least) during summer as well as reducing energy consumption by 30% [3]. Therefore, the MIE started advising the customers to reduce their loads by supplying the energy conservation methods and techniques. At the same time electric utilities guide the customers and follow-up their efforts to achieve the established goals.

First step towards achieving the MIE goals for energy conservation and peak load reduction, is to conduct an energy audit in a building and find out the areas for energy and power savings. To the best of the knowledge of the authors, measured experimental values of actual electrical energy consumption by individual equipment: chillers; air handling units; different lighting systems; office equipment and other associated electric appliances in an office building are not complete in the literature. This paper presents an energy audit in a newly constructed multi-storey Saudi office building and also identifies the areas for energy and power savings therein.

2. Building Design and Orientation

The King Abdulaziz City for Science and Technology (KACST) based in Riyadh are having a number of multi-storey office buildings. A six-storey office administration, building-26 of KACST, is being selected for conducting the energy audit and to propose energy conservation therein. The building represents a typical example of a Saudi office building. The building is rectangular in shape and longitudinally oriented in east-west axes, and all around exposed to solar radiation. The exterior of the building is composed of tented-double glazed windows (46% of the total area) and the remaining are of composite metallic walls. Total floor area of the building is equivalent to 7384 m^2. Normally, the building is occupied from 0730hrs to 1530hrs five days a week (Sat-Wed) and the number of occupants exceeds 150. Some personnel remain in the building up to 2200hrs.

3. Electrical Power Supply to the Building

Electricity to the building is supplied through three transformers. Each transformer has an energy meter. Out of these three, one transformer supplies power to all three chillers. The power and energy profiles of this transformer were monitored by an electric load analyser. The sequence of equipment operation and other details are given in the following sections.

3.1 Non Air Conditioning Equipment in the Building

An inventory of office equipment, internal/external lights and other electrical appliances in the building has been made. It has been observed that the operating time of each equipment vary randomly. Total 2072 lighting fixtures of different individual rated power are used in the building. The total accumulated rated power is equivalent to 131.5 kW.

3.2 Air Conditioning Equipment in the Building

The cooling load of the building is supplied by three 30GB-150 Flotronic II, Air Cooled Reciprocating Chillers. The capacity of each chiller is 527 kW (cooling). These chillers are situated 80 meters away from the main building. Two chilled water pumps are used to pump chilled water from chillers to the air handling units (AHUs), situated at the roof level (sixth floor) of the building. The chilled water is pumped from chiller plant to the HVAC plant rooms in the building through 350 meter pre-insulated steel piping. All the three chillers are used to supply the peak cooling demand during the peak hours of summer season. The HVAC system is a variable air volume system. There are four AHUs serving the building. Each AHU supplies air at a constant temperature and a variable volume to the Variable Air Volume (VAV) terminal units, located in the ceiling voids of the office areas. Each VAV unit (or units) is controlled by a wall mounted thermostat. While the AHUs are controlled by the Building Automation System (BAS) and the VAV/CAV(control air volume) units are controlled by room thermostat. Control of comfort conditions inside the building is achieved through the use of the on-off room thermostats, which can be set at a desired temperature by the user's.

4. Electrical Power Measurement

As described earlier, three transformers supply electrical power to the building. Two transformer out of three, supply power to all the electrical load except chillers. The following section present methodology for measurement and results obtained from these measurements

4.1 Measurement Methodology, Results and Discussion

The electrical equipment in the building, such as computers, air handling units, etc., have various rating power and different function as well as different operational time. It has been observed from monitoring the building that all equipment are being used for different period of time. For example, the daily average operating time of each personal computer is 12 hours. Operational time of other equipment have also been estimated.

As described earlier, two transformers supplying electric power to all the equipment located in the building, and each transformer has an energy meter. Energy meter readings from these transformers have been recorded on hourly basis. The electric load of supply air fan (SAF), return air fan (RAF), and exterior lights were measured through load analysers. The remaining load, such as office equipment, lighting, miscellaneous load (for instance, electric cookers, hand dryers, electric water heaters), etc. of the building is estimated through two methods. The first method is an estimation on the basis of the equipment rated power and operational time duration. Table. 1 presents a list of all electrical equipment used in the building and their rated power. The table shows the total installed power equivalent to 680 kW. The second method is a determination procedure by calculating the difference obtained from the summation of the measured energy consumption of SAF, RAF, and exterior lights from the total energy meter reading. The illuminious measuremenin different area of the building was also conducted using LUX meter.

Instantaneous measurements of power drawn by the motors of the compressors, the pumps and the fans were made using power transducers as well as electric load analyser. Different measurements of these supply and return chilled water temperature, power, ambient temperature and relative humidity were recorded periodically using a data logger. Data were sampled every 15 minutes. Those information were off-loaded to a personal computer for analysis.

Table 1. List of electrical equipment used in the KACST's building

Equipment	Quantity	Total Rated Power (kW)

Chillers	3	103.5
Condenser fans	36	55.8
Distributions pumps	3	20.94
Supply fans	4	58
Return fans	4	32
Office equipment	324	114
Interior lighting	2072	124
External Lights	150	7.5
Exhaust fans	2	0.7
Power for Communication	1	0.5
Humidifiers	4	9.9
Electric Cookers	12	24
Hand Dryers	12	25
Electric Water Heaters	12	66
Lifts	3	37

Table 2. shows the quantities and their rated power of all types of office equipment in the building. This table also reveals accumulated rated power of different equipment equivalent to 114 kW. It has been also found that the operational period of all equipment is dependent on the occupancy level. The total daily energy consumption by office equipment is found to be equivalent to 770 kWh.

The daily average energy consumption by different non-air conditioning equipment is worked out according to the occupancy level as shown in Table. 3. This table shows that office equipment and interior lighting consume 40% and 45% respectively of the total non-air conditioning load. The table also shows that daily non-air conditioning energy consumption in the building is around 1263 kWh during 100% occupancy level. Similarly, the power profiles of chillers, SAF, RAF, pumps are obtained on regular interval. The results of those measurements are summarised in Table. 4, categorised according to the occupancy level.

Table 2. Quantity and rated power of office equipment used in the KACST's building

Equipment	Total Quantity	Rated Power (kW)	Daily Energy Consumption (kWh)
Personal Computer	108	20.7	248
Printers	61	21.6	151
Photocopy	29	41.3	248
Miscellaneous (a)	69	3.5	7
Miscellaneous (b)	20	8	8
Miscellaneous (c)	14	5	10
Miscellaneous (d)	23	14	98

(a): Typewriter, calculator and paper cutter; (b): Fax machine; (c): TV, VCR, Overhead projector;
(d): Water cooler, refrigerator, coffee machine, vacuum cleaner.
Note: All similar equipment have different power rating

Table 3. Average daily non-air conditioning energy consumption (kWh) in KACST's building

Time period (hours)	Occupancy Level (%)	Office Equipment	Interior Light	External Light [a]	Exhaust Fans	Telcom-munica tion	Miscellan -eous [b]	Total (kWh)
00:00 to 07:00	0	169.5	31.7	45	4.9	3.5	1.92	256.5
07:00 to 15:30	100	416.5	739.5	0	5.95	4.25	97.26	1263.5
15:30 to 00:00	15	184	118	45	5.95	4.25	73.99	431.2
Total Energy (kWh) % age Contribution		770 39.58	883 45.33	90 4.62	16.8 0.86	12 0.61	173.17 8.90	1944.9 100

[a] Operational Time from 18:00 to 06:00 [b] Miscellaneous : Electric cookers, Hand dryers, Electric water heaters and lifts

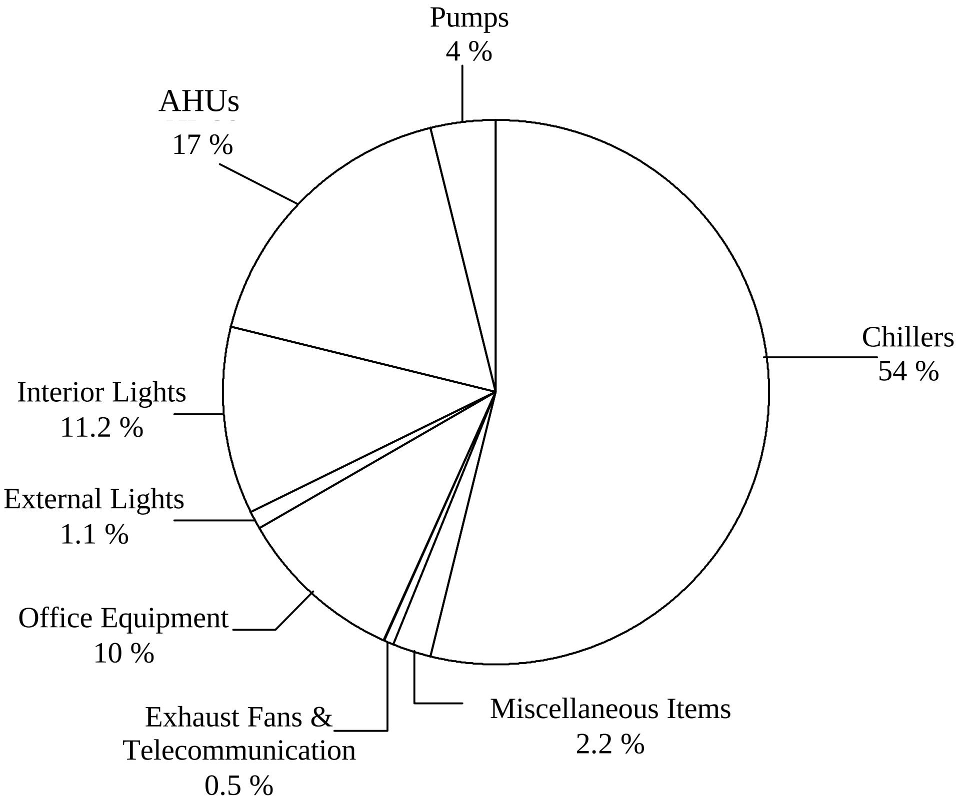

Figure 1. Total daily electrical energy consumption (kWh) in the KACST's building

Table. 4. Daily Energy Consumption (kWh) for facilitating Air Conditioning in KACST's building

Time Period (hrs)	Chillers & Fans	Pumps	Supply Air Fan	Return Air Fan
00:00-07:00	137	92	12	6
07:00-15:30	2431	112	494	272
15:30-00:00	1657	112	357	197
Total	4225	316	863	475

It has been found that total daily energy consumption in the building-is equivalent to 5879 kWh and 1946 kWh by air conditioning and non air conditioning equipment respectively. Figure. 1 shows that 75% of energy is consumed by the air conditioning equipment and the rest is used by the interior lights, office equipment, etc. Within the air conditioning system 72% consumed by chillers, 22.5% by AHUs and 5.5% consumed by pumps. Summation of all electrical energy measurements consumed by different equipment in the building revealed that the total monthly energy consumption is equivalent to 228,459 kWh.

An area-wise survey of LUX level was conducted at ten different locations on each floor. Table. 5. shows average LUX level in different areas of the building. It has been found that 11.2% of total daily energy is consumed just for energising interior lights. This can be reduced by using timers and occupancy sensors especially in offices.

Table. 5. Average Illuminance levels in different areas of the KACST's building

Area	Measured LUX Level	Recommended LUX values *
Offices (north side)	658	500
Offices (south side)	620	500
Partitioned Offices	448	
Corridors / passages	145	100/150
Mosque	400	
Lift lobby	62	100/150

* Manual of LUX meter from RS Components Limited

5. Suggestions for Energy and Power Savings

Salient climatic feature of Saudi Arabia is the long summer period of 7 months with an average daytime ambient temperature ranging from 42°C to 48°C. Cooling of buildings is therefore essential, requiring large demand of electrical power/energy (see Fig. 1). Following are the some of the proposals to be considered for energy and power saving in an office building.

5.1 Use of Programmable Thermostat

Most of the office buildings in the Kingdom are occupied for part of the day. The A/C system in these buildings, however, continue to operate at the set conditions throughout the day, for all days of the week. It has been observed in the building-under investigation, that chillers and AHUs were running even after occupied time schedule on working days as well as on non-working days. The operation of A/C system was continued till the outside air temperature reduces to 38°C. These preliminary results reveal, that the existing operation of HVAC in the building consuming enormous amount of electrical energy for running chillers as well as AHUs after office hours on working days even on non-working days. One of the way to conserve electrical energy in the building, is to change the sequence of operation of AHUs as per actual cooling requirement of each zone after office hours on working and non-working days. Programmable thermostats, have the facility to set desired room temperatures for different periods of the day and for different days of the week. They are the excellent device to save energy in the building with part-of-day occupancy. However, it has an adverse effect on the peak cooling demand as a result of the thermal energy stored in the thermal mass of the building. The increase in peak cooling demand results in an increase in the air conditioning system capacity and the demand on power supply. The problem is more critical on the first day (Saturday) after the weekend. Pre-cooling the building few hours prior to its occupancy schedule can minimise this negative impact. A comprehensive study is required to find out the precooling period of the building with different temperature offset in order to save energy and reduce the day-time cooling demand.

5.2 Use of Single Water Pump

At present, two chilled water pumps were always in operation irrespective of the number of chillers in use. During the non-occupancy period of the building in summer time and during the months of

November to March, the building cooling demand can be comfortable met by a single chiller. Under such operating conditions, the water flow rate of 600gpm was higher than the design value, resulting in a temperature drop of less than 3°C across the chiller. Use of single water pump with higher chilled water temperature setting to 7°C was found satisfactory after conducting an experiment. Operation of the system with one chilled water pump can reduced the motor power around 7 kW. There are other additional advantages such as reduction in pumping heat and improved chiller performance due to the increased temperature of leaving chilled water.

5.3 Ice Thermal Storage

It has been observed that if cooling is generated and stored during low demand night-time (off-peak period) for later dayt(on-peak period) use, more peak capacity would be available for other uses, and night-time capacity of the power plant would be more fully used. By this way the on-peak energy consumption will be shifted to off-peak periods. Hasnain [4] explained that installation of off-peak ice based air conditioning system in new Saudi office buildings will reduced peak electric load by 20% and peak cooling load by 30%. As peak electrical load of a building is reduced by 20% with storage, therefore there will be savings on: new power connection charges; costs of reduced size of transformer & switchgear.

6. Concluding Remarks

This paper presents measured values of actual electrical energy, consumed by individual chillers, air handling units, different lighting systems, office equipment and other associated electric appliances used in the multi-storey KACST's administration building-26. The building represents a typical Saudi office building. It has been found that 75% of energy is consumed by the air conditioning equipment, 11.2% by the interior lights, 10% by office equipment, etc. in this building. Within the air conditioning system 72% consumed by chillers, 22.5% by AHUs and 5.5% consumed by pumps.

This paper also identified areas for energy and power savings in an office building in order to achieve the MIE goals for energy conservation and peak load reduction. Methodology for use of programmable thermostats and use of single water pump in an existing building can be adopted for energy conservation. Whereas, incorporation of ice thermal storage system with the conventional central air conditioning system is found to be, one of the power saving tools, particularly in new installations.

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