AN INNOVATIVE APPROACH TOWARDS NATIONAL PEAK LOAD MANAGEMENT

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ABSTRACT

An innovative approach was developed and implemented in eight governmental buildings to reduce their load during the peak demand hours in summer of 2007. The innovative approach implemented in these buildings included pre-closing treatment (PCT) between 13:00 and 14:00 h and time-of-day control (TDC) after 14:00 h for air-conditioning (A/C) and lighting systems. PCT realized an overall reduction of 3.43 MW, a saving of 11.7% of the buildings peak power demand; while TDC realized a total savings of 8.67 MW at 15:00 h, a saving of 30.7% of the buildings peak power demand at that hour. The temperature build up inside the buildings due to PCT and TDC was within the acceptable range, which validated the technical viability of these measures.

The implementation of the innovative approach in the eight governmental buildings with a total measured peak demand of 29.3 MW achieved a reduction of 8.89 MW. This power is now available to other users leading to financial savings of $13.5 million for the nation towards the cost of constructing new power plants and distribution network equipment. More importantly, this reduction in peak power demand of well over 30% involved zero or limited expenditure. A nationwide implementation of this innovative approach in all the governmental and institutional buildings is likely to reduce the national peak power demand by 154 MW which amounts to a capital savings of $232 million towards the cost of new power generation equipment and distribution network.

Key words: Peak load, air-conditioning, time-of-day control, pre-closing treatment.

INTRODUCTION

In Kuwait, fast economic growth and rapid urbanization over the past few decades have resulted in ever increasing demand for electricity, which is well over 6% presently. During the past seven years, the power demand grew from 6750 MW in 2001 to 9075 MW in 2007 (MEW, 2002-2008). The power demand during the summer season apparently controlled by the demand for air-conditioning (A/C) equipment accounts for over 70% of total peak load (Al-Marafie et. al, 1989). For a typical summer day, the peak demand is mostly at 15:00 h while its lowest value is at 06:00 h as shown in Fig. 1. Also the average power increase between 13:00 and 15:00 h is 4% and the increase in power demand is almost equally split between 13:00-14:00 h and 14:00-15:00 h.

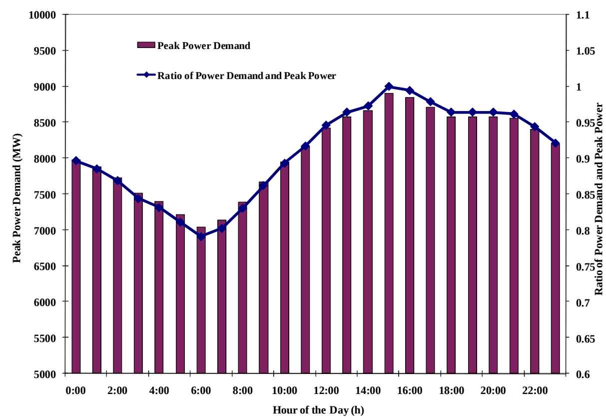

Figure 1. Peak power demand profile for a typical summer day in Kuwait

A common practice in Kuwait is to operate A/C systems with a fixed comfort temperature and continuous operation of various cooling distribution systems such as pumps and fans, in spite of the fact that most of the governmental and institutional buildings operate between 07:00 and 14:00 h, five days a week. Although, the operation of the lighting system is controlled to some extent either manually or through the Building Automation System (BAS). Operation of the A/C system in relation to the building occupancy, termed as Time-of-Day Control (TDC) is an excellent option to save a large amount of energy without adversely affecting the quality of comfort during the occupancy period. Likewise, availing the stored cooling in the building's thermal mass, satisfactory comfort conditions may be maintained between 13:00 and 14:00 h with less than required cooling production. This scheme defined as Pre-Closing Treatment (PCT), if applied in such buildings by limiting the cooling production at 13:00 h can help to achieve a 2% reduction in power demand between 13:00 and 14:00 h. Since Kuwait has many buildings with very high peak power demand, PCT followed by TDC for A/C and lighting equipment can be effective tools to reduce national peak power demand by 4%. These two schemes could freeze the national peak power at the level of 13:00 h. However, these measures have to be implemented with utmost care to provide thermal and visual comfort and to ensure that the temperature rise is acceptable during the PCT period and optimum pre-cooling is provided to compensate for thermal build up during the TDC period.

Implementation of TDC along with PCT was found to be very effective in reducing the peak power demand in governmental buildings (Al-Ragom, et-al, 2005). Accordingly, eight governmental and institutional buildings were selected to implement PCT and TDC measures during the summer of 2007. These buildings are Ministries Complex (MC), Justice Palace Complex (JPC), Liberation Tower Complex (LTC), Public Institution for Social Security (PIFFS), Ministry of Health (MOH), Kuwait Chamber of Commerce and Industry (KCCI), State Audit Bureau (SAB) and Public Authority of Youth and Sports (PAYS). This paper presents the findings of implementing this innovative approach in these buildings. The peak load in these buildings ranged between 0.93 to 12.0 MW and their total measured peak load was 29.3 MW.

BUILDINGS DESCRIPTION

Eight government and institutional buildings with a total air-conditioned area of approximately 439,400 m^2 were selected to implement the innovative approach for A/C and lighting systems. The important features of each building are summarized in Table 1.

DESCRIPTION OF AIR-CONDITIONING, LIGHTING AND BUILDING AUTOMATION SYSTEMS

Air-conditioning and lighting systems are the major power users in these buildings like in any other building in Kuwait. Also, there are miscellaneous other users. However, the present study has been confined to A/C and lighting systems.

Air-Conditioning system

All eight buildings have a central A/C system that comprises chillers, cooling production and distribution auxiliaries (CPADA), and air distribution system. Chillers are either with air-cooled (AC) or water-cooled (WC) condensers. The performance controlling parameter of the AC and WC chillers are ambient dry-bulb temperature (DBT) and the wet-bulb temperature (WBT), respectively. Due to the dry nature of the Kuwaiti weather, WC chillers are expected to perform more efficiently than AC chillers (Maheshwari and Mulla Ali, 2004). All buildings have WC chillers except the KCCI and PAYS buildings which utilize AC chillers. The total cooling capacity of chillers in all the buildings is 18,817 RT and their connected load is 16,617 kW as illustrated in Table 2.

Table 1. Summary of Important Building Features

Building	Year	Area (m^2)	Glazing type	Construction type
MC	1981	150,000	Single plain	Roofs and walls not insulated
JPC	1985	80,000	Single plain	
LTC	1993	21,000	Double plain	Roofs and walls insulated
PIFSS	2005	58,000	Double reflective with thermal breaks	
MOH	1988	29,000	Single plain	
KCCI	1999	36,400	Double tinted	
SAB	2007	40,000	Double plain, Argon charged	
PAYS	2004	25,000	Double reflective	
Total		**439,400**		

Table 2. Type and Cooling Capacity of Chillers for Different Building

Building	Chiller Type	Number of Chillers	Design Capacity (RT)	Connected Load (kW)
MC	WC	8+1[(1)]	7,920	6,880
JPC	WC	3+1	2,562	1,920
LTC	WC	5+1	2,853	2,270
PIFSS	WC	3+1	1,368	957
MOH	WC	2+1	870	888
KCCI	AC	4+1	1,004	1,410
SAB	WC	4+1	1,440	1,044
PAYS	AC	4+1	800	1,248
Total			**18,817**	**16,617**

Primary chilled water pumps are the only auxiliaries of the cooling production system with AC chillers, while WC chillers require primary chilled water pumps, condenser water pumps and cooling towers. Generally, an additional pump, called a secondary chilled water pump, is used for chilled water distribution to various air-handling units (AHUs) and fans coil units (FCUs). Although it is not uncommon to use only single chilled water pump for cooling production and distribution. Occasionally, a tertiary chilled water pump is used for special application as is the case of LTC building. The breakdown of the number of each component and their connected load of the distribution auxiliaries is given in Table 3 for each building. The total connected load of cooling production and distribution auxiliaries in the combined eight buildings is 4,901 kW.

Table 3. Connected Loads for Cooling Production and Distribution Auxiliaries

Building	Primary Chilled Water Pumps	Secondary Chilled Water Pumps	Condenser Water Pumps	Cooling Tower Fans	Other Loads	Total
	No. (kW)	**No. (kW)**	**No. (kW)**	**No. (kW)**	**kW**	**kW**
MC	4+1[(1)] (373)	8+4 (688)	4+1 (596)	6 (330)	N/A	**1,987**
JPC	3+1 (480)	N/A[(2)]	3+1 (480)	3+1 (113)	45	**1,118**
LTC	5+1 (110)	6+6 (159)	5+1 (150)	5+1 (75)	37	**531**
PIFSS	3+1 (45)	3+1 (113)	3+1 (168)	3+1 (90)		**416**
MOH	2+1 (90)	N/A	2+1 (90)	3x2 (111)		**291**
KCCI	4+1 (74)	N/A	N/A	N/A	N/A	**74**
SAB	4+1 (90)	3+3 (124)	4+1 (180)	4+1 (30)		**424**
PAYS	4+1 (60)	N/A	N/A	N/A		**60**
Total	**(1,322)**	**(1,084)**	**(1,664)**	**(749)**	**82**	**4,901**

[(1)] Operating + standby; [(2)]Not Applicable

Cooling from chilled water to air is transferred commonly through AHUs and FCUs. In some buildings dedicated AHUs are used for cooling of fresh air and these AHUs are referred to as fresh air AHUs. SAB, as a unique case, has units fixed in the floor for feeding air to the individual zones. These units are called Floor Tile Units (FTUs) and likewise, the units used for treatment of the air are called Air Coil Units (ACUs). The total connected load for the air distribution system in the eight buildings is 6,358 kW as illustrated in Table 4. Table 4 also presents the total quantity of air in circulation. AHUs are either of variable-air volume (VAV) or constant air volume (CAV). AHUs in JPC and LTC are of CAV type while the rest of the buildings have the VAV type. Furthermore, PIFSS and SAB have variable frequency drives (VFD) while the other three buildings have inlet guide vanes for regulating the VAV.

Table 4. Connected Loads of the Air Distribution System for Each Building

Building	Total AHUs	Fresh Air AHUs	Total FCUs	Connected load (kW)		
	No. (CFM)	**No. (CFM)**	**No. (CFM)**	**AHUs**	**FCUs**	**Total**
MC	158 (1,508,800)	26 (344,500)	N/A	2,390	N/A	**2,390**
JPC	98 (N/A)	N/A	900 (N/A)	950	180	**1,130**
LTC	120 (1,048,149)	16 (55,400)	414 (N/A)	964	42	**1,006**
PIFSS	24 (425,026)		39 (23,729)	394	44	**438**
MOH	20 (386,475)	N/A	12 (N/A)	301	3	**304**
KCCI	16 (327,050)		16 (9,776)	412	5	**417**
SAB	15 (204,000)	9 (59,320)	168 (98,000)	123	28	**434***
PAYS	21 (324,092)	N/A	47 (44,289)	233	6	**239**
Total						**6,358**

* Includes 174 kW for 98 ACUs and 109 kW for 904 FTUs for airflow of 522,000 CFM.

Lighting systems

Lighting systems are generally the second major contributor to the peak power demand and energy consumption after the A/C systems. Lighting systems account for nearly 20% of the peak power demand and 15% of the annual energy consumption. Offices in all the buildings under study are lit with fluorescent tubes which are more efficient and last longer than incandescent lamps. However, there are some variations in the types of lamps and their ballasts used for different buildings which are related to their year of commissioning. Buildings built in the early 80s, such MC and JPC buildings use T12 fluorescent tubes with magnetic ballasts. These lamps are becoming obsolete and are difficult to find in the local market. Buildings commissioned after 1987 use more efficient T8 fluorescent lamps with magnetic ballasts, while buildings built after the year 2000 use T8 fluorescent tubes with electronic control gears (ECGs) which are more efficient. PAYS building as a special case uses a combination of magnetic ballasts and ECGs. SAB building, the most recent and modern building use more energy efficient lamps. It has especially designed fluorescent lamps for the offices, besides using highly energy efficient light emitting diodes (LEDs). The corridors are mostly lit with fluorescent tubes and compact fluorescent lamps (CFLs). MC and MOH buildings have retrofitted some of their incandescent lamps with self ballasted (integral) CFLs as a measure to save energy. Buildings with atriums have high intensity discharge lamps (HID) for night lighting. However, they are rarely used since most of the office buildings have no occupants during the night. More importantly, it was noticed that the lights in daylit areas are normally switched on during the daytime.

Building Automation Systems

All the buildings except MOH have BAS with different features. The BAS in these buildings have the facility to regulate on/off operations of AHUs. In all buildings except JPC and MOH, the BAS can control the supply air temperature from AHUs. The zonal space temperatures through the BAS can be controlled in SAB building, while KCCI and PIFFS buildings have added this feature recently to their BAS based on KISR's recommendation. An additional important feature is the control of duct pressure through BAS. This is available in MC, PIFFS, KCCI, SAB and PAYS buildings. Also, the BAS in MC, SAB, PIFFS and PAYS buildings are equipped to control on/off operations of the lighting system.

The facility to control the lighting system through the BAS is carried out by switching the lights on/off according to the distribution boards (DBs) connections. This facility is available in MC, PAYS and PIFFS buildings, while SAB building uses advanced Delmatic software that controls each individual lamp in a fixture. However, JPC, LTC and KCCI buildings have no facility to control the lighting system through the BAS and MOH building does not have a BAS.

Summary of Loads

The total connected loads of A/C and lighting systems for the eight buildings is 34,510 kW. The minimum and maximum percentage shares of connected loads for different users are shown in Fig. 2. The percentage share of chillers was found to be ranging between 38 and 67%, while the same for the CPADA is varying from 3 to 19%. For PAYS and KCCI buildings with air-cooled chillers, the percentage share of the chiller load was considerably high, while the percentage share of the CPADA load was the least. The share of the air distribution varied between 13 and 24% and for the lighting system it varied from 10 to 33%. The percentage shares of chillers, CPADA, air distribution and lighting systems with respect to total loads of A/C and lighting systems in all buildings were 50, 13, 18 and 19%, respectively.

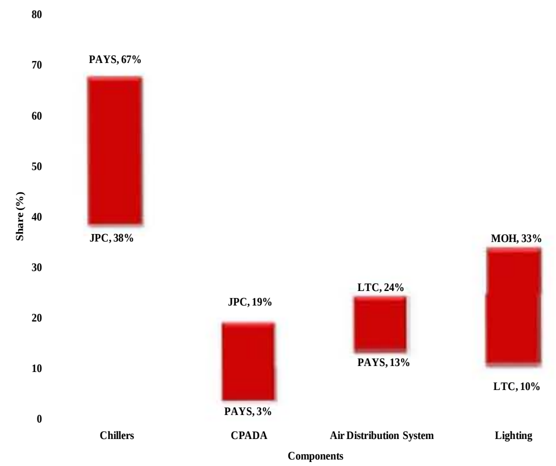

Figure 2. Minimum and maximum percentage shares of connected loads for different users in all buildings combined

DEVELOPMENT AND IMPLEMENTATION OF THE INNOVATIVE APPROACH

The innovative approach were developed and finalized in consultation with the facility managers and their technical team. Prior to the development of the innovative approach for any building, critical areas were identified in consultation with the facility managers. Critical areas are the zones in the building where the comfort quality, particularly the space temperature, has to be maintained at constant level for most of the day. This requirement could be either due to their occupants, such as ministers and other top executives or in house equipment as is the case with the LTC building. Buildings such as PIFFS, MOH and MC have an independent cooling system for its server room to facilitate the implementation of energy efficient operation strategies for the rest of the building.

Pre-Closing Treatment. As a first step to reduce the peak power demand, the Pre Closing Treatment (PCT) between 13:00 and 14:00 h, when the buildings were still occupied, was explored for all the buildings. PCT for fresh air was applied only in MC and SAB buildings as they have independent fresh air AHUs. For the other buildings, the fresh air intake is through common AHUs and dampers regulating the fresh air were not connected to the BAS. Most of the facility managers were against implementing PCT for cooling production and distribution systems when the buildings were still occupied. After a great deal of persuasion, the facility managers were convinced to implement PCT for cooling production and distribution systems in all the buildings except the PIFFS and KCCI buildings.

Time-of-Day Control. Time-of-Day Control (TDC) for AHUs and lighting systems along with the cooling production and cooling distribution systems was applied at 14:00 h, after the end of work and in line with the building occupancy. A summary of TDC measures implemented in the buildings along with their occupancy periods are presented in Table 5. All the buildings except the LTC have a limited occupancy between 7:00 and 14:00 h. However, prior to implementation, their cooling production operated at full capacity round the clock except for the MC which had a full closure of between 19:00 and 03:00 h the next day. Likewise, the operation schedules of the air distribution system was not any better. Air distribution systems in all the buildings with the exception of MC operated round the clock, and KCCI had a partial closure between 01:00 and 04:00 h. Operation schedule for the lighting systems was somewhat better. Except for JPC and LTC, all the buildings had partial closure of lighting systems for different timing while MC had a full closure between 17:00 and 5:00 h the next day. TDC implementation for the AHUs was carried out through the BAS except for MOH and PAYS buildings. Also, the FCUs, which have a sizable load particularly in the older buildings, were regulated manually.

Table 5. Implementation of TDC in Different Buildings

Building	Occupancy Period	Cooling Production	Cooling distribution	Air Distribution		Lighting
				AHUs	FCUs	
MC	7:30 to 15:30	✓	✓	✓	✓	✓
JPC	7:00 to 14:00	✓	-	✓	-	✓
LTC	24 hrs	✓	-	✓	-	-
PIFFS	7:00 to 14:00	-	-	✓	-	✓
MOH	7:00 to 14:00	✓	-	✓	-	✓
KCCI	8:00 to 22:00	-	-	✓	-	✓
SAB	7:00 to 15:00	✓	-	✓	-	✓
PAYS	7:00 to 14:00	✓	-	✓	-	✓

* Modified after KISR's recommendations.

RESULTS AND DISCUSSION

Table 6 presents the building wise reductions in power demand achieved during the peak demand hours between 13:00-17:00 h along with their respective savings as percentage of the baseline power demand. Also, the combined reductions of the eight buildings are shown in Fig. 3. PCT, implemented between 13:00 and 14:00, achieved a reduction in peak power demand of 3,427 kW, equivalent to 12.5% was achieved. More importantly, the temperature build up did not exceed 1°C in any of the buildings as shown in Fig. 4. This ensured that comfort levels were not adversely affected during the PCT implementation, which in turn validated its technical viability.

Table 6. The Peak Power Reduction and their Percentage Savings for Each Building

Building	13:00-14:00 (h)		14:00-15:00 (h)		15:00 -16:00 (h)		16:00-17:00 (h)	
	kW	%	kW	%	kW	%	kW	%
MC	970	8.3	4,851	42.6	5,973	56.5	7,185	76.8
JPC	600	16.2	1,003	29.1	820	24	500	16.1
LTC	116	3.1	885	24.1	931	26	494	13.8
PIFFS	495	19.4	391	15.9	500	20.8	450	19.6
MOH	440	20.8	572	30.8	609	36.1	490	32.8
KCCI	190	10.9	268	15.5	94	5.4	205	11.9
SAB	463	16	668	23.4	967	34.1	1,088	38.9
PAYS	153	16.4	261	31.3	306	42	292	41.5
Total	3427	12.5	8899	34.3	10200	40.8	10704	45.8

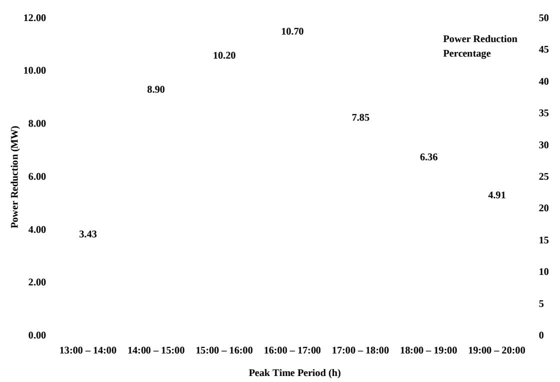

Figure 3. Total power demand savings for all buildings combined.

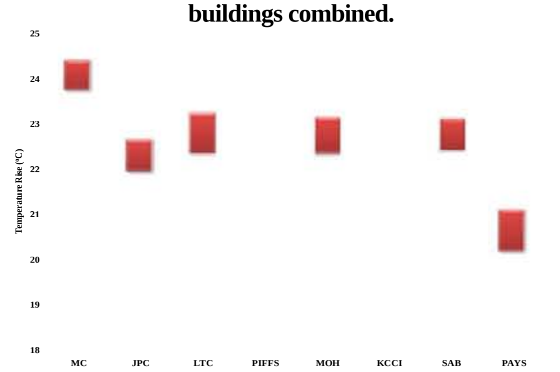

Figure 4. Temperature build up inside the buildings due to the implementation of PCT scheme

TDC implementation after 14:00 h achieved a maximum reduction in power demand of 10.7 MW between 16:00 and 17:00 h, equivalent to 45.8%. Although between 14:00-15:00 h, considered to be crucial hour for the national demand, the reduction in the power demand was 8.9 MW, equivalent to 34.3 %. A reduction of 42.6% was maximum in the MC and at 15.5%, it was least in the KCCI.

During the TDC implementation, the temperature build up inside these buildings was between 2.1 and 7.9^oC as shown in Fig. 5. In the old buildings such as MC and MOH, the temperature build up was significantly higher (7-8^oC) as the walls and roof of these buildings are not thermally insulated and their glazing quality is extremely poor; while for the other buildings which are relatively new and have energy efficient envelope, the temperature build up did not exceed 3^oC. These findings ensured that the compete closure of the AHUs during the non-occupancy period is feasible as the modest temperature build up is unlikely to damage building interior, and will have no adverse effect on the peak power demand or the comfort quality during the occupancy period.

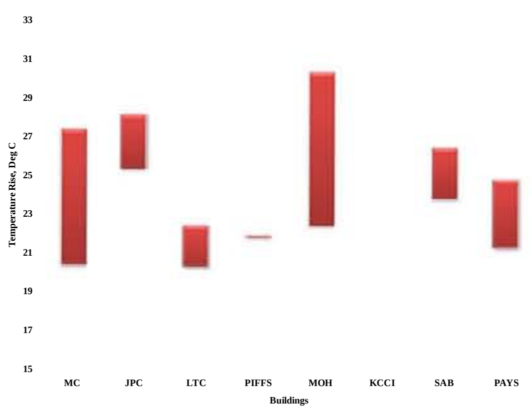

Figure 5. Temperature build up due to the implementation of TDC for AHUs.

CONCLUSIONS AND RECOMMENDATIONS

The specific conclusions and recommendations of the project can be summarized as follows:

1. The implementation of innovative approach in the eight governmental buildings with a total peak demand of 29.3 MW achieved a reduction of 8.9 MW. This power is now available to other users leading to financial savings of $13.5 million for the nation towards the cost of constructing new power plants and distribution network equipment. More importantly, this reduction in peak power demand of well over 30% involved zero or limited expenditure. Furthermore, reduction in peak power demand is associated with reduction in energy consumption which leads to a substantial reduction in fuel consumption and CO_2 emissions. This low-cost and extremely effective measure should therefore be implemented in all the governmental and institutional buildings in Kuwait at the earliest.
2. PCT and TDC for A/C and lighting systems have proved to be effective for peak load management in Kuwait. More importantly, the temperature build up of less than 1^oC during the PCT implementation was not high enough to adversely affect the occupants' comfort level. Likewise, the temperature build up of less than 8^oC during the TDC was acceptable for the safety of building interiors and for ensuring comfort levels during the occupancy period through adequate pre-cooling.
3. A nationwide implementation of the innovative approach in all the governmental and institutional buildings is likely to reduce the national peak power demand by 154 MW which amounts to a capital savings of $232 millions towards the cost of new power generation equipment and distribution network.

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