Management of Power Demand Through Operations of Building Systems

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ABSTRACT

In hot summers, the demand for electrical power is dominated by the requirements of the air-conditioning and lighting systems. Such systems account for more than 80% of the peak electrical demand in Kuwait. A study was conducted to explore the potential for managing the peak electrical demand through improved operation strategies for building systems. Two buildings with partial occupancy patterns and typical peak loads of 1 and 2.2 MW were investigated. Changes to the operation of building systems included utilizing the thermal mass to reduce cooling production and distribution during the last hour of occupancy, time-of-day control of chillers and auxiliaries, and de-lamping. The implemented operational changes led to significant reductions in building loads during the hours of national peak demand. The achieved savings reached 31% during the critical hour, and up to 47% afterwards. Daily energy savings of 13% represented an added benefit. Additional operational changes could lead to further savings in peak power when implemented.

Key words: Demand management, peak load, air-conditioning systems, building operations.

INTRODUCTION

The demand for electrical power in hot regions increases considerably during the summer season. In Kuwait, air-conditioning systems account for about 70% of electricity demand during peak hours (Al-Marafie et al., 1989), in addition to an estimated 10% for lighting systems. Therefore, power plants operate at an average annual capacity factor below 60% (MEW, 2008). Yet, the annual increase in peak electrical demand necessitates building new power plants. Over the last few years, rolling blackouts continued to pose a threat to electricity consumers.

Efforts to manage the rising demand for electricity have shown some success. An energy code, enforced since 1983, restricted the maximum allowed Watts per unit area for different types of buildings. The energy code helped curb the growth of power demand (Meerza and Maheshwari, 2002). However, the peak demand kept rising at high annual rates, averaging 5% over the last 6 years (MEW, 2008). Although the rise in power demand is largely due to economic expansion, heavily subsidized electricity prices hinder energy management efforts.

One of the most cost effective methods to manage power demand, even with subsidized energy, is though improved building operations. This article aims at assessing the use of improved operation strategies for building systems to manage national power demand. Two government buildings were studied and new operation strategies were developed and tested for the buildings. The effect of new operations on occupant comfort was examined and the impact on power demand during peak hours was evaluated.

BUILDINGS AND SYSTEMS DESCRIPTION

This investigation considered two government buildings, as part of a larger study. The two buildings were representative of typical structures and building systems in Kuwait. The first building, Public Authority for Youth and Sports (Bldg-1), had 9 levels of occupied space with an atrium in the middle, in addition to an attached 2-storey section. The second building, Ministry of Public Health (Bldg-2) extended more horizontally with 4 levels of occupied space. The air-conditioned areas were 25,000 m^2 (269,000 ft^2) for Bldg-1 and 29,000 m^2 (312,000 ft^2) for Bldg-2.

The air-conditioning (A/C) system for Bldg-1 was air-cooled, whereas Bldg-2 had a water cooled system. For Bldg-1, four air-cooled chillers, each having 7-step compressors, delivered 800 Refrigeration Tons (RT) (2,810 kWc). Four primary chilled water pumps circulated water between the chillers and 21 air-handling units (AHUs) and 47 fan coil units (FCUs). For Bldg-2, two water-cooled chillers with centrifugal compressors delivered 870 RT (3,060 kWc). Two primary chilled water pumps circulated water between the chillers and 20 AHUs and a few FCUs.

The lighting systems for both buildings consisted mainly of fluorescent lamps with magnetic ballasts. However, parts of Bldg-1 had electronic control gear with better efficiency. Some compact fluorescent lamps (CFLs) were also used in both buildings. The first building had an atrium and more glazing area, leading to more daylight within the building. Both buildings had high light intensity levels, as will be discussed later.

The occupancy patterns were similar for both buildings, which were mainly occupied from 7:00 till 14:00h, five days a week. In each building, some areas were occupied after business hours or required extended operation such as computer rooms. Such critical areas were identified, so that they would not be negatively affected by changes in operations.

The major connected loads of the buildings consisted of chillers, cooling auxiliaries, air distribution systems, and lighting systems. The cooling auxiliaries included chilled water pumps, condenser water pumps, and cooling tower fans. The air distribution loads included air-handling units and fan coil units. The second building had additional split A/C units for a detached section. Table 1 lists the major connected loads and the measured actual loads for both buildings.

Table 1. Major connected loads and measured peak loads of buildings.

Component	Electric load (kW)	
	Bldg-1	Bldg-2
Chillers	1248	888
Auxiliaries	60	291
Air distribution	239	304
Other A/C*	-	202
Lighting	291	764
Major connected loads	1,838	2,449
Measured peak load	950	2,210

* Split A/C units

The existing operation schemes for the air-conditioning and lighting systems were examined for both buildings and the total electrical loads were monitored. Figure 1 shows the hourly load profile for Bldg-2, along with the percentage load profile for the nation. The building load increases slowly during occupancy period and peaks at the 14th hour of the day, then drops gradually until the pre-occupancy hours of the following morning. On the other hand, the national load peaks at 15h. A high-demand period extends from 13:00h till 21:00h. The peak hours of national load, from 13:00h till 18:00h, are particularly interesting because the peak could be shaved or "flattened." The target of this investigation was to reduce the loads of buildings during these hours of national peak through improved building operations.

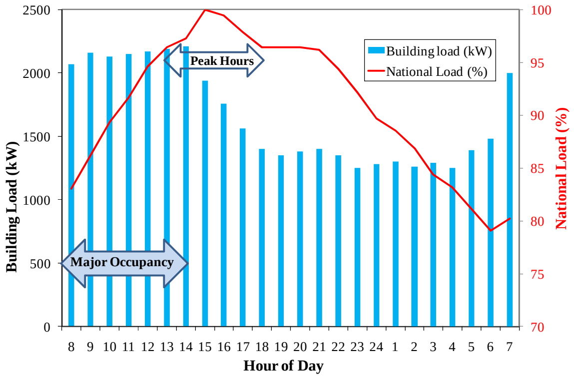


Figure 1. Hourly load profile for Bldg-2 and percentage load profile for Kuwait.

NEW STRATEGIES OF OPERATION

New strategies were proposed for improved operation of the buildings. The strategies aimed at reducing building loads during the peak period of 13:00h to 18:00h. Both buildings were fully occupied during the first hour of this period, but only partially occupied during the remaining 4 hours. The new operation strategies included:

Proper Use of Thermal mass

The buildings considered were concrete structures with high thermal masses. Existing operations considered the thermal mass a deterrent from switching off A/C systems because of the long time required for pre-cooling. During the commissioning of Bldg-1 in peak summer, indoor temperatures took 3 days to stabilize at desired levels. The new strategy took advantage of the thermal mass to reduce cooling supply to the building during the last hour of operation. Temperature measurements were recorded for different representative parts of the buildings to assess the impact on occupant comfort during that hour.

For the partial occupancy period, new operations included stopping the cooling supply to major parts of the buildings which were unoccupied. The new strategy raised two comfort-related concerns by building operators. The first was regarding space temperature rise. Since ambient temperatures reached 49°C (120°F) for extended periods, the indoor temperature rise could cause furniture damage. The second concern was about getting adequate pre-cooling to the buildings to ensure comfort during the next occupancy period. Tests were conducted on weekends to monitor the temperature rise during the no-cooling period and the temperature drop during pre-cooling.

Improve Time-of-Day Control

Existing operations implemented some time-of-day control of the air-conditioning and lighting systems. Office lightings in both buildings were mostly switched off during the non-occupancy period. The cooling supply to each building was reduced after hours of major occupancy. This was achieved by raising the leaving chilled water temperature for Bldg-1, and turning off a chiller for Bldg-2. However, these measures were implemented after the ambient temperature had subsided around 18:00h, rather than during peak hours.

The new operation strategy improved time-of-day control by stopping the cooling supply to non-critical areas at 14:00h. Total cooling supply to each building was also reduced at the same time. As mentioned earlier, tests were carried out to address comfort-related concerns about temperature build-up and pre-cooling. In addition to comfort requirements, sufficient pre-cooling was needed in early morning hours to avoid higher chiller loadings during peak hours. This new time-of-day control led to significant reductions in power demand by chillers and air-distribution systems.

Reduce excessive light intensity

Measurements of light intensity levels in different parts of the buildings indicated higher levels than recommended by the local code. De-lamping was implemented to remove selected lamps and their ballasts and reduce the buildings' loads. The de-lamping of corridors and parking areas reduced the power consumption during both occupancy and non-occupancy periods. Tests were performed to determine appropriate levels of de-lamping and the corresponding light intensities, so that safety and visual comfort were not compromised.

CHANGES TO OPERATIONS

The changes to operations of building systems can be summarized as follows:

Cooling Production

The cooling production in both buildings was reduced starting at the last hour of major occupancy. For Bldg-1, the leaving chilled water temperature was raised from 45°F (7.2°C) to 50°F (10°C) at 13:00h, leading to unloading of compressors. For Bldg-2, one chiller out of two was turned off at 13:00h. These measures were reversed at 5:00h the next morning.

Auxiliaries

The power consumption by cooling auxiliaries was reduced at 13:00h. For each building, one of two operating primary chilled water pumps was turned off. In Bldg-2, the cooling tower fans were operated at half capacity starting at 13:00h.

Air Distribution

The air-handling units feeding non-critical areas were switched off at 14:00h, which was the end of major occupancy period. In Bldg-1, 15 of 21 AHUs were switched off, whereas 12 out of 20 AHUs were turned off in Bldg-2. The AHUs were switched back on at 22:00h in Bldg-1 and 00:30h after midnight in Bldg-2.

Lighting System

De-lamping was conducted mainly in the corridors, lobbies, and parking areas of the buildings. Although tests were conducted for offices, the owners decided not to implement de-lamping there. Based on light intensity measurements, the general de-lamping rate in lobbies and corridors was half of the original lighting. For example, four-lamp fixtures were cut to two, and single lamp fixtures were alternately disconnected. This rate changed in some areas depending on proximity to daylight from atrium of external windows.

RESULTS AND DISCUSSION

The goal of this study was to achieve power reduction during peak hours without compromising comfort. Thus, the effects of operational changes on comfort and safety are presented first.

Impact on Comfort

The effect of reducing cooling supply during the last hour of operation on space temperature was tested in both buildings. Figure 2 shows the temperature range during that hour for different zones of Bldg-2. The figure demonstrates that no significant rise in space temperature was observed. A similar result was obtained for Bldg-1, with most zones having a temperature rise of less than 1°C (1.8°F). Thus, the reduction in cooling supply during the last hour did not have adverse effects on occupant comfort.

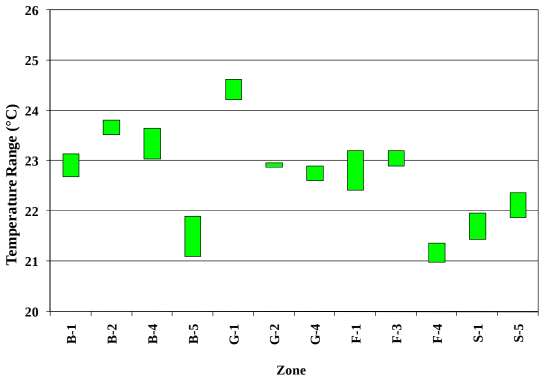


Figure 2. Space temperature ranges in different zones of Bldg-2 during last hour of occupancy.

Another operational change with potential impact on comfort was the switching off of AHUs in non-critical areas after occupancy. Two comfort concerns were related to the maximum temperature rise and the pre-cooling time needed for spaces to reach satisfactory temperatures before the next occupancy period. Figure 3 shows room temperature ranges for tested zones of Bldg-1 when the AHUs were off. The room temperatures rose to a maximum of 26°C (79°F) during this non-occupancy period. Bldg-2 showed higher temperature rises reaching up to 31°C (88°F), as shown in Figure 4. This temperature rise was deemed acceptable by building owners.

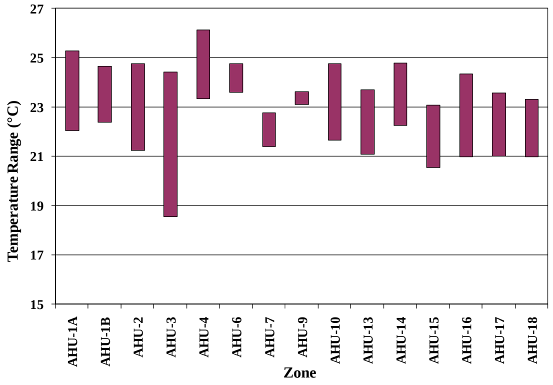


Figure 3. Room temperature ranges for tested zones of Bldg-1 when AHUs were off.

The second concern related to AHU closures was about pre-cooling. Space temperature profiles for selected zones of Bldg-2 are presented in Figure 4. These measurements indicate that the temperature rises relatively quickly to a maximum when an AHU is switched off and stabilizes. Turning the AHUs back on at 00:30h allowed enough time for pre-cooling before the next occupancy period. Thus, the no-cooling period of selected zones was an acceptable strategy of operation for the two buildings.

It should be noted that the acceptable pre-cooling period depends on the conditions of the building. For example, when a chiller of Bldg-2 was under maintenance on a weekend, no cooling was supplied for an extended period of 15 hours. The regular pre-cooling period starting at 00:30h was not sufficient for reaching comfortable temperatures.

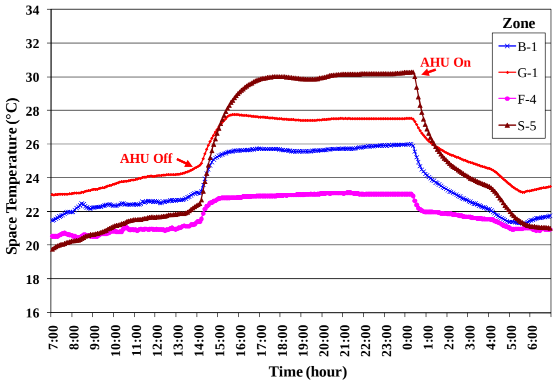


Figure 4. Space temperature profiles for selected zones of Bldg-2 showing temperature changes when AHUs were switched off and on.

Changes to the lighting systems also raised issues of comfort and safety. De-lamping changes, described earlier, aimed at reducing power consumption by the lighting systems, while maintaining light intensity levels at or above code recommendations. Table 2 lists the measured intensities before and after de-lamping changes for both buildings, along with the values recommended by the local energy code in Kuwait. The numbers indicate that existing operations maintained excessive light intensities. After implementation of de-lamping, the light intensities were still above recommended values.

Table 2. Light intensity levels for different areas of the buildings before and after de-lamping.

Area	Light Intensity Level (lux)				
	Bldg-1		Bldg-2		Code*
	Old	New	Old	New	
Corridor-Internal	341	230	360	180	100
Corridor-Glazed/Atrium	565	253	630	500	100
Lift Lobby	550	176	435	255	150
Parking	240	98	-	-	50
Offices	900	560	720	590	500

* Values recommended by the local energy code in Kuwait (MEW, 2004).

Power Savings

The baseline hourly power profile of each building was compared to the profile after implementation of new operation strategies. Days with similar weather temperatures were selected for the comparison. Figure 5 shows the hourly power profiles of Bldg-1 as percentages of the baseline peak demand. The profiles demonstrate the reductions in building load achieved during peak hours. Although the original profile dropped after the 14th hour, the new operation strategies led to higher reductions. Moreover, load reductions were achieved during the 14th hour, when the building was occupied. The new load profile was higher after 23h till the next morning, due to higher chiller loading to pre-cool the building. The total rise in consumption during pre-cooling period was less than the drop during peak period, leading to a net energy saving, as will be discussed later.

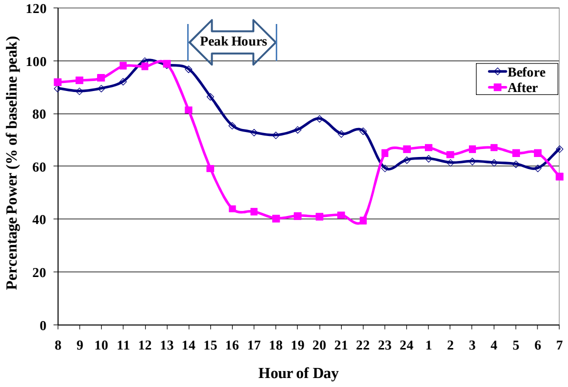


Figure 5. Power profiles of Bldg-1 as percentages of the baseline peak demand.

Figure 6 shows the hourly load profiles and percentage power savings for each building during the period of high national demand, 13:00h to 21:00h. For the first hour of the peak period, power savings of 16% and 24% were achieved in Bldg-1 and Bldg-2, respectively. These savings occurred during full occupancy of the buildings. The savings exceeded 30% for each building during the national peak hour, 15h. Larger power savings were achieved during the afterwards, reaching 47% for Bldg-1 and 39% for Bldg-2. Energy savings over a complete day reached 12.5% for Bldg-1 and 12.9% for Bldg-2.

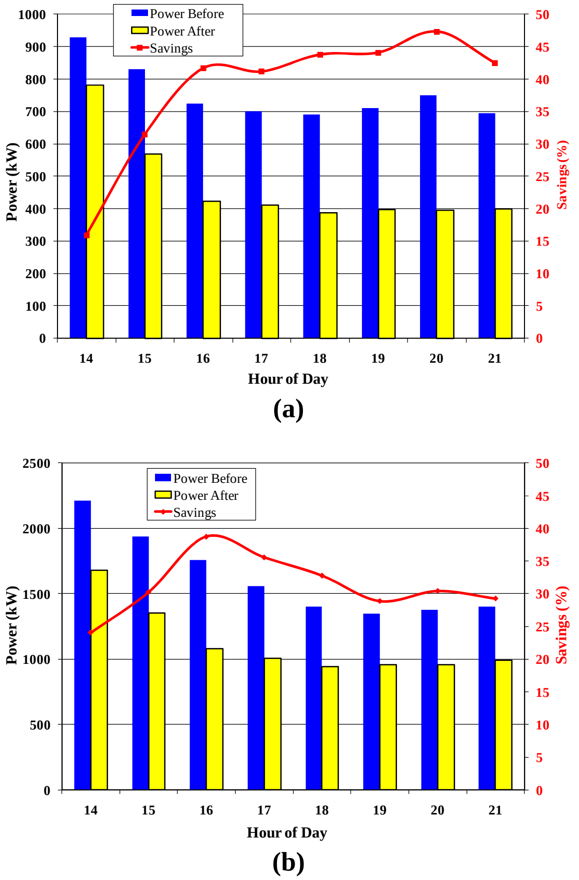


Figure 6. Hourly load profiles and percentage savings for the period of high national demand for (a) Bldg-1, and (b) Bldg-2.

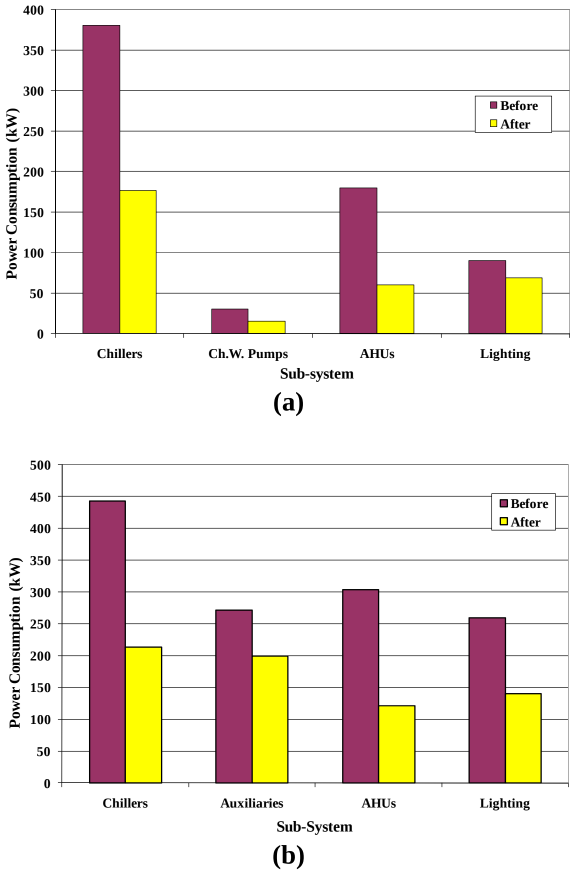
The large power savings obtained in this study are valuable, considering that they resulted from changes to building operations, without new investments. The combined power savings for both buildings during the peak hour reached 850 kW. This saving is equivalent to $1.2 million towards the cost of new power generation equipment. If the new operation strategies are implemented in other similar government buildings in Kuwait, savings in power generation costs could reach $210 millions. The energy savings of 12.5% for hot summer days represent an added benefit. Nationwide energy savings will save fuel cost for the government, as well as CO_2 emissions.

Contributors to Savings

The measured savings in power demand could be linked to the changes in operations of the two buildings. Changes to the lighting systems focused on public areas that were continuously lit. Therefore, they led to constant power savings during both occupancy and non-occupancy periods. These savings accounted for 2.1% and 5.5% of the building peak load for Bldg-1 and Bldg-2, respectively. Additional savings were achieved during the 14th hour due to the measures implemented to reduce cooling supply and take advantage of the thermal mass, as described earlier. Further savings were achieved by turning off AHUs after 14:00h. These power savings consisted of direct savings of fan power, and indirect savings due to relieving the chillers from the cooling loads of zones served by the AHUs.

The contributions of key subsystems to building loads and power savings are summarized in Figure 7. In both buildings, the largest consumer and contributor to savings were the chillers. Air-handling units were the second highest load and savings contributor. These numbers represent only direct loads of AHUs. The lighting system of Bldg-2 had a larger share in the load and savings than Bldg-1. Also, the cooling auxiliaries for Bldg-1 had a small role, because the air-cooled system had only primary water pumps as auxiliaries. The Auxiliaries of Bldg-2 had a large share in the load, and a small share in savings.

The small savings in daily energy consumption could be attributed to two main reasons. The first is the elimination of fan energy by switching off AHUs. Continuous fan operation adds direct and indirect loads to buildings. The second reason is operating the chillers at favorable weather conditions with higher efficiencies. The ambient temperature during early morning hours is typically 16°C (29°F) lower than hot afternoon hours. Therefore, shifting chiller operations to early morning hours saves power during peak hours and saves energy by improving operating efficiency.



(a)

(b)

Figure 7. Power consumption by key subsystems before and after new operation strategies for (a) Bldg-1, and (b) Bldg-2.

Other Opportunities

Through this investigation, other opportunities for power and energy savings in the studied buildings were identified but not utilized. For example, de-lamping was not implemented in offices. Based on light intensity tests, de-lamping of offices could lead to additional power savings during occupancy of 2.6% for Bldg-1 and 4.6% for Bldg-2. In this case, the total power savings during occupancy from the lighting system of Bldg-2 would reach 10.1%.

The air-distribution system of Bldg-1 represents another opportunity for savings. Data from the AHUs indicated that inlet guide vanes (IGVs) were only partially open for most of the time. Figure 8 shows the ranges of IGV openings for different AHUs in Bldg-1. Using variable frequency drives instead of IGVs to control air flow through AHUs could lead to significant power savings during occupancy and partial occupancy hours.

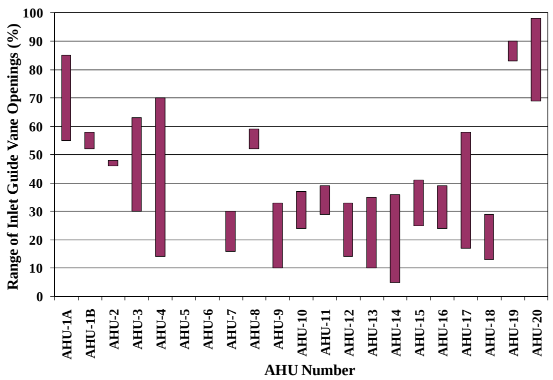


Figure 8. Ranges of IGV openings for AHUs of Bldg-1 in a summer day.

CONCLUSIONS

This investigation tested the potential for managing peak electrical demand through enhanced operation strategies in government buildings. Two buildings with peak loads of 1 and 2.2 MW were considered, with the target of reducing their loads during hours of national peak demand. Existing operation schemes for the air-conditioning and lighting systems were studied, and new operation strategies were developed, tested, and implemented. The new strategies focused on improving the use of thermal mass and time-of-day control, and reducing excessive lighting. Decreasing the cooling supply to the buildings during the last hour of occupancy did not have adverse effects on comfort. Most space temperatures changed by less than 1°C (1.8°F). Similarly, switching off AHUs of non-critical areas led to acceptable changes in space temperatures, when sufficient pre-cooling time was provided. The maximum space temperature reached 31°C (88°F). De-lamping tests and light intensity measurements were also conducted to ensure comfort and safety with the new operations.

The new operation strategies led to significant reductions in building loads during peak hours. Savings of 16% and 24% were achieved during the last hour of occupancy for Bldg-1 and Bldg-2, respectively. Power savings after occupancy reached 47% for Bldg-1 and 39% for Bldg-2. Additional savings of about 13% in daily energy consumption were achieved. In both buildings, chillers contributed the most to power savings, followed by AHUs. Opportunities for further power savings were identified, such as de-lamping of offices and using variable-frequency drives for AHUs in Bldg-1.

The success of the new operation strategies in reducing loads demonstrated that significant reductions in national peak could be achieved through changes to operations with minimal-cost. Wide-scale implementation of these operation strategies could lead to savings of $210 millions in power generation costs, in addition to savings in fuel and CO_2 emissions.

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