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ABSTRACT

A great deal of research has examined the weather sensitivity of energy consumption in commercial buildings; however, the recent power crisis in California has given greater importance to peak demand. Several new load-shedding programs have been implemented or are under consideration.

Historically, the target customers have been large industrial users who can reduce the equivalent load of several large office buildings. While the individual load reduction from an individual office building may be less significant, there is ample opportunity for load reduction in this area.

The load reduction programs and incentives for industrial customers may not be suitable for commercial building owners. In particular, industrial customers are likely to have little variation in load from day to day. Thus a robust baseline accounting for weather variability is required to provide building owners with realistic targets that will encourage them to participate in load shedding programs.

OVERVIEW

The objective of this analysis is to examine the weather sensitivity of peak loads in California, load shedding strategies, and economic incentives to shed load during peak demand periods. Modeled results as well as a case study results were used. Strategies may vary for different climates, humid climates in particular.

While demand management programs such as interruptible and curtailable rate structures have been used for decades, recent energy shortages in California have resulted in a proliferation of incentives to reduce demand during peak periods that have attracted a great number of participants. At the same time, many customers locked in to interruptible rate programs, i.e., those receiving discounted rates in exchange for agreeing to curtail load when needed, persuaded the California Public Utilities Commission (CPUC) to allow customers to opt out of these programs, using the reasoning that “the electricity system is operating outside any reasonable bounds...” (CPUC, 2001).

Traditionally, interruptible rate programs have been targeted at industrial and large commercial customers (CPUC, 2001). It has been known for many years that commercial customers are more likely to have weather-dependent loads than industrial customers (EPRI 1988). However, in an effort to simplify programs, weather factors have not been included in California’s curtailment programs. Although many of the new participants in these programs do come from the commercial sector, modifying the program design for these customers has been less of a priority then addressing shorter-term concerns.

The increased participation in demand programs is due to the greater flexibility of these programs as well as the increase in financial incentives. For example, any customer who can offer an aggregate reduction of 1 Megawatt (MW) during a curtailment period, for any number of meters, can participate as a load aggregator in the California Independent System Operator (ISO) Summer Demand Reduction Program (DRP; see Load Reduction Incentives).

The U.S. General Services Administration (GSA) Pacific Rim Regional Office is one new participant that has bid 1.2 MW aggregate curtailment for four California Federal buildings. In addition, GSA received funding made available by the California Legislature in 2000 for installing measures that would reduce peak demand by June 2001.

While it is hoped that these measures will reduce California’s peak demand by 20 percent in Summer 2001, there is some concern among new participants about how the curtailment is calculated. In most cases, a baseline is used that is calculated from usage on the days preceding the curtailment order. Many believe that this creates an incentive to use more power during non-curtailment periods.

LOAD REDUCTION INCENTIVES

The number and characteristics of load reduction programs has been changing rapidly, and no comprehensive guide exists. California set aside over $2 billion in the last year for demand responsive and conservation technologies.

Summer 2001 Demand Relief Program

The California ISO Summer Demand Relief Program is offering an incentive of $20,000 per MW each month in addition to $500 per MWhour for actual curtailment. Participants who fail to meet the target will be paid on a sliding scale, and must achieve at least 25 percent of the promised target to receive any incentives; however, there is no penalty for failure to meet curtailment orders (ISO, 2001).

Many California utilities are participating as load aggregators under the ISO program, in addition to implementing their own programs.

Baseline Calculation

A key component of these programs is how payment and program compliance are determined. Determination of curtailment requires an estimate of what the load would have been if the curtailment order had not been issued. Typically a baseline is calculated by comparing the load for each hour during the curtailment period to the average load for the same hour, during the previous ten days, excluding weekends and other demand reduction days. In response to participant concerns, the ISO changed the baseline calculation for the Summer 2001 Demand Reduction Program to use the average based on the lowest ten out of eleven most recent days.

WEATHER FACTORS

The California Energy Commission recognizes sixteen different climate zones, which makes it difficult to adjust for weather uniformly across the state. The fact that a calculation method for weather adjustments might be different for different climate zones increases the resistance to adopting a climate sensitive model. The average temperature may be significantly different from the average temperature for the state.

An example of the correlation between office building electricity use and temperature is shown in **Figure 1**. This example is for a typical office building located in a climate with hot summers and cold winters. As expected, the load is cooling dominated.

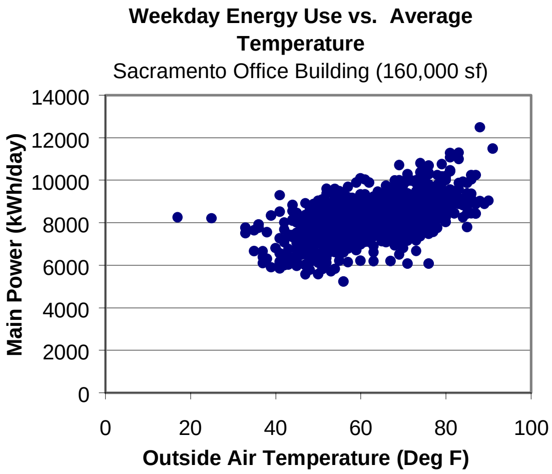


Figure 1. Building Energy vs. Outside Temperature for a Sacramento office building.

Figure 2 shows a similar correlation for the Dellums Federal Building, located in the milder climate of Oakland. The correlation appears stronger, as only the hours of peak use are used to find the daily average power. This is important, as these are the hours when demand shedding is most important and when the ISO is most likely to issue a curtailment order.

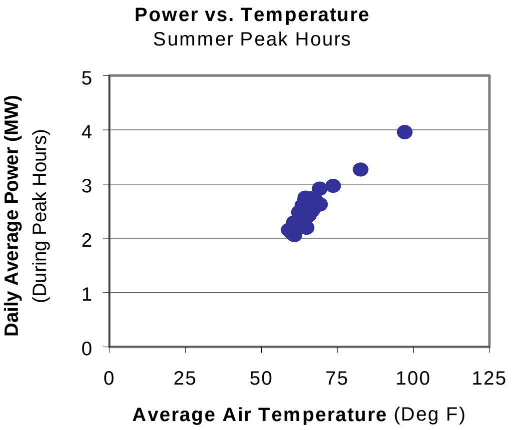


Figure 2. Building Power vs. Outside Temperature for Summer DRP hours (12p-6p), Dellums Building

LOAD SHEDDING WITH HVAC

Some strategies for shedding cooling loads include:

1. Setting up zone temperature set-points
2. Reducing air handling unit fan capacity
3. Reducing air handling unit fan capacity and increasing supply air temperature and chilled water set-point temperatures

The first strategy is the simplest way to implement load shedding if the zone temperature controllers are digital and network-addressable, i.e., zone temperature set-points can be changed with a global command. Typical increases are in the range 2 to 5°F. The second and third strategies can be used if the zone temperature controllers are not network-addressable but they have the disadvantage that the degree, duration and location of the discomfort cannot be controlled directly. Increasing the supply air and chilled water temperatures is a way of further reducing demand without significantly degrading air distribution in the occupied spaces, particularly for constant air volume (CAV) systems, which, unlike variable air volume (VAV) systems, are not designed to provide acceptable air distribution at reduced air-flow rates. In a VAV system, increasing these temperatures without limiting the fan capacity would be counter-productive, as it would cause an increase in supply air flow and a corresponding increase in fan power, unless running at maximum capacity.

The DOE-2 simulation program has been used to examine peak load shedding using the three strategies described above. A prototypical medium size (6 story, 100,000 sf) commercial office building has been simulated in five climates: Oakland, Pasadena, Sacramento, Fresno and Las Vegas. Two HVAC systems, representing the extremes of existing building systems, were studied: single duct VAV and dual duct constant volume (DCAV). The HVAC system is assumed to operate between 7am and 6pm during working days. The cooling set-point for the base case is 75°F, although the savings and discomfort estimates presented below should be similar for other base-case set-points (~72-78 °F) since they are presented in terms of the amount of set-point increase.

Setting Up Zone Temperatures

Figure 3 shows the expected demand reduction for both VAV and DCAV systems when the set-points for the zone temperatures are increased by the amount shown on the horizontal axis. The reduction is averaged over a four-hour period from 2pm to 6pm. The lines are good fits to simulation results for set-point increases of 1, 2 and 5°F. The savings, which are expressed in Watts per square foot of conditioned floor area, are essentially independent of climate for the climates studied. The reductions expected from DCAV systems are significantly less than those expected from VAV systems because there is no reduction in fan power in the DCAV systems.

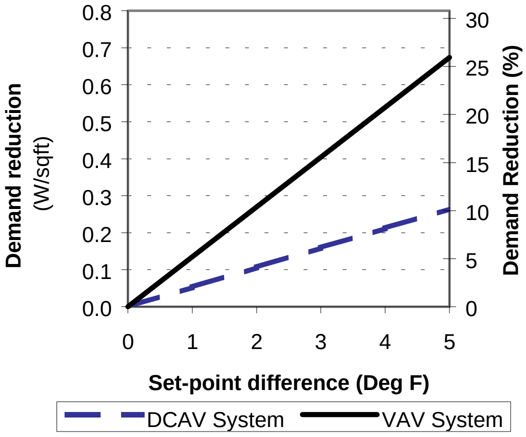


Figure 3. The peak demand savings *vs.* zone temperature set-point increase for VAV and DCAV systems.

Figure 4 shows the peak demand reduction obtained in different climates for VAV systems using the second and third strategies. Reducing fan capacity by 20% in terms of flow rate results in load reductions of 0.45-0.65 W/sqft, depending on climate. If, in addition to a 20% reduction in fan capacity, the supply air temperature is increased by 5^{o}F and the chilled water temperature by 7^{o}F, the reduction in load is 0.7-0.9 W/sqft. The fan capacity reduction and temperature reset values used here are purely illustrative; the optimum combination of fan capacity reduction and reset of supply air and chilled water temperatures is specific to the particular building and HVAC system.

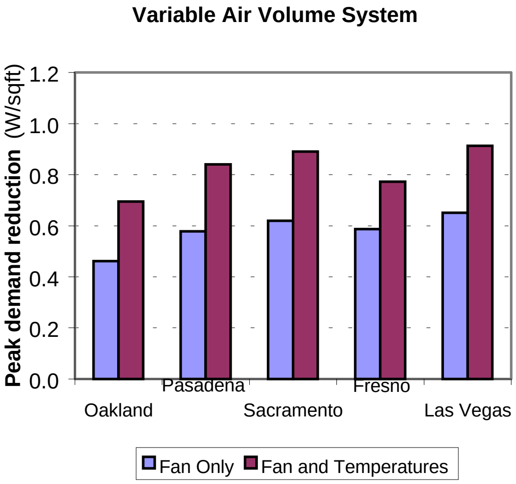


Figure 4. Load reductions obtained from reducing fan capacity by 20% (Fan Only) and reducing fan capacity by 20%, increasing supply air temperature by 5^{o}F and increasing chilled water temperature by 7^{o}F (Fan and Temperatures) in VAV systems

The fan capacity was limited to 80% of the maximum capacity actually used in the base case. In practice, many fans in VAV systems do not operate at full capacity even without load shedding, so it is necessary to determine the actual maximum fan capacity used in normal operation and use this as the baseline for fan capacity reduction. This points to the need for performance monitoring to identify the most appropriate values to use when modifying system attributes not under feedback control.

Figure 5 shows the peak demand reduction obtained in different climates for CAV systems using the second and third strategies. Reducing fan capacity by 20% in terms of flow rate results in load reductions of 0.7-0.85 W/sqft, depending on climate. If, in addition to a 20% reduction in fan capacity, the supply air temperature is increased by 5^{o}F and the chilled water temperature by 7^{o}F, the reduction in load is 0.85-1.1 W/sqft. As with VAV systems, the optimum combination of fan capacity reduction and reset of supply air and chilled water temperatures is specific to the particular building and HVAC system. The demand reductions obtained for the DCAV systems are greater than those obtained for VAV systems because the set-point for the supply air static pressure was not reduced in the VAV systems.

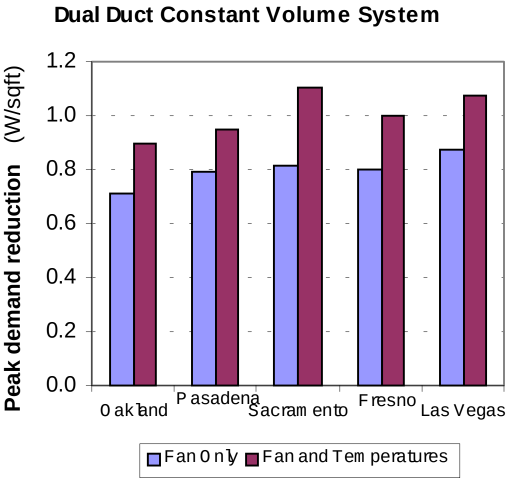


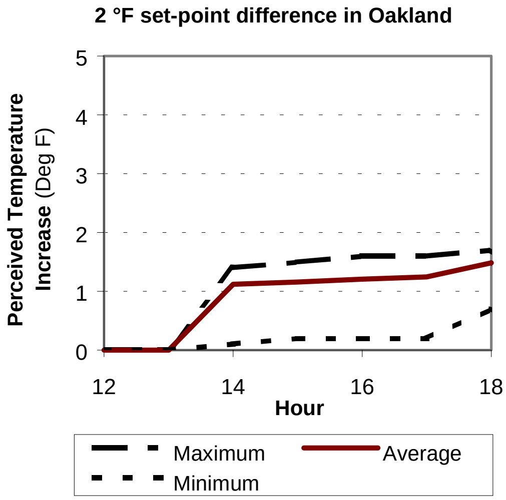
Figure 5. Load reductions obtained from reducing fan capacity by 20% (Fan Only) and reducing fan capacity by 20%, increasing supply air temperature by 5^{o}F and increasing chilled water temperature by 7^{o}F (Fan and Temperatures) in DCAV systems

If it can be achieved, reducing fan capacity plays a significant role in reducing load in CAV systems. If the zone temperature controllers are network-addressable, reducing fan capacity captures higher savings while retaining the advantage of direct control over zone temperature. If the zone temperature controllers are not network-addressable, reducing fan capacity while increasing zone temperatures captures most of the load reduction in the example case presented above. However, unlike VAV systems, it is difficult to reduce fan capacity intermittently in CAV systems and so the potential demand reductions for CAV systems presented here are not applicable to curtailment programs in most cases.

Fan capacity reductions could be implemented on a permanent basis if on-site measurements and engineering analysis show that adequate air distribution can be maintained and that the resulting reduction in cooling capacity could be compensated for by reducing the supply air temperature when load curtailment is not required.

Thermal Comfort

Implementation of cooling load reduction will naturally result in a change in thermal conditions. Some adjustment is required by building occupants to make higher temperatures acceptable. Changes in dress codes may be necessary in some cases.


2 °F set-point difference in Oakland

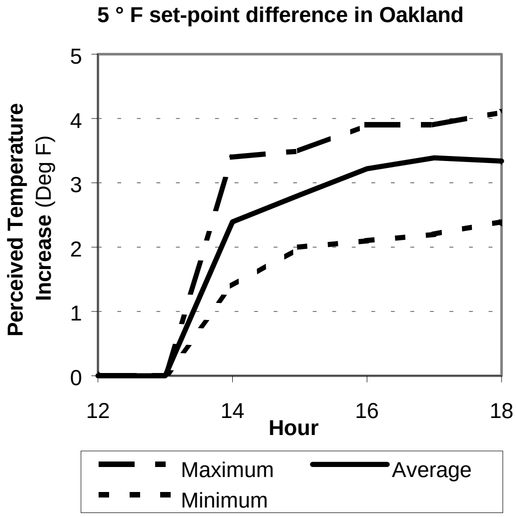
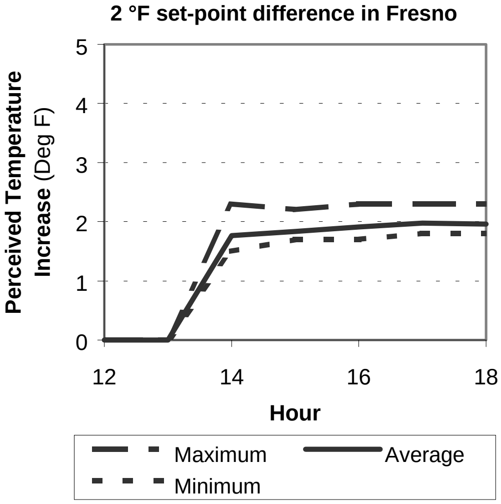

5 ° F set-point difference in Oakland

Figure 6. Rise in temperature perceived by the occupants over time for 2^{o}F (top) and 5^{o}F (bottom) zone temperature set-point increases in Oakland

Thermal comfort depends on both the air temperature and the radiant temperature. Humidity has less impact in California climates. The radiant temperature depends on the surface temperatures in the space. When the cooling supplied by the HVAC system is reduced, the air temperature in the space rises fairly quickly because of heat gains from equipment, occupants and lights. The surface temperatures respond more slowly, especially if the surfaces are heavyweight.


2 °F set-point difference in Fresno

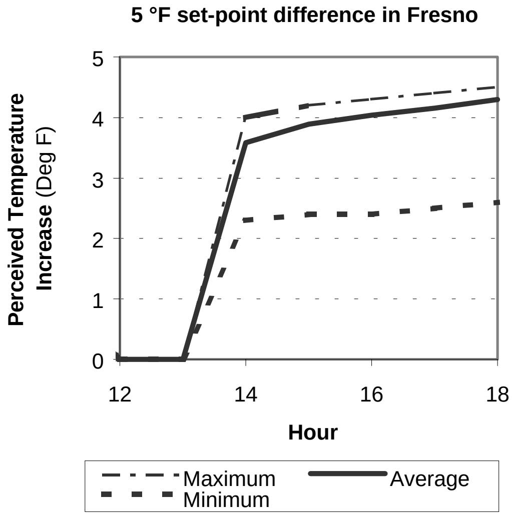

5 °F set-point difference in Fresno

Figure 7. Rise in temperature perceived by occupants over time for 2^{o}F (top) and 5^{o}F (bottom) zone temperature set-point increases in Fresno.

The rise in comfort temperature for different set-point increases is shown in Figure 6 for a Bay Area location such as Oakland and in Figure 7 for a Central Valley location such as Fresno. In each case, the maximum perceived temperature rise occurs in the west-facing zone of the top story. Temperatures rise more rapidly in Fresno because the greater cooling load heats up the thermal mass of the building more quickly when the supply of cooling is significantly reduced.

Commercial vs. Industrial Loads

For commercial buildings, the loads that can be reduced in response to power emergencies tend to be cooling loads and to a lesser extent, lighting. This can present a problem for commercial customers participating in the Summer DRP if there is less cooling (or no cooling) on the baseline days compared to the curtailment day. This is particularly a problem in milder climate zones with shorter hot spells.

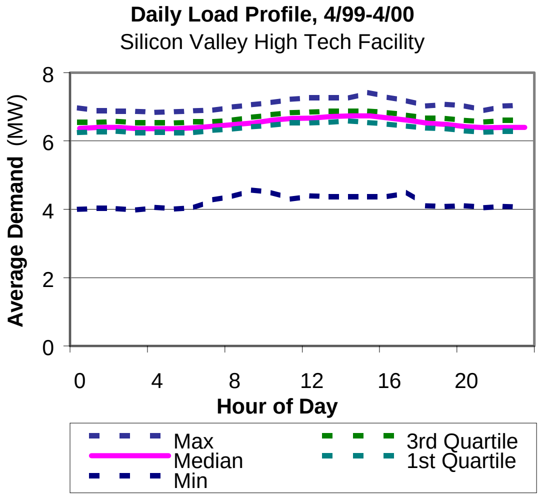


Figure 8. Sample Industrial Load Profile

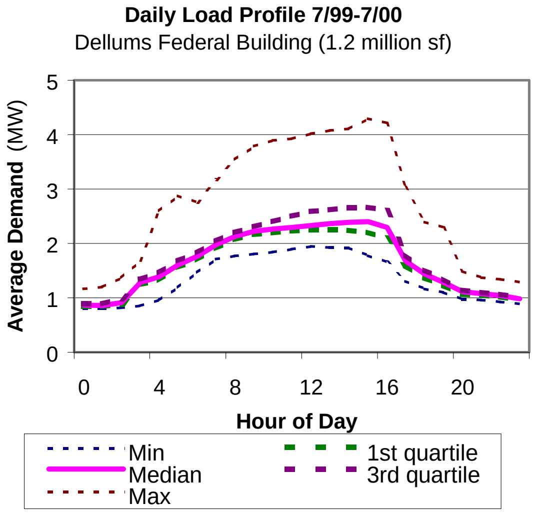


Figure 9. Ronald V. Dellums Federal Building, Oakland Load Profile

A typical load profile for an industrial facility is shown in **Figure 8**. The daily load profile is essentially the same from day to day, independent of weather, and establishing a baseline is a simple matter. Contrast this with the office building profiles shown in **Figures 9 and 10.**

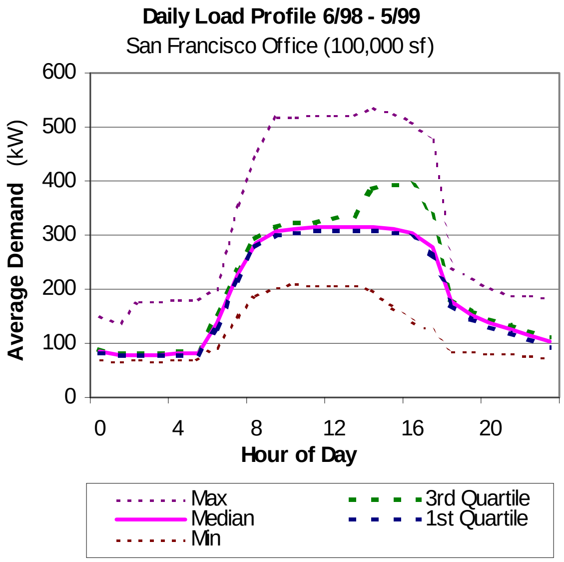


Figure 10. Sample Office Building Load Profile

GSA EXAMPLE

As previously mentioned, the U.S. General Services Administration (GSA), which oversees the operations of all Federal properties, is participating in the California ISO Summer Demand Relief Program. GSA bid a 1.2 MW load reduction aggregated over four California buildings, which was later reduced to two buildings due to the absence of interval metering in two of the buildings. The remaining participants are the Ronald V. Dellums Federal Building in Oakland (1.45 million square feet), and the Phillip Burton Federal Building in San Francisco (1.2 million square feet).

GSA will be implementing some of the measures described above to reduce load during power emergencies. Lighting reduction strategies will also be explored. As seen in **Figure 9**, the 3^{rd} quartile line indicates that 75 percent of the time, the Dellums Federal Building in Oakland operates at or below 2.7 MW. With a peak in 2000 of 4.2 MW, there is expected to be ample opportunity to shed load. In connection with the launch of GEMNet (see below), the controls, plant, and fan systems are being re-commissioned to improve performance. This commissioning effort is focused on the control sequences and EMCS data reliability. This will provide the remote operator with more reliable data and control necessary to respond to load shedding requests.

GEMNet

GSA Pacific Rim Region is in the process of bringing all of its buildings onto an Internet-based network known as the GSA Energy Management Network, or GEMNet. GEMNet consists of a remote monitoring infrastructure, maintenance management software and energy reporting and diagnostic tools, linked to individual building automation systems though a global front-end package. It utilizes the BACNet communications protocol, with gateways for systems that are not BACNet compliant. The open protocol will also facilitate communication with utilities and scheduling coordinators.

A remote operator will be responsible for actively supporting programming and optimization of building systems, and will also be implementing global triggering of operating sequences, including demand responsive strategies. For Summer 2001, the GEMNet operator will in fact be the point of contact for the ISO curtailment orders, and will be responsible for coordinating the response to curtailment orders and executing the load sheds in the four buildings.

A central server will archive energy consumption and other monitored data from key mechanical and electrical systems. Diagnostics software capable of analyzing trends in equipment performance will assist in identifying problems and detecting equipment failures in the various buildings. The operator will also have the ability to control some of the connected buildings remotely via an Internet connection, depending on the capabilities of the building's automation system. This will allow the operator to initiate demand shedding control strategies remotely.

Currently, the basic network infrastructure is in place and operational, with a few pilot buildings connected, including the Dellums Building in Oakland.

Curtailment Scenarios

Although GSA was not a participant in the Summer 2000 Demand Reduction Program, whole-building power data from the Dellums Federal Building were examined for the curtailment hours called in Summer 2000 and the baseline calculation method for Summer 2001 DRP was applied.

Figures 10 and 11 depict load curtailment scenarios under different weather conditions. In both cases, the baseline is approximately the same; however, as expected, the amount of curtailment would be much greater in the first case. The baseline and the curtailment are calculated separately for each hour, so only one hour in the afternoon is shown here. The grey bars indicate baseline days; the black bars the actual demand reduction day. The horizontal line represents the average load during a given hour for the baseline days and hence, the baseline.

Figure 10 shows the load reduction that would have been required on the peak day of 2000. This is an extreme case, as the temperature in Oakland rarely reaches 103°F as it did on June 14. However, it does illustrate the challenge of demand reduction in a mild climate. For most of the days preceding the peak day, temperatures were over 30°F cooler. In this particular case, the building would have had to shed over 30% (1.5 MW) just to *meet* the baseline (2.5 MW), and an additional 0.75 MW to meet its target demand reduction promised to the California ISO. Analysis of operation data collected from the EMS on that day suggests significant room for load reduction by improving chiller operation and sequencing (Piette et al., 2001).

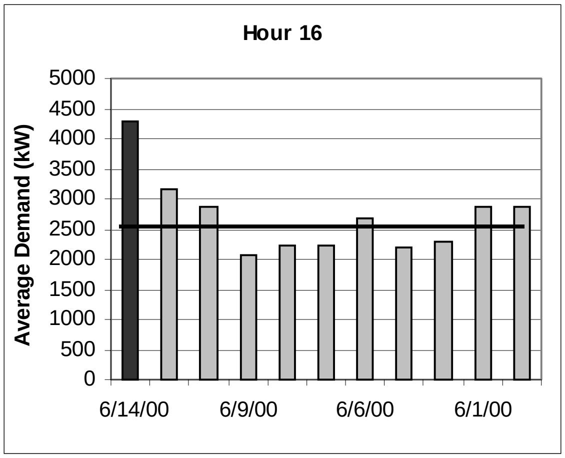


Figure 10. Peak Day Load Shedding Scenario

The load reduction scenario shown in Figure 11 is for an ISO demand reduction day which had similar weather conditions to the previous days. With the load much closer to the baseline, it would be much easier to demonstrate a load curtailment in this case; however, without the cooling plant in operation, there are fewer loads to curtail. The curtailment may still be achieved on non-cooling days by implementing fan and lighting and load reduction strategies.

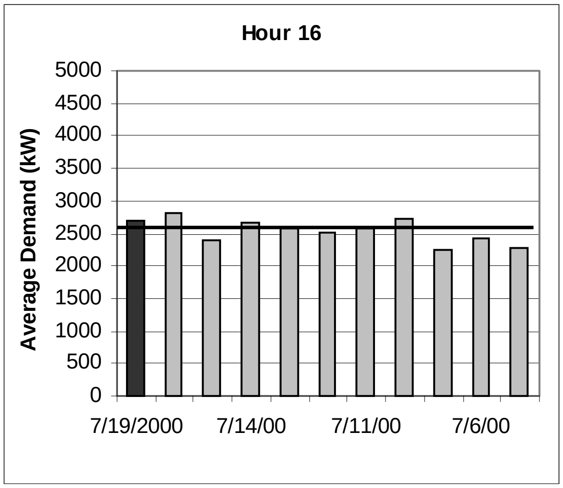


Figure 11. Cool Day Load Shedding Scenario

CONCLUSIONS

The ability of commercial office buildings to shed load during power emergencies is affected by temperature and cooling loads. In particular, there may be less incentive to participate in demand relief programs for commercial property owners and managers as the definition of shedding depends on the level of electricity use during the preceding days.

Never before has California invested as much in peak demand management as it has for Summer 2001. Analysis of weather variables and customer response to load shedding programs for this Summer should be analyzed and weather factors incorporated into future programs.

ACKNOWLEDGEMENTS

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