The Impact of Real-Time Pricing of Electricity on Energy Use, Energy Cost, and Operation of a Major Hotel

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In cooperation with the Pacific Gas and Electric Company, a major hotel in downtown San Francisco is undertaking an upgrade of its control systems. The upgrades to the 40-story, 1500-room facility include replacing the building management system (BMS), extending BMS control to additional building equipment, and automating control strategies to make them responsive to real-time pricing (RTP) for electricity.

As part of planning replacement of the control system, electricity consumption and price data was assembled and analyzed. The hotel's energy performance was examined in relation to electricity prices and other parameters. This paper describes the energy use characteristics of the facility, including daily load profiles under typical and peak conditions. The data for this site shows a strong correlation between daily peak load and daily total energy use.

The paper describes the local utility's RTP rate structure and discusses the primary strategies used by the hotel's operating staff to respond to high electricity prices. The impact of these strategies on energy performance, operating cost, and overall facility management are examined. It was found that the RTP rate is very attractive to the customer, reducing energy operating costs by upwards of 20%. However, these savings come at some expense in terms of the operator effort required to intervene in normal operating sequences to implement price-responsive strategies. The paper suggests that automation of price response could substantially enhance cost savings.

INTRODUCTION

This report describes analyses performed using hourly electrical load data from a major hotel located in downtown San Francisco, California. The work was performed as part of a project directed at automating operator response to real-time pricing (RTP) in the hotel. This is a joint effort being undertaken by the San Francisco Marriott Hotel with Pacific Gas and Electric Company (PG&E). As part of the project, a new building management system (BMS) is being installed, and a broad range of systems that were previously operated manually are being brought under control of the BMS.

There were two primary motivations for this study. First, the utility is interested in identifying control technologies that benefit both the customer and utility, such as operating strategies that are responsive to RTP for electricity. Under RTP, electricity prices more accurately reflect the utility's cost of providing service than do traditional rates. If the utility's price signals are successful in prompting load management actions by customers, then the customer benefits from lower energy costs. These load management actions also benefit the utility by (1) reducing use of supply options on the margin, which are typically more expensive to operate, and/or (2) delaying capital expenditures to increase capacity in the generation and/or transmission and distribution (T&D) systems.

A second motivation for this study is to learn more about the effectiveness of alternative utility rate structures. Although the future of current rate structures is uncertain due to impending deregulation, it is likely that some forms of dynamic rates will be available for at least the larger utility customers, and in fact may be mandatory. Thus, the hotel offers a relatively unique opportunity to examine what is being done at present in response to RTP, and to explore options that might be attractive in the future.

BACKGROUND

There have been few studies of energy use in hotels. The most recent (Zmeureanu et al. 1994) examined billing and survey data for hotels in Ottawa, Canada. Gross energy use characteristics, end-use breakdowns, and climate sensitivity were examined for 16 buildings, most of which were considerably smaller than that of interest here.

Real-time pricing for electricity is a relatively new approach in utility rate making. Much of the published information about RTP deals with rate design; less has been written about how the customer can take advantage of these evolving rates. Two noteworthy publications include examinations of optimal control of HVAC equipment under RTP (Daryanian & Norford 1994) and optimal control of thermal energy storage systems used for heating and cooling (Daryanian, Tabors & Bohn 1991; Daryanian, Norford & Tabors 1994). These studies focus on development of methodologies for achieving effective control of specific systems under RTP, but provide limited guidance as to which control strategies should be considered in a particular situation.

FACILITY DESCRIPTION

The hotel, located in downtown San Francisco, is a 1.5 million ft^2 facility that opened in 1989; the hotel has been on the local utility's RTP rate since that time. The hotel is oriented towards convention business, with 1,500 guest rooms and about 80,000 ft^2 of meeting space, as well as a large complement of public spaces, restaurants, and retail facilities. The hotel has a 5-story low-rise section and a tower rising to 40 floors. The low-rise section includes the main kitchen, administrative spaces, tenant offices, meeting rooms, restaurants, and other public spaces.

The central plant contains two 900-ton chillers and two 350 bHp gas-fired boilers that provide hot water for domestic uses and space heating. Recently, an additional 150-ton chiller was installed in conjunction with a 3000 ton-hour thermal energy storage (TES) system. There are 375 Hp in chilled water pumps, 150 Hp in condenser water pumps, and 80 Hp in cooling tower fans.

The facility includes 42 air handlers with a total of over 1000 Hp in supply and exhaust fans. Meeting rooms, public spaces, recreational areas, administrative offices, and retail facilities are served by a combination of variable-air-volume and constant-volume systems. Four pipe fan coil units are used for conditioning guest rooms.

In this study we examine electricity use by the hotel and its relation to price parameters; natural gas use was not included, as customer costs for natural gas are less than 10% of total energy operating cost for the hotel. The electric load data used in the analysis was obtained from the utility. Climate data gathered at San Francisco International Airport was used in some analyses. Both manual and automated checks were performed to examine the completeness and internal consistency of the electric load data set; the data were also graphed and examined visually to identify outlier points and other data that appeared inconsistent. Suspicious data was examined in more detail, and, where appropriate, either confirmed, corrected, or removed from the data set.

RESULTS

The first section below focuses on electricity consumption in the hotel. The second section examines the real-time pricing response of the facility and the resulting energy operating costs.

Hotel performance characteristics

Electricity Use. Figure 1 shows daily electrical energy use of the hotel for the period from 1 September 1992 through 31 August 1993. The substantial daily variation in total electricity consumption is due largely to the nature of the hotel's clients: this is primarily a convention hotel, and energy use is strongly affected by the level of meeting activity, which varies from day to day.

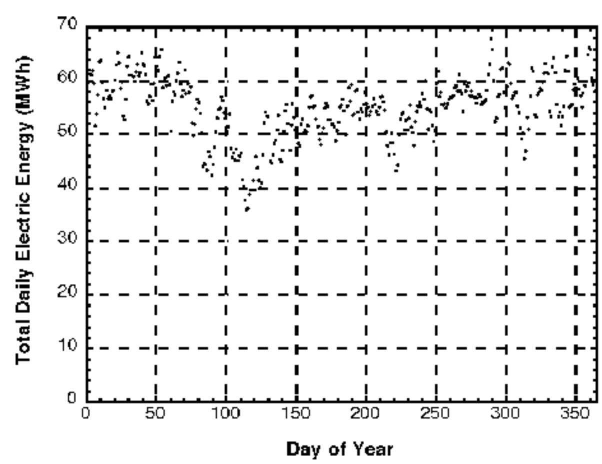
Some seasonal structure is evident in Figure 1, but consumption appears to be more closely related to function, as suggested by the substantial decreases in total consumption coinciding with holiday periods (Thanksgiving near day 85, Christmas near day 120, and Independence Day near day 315) and with a period of low occupancy near day 225 (early April 1993). These effects are also traceable to the convention-driven occupancy of the hotel.

Daily peak loads were examined and found to be strongly linearly correlated (R = 0.96) with daily total load:

$$(\text{Electric Energy}) = 5.5 + 18.0 * (\text{Peak Demand})$$

where the units for energy and demand are MWh and MW, respectively. That the slope in this relationship is so large

Figure 1. *Daily Total Electricity Consumption*

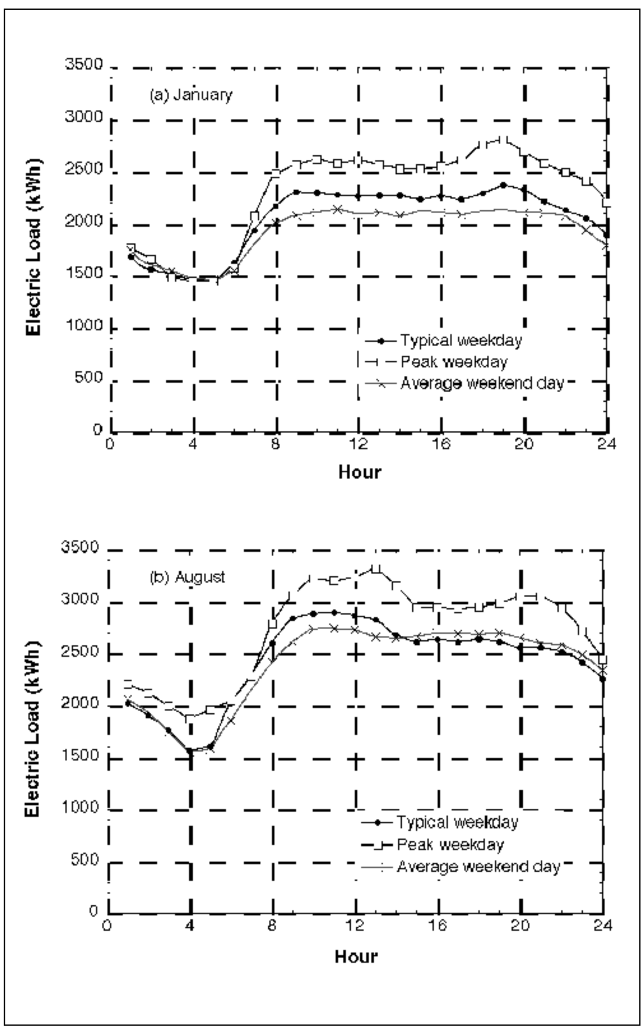


implies a load profile that is relatively flat on a given day, and the goodness of fit implies that the underlying shape of the load profile does not change dramatically from day to day.

Figure 2 shows typical daily electric load profiles; Parts a and b of the figure are derived, respectively, from the January and August 1993 data. For each month, days were categorized as peak days (those whose total integrated load is in the top 10% of all days in the month), typical weekdays (weekdays other than peak days), or weekend days. For each category, the hour-by-hour average electricity demand was calculated and plotted in Figure 2.

In each month, the basic shapes of the load profiles are very similar. In the winter, the load profiles are nearly flat through the day, and there is a small peak in the early evening. In the summer, there is a broad peak in mid- to late morning, and the profiles are relatively flat through the evening. During the winter, it is somewhat surprising that the portions of these load profiles between midnight and 6:00 am are so similar. In August, weekend days are quite similar to typical weekdays except for the absence of the broad daytime peak. That peak is probably due to electricity use for operation of the meeting facilities, which are less commonly used on weekends. It is interesting that the daily minimum electrical energy use at 4:00 to 5:00 am is season-independent at about 1.5 MW. Note that these load profiles are consistent with the suggestions of the correlations of daily peak demand and total electricity consumption.

__Figure 2.__ Daily Electricity Consumption Profiles



Both hourly electric loads and daily total electric loads were examined in relation to hourly and daily average drybulb and wetbulb temperature, and to cloud cover data. Daily peak electricity demand was also examined in relation to temperatures. Not surprisingly, the climate signature of the building is quite weak.

Real-Time Pricing

RTP rate description. RTP rates are intended to more accurately reflect marginal energy and capacity costs to the utility than do traditional TOU rates. Typically, these rates vary from hour to hour and from day to day, depending on the utility's cost of providing service, and the hourly prices are transmitted to the customer in advance. During periods when the cost of providing service is high, prices will be high, thereby providing the customer with an incentive to reduce energy use.

The utility's RTP rate as it is currently designed is described below. For each hour, the price has three components:

- A fixed base rate of about $0.035/kWh.
- A variable component dependent on the spot gas price and a 24-hour projection of the system incremental cost.
- ''Adders'' that are triggered by indicators of system load conditions (e.g., summer peak temperatures at selected locations in the service area) and capacity availability on a given day (e.g., spinning reserve). An adder is a multi-hour incremental price profile that varies with the hour of the day, but does not vary from day to day. Three different adders can be triggered. The daily T&D adder and the threshold T&D adder account for local transmission and distribution capacity costs. The LMPS (load management price signal) adder accounts for generation and bulk transmission capacity costs. The T&D adders affect prices from 9:00 am to 9:00 pm, while the LMPS adder affects prices between 12:00 noon and 7:00 pm.

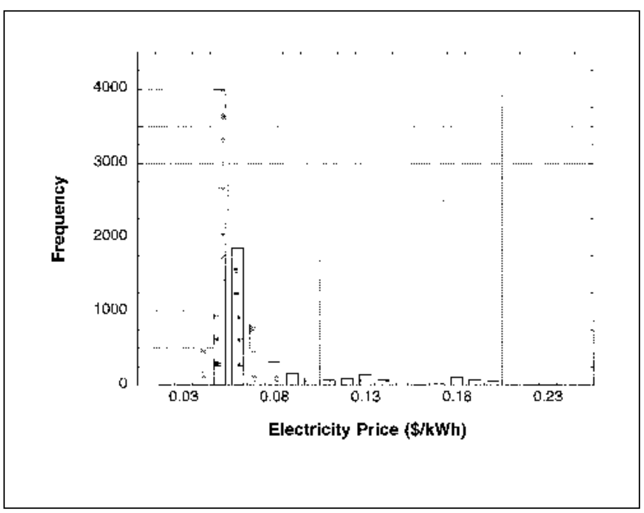
Under normal operation, 24 hourly prices are transmitted by the utility before 4:00 pm to printers located at the customer's site; these prices apply starting at midnight following the transmission. It is the customer's responsibility to review the prices and plan its operation to take advantage of them. The only deviations from day-ahead pricing occur on those days when the LMPS adder is invoked; on those days the prices for the LMPS period can be updated as late as 11:00 am on the day when these much higher prices will apply.

The adders in the utility's RTP rate serve a revenue purpose similar to that of demand charges under TOU rates. The T&D threshold adder and LMPS adder have maximum values of about $0.30 and $0.80/kWh from 2:00 pm to 5:00 pm on days when they apply, and are smaller during the 2 hours preceding and following these peak hours. Regulatory requirements limit to 10 the number of days that the LMPS adder can be invoked each year. The T&D threshold adder can be invoked 25 days during the summer, and 25 days in the winter. It is expected that 15–20% of a customer's total electricity cost will be due to the T&D threshold adder and the LMPS adder.

In addition to the energy charge, the RTP rate includes a relatively small demand charge. This is intended to account for distribution costs for serving the highest demand, independent of when it occurs.

RTP rate characteristics. Energy costs under the utility's RTP are highly dynamic, varying from a low of about $0.035 to nearly $1.50/kWh. Figure 3 shows the frequency of prices during the one-year period from 1 September 1992 to 31 August 1993. The horizontal scale in this figure extends only to $0.50/kWh. During this period, there were a few occurrences of prices up to about $1.40/kWh, but these points were not included in the figure because they were so infrequent. Prices larger than about $0.40/kWh only occur on LMPS days; during the one-year period shown here the LMPS adder was in effect for only a single day because the summer was relatively mild and there was an abundant hydroelectric resource.

Figure 3. *Annual Distribution of Real-Time Prices*



As is evident in Figure 3, the price frequency distribution has a strong peak near $0.05/kWh; prices are between $0.04 and $0.05/kWh for nearly 50% of the hours of the year. The RTP distribution drops sharply on both sides of the peak, and there is a tail at higher prices. There is a relatively high frequency of prices out to $0.40/kWh, with about 250 occurrences of prices from $0.17 to $0.20/kWh and about 30 occurrences of prices between $0.30 and $0.40/kWh.

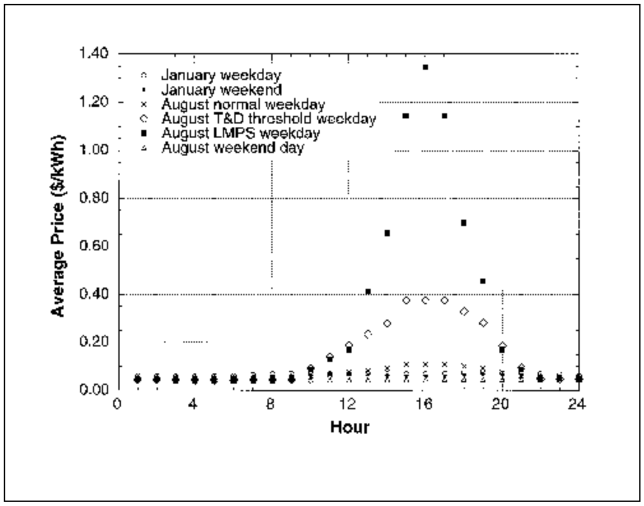
For reference, it is noted that one would have a similar peak in the price frequency distribution for the applicable TOU rate (the utility's E-20S rate), but it would occur at a price about $0.01/kWh higher than that for RTP; the peak in the TOU price distribution would be associated with the off-peak period. Also, the alternate TOU rate has a maximum energy charge of slightly less than $0.10/kWh; these prices occur during peak hours in the summer.

Though there are similarities between the RTP and E-20S TOU price distributions, direct comparison of the rates are difficult because of the large difference in the way that peak demand is priced. With the TOU rate there is a demand charge of nearly $16.00 per peak kW, while for the RTP rate the demand charge is $2.55/kW. As discussed earlier, RTP prices higher than about $0.12/kWh are attributable to the T&D and LMPS adders, and are intended to generate revenue for purposes similar to the demand charges on the alternate E-20S TOU rate. Effective comparison of the rates requires that they be viewed in the context of customer load profiles.

Figure 4 shows typical 24-hour price profiles for the RTP rate; the data is from January and August 1993. The profiles for each category (e.g., August T&D days) are based on hour-by-hour averaging of the data from all days in the month that are in that category. The price at night is typically in the range from $0.04 to $0.06/kWh for all days of the week in both seasons. For a particular hour, the LMPS and T&D adders are constant from day to day; at their peak, they are large relative to the sum of the constant base rate plus the variable component (these two components are typically less than $0.11/kWh). Therefore, there is little difference in the price profile for all days where neither the LMPS nor T&D threshold adder is in effect.

On weekends in both seasons, the prices remain relatively constant in the $0.04 to $0.06/kWh range, similar to the rates at night. During summer weekdays when neither the LMPS nor T&D threshold adder is in effect, prices increase

Figure 4. Typical Daily Real-Time Price Profiles



for about eight hours during late morning and through the afternoon hours, peaking during the late afternoon at about $0.11/kWh. The behavior during winter weekdays is similar, but the average peak price reaches only about $0.07/kWh. It is noted that recent revisions to the RTP rate design provide substantially larger price variations during winter weekdays, and in some cases produce higher prices during nighttime hours than during the day.

Building operation under real-time pricing

Under time-varying rates for electricity, operating strategies that alter the electric load profile can be effective in reducing energy costs. Three distinct types of electric ''load management'' strategies can be defined:

- Load shifting: Movement of selected electric loads from periods when electricity costs are high, to periods when they are low. Example: TES for cooling.

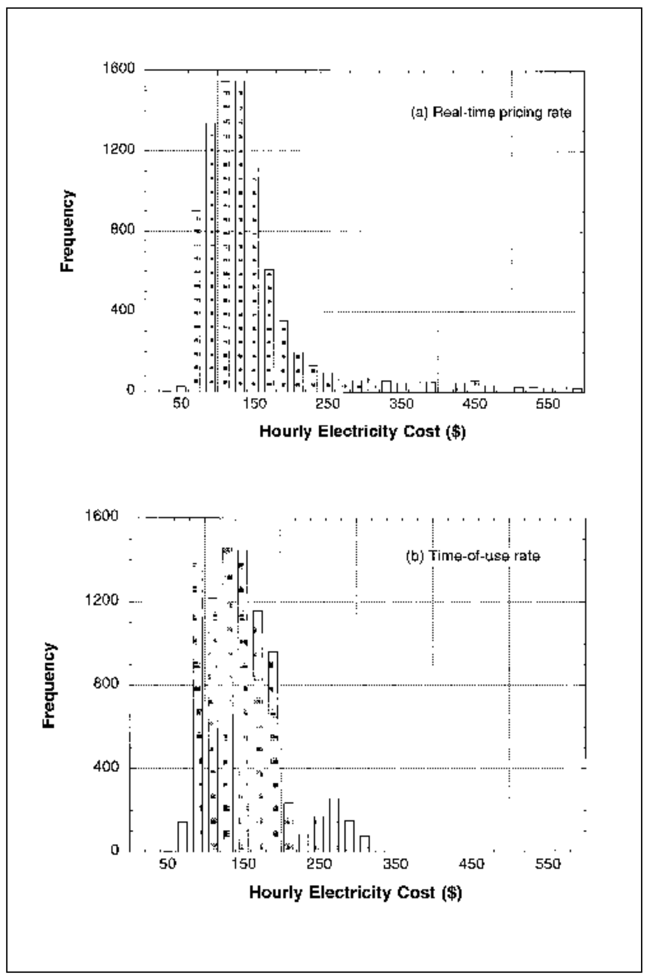
- Load sharing: Reduction in the amount of electricity purchased from the utility during periods when electricity costs are high, and replacement with either (1) electricity from other, lower-cost sources or (2) non-electric energy sources. Example: Use of emergency generators as a non-emergency supplement to utility service.

- Load shedding: Elimination of selected electric loads during periods when costs are high. Load shedding includes both modulating and shutting off of devices; this may or may not involve a modest compromise of comfort conditions or productivity in the facility. Examples: Turning off equipment in unoccupied space (non-intrusive); cycling of air handler fans (intrusive or non-intrusive, depending on the situation); raising thermostat settings to reduce cooling requirements (intrusive).

Load management strategies in any of these categories can be used to reduce energy operating costs under standard TOU rates, curtailable rates, or RTP. The effectiveness of a particular strategy will depend on the structure of the electricity rate and on the magnitude of the effect of the strategy on the electric load profile over time (e.g., over a rate cycle or day). The acceptability of a strategy will depend on the extent of the intrusion on critical functions, on the effort required of the operating staff to implement the strategy, and on how often the strategy must be implemented in order to have an appreciable effect on operating cost.

Energy cost characteristics. Hourly electricity consumption and price data have been used to calculate hourly electric energy costs for the hotel assuming either RTP or TOU rates. Figure 5 shows frequency distributions of hourly energy cost; Part a of the figure is for RTP rates, and Part

Figure 5. Annual Distribution of Hourly Electrical Energy Cost



b is for the applicable TOU rate. The cost distribution under RTP rates peaks at about $120 per hour; there is a relatively high frequency of hourly rates in the range from $60 to $180. The frequency distribution has a long tail, attributable to the LMPS and T&D threshold days, that extends to hourly costs of up to $600; there are a few occurrences of costs above $800 per hour.

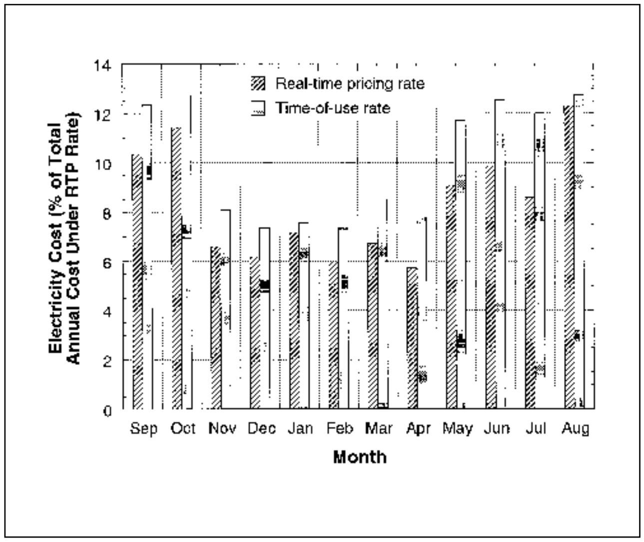
The one-year period over which this analysis was performed was atypical in two ways. First, there was only a single occurrence of LMPS prices; typically there have been 5–10 LMPS days each summer. Second, prior to changes made in the rate design in 1994, T&D threshold prices did not occur during the winter months. Therefore, under normal circumstances one would expect the tail of the cost frequency distribution to be more prominent, and to extend to somewhat higher prices.

Had the hotel been on the alternate TOU rate, and had the electric load distribution been the same as for the actual operation under RTP rates, then the frequency distribution of hourly electricity cost would be as shown in Figure 5b. Here the distribution is less strongly peaked and somewhat flatter in the hourly cost range from about $80 to $190. There is an obvious secondary peak at about $270 per hour, attributable to the on-peak energy cost. Finally, the hourly cost distribution under TOU rates cuts off at about $320 per hour, and does not have a tail extending to the higher prices customers occasionally experience under RTP.

Comparing the RTP and TOU distributions, it is evident that the RTP customer will occasionally see relatively high hourly costs, and that the integrated cost under the high price conditions is appreciable. Whether it is more advantageous to focus RTP response on the relatively small number of high-price hours where the hourly savings can be large (e.g., $1.00/kWh), or to concentrate instead on the large number of hours where the prices are relatively low so the hourly savings will be low (e.g., $0.15/kWh) will depend on the opportunities and constraints the customer's facility offers. Because RTP control typically requires considerable manual intervention (at this point in time), it is suggested that the customer is forced to concentrate on the high-price periods. Clearly, the bulk of actual total cost occurs at lower prices; if RTP-responsive control and operating strategies can be automated, then substantial additional savings are possible.

Figure 6 provides a month-by-month comparison of total electricity costs for this hotel under RTP and TOU rates. The monthly costs have been calculated using actual load data from the hotel, and actual RTP and TOU rates, assuming that the billing periods coincide with months. Demand charges are included in the monthly totals for both rates, but customer charges, power factor adjustments, and tax are neglected. Monthly costs under both RTP and TOU rates

Figure 6. *Total Electricity Cost*



have been normalized by the total annual cost under the RTP rate to preserve the customer's privacy. In spite of the normalization, the month-to-month relationships of total electricity costs under each rate, and the relationship of costs between the two rates, are properly represented by the figure.

Figure 6 indicates that the costs under the TOU rate are higher than under the RTP rate for every month of the year, in some cases by up to 30%; aggregated across the year, total energy costs under RTP are about 20% less than with the applicable TOU rate. These comparisons assume that the electric load that was actually obtained with the RTP rate would also be experienced with the TOU rate in effect. As discussed later, load management actions are being taken by the hotel staff in response to RTP, so some caution must be used in interpreting the comparisons in Figure 6.

Another reason for caution, as discussed earlier, is the atypical infrequency of LMPS conditions and of T&D threshold conditions during the winter, which produce a bias toward lower-than-normal costs under RTP. In spite of these caveats, the magnitude of the difference between costs under the two rates is surprising.

RTP-responsive control strategies. There is no well-defined and generally-accepted list of RTP-responsive control and operating strategies that utility customers can turn to for guidance. Taking full advantage of utility cost saving opportunities typically requires considerable experimentation by the customer in order to identify strategies that reduce costs without unacceptably compromising functional conditions. Further, because existing control technology has limited capability to automate price-responsive actions, the experimentation often requires manual intervention by the operators.

This hotel appears to be highly innovative in its response to RTP, and they actively seek new opportunities to realize energy cost savings under RTP. In the period during which the data examined here was collected, three strategies were regularly used: reset of the discharge air temperature of air handlers in the meeting facilities, pre-cooling meeting rooms, and chiller shutdown.

The 12 air handlers serving the 80,000 ft^2 of major meeting room space were designed as variable air volume (VAV) units, but are operated essentially as constant volume (CV) units. Under normal operation, the dampers are set for air volumes that have provided acceptable comfort conditions based on past operating experience; these damper settings are considerably smaller than 100% open. The dampers are adjusted in response to occupant feedback or examination by the operating staff. During periods when RTP prices are high, discharge air temperatures are reset upwards, reducing the load on the chilled water loop.

If the air handlers were operated in the VAV mode, the increased discharge air temperature would reduce chiller load, but delivered air quantities would increase, so fan energy would increase. With CV operation of the air handlers, resetting discharge air temperature will result in higher space temperatures, and unless occupant complaints force damper reset in all spaces, the net effect is to reduce chiller electricity requirements. The operating staff has sufficient experience with this strategy that the discharge air temperature reset is not large enough to prompt response from all occupants.

The second RTP-responsive control strategy used was pre-cooling spaces, primarily for the ballroom and major meeting rooms. Air handlers began operating sufficiently before the beginning of occupancy, during periods when electricity costs were low, to ensure that the room temperature was at the bottom of the comfort range at the beginning of the occupied period. The space temperature was then gradually relaxed during high-price periods, reducing cooling requirements.

The third strategy was to completely shut down the chillers; this was generally limited to days when the LMPS adder was in effect and prices were highest. The hotel has a chilled water loop containing about 30,000 gallons of water with a design chilled-water temperature of 55°F. On a day when mid- to late afternoon electricity prices were expected to be high, the chilled water loop temperature was reset downward to about 44°F early in the day before the LMPS adder went into effect. The loop was pre-cooled during the low-cost periods, allowing the chillers to be shut down and the building to coast through the highest-cost period. Depending on local climate conditions and occupancy load, the chillers could remain off for three hours or more; during this period the chilled water loop temperature floated up to perhaps 65°F.

The practicality of the chiller shutdown strategy for the hotel is enhanced by two factors. First, latent energy removal requirements in the San Francisco climate are typically modest, so operation at chilled water loop temperatures as high as 65°F is possible without seriously degrading comfort conditions. Second, because of regional climate and microclimate conditions, the days when electricity prices are highest typically do not coincide with severe conditions in San Francisco: as a result, the hotel typically is not operating under peak conditions when the prices are highest.

Impact of RTP responses on energy use and operation. Attempts have been made to identify the hotel's energy and energy cost savings directly attributable to the RTP strategies. Two of the strategies (pre-cooling and reset of discharge air temperature) will primarily affect chiller electricity use, by reducing the load on the chiller during high-price hours. Direct observation of their impact is very difficult because (1) the chillers are not submetered, and (2) these strategies are expected to have an effect on total electricity consumption that is small relative to instantaneous electricity demand for the entire hotel. Attempts to identify this effect using standard engineering analyses would be confounded by variations in occupancy loads and climate conditions.

The utility's annual reports for the RTP program (see, e.g., Tabors Caramanis & Associates 1995) have included an analysis of the price sensitivity of demand based on estimation of price elasticity. The analysis assumes a simple relationship between load and price:

$$\text{Electric Load} = C * (\text{Electric Price})^{E}$$

where C is a constant and E is the elasticity (i.e., the percent change in electric load in response to a 1% change in electric price). The elasticity is determined by linear regression of the logarithm of electric demand on the logarithm of electric price. In estimating standard errors, appropriate measures are taken to account for serial correlation in the load data.

The statistical analyses were performed for data from the hotel for the past several years, and were not repeated in the present study. Prior to 1994, the price elasticity estimates from the utility's analysis were not considered statistically significant. Whether this is an indication that the RTP response is negligibly small or is an artifact of the simple model is not clear. The most recent analysis of 1994 load and price data estimated a price elasticity of about 0.04% in the summer, and 0.07% in the winter; these estimates were considered statistically significant. It is noted that in late 1994 the hotel began operating an ice storage system.

At least some of the utility RTP program annual reports have included a somewhat more engineering-oriented examination of the response to LMPS and T&D threshold adder days. These analyses have implied that the hotel shows an occasional response to the higher prices experienced on these days.

In the present study we have looked more closely at the load data on LMPS days when the chiller shutdown strategy was used. As noted earlier, there was a single occurrence of LMPS conditions during the year for which the bulk of the data analysis reported here was performed. In order to encompass a larger number of LMPS days, we examined electric load, electricity price, and climate conditions for the period from 1 January 1992 through 31 August 1992 (the 8 months preceding the beginning of the period examined here). This period included 5 additional LMPS days.

The load, price, and climate data for the five days when the LMPS adder was used during 1992 were separated from the rest of the data for comparative analysis. The data for non-LMPS days was further segregated between weekends and weekdays. Figure 7a shows the hotel's load profile for the five LMPS days in comparison to the hourly average of the loads for all other weekdays during July and August. It is readily apparent that on most LMPS days there is a significant reduction in the hotel's load that coincides with the highest prices. Presumably this is due to load management actions taken by the operating staff. On one of the LMPS days (17 August), it appears that no effective load management actions were taken.

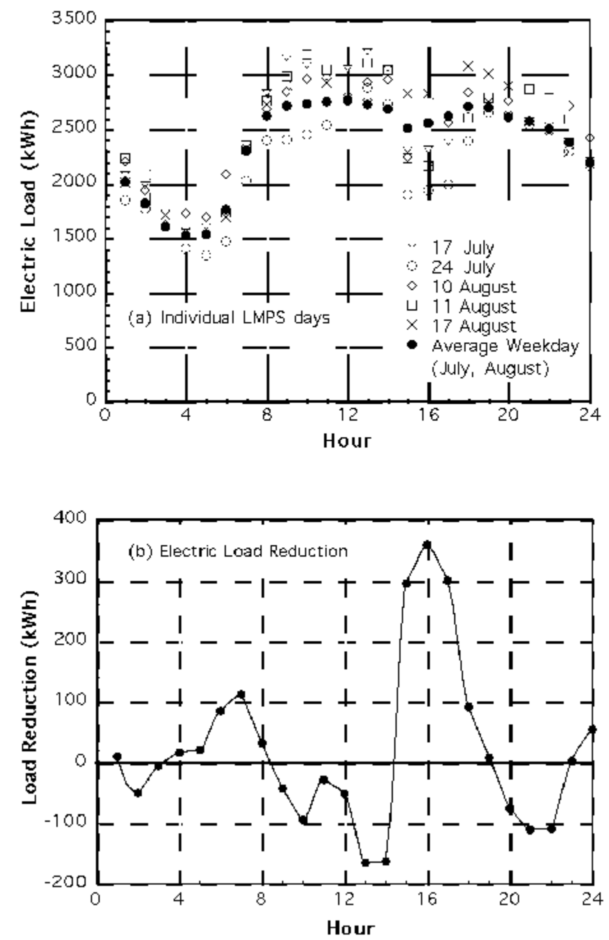
In order to estimate the load reduction in response to LMPS signals, the load profiles for the four LMPS days when effective load reduction actions were taken were averaged and compared to the normalized average load profile for all non-LMPS weekdays during July and August. The average profile for the non-LMPS days was normalized by multiplying the hourly load by the following ratio:

$$E_{LMPS}/E_{non\text{-}LMPS}$$

where E_{LMPS} is the total electrical energy used between midnight and noon on the average for all LMPS days, and $E_{non\text{-}LMPS}$ is the total used during the same time period on the average non-LMPS day.

Figure 7b shows the difference between the load profiles for the average LMPS day and the normalized average weekday. According to this analysis, the load reduction in the hotel approaches 350 kW at the time of the maximum price. This reduction is not unreasonable assuming the chillers are running at somewhat less than 50% of full load, which is a common occurrence in the hotel. Note that for a few hours both before and after the peak price period (hours 13 and

Figure 7. *Comparison of Electric Load under Typical and LMPS Conditions*



14, and hours 20, 21, and 22), the difference is negative. These periods correspond respectively to the pre-cooling of the chilled water loop before chiller shutdown, and pulldown of the chilled water loop temperature when the chillers are restarted. The total area under the difference profile is 502 kWh; counting only the hours between 8:00 am and 11:00 pm, the area is 222 kWh. This may indicate that load shedding is taking place in response to price, in addition to the load shift that is indicated by the shape of the difference profile.

Note that the load reduction estimated here is in comparison to the average weekday (not including LMPS days). On essentially all of the days that enter into the weekday average, the T&D adder is in effect, so prices approach $0.20/kWh each day. If there is a response on the part of the operating staff to these prices, then our estimate of load reduction due to the LMPS adder may be underestimated. Based largely on discussion with the hotel's operation staff, we expect that there may be some daily response to the T&D adder (e.g., pre-cooling meeting rooms), but that it has a relatively small effect on total load. This is consistent with the conclusions of the independent analyses reported in the annual reports.

Responding to real-time prices clearly can lead to energy cost savings. However, there are operational costs associated with RTP response, and they are often difficult to quantify. For example, most RTP customers implement responses by manually intervening in control: when the hotel manually shuts down its chillers, operators must monitor chilled water loop and space temperatures, and manual intervention is also necessary in discharge air temperature reset and in pre-cooling. Estimating labor costs associated with such activities is not a straightforward process.

The need for building operators to invest effort in implementing RTP response is a significant barrier to successful application of RTP. Response will generally be limited to those situations where the marginal cost for effort to take action is smaller than the energy cost savings that can be achieved; that is, response typically will be limited to the highest-cost periods.

We believe that development of effective means for automating response to RTP will greatly increase cost savings to the customer by allowing implementation of load management actions for which marginal benefits are smaller than is presently practical. As an example, automation of chiller shutdown could allow the hotel to achieve load reductions on every weekday of the summer that are comparable in magnitude to those now achieved on LMPS days. Although the per-kWh savings are smaller by a factor of about 5 or 6 on the typical weekday, the number of these days is larger by a factor of perhaps 10, so cost savings with the automated control should at least double or triple.

ADDITIONAL CONSIDERATIONS

In the course of this project, data that provides a relatively complete description of the hotel's operation also was assembled and used to examine the impact on electricity consumption of guest room occupancy, meeting room use, restaurant and banquet meal service, and more traditional parameters such as climate. These exploratory analyses showed that the daily total electric load is not amenable to prediction based on the commonly available functional parameters for the hotel, and using simple linear modeling techniques. As an alternative, efforts are currently under way to develop an artificial neural network model for predicting the hourly electric load for the hotel based on these same explanatory variables. The results of these efforts will be described in a separate publication (Kreider et al. In preparation).

The control system being installed in the hotel will allow a much higher degree of automation in operating the facility. This will allow implementation of control actions that are presently not practical because of the effort required on the part of the operating staff. It is expected that these new capabilities will allow testing and evaluation of a broad range of new operating strategies and control technologies in the future.

Finally, it is noted that the hotel recently installed a TES system for use in cooling the building. This technology appears to be very attractive in conjunction with RTP or other dynamic rates. However, TES system sizing is complex, even with straightforward TOU rates; RTP or other dynamic rates will alter the cost-benefit picture in a complex way. Furthermore, dynamic rates will add considerable complexity to TES control requirements. These are areas where study is needed.

CONCLUSIONS

Basic electrical energy use characteristics for a large hotel have been examined. The following observations have been made:

- Daily total electricity energy use appears to be most heavily influenced by occupancy. However, no strong causal relationships have been observed to specific functional parameters that are available (e.g., meals served or number of guests).
- There is a strong correlation between peak load on a given day, and total energy consumption on that day.
- The underlying shapes of the daily electric load profiles are relatively invariant. The daily minimum load is constant throughout the year. The daily peak load scales upwards and downwards without appreciable change in the basic load shape.

Comparisons were made between the operating costs for the hotel under the local utility's RTP rate and the TOU rate that the facility would otherwise be on. These comparisons indicate that there is substantial operating cost benefit in the RTP rate, due largely to the difference in demand charges for the two rates.

Manual response to RTP appears to be quite effective for the building examined here. However, because it is labor-intensive, its practicality is probably limited to circumstances where high prices are quite infrequent and well-defined. In a case where prices were more dynamic and more continuous than with the adder structure used by the local utility, typically it would be more difficult to decide when the additional effort should be expended. We believe that development of control technology that will allow automation of RTP responses would substantially increase energy cost savings for customers on RTP rates now in effect, and simplify operator decisionmaking in the future when more dynamic rates will probably be common.

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