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An analysis of load reduction and load shifting techniques in commercial and industrial buildings under dynamic electricity pricing schedules

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ABSTRACT

Due to fluctuations in the supply and demand for electricity throughout the day, the wholesale cost to an electric utility to produce and provide electricity to customers varies continuously throughout the day. Presently, certain utilities are devising alternative electricity pricing structures that vary cost based upon the time in which electricity is used. Energy efficiency retrofits are typically conducted with consideration to static pricing plans for electricity and are indifferent to dynamic pricing policies. To be most effective, energy efficiency measures should be considered with regard to the time energy is used. This study investigates potential cost conservation measures that focus on reducing energy at times of higher energy costs to maximize energy savings. It is shown that shifting work schedules of office buildings with one shift 1 h early can slightly reduce monthly electricity rates by 1–3% and that thermal energy storage systems can be cost effective for retrofits with dynamic pricing schedules and areas that need full replacement of air conditioning.

1. Introduction

Due to the continuous variability of supply and demand of electricity and the fact that there are no economically viable options for the storage of electricity, the cost to an electric utility to provide electricity to customers fluctuates continuously [1]. Despite the variability in cost to provide electricity, utilities have historically charged a flat rate for electricity without regards to the time in which energy is consumed. In this scenario, since the consumer of electricity is not charged for the real time cost of production of electricity, they have no economic incentive to reduce their energy usage during times of high production cost. This can cause long run inefficiencies to the utility by having to build additional generation capacity to meet times of peak demand.

The reason that utilities historically charged a flat rate for electricity despite the variable cost of production of electricity was due to the technological constraints of measuring the real time power usage of customers. However, this has now begun to change as advanced metering infrastructure, also known as smart meters, have become technologically feasible [2]. Advanced metering infrastructure allows both the electric utility and the end consumer of electricity to know the amount of electricity that is being consumed by the end user on a continuous basis. As penetration of advanced metering infrastructure has increased to 22.9% of electric customers in 2012, the number of customers on dynamic electricity pricing structures has also increased, albeit at a much smaller rate [3].

When both the consumer and producer can measure how much electricity a consumer is utilizing at a specific moment, two events can happen. The first is that the utility can charge consumers for electricity based on their cost of producing electricity. These cost structures are called dynamic pricing schedules. While some electric utilities, such as the Hawaiian Electric Company (HECO), which serves the Island of Oahu in the State of Hawaii have initiated optional, opt-in dynamic electricity pricing schedules for commercial and industrial customers, other electric utilities, such as Pacific Gas and Electric (PGE), which serves the San Francisco Bay Area, and Southern California Edison (SCE), which serves the Los Angeles metropolitan area, each have mandated forms of dynamic pricing schedules for commercial and industrial customers. The second event that can happen is that when a customer is aware of the time in which they use electricity and the time in which electricity is more expensive, they can react to times of high pricing by reducing their electricity usage at those times. Dynamic pricing of electricity for residential customers has been shown to their reduce electricity usage and peak demands [4]. However, under certain mandated

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dynamic electricity cost structures for commercial and industrial buildings, the reduction in electricity usage and peak demands was less pronounced [5,6].

Due to the rising costs of electricity and growing concern about the long run effects of pollution caused by electricity generation, energy efficiency solution providers have been working on finding measures to reduce electricity usage in buildings. However, since utilities have been typically charging flat rates for electricity, these energy efficiency solution providers focused solely on reducing energy usage within a building while indifferent to the time in which energy usage was reduced. When energy efficiency solution providers make energy conservation recommendations indifferent to dynamic pricing, it has been noted that monthly bill reductions due to these energy conservation recommendations are lower when a building transitions to a dynamic pricing structure.

To compensate for this deficiency, energy efficiency solution providers should expand their focus to also suggest measures to commercial and industrial consumers of electricity to shift their demands to times when electricity prices are lower and to reduce overall peak demands. This study suggests several measures to shift electricity usage to off peak times for commercial and industrial customers when electricity prices are lower. Subsequently, the anticipated daily energy usage and daily electricity cost under dynamic pricing schedules after these measures are enacted is measured for multiple case studies. These case studies are from buildings that have undergone energy efficiency studies and represent a variety of commercial and industrial building types, including office buildings and condominium residences. From this information, the viability of these measures is discussed for each building type.

2. Methods

In this study, specific cost saving measures that account for dynamic pricing structures are suggested. These cost savings are designed not specifically to reduce energy, but to either shift energy usage to times when electricity is less expensive or to reduce the overall peak demand of electricity usage. The suggested cost savings measures are then analyzed for their cost savings in various dynamic pricing structures of various utilities. In the following sections, specific dynamic pricing structures used by utilities and suggested cost conservation measures are described.

2.1. Dynamic pricing structures

As opposed to flat rate electricity pricing schedules in which consumers are charged a flat rate for electricity regardless of the time in which it is consumed, there are alternative dynamic pricing policies utilized by electric utilities which charge a variable price for when the energy is produced. Types of dynamic pricing structures include Time-of-Use (TOU) pricing, which has two or three tariffs for energy consumption, critical peak pricing (CPP), which has an additional critical peak price tariff on certain high demand days, and real time pricing (RTP), where the price of electricity continuously varies based upon supply and demand conditions. These are explained further in detail by reports by the Electric Power Research Institute (EPRI) [8] and the Electricity Innovation Lab of the Rocky Mountain Institute [9].

2.2. Proposed cost conservation measures

In this study, several potential cost conservation measures that can both reduce peak demand of commercial and industrial buildings and shift their energy usage to off-peak times when electricity is not as expensive are evaluated. The considered cost conservation measures include alternative scheduling, and installation of thermal energy storage systems. This list is not exhaustive and other methods of further reducing costs under dynamic pricing schedules could be devised.

2.2.1. Alternative scheduling

One manner in which electricity loads could be shifted from on peak times to off peak times in all dynamic pricing schedules could be by shifting the time when occupants are present in a building. For commercial and industrial environments, this could be accomplished by shifting the schedule of employees. Schedules could be shifted 1 h earlier than usual so that commercial and industrial buildings would not use as much electricity in the late afternoon as usual. This could partially shift their electricity usage to off peak periods. Besides having workers come in 1 h early and leave 1 h earlier, there are numerous permutations of schedules that could be enacted in order to reduce electricity costs.

One clear advantage to schedule shifting is that it represents an action that can be utilized to save money without any upfront investment. One disadvantage to shifting schedules in any form is the fact that it requires behavioral changes that could be disruptive to businesses that operate in a traditional office environment.

2.2.2. Thermal energy storage

Presently, in an air conditioned building, air conditioning is provided at the moment that it is needed. Alternatively, with a thermal energy storage system, air conditioning systems could be run to produce chilled water or ice at unoccupied times of the day. During these times, electricity prices would be lower. The chilled water or ice, which is then left in storage tanks, can be called during occupied times when it is needed.

Thermal energy storage systems can be used on large scale chilled water systems. There are two strategies to installation of a chilled water thermal energy storage system. One strategy would be to retrofit a thermal energy storage system onto an existing chilled water system in order to transfer all of the needed energy into cooling of a building from daytime to the nighttime. The other strategy would be to install a smaller chilled water system with thermal energy storage that would run continuously. Then air conditioning could be provided from both the chilled water system and the thermal storage system. Thermal energy storage systems can be installed onto chilled water systems at a cost of approximately $250 per ton h of cooling storage (this is equivalent to approximately $71 per kWh of cooling storage) [10].

In addition to thermal energy storage systems for chilled water systems, thermal energy storage systems designed for use with direct expansion split air conditioning systems and rooftop packaged air conditioning systems that are in use small and medium sized commercial and industrial buildings have been recently developed. Specifically, this type of thermal energy storage system is designed to store 30 ton h of cooling storage (∼105.5 kWh cooling storage) cooling at a rate of 5 tons cooling (∼17.58 kW cooling) for 6 h at a cost of approximately $833 per ton h (this is equivalent to approximately $237 per kWh of cooling storage). While this is more expensive than thermal energy storage for chilled water systems, it could be installed on smaller capacity air conditioning systems, and therefore not require as high of an upfront investment [11].

The main advantage to a thermal energy storage system is that it can shift the use of air conditioning equipment to off-peak periods of electricity pricing while still providing air conditioning at needed times. In this way, thermal energy storage does not require behavioral change to a building's occupants. The main disadvantages of thermal energy storage systems are that they require an upfront investment of equipment and their use and maintenance may not be readily familiar with building management staff. However, this makes installation of thermal energy storage systems equivalent to

Table 1
Reference buildings.

Building designation	Building type	Building occupancy schedule	Surface area (m^2)	Average electricity usage (kWh/year)
Building A	Commercial office	One shift	3600	600,000
Building B	Commercial office	Continuous, majority first shift	2900	550,000
Building C	Residential condominium	Continuous residential	70,000	4,200,000

other energy conservation measures that require new equipment and upfront investment.

3. Results

To analyze the change in electric utility costs from adoption of cost conservation measures designed to either shift electric loads to lower peak times or to reduce overall peak electricity demands, energy consumption data for multiple buildings has been procured. The data utilized is from energy efficiency studies conducted on a variety of building types on the Island of Oahu, Hawaii. While some of this data is the same that was used in Yalcintas et al. additional data was procured from additional energy efficiency studies, also on the Island of Oahu.

Since a wide variety of cost conservation measures are proposed in this study, multiple commercial and industrial buildings that have different sizes and purposes were utilized to analyze the effectiveness of different cost conservation measures. A table of these buildings including their surface area and purpose is included in Table 1.

Originally, baseline energy usage for the building was determined for these energy studies through interviews with building staff, power monitoring of equipment, and site visits of each building. Subsequently, energy conservation measures were suggested. The energy conservation measures that were considered for these buildings were based upon a static pricing structure for electricity. Dynamic pricing structures were not considered because the default electric rate option for commercial and industrial buildings under HECO, the utility that serves the Island of Oahu, Hawaii, is a flat electricity rate structure.

For the purposes of this study, several cost conservation measures beyond what was previously considered were analyzed. These cost conservation measures were considered for shifting energy usage to lower priced times and to reduce peak electricity usage. The savings of each cost conservation measure based upon multiple different dynamic electricity pricing structures from several utilities are provided.

The cost schedules of several electric utilities were utilized. These utilities include the Hawaiian Electric Company (HECO), which services the Island of Oahu, in the State of Hawaii, Pacific Gas and Electric (PGE), which services the San Francisco Bay Area, and Southern California Edison (SCE), which services the Los Angeles Metropolitan Area.

Presently for commercial and industrial buildings, HECO has a flat rate electricity pricing schedule and several optional, opt-in Time-of-Use rates. These Time-of-Use rates do not have any critical peak pricing component. For this study, the standard commercial and industrial electric rate was used and Rider T of the commercial and industrial electric rate was used for Time-of-Use calculations. Details regarding these specific cost schedules may be found on the HECO website [12].

Presently for commercial and industrial buildings, PGE has a mandatory Time-of-Use rate with a critical peak pricing plan. In the PGE critical peak pricing plan, PGE may call between 9 and 15 critical peak intervals during the summer period. For this study, the standard Time-of-Use with critical peak pricing rate was used for calculations. For critical peak pricing intervals, 2 monthly critical peak events were simulated to be called between the summer months of May and October. Details regarding the specific cost schedules may be found on the PGE website [13].

Presently for commercial and industrial buildings, SCE has a mandatory Time-of-Use rate with a critical peak pricing plan. The critical peak pricing plan includes exactly 12 critical peak days that are to be called at the discretion of SCE. Additionally, there is an optional, opt-in real time pricing plan. This real time pricing plan lists hourly costs based upon several factors to simulate actual load conditions on the grid of the SCE service territory. These factors are seasons (summer and winter), days of the week (weekdays and weekends), and temperature. The temperature is based upon the previous maximum recorded by the National Weather Service the previous day.

For this study, both the Time-of-Use with critical peak pricing plan and the real time pricing plan are analyzed. To simulate the number of critical peak days, maximum temperature weather data of the Los Angeles metropolitan area from the year 2013 from the National Weather Service was utilized. The 12 hottest summer weekdays were stated to be critical peak days for this study. This temperature data from the National Weather Service was also utilized to determine the hourly costs of electricity under the real time pricing plan [14]. Details regarding the specific cost schedules may be found on the SCE website [15].

3.1. Alternative scheduling

One manner to reduce electricity costs and shift peak loads is to devise alternative working schedules. While there are an infinite amount of different schedules that could be implemented in a working environment, including shifting schedules to different seasons, different days of the week and earlier or later hours in the day, the schedule that is going to be analyzed for this study is beginning the working day 1 h earlier and departing 1 h earlier than the normal schedule. For this cost conservation measure, Buildings A and B, which are two office buildings, are utilized. Building C, which is a residential condominium, is not utilized for this cost conservation measure because as a residence, there is no feasible way of dictating the schedule of residents.

3.1.1. Building A

Building A is an office building with an occupied shift between 6:00 am and 6:00 pm. While air conditioning and lighting are operational at only these times, there are IT Server systems that have to be utilized 24 h a day. The average daily power usage for Building A is displayed in Fig. 1. For the purposes of this study, the operation of this office building was shifted from 6:00 am to 6:00 pm to 5:00 am to 5:00 pm. While the power usage for the equipment that is not dependent on occupancy is not shifted, the power usage for the air conditioning and the lighting equipment is moved 1 h earlier. The average daily power usage for Building A in the modified schedule is displayed in Fig. 2.

When enacting this schedule change, the annual electricity costs are reduced under all electricity cost schedules. While the annual electricity costs are only reduced by 0.25% under the flat rate from HECO, costs from shifting the schedule of Building A 1 h earlier in the dynamic electricity pricing schedules from HECO, PGE and SCE are reduced by between 1% and 3%, with the greatest cost reduction

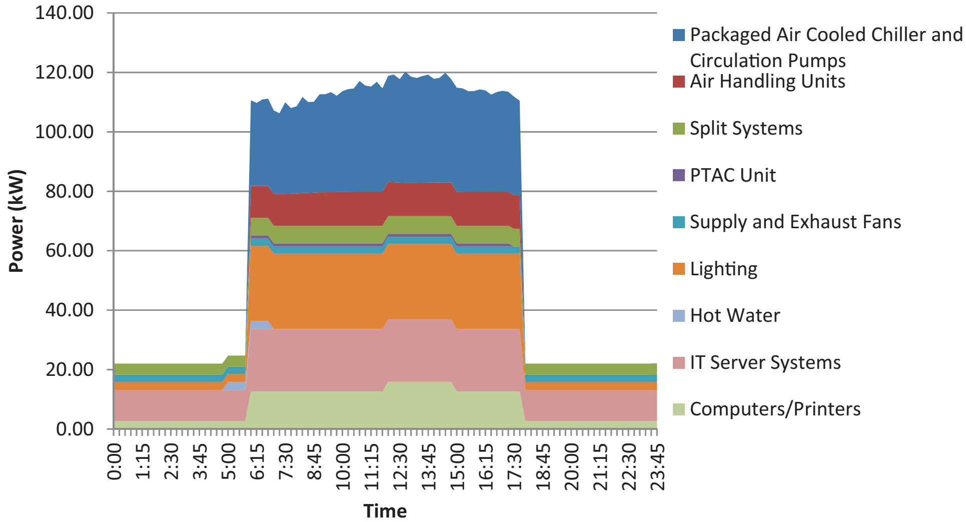

Fig. 1. Building A load profile (original schedule).

of 2.96% occurring by changing schedules under the SCE Time-of-Use rate.

While the 1 h schedule shift reduces monthly electricity costs for all months within Building A, monthly electricity bills were reduced by a greater amount during the summer months. This is due to the fact that electricity is more expensive during summer periods due to higher electricity demands due to increased needs for air conditioning. By moving the schedule of Building A forward 1 h only during the summer season, monthly electricity rates during the summer are reduced by approximately between 2.5% and 5.5% under the dynamic cost schedules of PGE and SCE, where the greatest reduction of 5.50% occurs under the SCE Time-of-Use rate. Having building occupants arrive 1 h earlier only during the summer could prove a way to retain the majority of the electricity savings while being less disruptive to nominal business operations.

For even less disruption, schedule shifting could only occur on a critical peak interval day for customers under a critical peak pricing schedule and only under days of extreme energy costs under a real time pricing schedule. For example, in Building A, reductions in daily electricity costs by arriving 1 h earlier under a day with extremely high costs under real time pricing or a critical peak pricing day can range between 10% and 16%, with the greatest daily cost reduction occurring of 16.21% occurring under the SCE critical peak pricing rate. Having building occupants arrive 1 h earlier only during high cost days would be the least disruptive to nominal business operations while providing the greatest amount of cost savings per days changed.

In the event that it is necessary that an office have employees present at specific hours, due to the nature of their business, the staggered work schedule could be done in groups. For example, half of the employees of an office could arrive at 6:00 am and leave at 3:00 pm and the other half could arrive at 10:00 am and leave at 7:00 pm. This type of staggered work schedule could allow for a partial reduction in energy usage during the critical peak time while still allowing employees to be present at all times. By enacting this change, there could also be an overall demand reduction. There is also overlap between the two groups so that all groups can work together.

3.1.2. Building B

Building B is an office building that is occupied continuously. While the building is continuously occupied, there are fewer

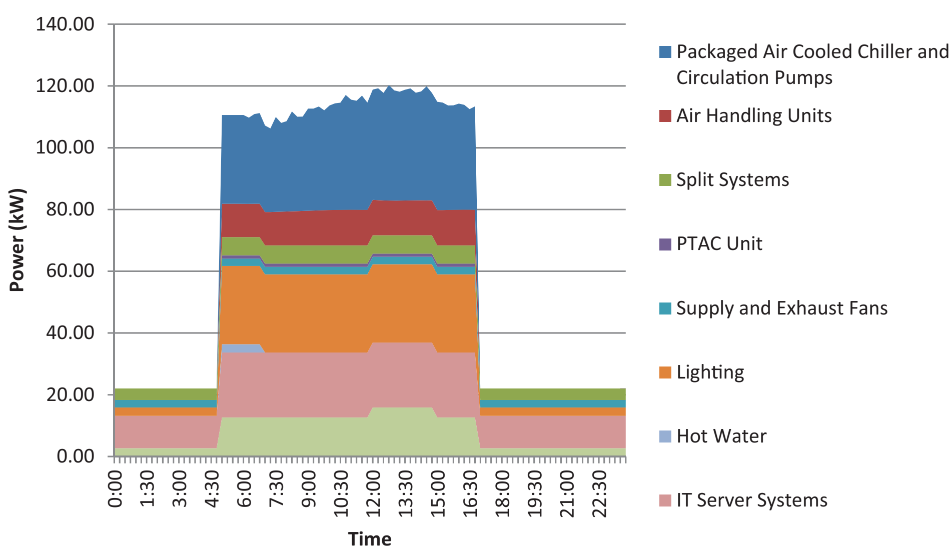

Fig. 2. Building A load profile (modified schedule).

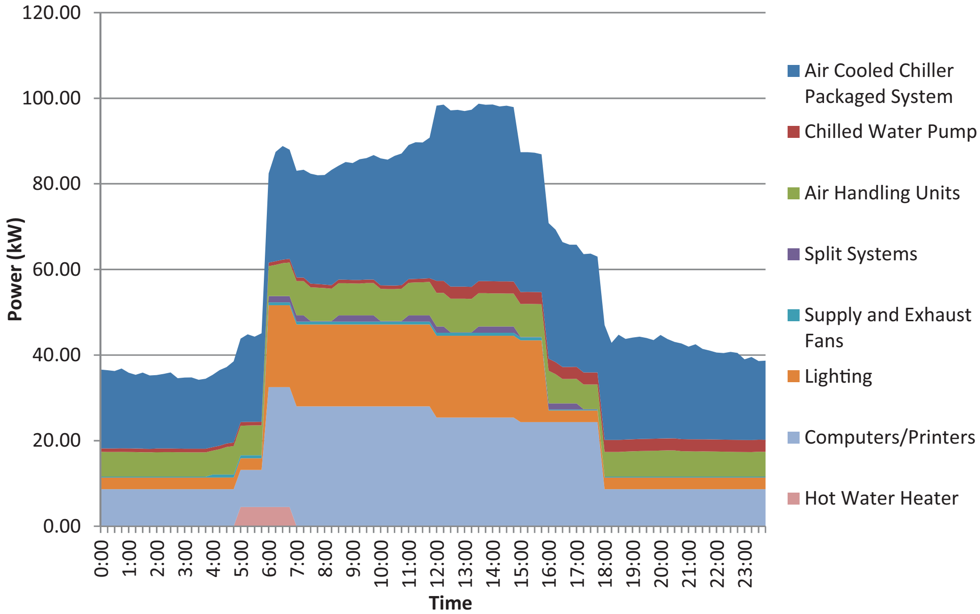

Fig. 3. Building B load profile (original schedule).

occupants in the evening period. The building's first shift is between 6:00 am and 4:00 pm, while the second shift is between 4:00 pm and 6:00 am. In this building, air conditioning, lighting and the usage of computers is continuous, but is slightly reduced during the second shift.

The average daily power usage for Building B is displayed in Fig. 3. For the purposes of this study, the operation of the first shift of this office building was shifted from 6:00 am to 4:00 pm to 5:00 am to 3:00 pm. To account for this, the first shift usage of equipment is from 5:00 am to 3:00 pm. The average daily power usage for Building C in the modified schedule is displayed in Fig. 3.

When enacting this schedule change, the annual electricity costs are reduced under all electricity cost schedules, except the flat rate under HECO. While the annual electricity costs are not reduced with the flat rate from HECO, shifting the schedule of Building B 1 h earlier in the dynamic electricity pricing schedules from HECO, PGE and SCE reduce costs by between 0.5% and 2%, with the greatest cost reduction of 1.96% occurring under the SCE real time pricing rate (Fig. 4).

3.2. Thermal energy storage

In this study, the effect of installation of thermal energy storage systems for both chilled water systems and split air conditioning systems under multiple dynamic cost schedules is considered.

Due to lower ambient temperatures during the evening, air conditioning systems are more efficient at providing cooling. However, thermal energy storage systems store cooling in the form of ice, which air conditioning systems are less efficient at producing. Depending on the location of the thermal energy storage system, this could render production of cooling either more or less efficient during evening production of ice. Therefore, for the purposes of this study, the exact amount of energy usage consumed for air conditioning during the day was shifted to the evening. This would have

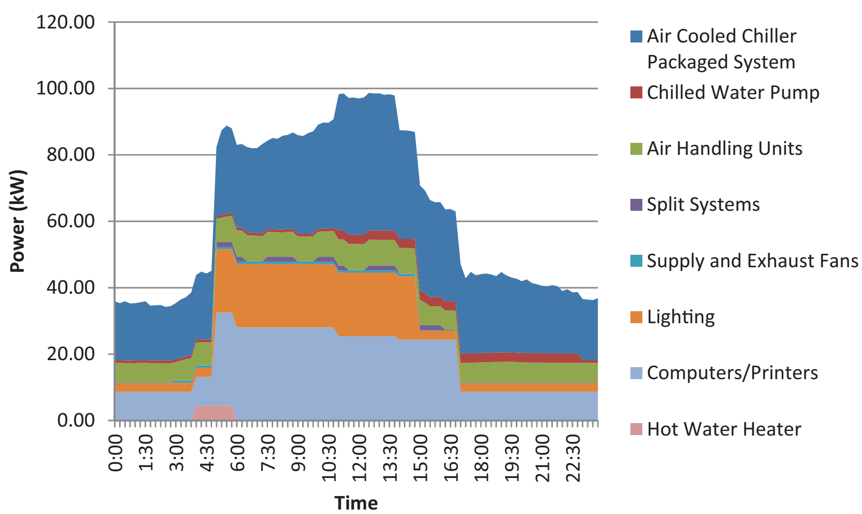

Fig. 4. Building B load profile (modified schedule).

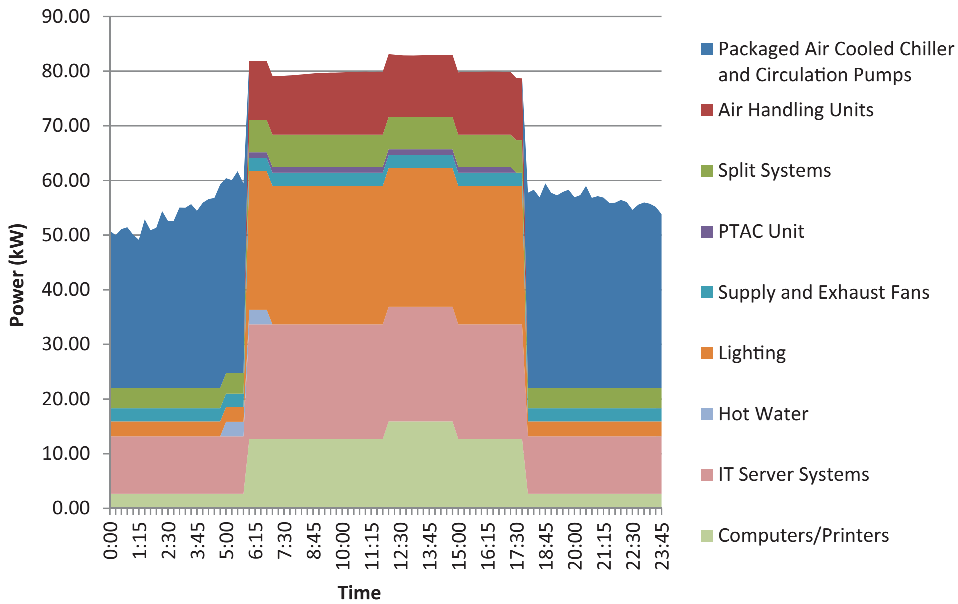

Fig. 5. Building A load profile (chilled water system thermal energy storage).

to change based upon the location in which the thermal energy storage system would be installed.

3.2.1. Building A

For Building A, which is primarily conditioned by a chilled water system, the effect of utilizing thermal energy storage to fully shift the electric load of the chiller from the daytime into the evening is analyzed. The original power usage graph is displayed in Fig. 1, while the modified power usage with a thermal energy storage system fully storing the cooling during the evening is presented in Fig. 5. In this scenario, the peak electricity demand for Building A is reduced from approximately 120 kW to 83 kW, while total amount of energy utilized is the same at approximately 50,000 kWh per month.

The estimated cost for a chilled water thermal energy storage system is based upon a required cooling capacity of 300 ton h (1055 kWh of cooling capacity) and an estimated cost of installation of the thermal energy storage system of $250 per ton h ($71 per kWh of cooling capacity). This estimated cost is $75,000. From this cost estimate, a simple payback period that is based on the estimated cost for a thermal storage system that will fully store the required cooling for this building and the reduction of demand charges and on peak energy usage can be calculated.

At 14.4 years, the thermal energy storage system has a longer payback period under the HECO flat rate schedule than the dynamic pricing schedules, which have simple payback periods ranging from 6.5 to 11.1 years, with the shortest payback period of 6.5 years occurring under the SCE Time-of-Use rate. In this case, these simple payback periods make thermal energy storage a more attractive investment for areas with dynamic pricing schedules.

3.2.2. Building B

During energy efficiency studies for this building, the chilled water system for Building B was noted to be in poor condition and it was recommended to eventually replace the chiller. In this building, the maximum cooling capacity needed for this building was approximately 65 tons (229 kW) while the second shift has a cooling capacity of approximately 15 tons (53 kW). For this study, instead of replacing this chiller with a 65 ton (229 kW) chiller, the alternative of replacing this chiller with a 52 ton (183 kW) chiller with 100 ton h (352 kWh of cooling capacity) of thermal energy storage is considered. This would allow the chiller to operate continuously and store some of the cooling capacity needed during the evening for use during the peak period.

The original power usage graph is displayed in Fig. 3, while the modified power usage with a thermal energy storage system partially storing the cooling during the evening is presented in Fig. 6. In this scenario, the peak electricity demand for Building B is reduced from approximately 99 kW to 87 kW, while total amount of energy utilized is the same at approximately 45,000 kWh per month.

When using an estimated cost of installation of a chilled water system at $1200 per ton ($341 per kW), the cost of installation of a 65 ton (229 kW) chiller is approximately $78,000. The cost of installation of a 52 ton (183 kW) chiller with 100 ton h (352 kWh of cooling capacity) of thermal energy storage is approximately $87,000. This renders the net cost of installation of a thermal energy storage system at approximately $9000.

Using these prices under a chiller replacement scenario, a partial storage thermal energy storage system has a relatively short payback period for all schedules under the utility. However, the payback periods follow the same approximate pattern with the full storage option in Building A. The payback period for the static pricing structure of HECO is 5.3 years while the payback period for the dynamic pricing structures ranges from 2.1 to 3.5 years, with the shortest payback period of 2.1 years occurring under the SCE Time-of-Use rate. Therefore, although simple payback periods are acceptable for all schedules, thermal energy storage is still a more attractive investment for areas with dynamic pricing schedules for this type of building.

3.2.3. Building C

Building C is a residential condominium. Since this is a residential condominium, the building has a continuous power demand that increases at approximately 6:00 pm, when residents return home for the evening. Since the peak demand for this building is approximately at 5:00 pm, the thermal energy storage system is designed to provide cooling at this time until midnight, while the thermal energy storage system would fully charge between 2:00 am and 9:00 am. The power demand for the original usage case without chilled water thermal energy storage and the power demand with chilled water thermal energy storage are displayed respectively in Figs. 7 and 8. In this scenario, the peak electricity

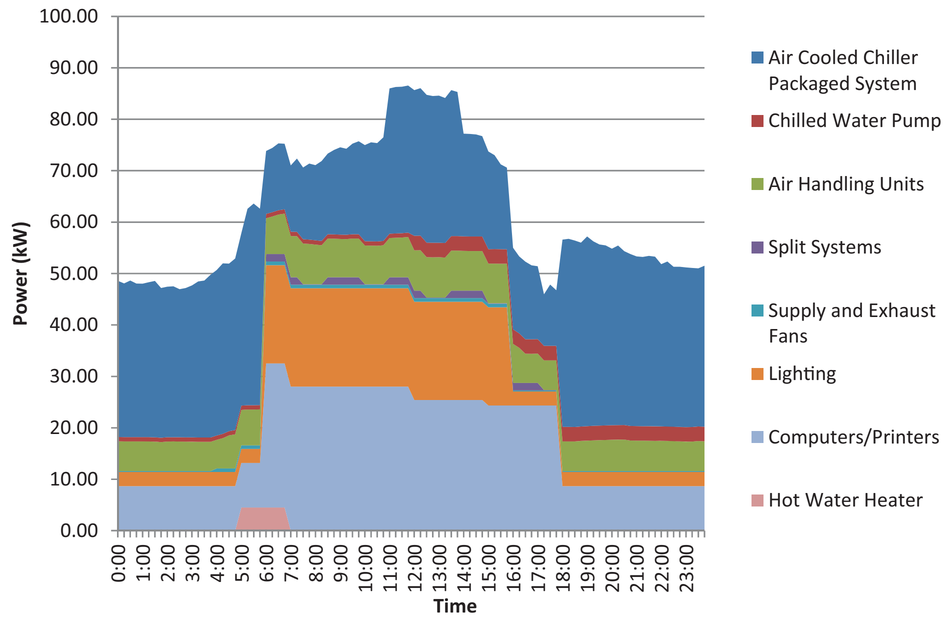

Fig. 6. Building B load profile (chilled water system thermal energy storage).

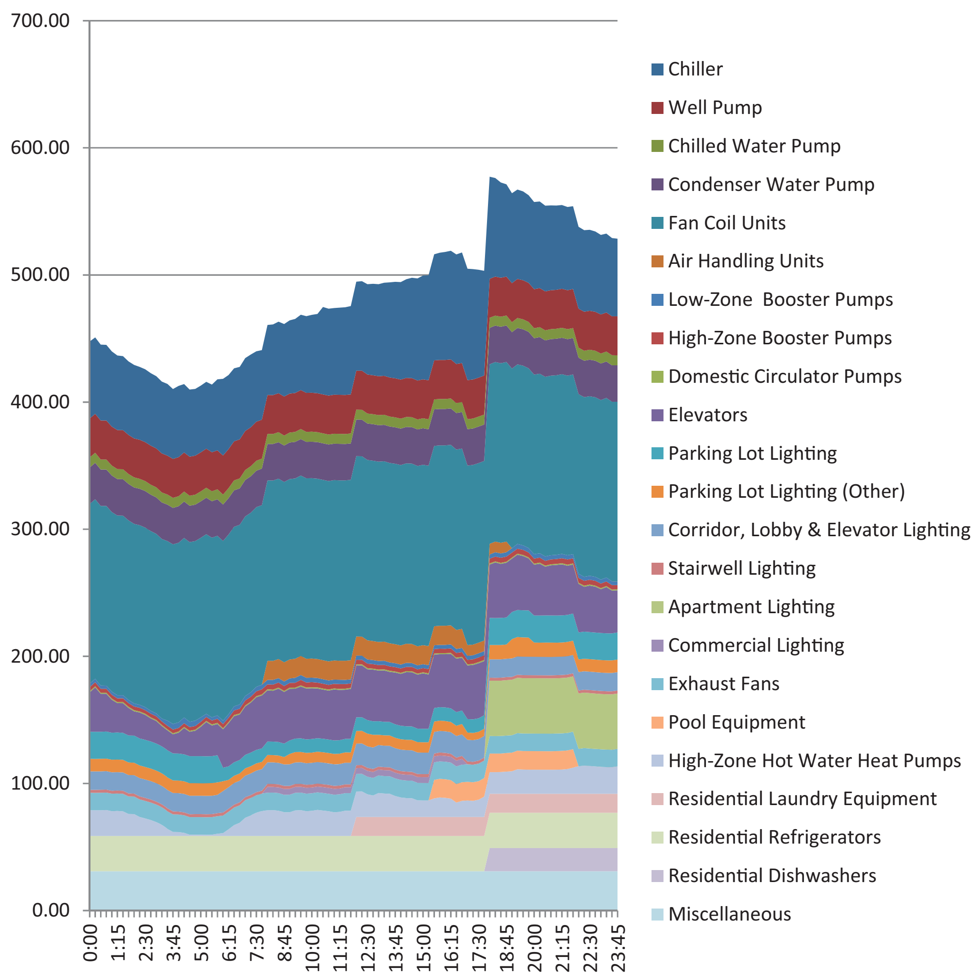

Fig. 7. Building C load profile (no chilled water system thermal energy storage).

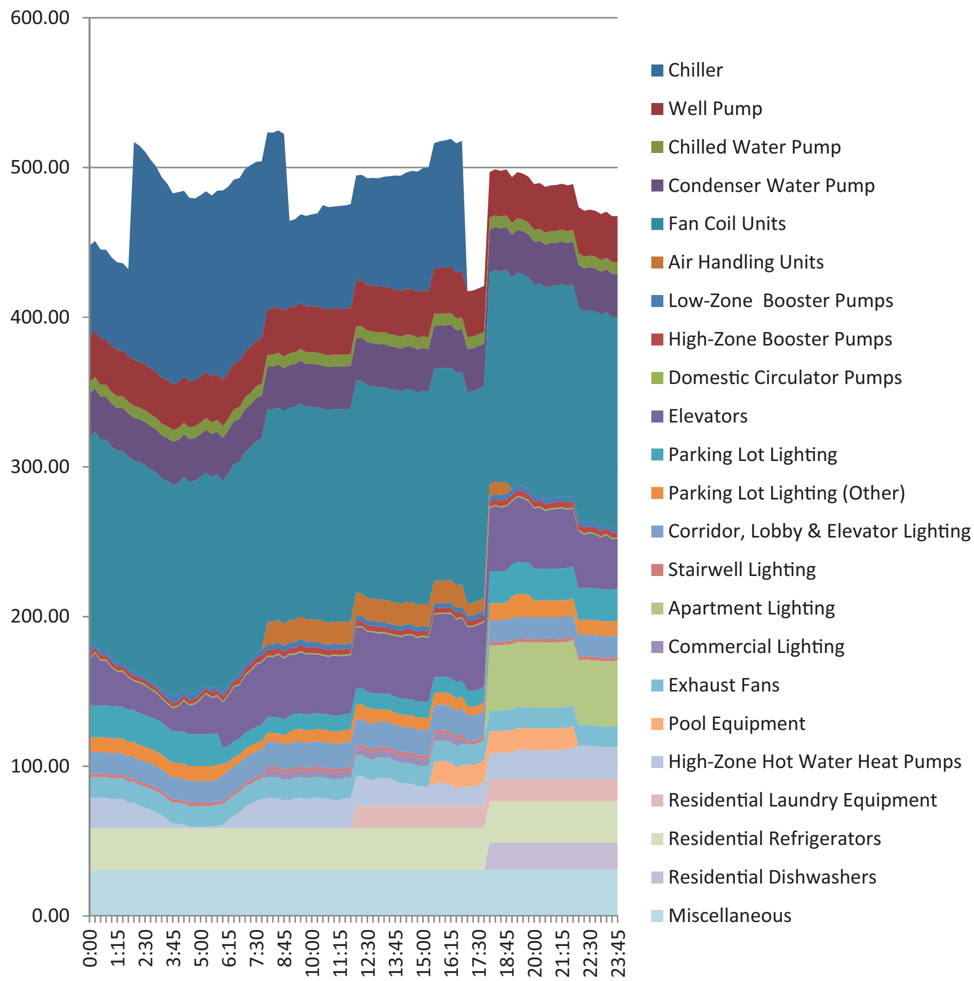

Fig. 8. Building C load profile (chilled water system thermal energy storage).

demand for Building C is reduced from approximately 577 kW to 525 kW, while the total amount of energy utilized is the same at approximately 350,000 kWh per month.

The estimated cost for a chilled water thermal energy storage system is based upon a required cooling capacity of 450 ton h (∼1583 kWh of cooling capacity) and an estimated cost of installation of the thermal energy storage system of $250 per ton h ($71 per kWh of cooling capacity). This estimated cost is $112,500. From this cost estimate, a simple payback period that is based on the estimated cost for a thermal storage system that will fully store the required cooling for this building and the reduction of demand charges and on peak energy usage can be calculated.

Unlike the other thermal energy storage system payback periods, the simple payback period of this building for both the flat rate and Time-of-Use rate for HECO, at 7.3 years and 6.1 years respectively, is slightly lower than the Time-of-Use rates for PGE and SCE, at 8.8 and 10.0 years respectively. This is due to the fact that the demand cost for HECO is significantly higher than the other areas. For the Time-of-Use options, since Building C has such a high electricity demand, these schedules have a smaller difference between off peak and on peak electricity rates. Since this measure effectively reduces the peak demand by 52 kW, the higher demand cost leads to greater annual electricity cost savings. Additionally, under the real time pricing schedule of SCE, the payback period is shortest at 4.5 years. This is due to the fact that prices in the afternoon are much more expensive in the real time pricing rate and this measure was designed to reduce electricity at exactly those times.

4. Discussion

For each of the studied buildings, an approximate daily load curve was determined. In the office buildings that utilized one office shift, similarities between the magnitudes of power used was noted. While the actual amount of energy utilized by a building is dependent upon both the size and the amount of occupants in a building, daily load profiles of buildings typically follow the same pattern according to building type. For example, commercial office buildings with one shift typically use the most energy during the hours between 6:00 am and 6:00 pm and residential buildings use the most power in the evening. In a measurement of daily electric load profiles for residential and commercial buildings Jardini [16] found similar typical daily usage patterns. If individual buildings follow the same load patterns, similar cost conservation measures and load shifting techniques could be more generally applied to building types.

4.1. Alternative scheduling

A 1 h schedule shift was assessed for several commercial and industrial buildings. For Buildings A and B, which had either one shift or the majority of the energy utilized during a one shift period, there were clear monthly electricity savings under dynamic electricity pricing schedules between 0.5% and 3%, depending on the utility.

While the monthly reductions in energy costs due to a schedule shift may seem too small to make changes to employment policy of a large office building or industrial factory, other extenuating circumstances may help decide the suitability of alternative work scheduling. For example, commuting times for employees could also be reduced if the working day began before the majority of other businesses, due to reduced automobile traffic at earlier hours. This could improve worker morale and potentially improve productivity. These working needs would have to be assessed for each individual commercial and industrial consumer of electricity.

In addition to starting business activities 1 h earlier and ending them 1 h earlier, there are other types of schedule shifting that could occur. Shifting could also occur from weekdays to weekends or from time in the winter to time in the summer. Daily shifting could occur by having business workers arrive and leave more than 1 hour early to a business. There are countless permutations of alternative scheduling that could be proposed to avoid using electricity during peak times. Since the working situation of each commercial and industrial building is different, an alternative working schedule would have to be jointly assessed by energy efficiency solution providers and managers of commercial and industrial buildings to be most effective.

4.2. Thermal energy storage

For each of the buildings, either a partial thermal energy storage or full thermal energy storage system for the chilled water system was considered. For Buildings A and C, a full storage system was considered. Under the flat rate pricing of HECO, the payback period, although shorter than the estimated 25 year lifetime of a chilled water thermal storage system, was not as attractive as certain other more common energy conservation measures. However, the simple payback period of the energy storage system under the HECO flat rate was less than 10 years for Building C. Under dynamic pricing structures, full thermal storage systems had simple payback periods of between 4.5 and 11.1 years.

For Building B, a partial energy storage system, along with replacement of the chilled water system was considered. This was because the chiller at this building was noted to be old and needed to be replaced anyways. When sizing down the cooling capacity of the chiller along with adding partial storage options, thermal energy storage systems only represent a meager increase to the cost of installation of a system. Using this cost increase, for both flat rate and dynamic rate utility structures, simple payback periods for partial storage thermal energy storage ranged between 2.1 and 5.3 years. Therefore, if a chiller needs to be replaced, it would be advantageous to consider a supplemental thermal energy storage system.

From analysis of thermal energy storage systems, it is noted that for maximum cost reduction, thermal energy systems should not only focus on using energy when the price is the lowest, but also on reducing peak demand of electricity usage as much as possible.

One of the main advantages to thermal energy storage is the fact that is does not require changes in behavior of building occupants. This contrasts with the alternative scheduling plans, which would require workers to come in earlier or later based upon the cost of electricity. A further benefit to thermal energy storage that was not quantified in this study was the ability to allow for demand response if a utility has such a curtailment program available. This could make thermal energy storage even more favorable for commercial and industrial buildings.

4.3. Real time pricing and incidence and magnitude of higher electricity costs

For SCE, the hourly generation rates for electricity in their real time pricing structure are based upon the maximum temperature of downtown Los Angeles as measured by the National Weather Service. There are brackets for hourly cost of generation based upon certain maximum temperatures. The most expensive brackets in the SCE real time pricing cost structure are Summer Weekdays 95 °F and hotter and Summer Weekdays between 94 °F and 91 °F. These most expensive brackets have generation costs in the early afternoon that exceed the Critical Peak interval cost under the critical peak pricing cost structure of SCE.

In the SCE real time pricing scenario, there are fewer days in which electricity is more expensive, but the magnitude of the difference in cost is much greater. For example, in Schedule TOU-GS-2-RTP, which Building A would utilize, the cost of electricity at 4:00 pm on a summer weekday that is hotter than 95 °F is $4.05223 per kWh. This is more than twice as much as the Critical Peak surcharge of $1.37453 per kWh. However, in the 2013 maximum temperature data for downtown Los Angeles from the National Weather Service, there was only 1 summer weekday that was hotter than 95 °F and 6 summer weekdays that were between 94 °F and 91 °F. This contrasts with the mandatory 12 Critical Peak days under the SCE critical peak pricing structure. This scenario makes real time pricing have lower incidence of high price periods, but of greater magnitude. Under a simulation of the Pennsylvania-Jersey-Maryland electricity market, real time pricing causes peak prices to increase [17]. If real time pricing has lower incidence, but greater magnitude of higher prices, measures enacted on days of high price under an real time pricing schedule could save more money on a per day basis, but would have to occur less often.

For residential condominiums, it could be possible to have the air conditioning systems within each residence automatically be set to a higher temperature during critical peak hours and during hours of high price under a real time pricing schedule. However, instituting such control over tenant's usage of electricity may not be acceptable to tenants. In this instance, it may be more equitable for a building to institute forms of submetering to tenants that take into account both demand charges and whatever dynamic electricity pricing structure is in place at the building.

5. Conclusions

Adoption of dynamic electricity pricing schedules will allow commercial and industrial buildings and energy efficiency solution providers to implement new cost conservation measures to reduce electricity costs.

Certain cost conservation measures, such as shifting employee schedules and reducing energy usage during critical peak intervals and other times when energy is expensive, are measures that can reduce costs without significant upfront investments but require behavioral changes. Other cost conservation measures, such as installation of thermal energy storage systems, are measures that can reduce costs without behavioral changes but require significant upfront investments. However, if upfront investments are going to be made anyways, such as during the replacement of a chiller, thermal energy storage can reduce both installation costs and electricity costs by installation of a partial storage system.

Thermal energy storage for a chilled water system can be effective for both office buildings and residential condominiums in both partial storage and full storage scenarios under dynamic pricing schedules. In certain cases, cost conservation measures such as thermal energy storage can be cost effective even with a flat rate electricity pricing structure with a demand charge, due to demand reduction.

Under critical peak pricing and real time pricing, behavioral changes need only occur on days of extreme high electricity costs. This could minimize disruptions to work due to responding to high electricity prices. If real time pricing has lower incidence, but greater magnitude of higher prices, measures enacted on days of high price under a real time pricing schedule could save more money on a per day basis, but would have to occur less often.

As with energy efficiency recommendations that are indifferent to dynamic pricing, residual benefits and detriments to employee productivity and residential comfort should be considered when formulating recommendations designed to shift and reduce peak demands.

The suggestions listed in this study only represent some ideas that can be enacted for load shifting and reduction of peak electricity demands. If electric utilities more fully embrace dynamic pricing schedules and make them mandatory for commercial and industrial customers, the managers of commercial and industrial buildings, energy efficiency solution providers and electric utilities will find ways to further reduce monthly costs for electricity while retaining the full value that electricity provides to the building and the overall economy.

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