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Control of Thermal Energy Storage in Commercial Buildings for California Utility Tariffs and Demand Response

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Nance Matson (Demand Response Research Center) for project management and review assistance effort
Bob Jones (Irvine Company Office Properties) and Craig Dawson (Sonoma State University) for coordination of efforts, data sharing, and openness to collaborate

Energy Research and Development Division
FINAL PROJECT REPORT

CONTROL OF THERMAL ENERGY STORAGE IN COMMERCIAL BUILDINGS FOR CALIFORNIA UTILITY TARIFFS AND DEMAND RESPONSE

Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory

AUGUST 2015
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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Control of Thermal Energy Storage in Commercial Buildings for California Utility Tariffs and Demand Response is the final report for the project (contract number 500-03-026, work authorization number 3 conducted by the Demand Response Research Center. The information from this project contributes to Energy Research and Development Division's Energy Systems Integration Program.

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ABSTRACT

Thermal Energy Storage (TES) is an established technology that shifts heating or cooling energy use from an on-peak period when demand and rates are highest to an off-peak period, when rates are lower. This study evaluates the two main types of TES systems: Full storage TES systems designed to shift the entire cooling system load to the off-peak period, and partial storage TES systems, which are designed to shift only a portion of the cooling load off-peak. The cooling load profile on the peak day is selected for the TES system design, which ensures that a full storage TES system is sufficient to meet the cooling load requirement. For a utility tariff that has a monthly demand charge and on-peak demand charge as well, a full storage system can provide bill savings by reducing both peak demand and energy use. For a partial storage system, the cooling system supplements the TES system during peak hours, which can reduce a portion of peak demand with reduced cooling plant capacity. TES systems shift electricity use from on-peak periods to off-peak periods on a recurring basis, which is characterized as permanent load shifting (PLS). For TES' participations in DR, partial storage TES systems are better suited than full storage systems for participating in demand response (DR) programs because full storage systems create peak period baselines with little to no room for shedding cooling related loads. For DR events called on peak demand days, the integration of partial TES systems with typical DR control strategies (e.g. global temperature adjustment (GTA)) can also provide one-hour or 20-minute load shed resources by aggregating the cooling load reduction during the GTA deployment period. Buildings with partial TES systems can be good resources for participating in DR programs requiring faster response times and shorter response durations. TES demand shifting and economic payback is greatly influenced by the following factors: (1) utility rate structures; (2) building load characteristics (e.g. load pattern, ratio of on-peak and off-peak cooling load); (3) climate; and (4) available physical space for retrofit installations. In this study, a matrix of various TES use cases was simulated to evaluate the impact of building load, climate and California utility tariffs.

Simulations show that typical TES installations will have enough excess capacity to provide cooling demand shifting on most days. TES is fully discharged on less than 5% of the total number of weekdays during the year because the TES storage capacity is designed based on the total cooling load on the peak day. With current retail DR programs that have a relatively small number of "event" days, typically on the hottest days—the amount of excess capacity is minimal, and, so is the benefit to customers of participating in DR with only TES. Because the cooling load is lower on non-peak days, partial TES systems have excess capacity that can be used during DR event hours, which will enable customers to participate in DR by turning off chiller(s). For older office buildings in PG&E territory, bill reduction is greatest with a full 9-h TES, but payback is faster with a full 6-h TES. Similarly, for old and new office buildings in SDG&E territory, a full 9-h TES provides the lowest annual utility costs, but payback is faster with a partial 9-h. Utilities currently look to TES to provide maximum peak period reduction. In most cases studied here, the TES configuration that provided the greatest economic benefit to the customer also provided the greatest peak period load reduction to achieve the demand

charge savings. However, small-to-medium retail customers will have the lowest utility costs with a partial storage system, which only provides a fraction, typically half, of peak period demand reduction compared to that of a full storage system. Older less efficient buildings have higher peak period loads and present greater potential demand reductions that can be achieved with TES. Incentives structured as dollar per kW of TES installed will achieve greater peak period reductions per dollar of incentive if targeted at new buildings, but, all other things being equal, the peak period load reduction provided by TES will be lower with a newer building.

Keywords: Thermal Energy Storage; Full Storage; Partial Storage; Demand Response; Ancillary Service

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In October 2013, the California Independent System Operator (ISO), the California Public Utilities Commission (CPUC), and the California Energy Commission (CEC) established an energy storage target of 1,325 MW for public utilities by 2020, with installations required no later than the end of 2024. California has also introduced a standardized Permanent Load Shifting (PLS) program applicable to SCE, PG&E and SDG&E, three of California's public utilities. PLS refers to the shifting of energy usage from peak to off-peak hours on a recurring basis. Each investor-owned utility (IOU) developed their own Permanent Load Shift – Thermal Energy Storage (TES) Program as part of energy storage installation capacity. The Demand Response Research Center (DRRC) conducted the study presented here to investigate the cost-effectiveness of TES system implementations in each IOU's territory and the use of TES for participation in demand response (DR) programs. The project's objectives were to:

- Assess the potential value of TES and its relation to DR and bill savings for customers.
- Evaluate the cost-effectiveness of full and partial storage TES system in existing building retrofits and new construction (office and retail) under each IOU's territory.
- Investigate the current issues related to design, installation, operation, and maintenance of the TES systems.

To achieve the objectives, the research had three key elements: 1) develop a methodology of using EnergyPlus simulations to study the additional benefit of TES systems for demand response; 2) conduct scenario analysis to quantify the effects of partial and full storage TES systems in different building types, climates, and utility rates; 3) conduct field survey of a large office building and a campus building.

TES can either be full storage, where all peak cooling loads are satisfied from storage, or partial storage, where part of peak cooling loads are satisfied from storage with the rest satisfied by chiller operation. Full storage requires larger and more expensive system implementation in comparison with partial storage systems, but achieves the most cost savings by shifting electricity usage from on-peak hours to off-peak hours. Partial storage requires the chiller plant to provide partial cooling load, which has flexible load capability in terms of the operation of the storage and the chiller plant. The results of the use of TES systems for demand response show that:

- Buildings with partial storage TES systems can provide a reliable and fast load shed by turning off chiller plants without any impact on thermal comfort of building occupants.
- Partial storage TES is more compatible with current DR programs targeted at reducing peak period electric demand because, unlike full storage systems, partial system capacity is sized to provide about half of the peak cooling load on the summer design day with the other half being provided by chiller operation. The chiller load can be shed in a DR event.
- For DR events called on peak days, the integration of partial TES systems with typical DR control strategies (e.g. global temperature adjustment) can also provide one-hour or 20-minute load shed resource on the peak day by aggregating the cooling load reduction during the GTA deployment period.

The benefits that can be provided by TES are influenced by the following factors: (1) utility rate structures; (2) building load characteristics (e.g. load pattern, ratio of on-peak and off-peak cooling load); (3) climate; (4) retrofit of existing cooling system and (5) available physical space for installation. The simulation and anlaysis of TES systems in this study show that:

- Using the payback period as the comparison metric, TES applications are more attractive in new buildings. TES applications provide more value in existing buildings based on the amount of demand savings (kW) and the annual utility bill savings ($).
- Under the PG&E's tariff rate, TES applications are relatively more attractive in climate zone CZ04. In the SCE's territory, TES applications are more attractive in climate zone CZ09 than in CZ10 even though both would be considered hot climate zones.
- The majority of the cooling load is distributed between 12pm to 6pm for small- and mid-sized retail. This kind of load pattern leads to more favorable TES deployment during the on-peak hours for all IOU tariffs studied here. On the other hand, the portion of the cooling load in retail buildings (40~50%) is much higher than that in offices (30~32%).

Benefits to California

California has ambitious goals to increase energy storage to support renewable power generation and TES is a well-proven technology that can fill that need. This study shows that the increasing installation of TES systems in building retrofits and new construction provides many benefits to California utility customers. First, using TES for demand response can provide additional value to customers with TES. Second, understanding the utility-related costs of TES systems can help IOUs design appropriate PLS programs, encourage more installation of TES systems, and help customers to understand the potential cost saving benefits of TES systems. Third, the field survey results provide building owners and operators with specific guidance on TES control along with actual load patterns and impacts of evolving utility rates.

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CHAPTER 1: Introduction and Background

Installations of thermal energy storage (TES) systems have increased dramatically in the past few decades as a way for owners to decrease electric utility costs by shifting daily cooling (and heating) energy demand from higher cost periods to lower cost periods. A national survey of cooling thermal energy storage systems in 1994 estimated a total of 1500~2000 TES installations in the United States (Potter, 1994). Pike Research estimated installed TES capacity in the United States was 2.7 GW in 2011. Among those, installed cooling capacity of ice-based systems and chilled water systems are 1,000 MW and 355 MW, respectively. By 2020, projected TES capacity will increase by 4.5 GW, nearly tripling to a total of 7.2 GW (Pike Research, 2012).

The California Independent System Operator (ISO), the California Public Utilities Commission (CPUC), and the California Energy Commission (CEC) established an energy storage target of 1,325 MW for public utilities by 2020, with installations required no later than the end of 2024[1]. California has also introduced a standardized Permanent Load Shifting (PLS) program applicable to SCE, PG&E and SDG&E, three of California's investor-owned utilities. PLS refers to the shifting of energy usage from peak to off-peak hours on a recurring basis. As defined by the CPUC[2], PLS is not considered as a demand response program if it is not dispatchable or price responsive on a day-ahead or day-of basis (E3, 2011). Investor-owned utility (IOU) PLS programs provide a financial incentive of $875 per kW (up to a maximum of $1.5 million per project) to qualifying participants for the installation and operation of TES systems.

The DOE global energy storage database (GESD) provides details on 75 energy storage systems, with a total capacity of about 46 MW, installed or to be installed in California (DOE, 2015). The database provides free, up-to-date information on grid-connected energy storage projects and all the projects are verified through a third-party process.[3] Though the sample size of the reported thermal energy storage projects is quite small, it is sufficient to provide a general sense of thermal energy storage projects and their characteristics in terms of storage types, climate locations, TES capacity and TES duration hours. Ice thermal storage is used in 70 of the 75 reported projects and a majority of those are located in hot climate zones in California. All of the TES projects are located in warm to hot climate zones. Due to greater cooling loads, buildings in these areas will have proportionally higher peak daytime demand compared to off-peak and have greater incentive to shift cooling demand from higher priced daytime periods to other

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[1] Energy Storage Roadmap, https://www.caiso.com/informed/Pages/CleanGrid/EnergyStorageRoadmap.aspx

[2] California Public Utilities Commission – Energy Storage Proceeding R.10-12-007, http://www.cpuc.ca.gov/NR/rdonlyres/3590C5E8-55A4-4409-8841-948D658CD65D/0/DSMUseCasePermanentLoadShifting.pdf

[3] The DOE GESD provides free, up-to-date information on grid-connected energy storage projects and all the projects are verified through a third-party process, http://www.energystorageexchange.org/

periods of the day. Another benefit of TES in these areas is that chillers operate with higher efficiency when outside air temperatures are low during the night and early morning hours.

TES customers can participate in some demand response (DR) programs by shifting electricity usage in response to price or event signals from the utility provider. Generally, TES does not qualify as Demand Response unless the customer is willing to bring the TES on line only for DR purposes. However, TES may not be cost effective by comparing the program incentive with energy and demand savings from the normal time of use (TOU) rates. In addition to the TES deployment under the TOU rate schedule, TES has potential for providing value in renewable energy integration[4] for absorbing the renewable energy generation fluctuations in the grid and ancillary service that require fast response with short durations. Many DR programs are technically capable of providing ancillary services (Ma, 2013) and there are a few featured TES case studies showing the operation of TES as a demand response resource[5].

This study assesses the potential value of TES and its relation to DR and bill savings to customers. We evaluate the impact of TES on different time scales available in various DR programs and the technical potential and market value of using TES in California's electricity markets.

This report is organized into the following sections: Section 2 presents the problem statement of this study. Section 3 describes research methodologies of TES simulations and field studies. Section 4 describes the details of energy simulations of TES made in this study. Section 5 presents the value of TES for DR and Section 6 presents the results of cost effectiveness analysis of TES in each IOU territory in California. Section 7 presents conclusions and recommendations for future work.

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[4] Renewable Energy Integration, http://energy.gov/oe/technology-development/renewable-energy-integration

[5] CALMAC, featured case studies on http://www.calmac.com/

CHAPTER 2: Problem Statement and Research Questions

TES systems are designed in two modes: full storage and partial storage. Full storage systems, known as load shifting systems are designed to meet all day or on-peak cooling loads from storage. Partial storage systems meet part of the cooling load from storage and part directly from the chiller during the on-peak period. Partial storage systems can be operated using one of the following strategies: parallel operation, storage priority, and chiller priority. Clearly, full storage systems have larger and more expensive chiller and storage units compared to partial storage systems. However, full storage systems also capture the greatest savings possible by shifting more of the electricity demand from on-peak to off-peak.

The cost effectiveness of TES systems is impacted by a variety of variables, including customer load patterns, climates, utility rates, and TES system design and operation modes. Full storage systems are relatively attractive when demand charges are high, the differential between on-peak and off-peak energy charges is high and /or when the peak period is short. Partial storage systems are relatively attractive when electric rate incentives for load shifting are moderate, the ratio of peak to average load is high, and/or the on-peak period is long.

TES is generally considered for shifting load from on-peak hours to mid- or off-peak hours and not for DR unless the customer brings the TES on-line only for DR purposes. Utilities usually use 10-day average baselines to quantify the demand reductions achieved on DR event days. Daily operation of TES, as is done in PLS, results in a lower peak-period demand baseline, decreasing the amount of load shed that TES could achieve participating in a DR event or a DR program. However, TES can provide new values for some DR programs that require fast response time and short durations, such as turning off chiller during the DR event hours to respond to Base Interruptible Program (BIP) if the customer is enrolled in this program.

TES systems are highly sensitive to utility rate structures that have significant impacts on the return of investment. Greater energy savings can be achieved from a rate structure with stronger incentives to reduce the peak demand or higher demand charges. In addition, the change of utility rate structures and more offerings of various DR programs require facility managers or engineers to adopt new operational controls. In other cases, a lack of TES operation experience for some facilities may jeopardize the value of TES during the daily operation. The uncertainty surrounding the future of deregulation of the electric industry is a problem because TES economics are dependent on favorable rates and TES systems require long payback period. Overly conservative estimates of electric rates hurt the projected payback of TES projects.

In the past, TES was deployed to reduce energy and demand charges during peak periods. As these generally occurred daily, TES could be operated consistently by regularly charging at night to provide energy during daily peak periods. With the increased installation of TES capacity on the market, there is a need to explore the TES value in a larger picture. For example, we found that TES can also provide operational flexibility within a building or in the electric grid. However, the increasing penetration of wind and solar renewable energy brings more uncertainties of the utility tariff rates that have significant impacts on the economics of TES use. A set of key questions were defined in this study as follows:

- What is the additional value of TES in buildings to provide DR resource to the grid? Which types of TES operational mode are suitable for this purpose?
- For both utilities and customers, what are the impacts of TES operational modes, building load characteristics, climate locations, and utility rates on the TES cost effectiveness?
- What are issues related to design, installation, operation, and maintenance of the TES systems?

CHAPTER 3: Research Methodology

We conducted three sets of tests for this project. The first set of tests uses the analytical model, EnergyPlus to examine how TES is used with two selected DR programs. The second set of tests examines the range of responses under different DR programs. The third set of tests uses case studies to evaluate how utility DR program changes influenced TES usage.

3.1 TES and DR

To perform the analysis of use cases for TES and DR, we used a detailed whole building energy simulation tool, EnergyPlus, to represent prototypical commercial buildings in the U.S. and evaluate the performance of TES's load flexibility with various DR programs. For each TES use case, the storage capacity size is based on the whole or partial cooling load observed on the peak day. Excess storage is the designed storage capacity minus the required cooling capacity for one day. Excess storage on non-peak days could be used on DR event days to further decrease chiller use and thereby provide a measureable load shed compared to baseline. Partial storage TES is more compatible with current DR programs targeted at reducing peak period electric demand because, unlike full storage systems, partial system capacities are sized about half of the peak cooling load on the summer design day and have peak period chiller load that can be shed.

Two types of DR programs are selected to analyze the use of partial storage systems for DR: (1) Base Interruptible Program (BIP) and (2) Real-time Pricing Program (RTP). These were chosen because BIP can be called anytime and the response required is a significant, pre-contracted load reduction over the time period of the event whereas RTP exhibits dynamic pricing to which a building owner can choose to respond based on economic tradeoffs that also include business impacts from load reductions.

3.2 Framework of TES Cost Effectiveness Analysis

To study the cost effectiveness of TES, we examined the impact of TES on the operations of two distinct building types—office and retail—and two building vintages—those built before 1980 and new construction that complies with 2013 Title 24 building energy standard (Title-24, 2014). For each IOU's territory area, warm and hot climate zones are selected to evaluate the impact of climate on the TES performance. This study uses typical DR tariffs (TOU, PDP, and CPP).

The overall analysis approach is summarized below. Additional details regarding the analysis methodology and assumptions made can be found in section 7.

Figure 1 presents the overall simulation matrix of TES use cases in this part of the study. The cost-effectiveness of TES is quantified by comparing utility bill costs of buildings with TES to those with a conventional chiller only system. Utility bill calculations include energy charges, demand charges (on- and mid-peak demand charges, facility related demand charge), and incentives bundled with special rate programs (e.g. energy and demand credits of PDP, CPP events). For TES system types and control operations, we analyzed the following scenarios:

- Full storage systems: (1) TES discharging period from 8am to 6pm; and (2) TES discharging period from 12pm to 6pm.
- Partial storage system: (1) parallel-connected storage with chiller; (2) series-connected storage with chiller priority; (3) series-connected chiller with storage priority.

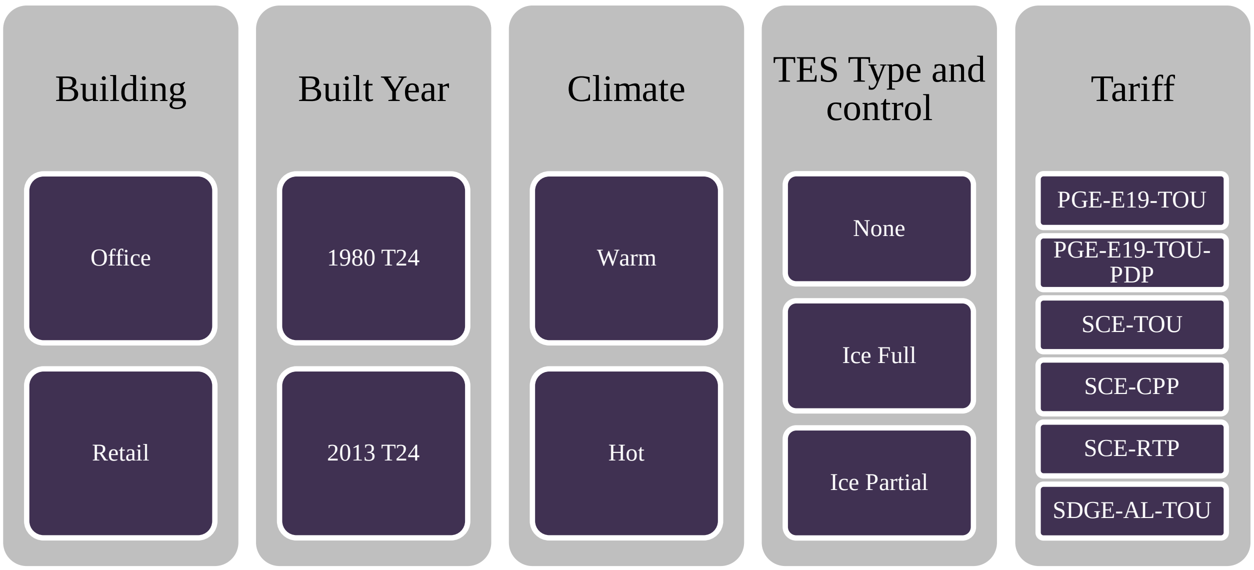


Figure 1: Simulation Matrix of TES Use Cases.

3.3 TES Case Studies

We conducted two case studies to review and analyze energy performance of TES systems in a large office and a campus in the southern California. We used a survey, site-audit and analysis of performance data to characterize the performance and historical data of the TES systems and their components. Issues identified were then grouped according to whether the issues related to design, installation, operation, and maintenance of the systems. Based on these characterizations, an EnergyPlus model was developed and calibrated to identify a new TES operation mode that could be expected to reduce the energy and demand charges expected under a proposed new utility tariff rate.

For the TES case study in a large office, the historical data of TES operations and monthly utility bill were compiled to evaluate the impact of the utility change on the TES performance and utility cost. Another case study on campus indicated the issue related to TES system design and operation, especially the change of facility management.

CHAPTER 4: EnergyPlus Simulations of TES

4.1 Model Descriptions

EnergyPlus simulates four types of thermal storage energy systems (EnergyPlus, 2014): (1) simple ice thermal storage; (2) detailed ice thermal storage; (3) chilled water mixed thermal storage; and (4) chilled water stratified thermal storage. Three common storage configurations are included in the EnergyPlus example files: (1) series – chiller upstream; (2) series – chiller downstream; (3) parallel chiller with storage tank, as shown in Figure 1. The diagram illustrates the use of detailed ice thermal storage in a parallel configuration with the chiller in parallel with the ice storage units for discharge. For charging, the chiller is in series, upstream of the ice storage unit. This is modeled using two chiller objects, one placed in parallel and one placed in series, both representing the same physical chiller.

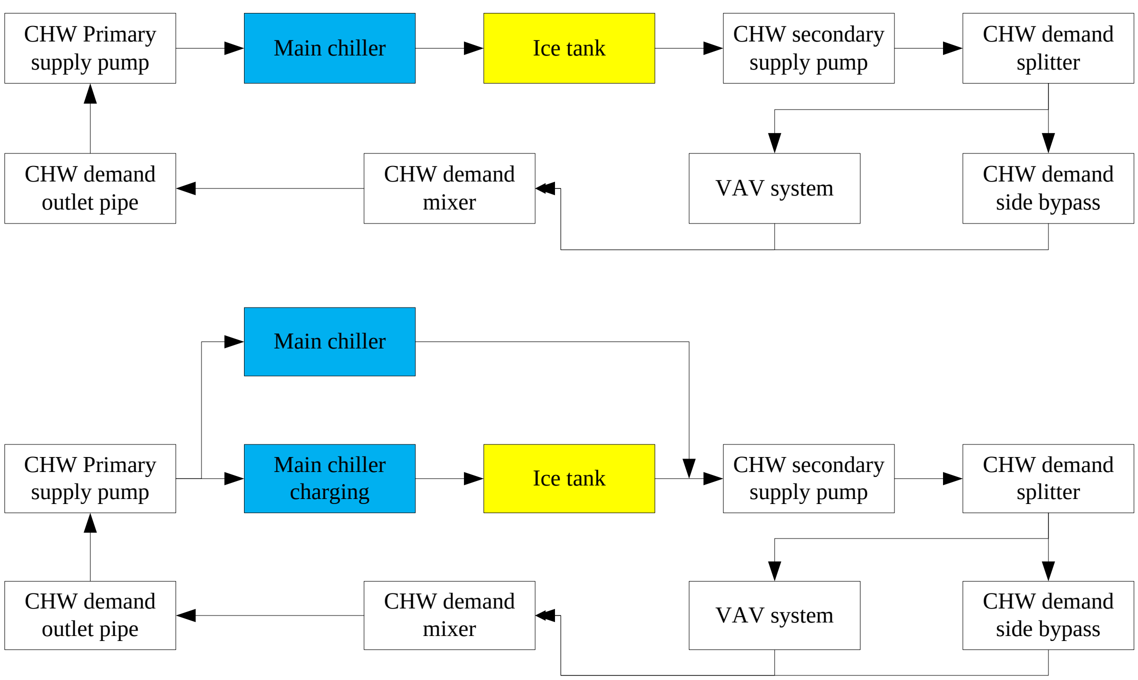
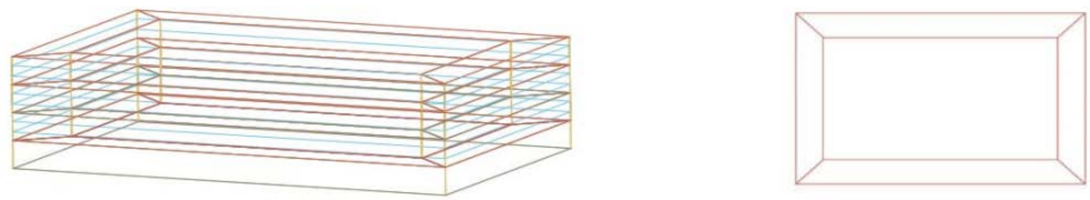


Figure 2. Series- and parallel-configuration of chiller and storage tank in EnergyPlus model.

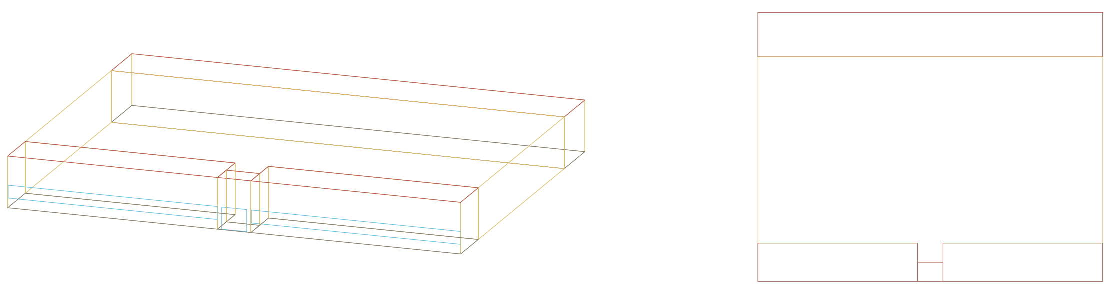
4.2 TES Model Parameters

4.2.1 Building Model

Commercial building prototype models were developed in collaboration between DOE, the National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Lawrence Berkeley National Laboratory (Deru et al., 2011). These reference prototype models are used to assess the deployment of TES technology in this study. Figure 2a shows the office building model geometry and the layout of thermal zones with four perimeter zones and one core zone. Figure 2b shows the retail building model geometry and layout of four thermal zones—a core shopping floor zone, one back stockroom zone, and two checkout zones.



(a) Office



(b) Retail

Figure 3. Prototype a) office and b) retail building model zone configurations.

4.2.2 TES Storage Parameters

The detailed ice storage model in EnergyPlus allows users to simulate specific manufacturers' ice storage units. One of the key input parameters of the ice storage model is storage capacity, which is the maximum amount of latent thermal storage in the ice storage system, expressed in units of GJ. Discharging and charging curves are another set of parameters in the model, which are introduced in terms of two sets of quadratic linear curves (EnergyPlus, 2014).

4.3 TES Types and Operations

TES can either be full storage, where all peak cooling loads are satisfied from storage, or partial storage, where part of peak cooling loads are satisfied from storage with the rest satisfied by chiller operation.

4.3.1 Full Storage

A full storage system can be deployed either on a full day (e.g. 8am to 6pm) or during on-peak period hours (e.g. 12pm to 6pm)[6], as shown in Figure 4 and Figure 5. It should be noted that the low temperature difference between the supply and return chilled water temperature leads to unmet building cooling load at the time of HVAC (Heating, Ventilation, and Air-Conditioning) start. This type of storage system requires larger and more expensive system implementation in comparison with partial storage systems, but achieves the most cost savings by shifting electricity usage from on-peak hours to off-peak hours. Full storage systems have a lot of applications on the site where they have enough space to house the storage tank and associated equipment, such as a campus[7]. For the deployment of TES systems with the limitation of space, ice storage systems require less space than chilled water storage systems because the phase change from water to ice can store more energy (ASHRAE Handbook, 2012).

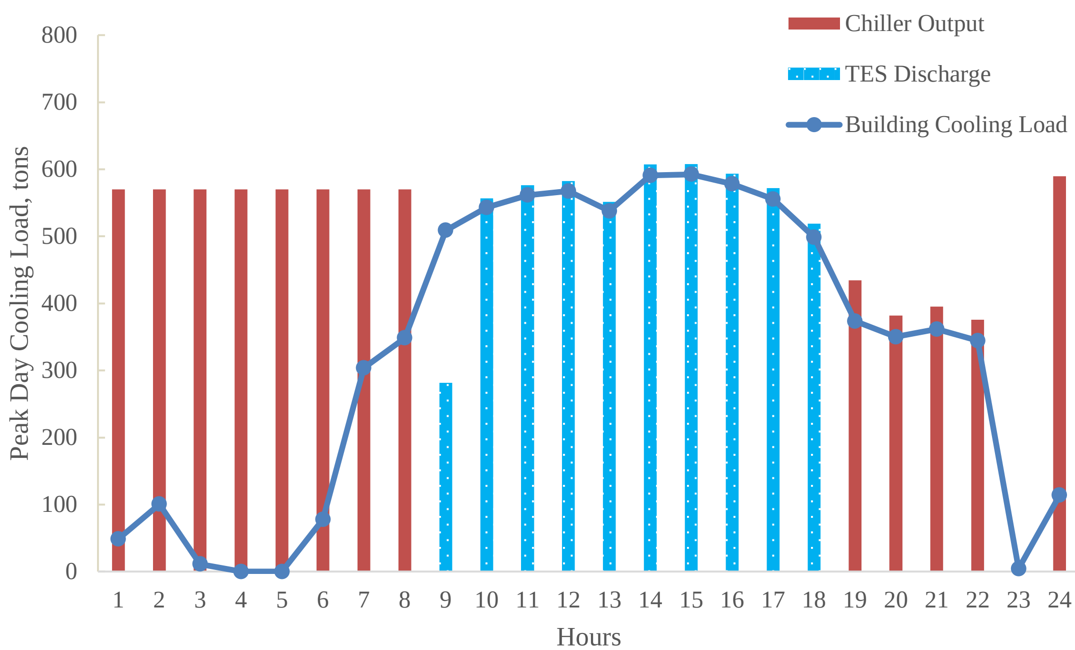


Figure 4. Full TES Operation (8am to 6pm) on a Peak Day

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[6] PG&E and SCE's on-peak period is from 12pm to 6pm and SDG&E's on-peak period is from 11am to 6pm.

[7] Thermal energy storage system at UC Merced, Best Practices Case Studies by the Green Building Research Center, at the University of California, Berkeley

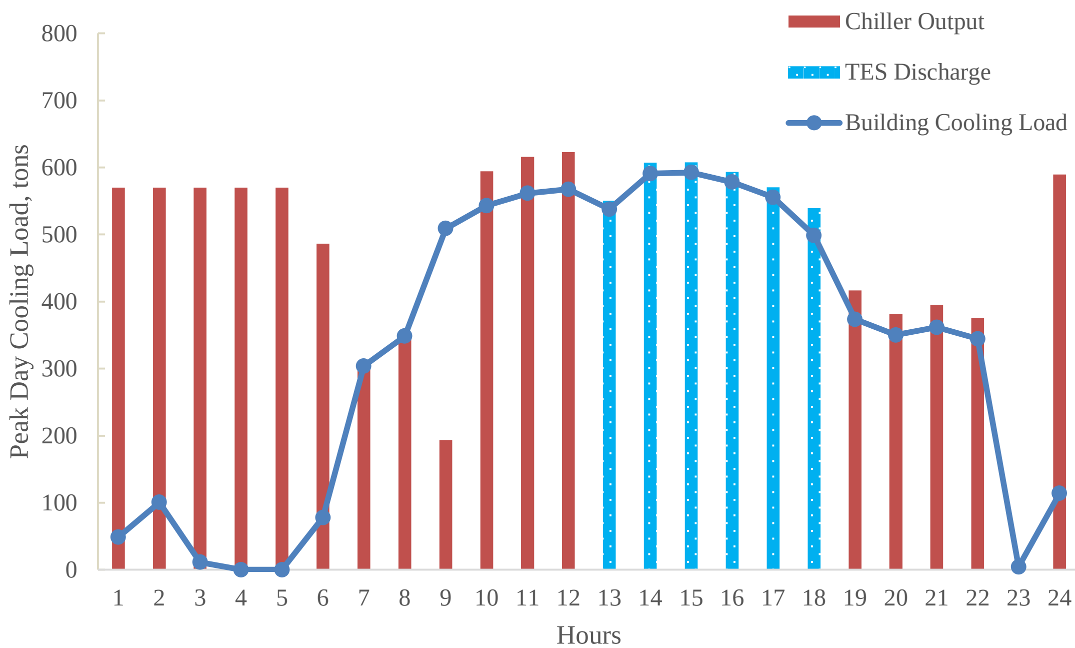


Figure 5. Full TES Operation (12pm to 6pm) on a Peak Day

4.3.2 Partial Storage

Partial storage systems can be configured as chiller-priority, storage-priority and parallel storage, as shown in Figure 6, Figure 7 and Figure 8, respectively. In this study, partial storage systems are operated for a discharging period of 10 hours from 8 am to 6 pm. Partial storage systems with chiller-priority are designed for the chiller to operate at full capacity for the charging and discharging period hours of the day. The storage tank gets discharged to satisfy the cooling load demand when the cooling load exceeds the chiller output. As shown in Figure 5, the series-connected chiller in the partial TES system operates at a limited cooling capacity constantly throughout the day to achieve a flat load profile. Figure 6 shows that the parallel chiller in the partial TES system provides about 50% of the cooling load along with the cooling discharged from the storage tank during the discharging period. Figure 6 presents the operation of partial TES systems with storage priority. Storage provides the required cooling first and then the chiller will meet the rest of the cooling load requirement when the storage is fully discharged.

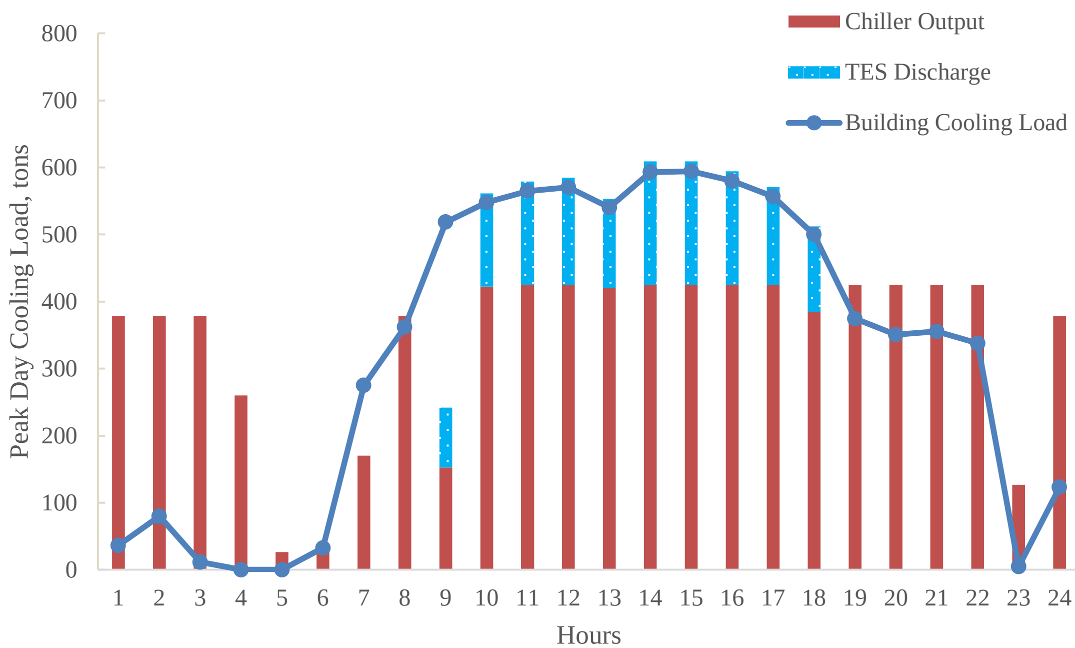


Figure 6. Partial TES operation (8am to 6pm) with chiller-priority on a peak day.

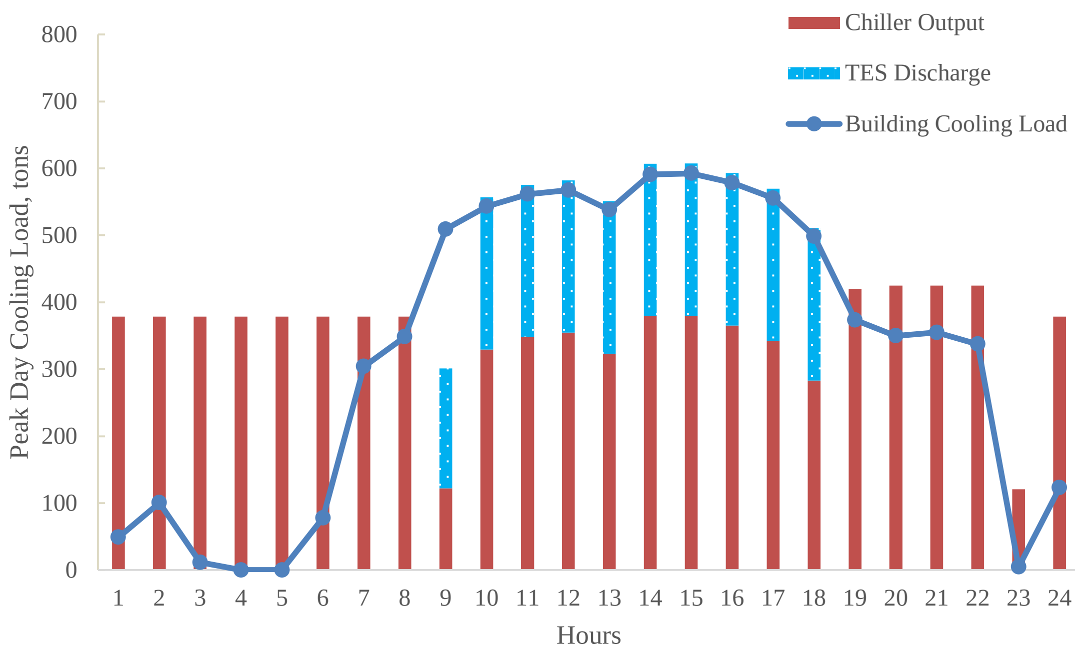


Figure 7. Partial TES operation (8am to 6pm) with parallel chiller on a peak day.

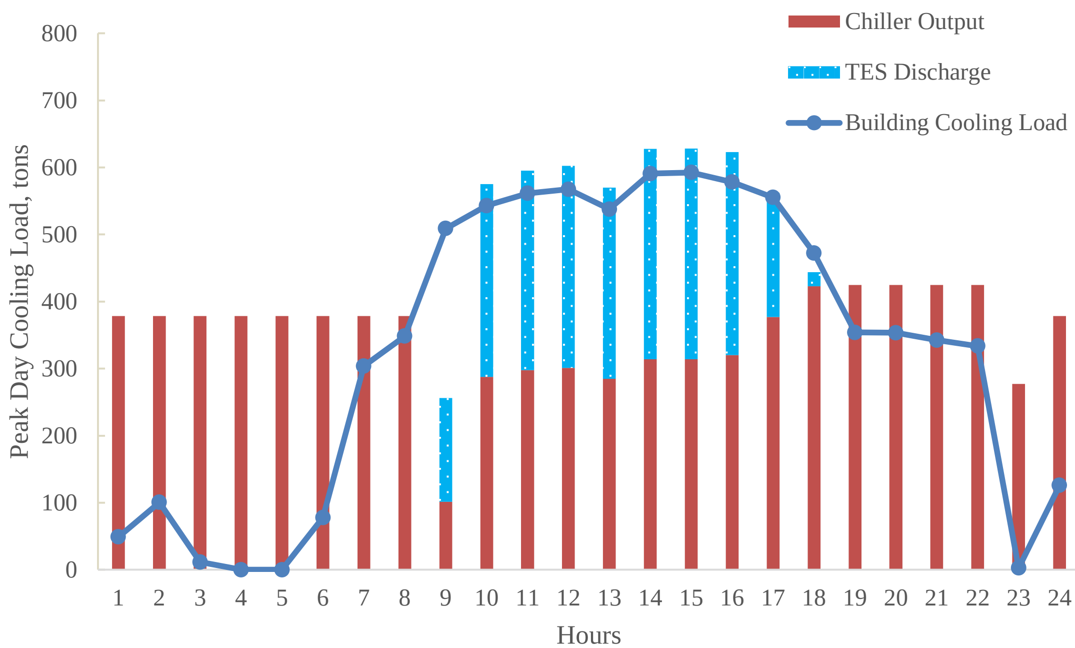


Figure 8. Partial TES operation (8am to 6pm) with storage-priority on a peak day.

Chiller-priority and storage-priority are two alternative operating strategies for cool partial storage systems (FEMP, 2000). For chiller-priority control, the chiller electricity use is attributed to the TES chiller during the unoccupied period and to the base-load chiller during the occupied period. During the on-peak period, chiller-priority control decreases the ice level since the TES system is used to partially meet building cooling load. In the case of storage-priority control, the ice is completely melted by the end of the on-peak period. To be effective, storage-priority control requires forecasting the building cooling load.

CHAPTER 5: TES and DR

Historically, TES has played a significant role in shifting load from peak to off-peak hours. On the supply side, TES provides a substantial benefit to the electric grid by transferring load from peak periods to off-peak hours. Electricity market structures such as time-of-use (TOU) rate schedules and tariffs with higher on- and mid-peak demand charges increase the potential economic benefit of TES implementation. TES is primarily used for peak demand shaving and TOU energy management. The load flexibility that TES provides can also help integrate intermittent renewable energy (RE) sources such as solar and wind. There are many DR and ancillary services market products directed at load participation (Ma et al., 2013). Table 1 presents the DR product definitions for participation in ancillary service, energy and capacity markets. TES can be used to provide many of these DR and ancillary services with existing controls.

For fast DR in commercial buildings, the existing communication and control system in the building automation system (BAS) can enable building end-uses to provide controllable fast DR participation. Previous studies have demonstrated that buildings can shed over 50% of HVAC related electric demand for both two-hour load shed events and 20-minute events for facilities with chiller units that can turn off compressors (Watson et al., 2012). The cooling storage capacity in the building thermal mass alone can be used to maintain comfort during a load shed event period, but the magnitude of the load shed is limited (Xu et al., 2008; Yin et al., 2010). In comparison to building thermal mass storage, the load shifting capability of TES systems can provide a reliable and fast load shed by turning off chiller plants without any interruption or impact on the building comfort service level.

Table 1. Product definitions for load participation in ancillary service, energy and capacity markets (Ma et al., 2013).

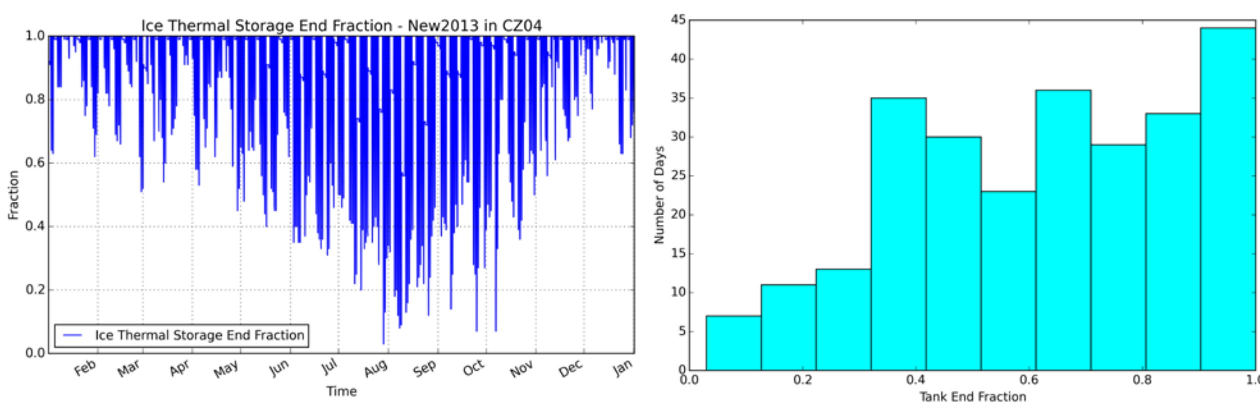
Product		**Physical Requirements**			
Product Type	General Description	How fast to respond	Length of response	Time to fully respond	How often called
Regulation	Response to random unscheduled deviations in scheduled net load	30 seconds	Energy neutral in 15 minutes	5 minutes	Continuous within specified bid period
Flexibility	Additional load following reserve for large un-forecasted wind/solar ramps	5 minutes	1 hour	20 minutes	Continuous within specified bid period
Contingency	Rapid and immediate response to a loss in supply	1 minute	≤ 30 minutes	≤ 10 minutes	≤ Once per day
Energy	Shed or shift energy consumption over time	5 minutes	≥ 1 hour	10 minutes	1-2 times per day with 4-8 hour

					notification
Capacity	Ability to serve as an alternative to generation	Top 20 hours coincident with balancing authority area system peak			

To determine the potential of TES to provide ancillary and DR services even when providing PLS, EnergyPlus simulations were run to quantify the amount of storage capacity that would remain each day after the TES had provided its peak period load shifting function. It is assumed that the remaining storage could be used for DR and ancillary services as described below.

5.1 Full Storage TES

EnergyPlus simulations of a 500 ksqft office building with a full ice storage system located in climate zone CZ04 (a "warm" climate zone; see Figure 19 for a map of climate zones) were run. The TES system was sized by first running the building model to determine the cooling load and using design days and ASHRAE guidelines (ASHRAE, 1993). Figure 8a shows the fraction of remaining TES storage for each day of the year and Figure 8b shows a histogram of the number of days of the year for each 10% increment of remaining storage. TES is fully discharged on less than 5% of the total number of weekdays during the year because the TES storage capacity is designed base on the total cooling load on the peak day. On all other days there is excess cooling storage capacity that can be used to provide DR and ancillary services. The simulation results indicate that the hourly discharging rate ranges from 0.1 to 0.15 for a full storage TES system. As seen in Figure 9, during the summer season, there are over 50 days where the storage tank end fraction can provide at least an hour's cooling capacity to the hour beyond the period of 8am to 6pm. However, almost all the DR programs require the load participation during the on-peak hours or daytime hours from early morning to late afternoon. Therefore, there is no room to shed additional electric demand when the chiller is completely turned off during the storage-discharging period.



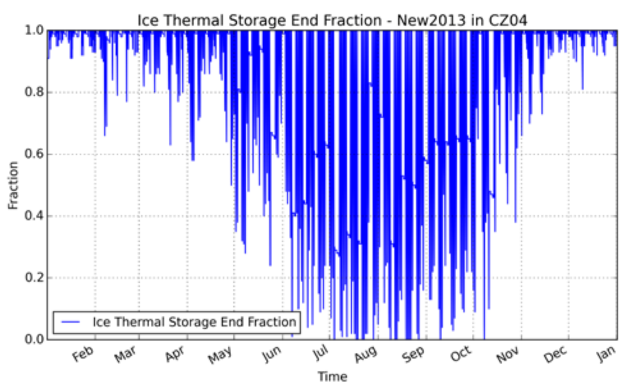
(a) End Fraction of Storage Tank throughout a Year

(b) Number of Days of Each Range of Storage Tank End Fraction

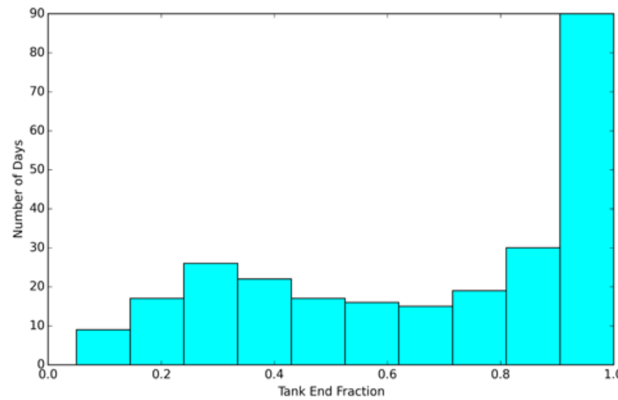
Figure 9. Excess cooling storage capacity of full TES systems for DR.

5.2 Partial Storage TES

Partial storage TES is more compatible for current DR programs targeted at reducing peak period electric demand because, unlike full storage systems, partial systems have peak period chiller load that can be shed. Simulations of typical office building in climate zone CZ04 with partial storage TES show that there is storage remaining on 95% of the days of a year (see Figure 10). This excess storage could be used on DR event days to further decrease chiller use and provide a load shed compared to baseline. Partial storage TES provides an opportunity to turn off the partial chiller plant by discharging the partial storage at higher rates than normal during load shed DR event periods, even at rates that would satisfy all cooling load in a given period,. Figures 11 and 12 illustrate load distribution between partial storage TES and chiller units and one- and two-hour load shed DR event responses, respectively.



(a) End Fraction of Storage Tank throughout a Year



(b) Number of Days of Each Range of Storage Tank End Fraction

Figure 10. Excess cooling storage capacity of partial TES systems for DR.

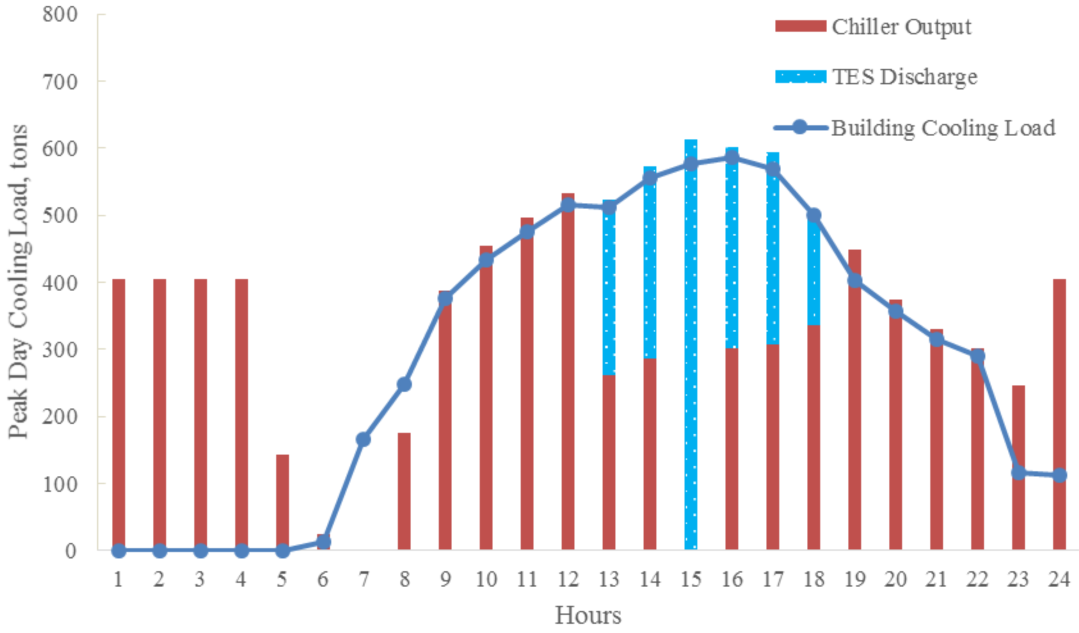


Figure 11. Partial storage TES systems for one-hour load shed events.

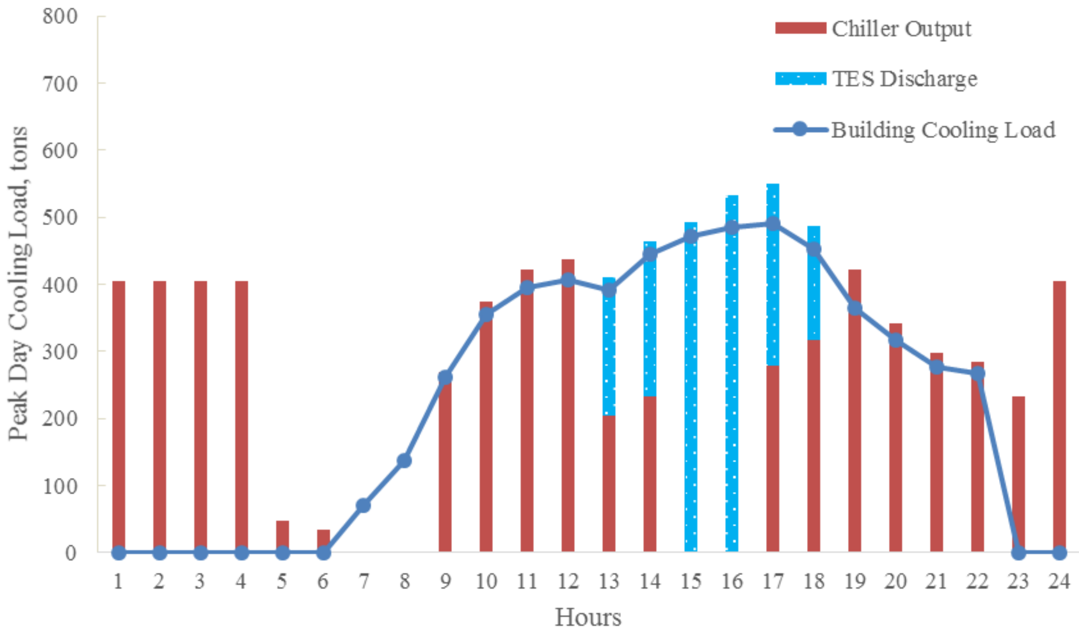


Figure 12. Partial storage TES systems for two-hour load shed events.

It is assumed that DR events are called on non-peak days, which are the hottest days, and then TES can be valuable by using the remaining storage capacity for DR. what if the dispatch is on the hottest days? The solution is to integrate with typical DR control strategies such as GTA. TES can aggregate each hour's small load shed from the temperature adjustment into the larger amount of cooling capacity for use in an hour or two hours.

5.2.1 TES for Base Interruptible Program

California utilities offer a demand response program known as the Base Interruptible Program (BIP). BIP is an emergency DR program offered by all three electric IOUs. BIP consists of a time-of-use tariff plus the customer must establish a firm service level (FSL) that they need to maintain during a DR event. Participants receive incentive payments in return for their obligation to reduce electricity usage to a specific FSL when BIP events are called. Participants who fail to reduce load down to or below their FSL are subject to a financial penalty assessed per kWh.

To evaluate how TES might be used in BIP we evaluate two sets of TES configurations: (1) full storage (full day storage from 8am to 6pm and partial day full storage from 12pm to 6pm) and (2) partial storage (different TES configurations and operational modes).

Full Storage

For a full TES system running either between 8am to 6pm or between 12pm to 6pm, the following scenarios are considered.

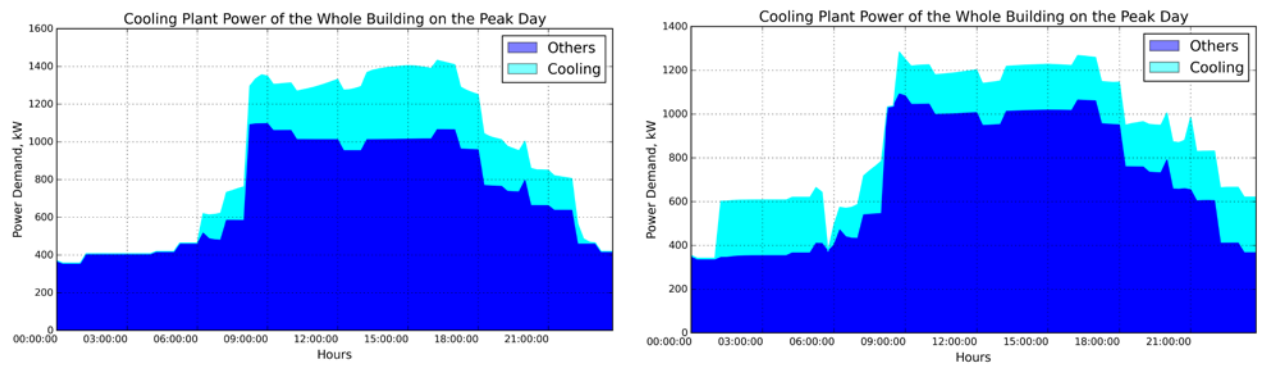
- By deploying the storage fully during the on-peak hours, the monthly summer on-peak demand of the cooling plant is zero. Therefore, there is no room to establish a FSL to get the potential of on-peak interruptible kW.
- For full storage deployed from 12pm to 6pm, the monthly summer mid-peak demand is the same as the base case without TES. So customers can shift the TES use from on-peak hours to mid-peak hours to get mid-peak interruptible kW. This approach requires that the BIP event be called during the mid-peak hours. However, all the previous BIP events in 2013 and 2014 were called during on-peak hours.

The only case where a full storage system can participate in BIP is to deploy the TES during the mid-peak hours, and run the chiller with TES during the on-peak hours to set a baseline of the monthly summer on-peak demand (the average demand over the summer on-peak hours). However, there is some risk of increasing customer costs; the results show that the loss of on-peak demand credit is more than that of BIP credit.

Partial Storage

A partial TES system reduces part of the cooling plant demand during the mid- and on-peak hours. It provides an opportunity to reduce more demand from the cooling plant (parallel- or series-connected chiller) by discharging more cooling energy from the storage tank during the BIP event hours. The risk with this possible operation scheme is that the storage capacity of a partial system may not meet the cooling load with the chiller shut down during the event hours. Unless the TES customer was notified of the BIP event before the start of the TES discharging mode, the building has to run some integrated DR control strategies (e.g. increasing cooling temperature set-points) to reduce the cooling load requirement during the BIP event hours.

BIP requires a minimum load reduction of 15% of the whole building power. For a partial storage system, the potential of on-peak interruptible kW is about 50% of the cooling plant power. However, for new construction, the cooling plant demand is about 25% of the whole building power, as shown in Figure 13. Turning off the chiller during the BIP event hours may not meet the required minimum 15% load reduction. Additional load reduction from other end-uses such as dimming lights, resetting the cooling temperature setpoints, or shutting down unnecessary equipment use in the building.



(a) Chiller Plant Demand of the Base Case without TES

(b) Chiller Plant Demand of Partial TES Systems

Figure 13. Chiller plant electric demand of base case and partial TES systems on the peak day.

SCE's BIP has two options: 15-minute notification and 30-minute notification. Incentives are somewhat greater for being able to respond more rapidly—15-min compared to 30-min. On the customer side, it is possible to shut down the chiller and other end-uses upon receiving the signal notification. Partial storage can participate in BIP by running normally from 12pm to the end of the day. For the use case of running the partial storage along with the chiller during a BIP event, the reduced chiller power is the on-peak interruptible kW and can be achieved by switching off the chiller and running the storage fully. Figure 14 shows the operation of shutting down the chiller during the BIP event hours. It can be seen that the chiller is required to meet the cooling load at the end of the peak period when the storage tank is fully discharged.

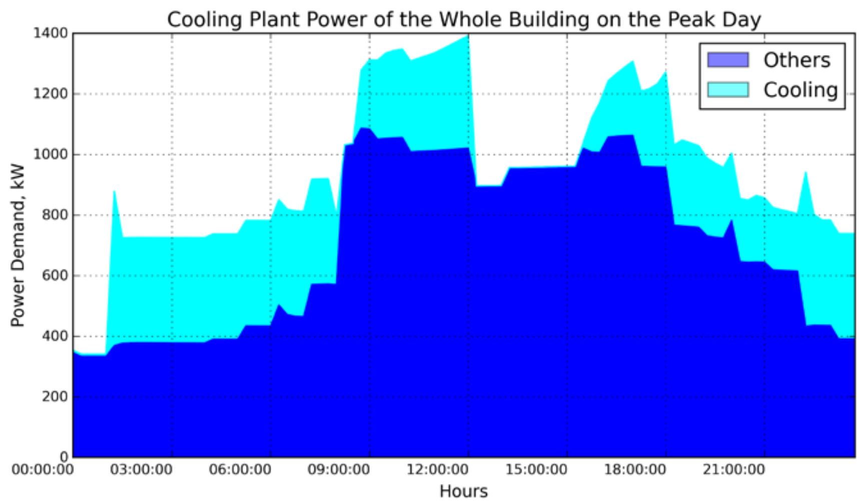


Figure 14. Load shed of the chiller plant during the BIP event hours.

For the option-A (15-minute of notification) BIP event, credit would be 1190 kW (Customer's Monthly Average Peak Period Demand) – 950 kW (Customer's Designated FSL) = 240kW × $21.11 = $5,066 (Monthly On-Peak Bill Credit).

The cost incurred in achieving the BIP credit equals the additional demand charge associated with the increased mid-peak demand, $779 (120kW × $6.49). The net benefit for the month is a fairly substantial $4287, making this an attractive use of TES.

5.2.2 TES and Real-Time Pricing

Real-time pricing (RTP) is structured with different hourly prices that varying depending on peak temperature as shown in Figure 14. TES customers with the flexibility to shift or reduce electrical usage can reduce energy bills with RTP. As with the BIP program, partial TES systems provide greater advantage with RTP in comparison to full storage TES systems.

Southern California Edison's RTP is set for non-holiday days according to season, temperature and time of day (see Figure 15). Temperature-based rates are determined by the previous day's high temperatures in downtown Los Angeles as recorded by the National Weather Service. RTP is beneficial if customers can reduce energy usage during hours with higher temperature-driven prices, and/or shift usage to lower priced hours. A TES system with higher flexibility can enable a customer to take greater advantage of RTP in comparison to a conventional cooling system without TES because chiller load can be shifted during the storage-discharging period.

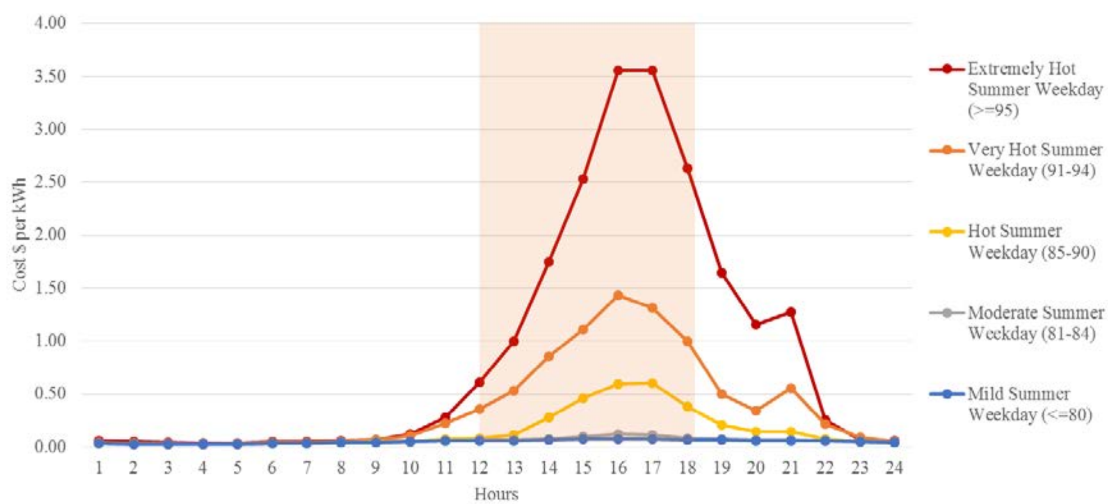


Figure 15. RTP pricing schedules on the day of season (source: SCE).

Cooling loads from a simulation of an office building with partial TES on a summer day with peak temperature > 95°F and SCE RTP prices are shown in Figure 16. TES discharge and chiller operation can be optimized to minimize electricity costs with RTP. An optimal operational scheme uses as much storage as possible to satisfy cooling when electricity prices are highest. The challenge in this control optimization is to accurately forecast the peak period cooling load and ensure that there is adequate storage to satisfy that load.

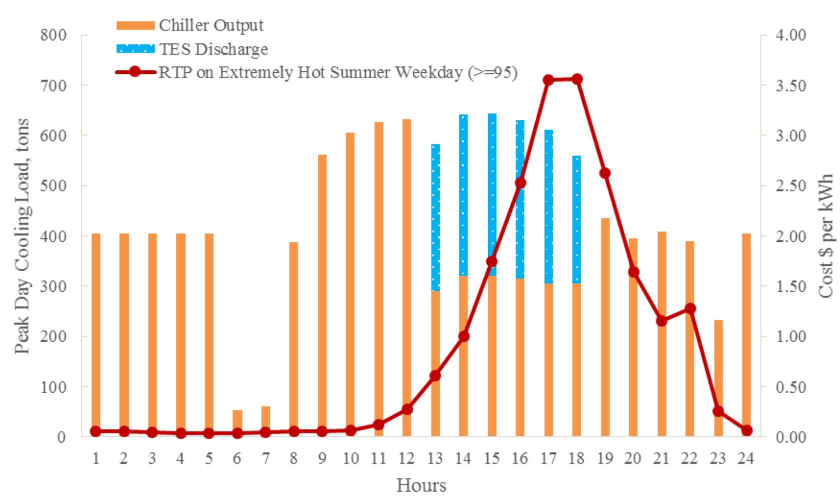


Figure 16. Normal operation of partial tes system on a extremely hot summer weekday.

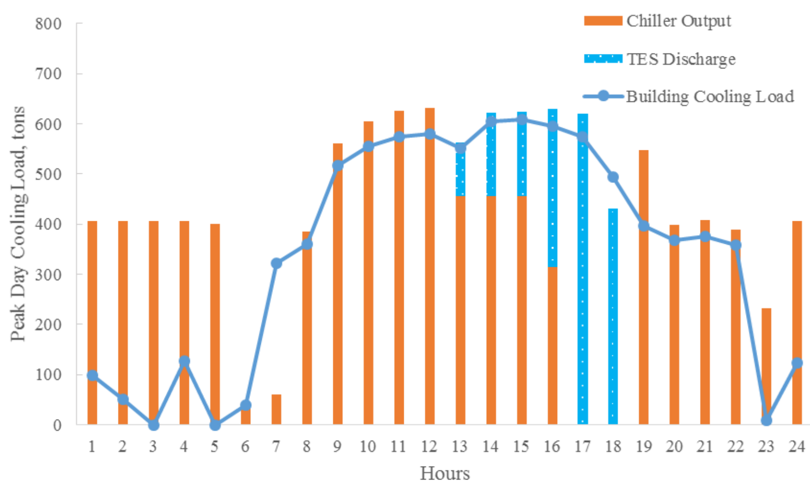


Figure 17. Optimal operation of partial TES system on an extremely hot summer weekday.

By running the optimal TES discharging scheme on an extremely hot summer weekday, utility cost can be reduced by $1,289, which is about 5.1% of the daily utility cost, as presented in Table 2.

Table 2. Energy Cost on an Extremely Hot Summer Weekday for RTP Rate.

Each day above 95°F	Daily energy cost with normal control ($/Kft^2)	Daily energy cost with better control ($/Kft^2)	Daily cost savings ($)	Daily cost savings (%)
	50.0	47.8	1,289	5.1%

CHAPTER 6: Analysis of TES Cost Effectiveness

California IOUs see a value in the load shifting that TES can provide their customers and encourage TES installations with financial incentives of up to $875 per kW of storage. Discussions with the IOU managers of the TES incentive programs indicated a need for greater insight of specific benefits for customers considering TES. The amount of savings a commercial customer can achieve with TES depends on a wide range of factors including: building type, age, climate zone, TES type, and utility tariff structure (see Fig 18). The impact of each of these factors was studied by performing a number of detailed building simulations.

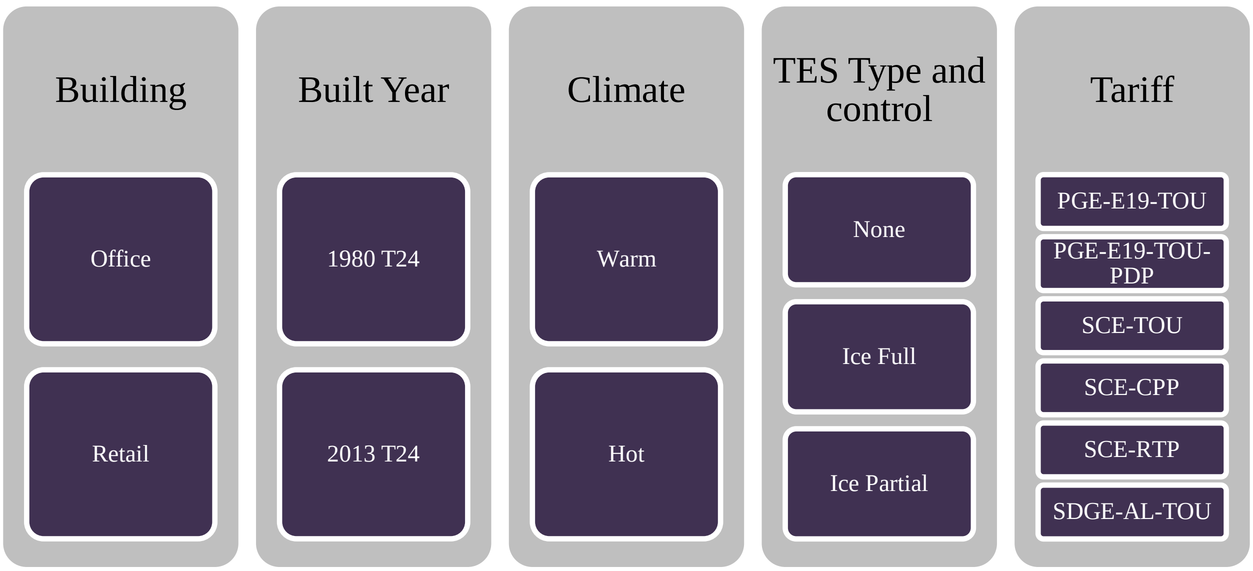


Figure 18. Simulation matrix of TES use cases.

6.1 Prototype Building Model

This study used prototype building models that were developed as part of DOE's support of commercial building energy codes and standards (NREL, 2011). The building models provide complete descriptions for whole building energy analysis using EnergyPlus simulation software. Prototype models representative of the office and retail building stocks in the U.S. were used in this study.

Two building stock ages were used to evaluate TES in California: (1) existing buildings built before 1980 and (2) new construction buildings that comply with the 2013 Title 24 building energy standard. Title 24 energy codes date back to 1978 when the CA legislature enacted the rules to control building codes and energy efficiency. The Title 24 building code has been updated every 2-3 years by the California Energy Commission (CEC) and the current rules became effective in 2014 (Title 24, 2013). For existing buildings, the cooling plant will have been operating for over 20 years and it would likely be cost effective to retrofit with higher efficiency equipment. The increasing attention on peak demand from the electricity market and potential utility bill cost saving makes it attractive to consider deploying TES with the cooling plant retrofit in existing buildings. As the building energy codes have changed over the years, the value of TES in new construction buildings may be different from that in existing buildings due to increasingly efficient building envelopes and HVAC systems.

Table 3 presents the prototype office and retail model parameters for existing buildings built pre-1980 and new construction buildings built in 2014 or later. Primary differences between those two prototype models are building envelope, lighting power density, HVAC system and plant efficiency, and control requirements of air economizer.

Table 3 (a) Prototype office model parameters for pre-1980 existing building and new construction and (b) Prototype retail model parameters for pre-1980 existing building and new construction.

Model Components	Office Pre-1980	Office New Construction
Floor area	500,000 ft^2	500,000 ft^2
People	People = 2,397 total, 5.38/100 m^2 (5.0/1000 ft^2); basement 2.69/100 m^2 (2.5/1000 ft^2)	
Lights	16.14 W/m^2 (1.6 W/ft^2)	8.61 W/m^2 (0.8 W/ft^2)
Plug and Other Loads	10.76 W/m^2 (1.0 W/ft^2) Elevators = 12 @ 25 HP each, 91% motor efficiency, motor heat exhausted directly	
Exterior Walls	U-value = 1.07 W/m^2□K	U-value = 0.35 W/m^2□K
Roof	U-value = 0.44 W/m^2□K	U-value = 0.37 W/m^2□K
Windows	U-value = 6.98 W/m^2□K SHGC = 0.71	U-value = 2.04 W/m^2□K SHGC = 0.25
Cooling Plant Efficiency	COP = 5.2 (>=300 Tons)	COP = 6.1 (>=300 Tons)
HAVC System	Variable-Air-Volume (VAV) with reheat system	
Cooling Plant	Base case: water-cooled electric chiller TES: electric chiller + TES	
TES	Full storage: on-peak hours and on-peak/mid-peak hours Partial storage: on-peak/mid-peak hours	
System operation	6am to 10pm on weekdays	

	6am to 6pm on Saturday No operation on Sunday & Holidays

Model Components	Retail Pre-1980	Retail New Construction
Floor area	24,692 ft^2	24,692 ft^2
People	Retail area 16.16/100 m^2 (15.0/1000 ft^2)	
Lights	16.14 W/m^2 (1.6 W/ft^2)	8.61 W/m^2 (0.8 W/ft^2)
Plug and Other Loads	Retail area = 3.23 W/m^2 (0.3 W/ft^2) Sale area = 21.52 W/m^2 (2.0 W/ft^2)	
Exterior Walls	U-value = 1.07 W/m^2□K	U-value = 0.35 W/m^2□K
Roof	U-value = 0.44 W/m^2□K	U-value = 0.37 W/m^2□K
Windows	U-value = 6.98 W/m^2□K SHGC = 0.71	U-value = 2.04 W/m^2□K SHGC = 0.25
Cooling Plant Efficiency	COP = 3.8 (<=150 Tons)	COP = 5.5 (<=150 Tons)
HAVC System	Variable-Air-Volume (VAV) with reheat system	
Cooling Plant	Base case: air-cooled electric chiller TES: electric chiller + TES	
TES	Full storage: on-peak hours and on-peak/mid-peak hours Partial storage: on-peak/mid-peak hours	
System operation	6am to 9pm on weekdays 6am to 10pm on Saturday 8am to 7pm on Sunday & Holidays	

The load patterns for office and retail buildings are better suited for TES compared to healthcare where load shapes are flatter between day and night and industry where cooling is smaller fraction of total load. Results for office buildings are applicable to educational buildings because the load shapes and fractions of total load are comparable for each (NREL, 2011).

6.2 Climate Zones

As indicated in the DOE Global Energy Storage Database, a majority of TES projects are located in the warm and hot climate areas since the cooling load here offers more potential of load shifting from on-peak hours to off-peak hours compared to cooler climates. In this study, we evaluate the value of TES in buildings in each IOU (Investor-Owned Utility) territory in California. The three IOUs are PG&E (Pacific Gas and Electric), SCE, and SDG&E (San Diego Electric & Gas). Figure 19 shows the California Electric Utility Service Areas and California climate zones. The California Energy Commission originally developed weather data for each climate zone for a representative city and weather year (representative months from various years) in what is called a typical meteorological year (TMY). The TMY is constructed to represent the meteorological conditions that would be typical for each hour of the year over the past 30 years and not the average hourly values[8]

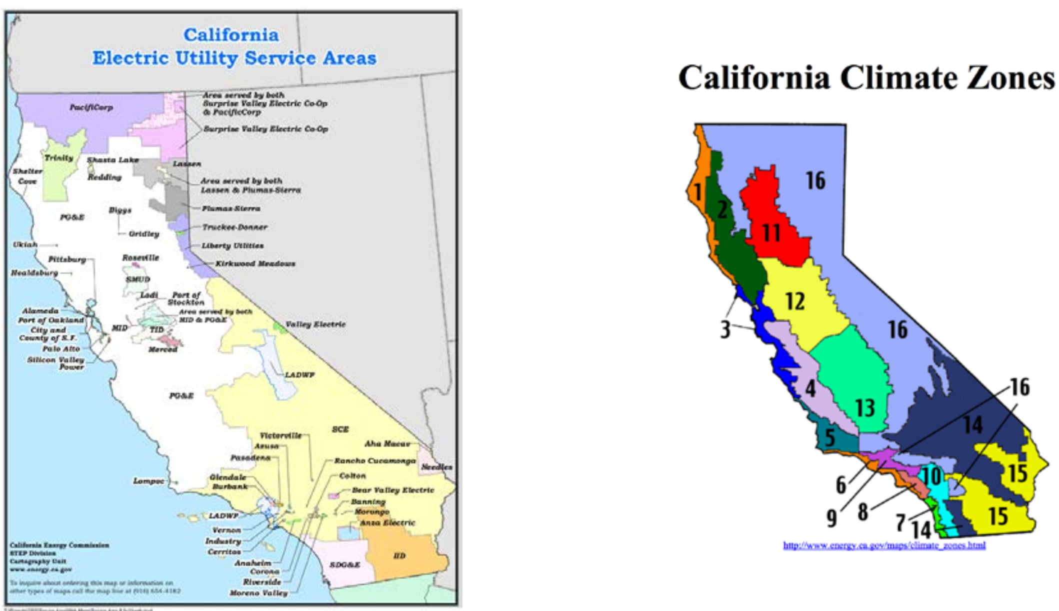


Figure 19. (a) California electric utility service areas and (b) California climate zones.

Table 4 presents the climate data of selected zones in each area of PG&E, SCE and SDG&E. For each territory area, two climate zones are selected for warm and hot weather simulations. The warm and hot climates are distinguished by the number of heating and cooling degree days. Heating degree days and cooling degree days are defined relative to a base temperature—the

[8] Weather data for simulation, http://www.energy.ca.gov/maps/renewable/building_climate_zones.html and http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_simulation.cfm

outside temperature above which a building needs no heating, the outside temperature below which a building needs no cooling, respectively.

Table 4. Climate data of selected warm and hot zones in each IOU territory (PEC, 2006).

Utilities	Climate Zones	Reference City	Heating Degree Days	Cooling Degree Days
PG&E	CZ-04	San Jose	2335	574
	CZ-12	Stockton	2702	1470
SCE	CZ-09	Los Angeles	1154	1537
	CZ-10	Riverside	1904	1714
SDG&E	CZ-07	San Diego	2009	505
	CZ-10	Escondido	1904	1714

6.3 Utility Tariffs

As part of cost effectiveness analysis of TES performance in buildings, the monthly and annual utility bills are metrics for quantifying the TES performance under different utility tariffs. As the base case, the Time of Use (TOU) tariff is defined as the default tariff for use in comparisons.

6.3.1 PG&E

E-19 is a utility rate for large commercial customers of PG&E. Customers under this time-of-use rate can also elect to switch to a time-of-use Peak Day Pricing (PDP) rate plan. PDP gives customers a discount on normal summer electricity rates in return for reducing the electricity usage during PDP event hours. Usually there are 9-15 PDP event days per year, typically the hottest days of the summer.

6.3.2 SCE

There are TOU-8 and TOU-8-RTP (Real-time Pricing) utility rate schedules for large commercial customers of SCE. Under the TOU rate schedule, the default rate structure is CPP (Critical Peak Pricing) that is similar to the PG&E PDP rate. In addition, there are options customers can select between. Option-A is available to customers who participate in Permanent Load Shifting (PLS). TES is one of the PLS technologies that is applicable to the Option-A rate structure. TOU-8, TOU-8-CPP, TOU-8-Option-A and TOU-8-RTP were applied to different TES use cases in simulations in this study.

6.3.3 SDG&E

SDG&E's business customers are divided into two classes: (1) small commercial and (2) medium and large commercial. AL-TOU is the rate schedule for medium and large commercial customers in SDG&E, which is applicable to customers with maximum monthly demand equal or greater than 20 kW for 12 consecutive months. There is only one option under this rate schedule. In addition to the default AL-TOU rate schedule, the Critical Peak Pricing (CPP) program is included to evaluate the value of TES under such a DR program.

Table 5 summarizes each IOU's typical rate schedules for TES simulations in this study. For the most part, each IOU's TOU rate schedules have similar structures that include the mid- and on-peak demand charges, and time-of-use energy charges. However, SD&E's TOU rate schedule has a much higher summer monthly demand charge, a lower summer on-peak charge and constant time-of-use energy charges. It indicates that limiting the monthly peak demand of the whole building is more important than reducing the on-peak demand for the TES deployment. For a TES system in a building, the impact on reducing the annual utility bill is different for each rate schedule. From a customers' point of view, the comparison of the annual utility bill can help make a cost-effective decision of the TES design and operation either for an existing or new building.

Table 5. Summary of each IOU's rate schedules for TES simulation.

Utilities	PG&E		SCE[9]				SDG&E[10]	
Rate Schedules	TOU	PDP	Option B	CPP	Option A	RTP	AL-TOU (EECC)	EECC-CPP
Meter charge	729.4	729.4	609.78	609.78	609.78	609.78	465.74	465.74
Summer on-Peak demand	19.03	19.03	22.95	22.95	0	0	10.37	10.37
Summer mid-peak demand	4.42	4.42	6.49	6.49	0	0	7.66	7.66
Summer monthly demand charge	13.67	13.67	15.57	15.57	15.57	15.57	24.43	24.43
Winter mid-peak	0.24	0.24	0	0	0	0	7.66	7.66
Winter monthly demand charge	13.67	13.67	0	0	0	15.57	0	0
Summer on-peak energy	0.16533	0.16533	0.14157	0.14157	0.39399	RTP*	0.12105	0.12105
Summer mid-peak energy	0.11193	0.11193	0.08704	0.08704	0.14099	RTP*	0.11125	0.11125
Summer off peak energy	0.07697	0.07697	0.06243	0.06243	0.06243	RTP*	0.08028	0.08028
Winter mid peak energy	0.10485	0.10485	0.08854	0.08854	0.08854	RTP*	0.09355	0.09355
Winter off peak energy	0.08097	0.08097	0.06765	0.06765	0.06765	RTP*	0.07197	0.07197
PDP/CPP charge	0	1.2	1.37453	1.37453	0	0	0	1.34412
PDP/CPP credits on peak demand	0	6.19	11.93	11.93	0	0	0	11.93
PDP/CPP credits on mid demand	0	1.34	0	0	0	0	0	0

[9] For SCE's RTP rate schedule, the energy charge of UG varies by previous day's Peak OAT (Outside Air Temperature), hour of day and seasonally.

[10] For demand charge of SDG&E's TOU rate schedule, there is winter on-peak demand charge in instead if winter mid-peak demand charge. For EECC-CPP rate schedule, an additional monthly charge is calculated by multiplying the Capacity Reservation Level (kW) with Capacity Reservation Charge ($/kW) on the monthly basis.

*Varies based on peak temperature recorded the day before.

6.4 Value of TES

The goal of conducting the cost effectiveness analysis of TES is to explore the market potential for the application of TES in existing building retrofits and new construction. The market has provided more demand response programs for customers with flexible load resources. The value of TES may vary between each other for TES application under each territory area. For each use case presented here, there is an optimal TES design and operation scheme for achieving the maximum utility bill savings. This analysis also provides insight to the level of incentives that IOUs may want to consider for TES for customers to participate in PLS and DR programs.

6.4.1 TES Value for Customers

The cost-effectiveness of TES is quantified by comparing utility bill costs of buildings with TES to those with a conventional chiller only system. Utility bill calculations include energy charges, demand charges (on- and mid-peak demand charges, facility related demand charge), and incentives bundled with special rate programs (e.g. energy and demand credits of PDP, CPP events).

A previous study to determine incentive values for TES for PLS (E3, 2011) estimated TES system costs range from $150 to $450 per ton-hr of TES storage capacity. To estimate total TES system first costs (not including O&M), we assumed $275 per ton-hr of TES storage capacity. TES system costs can vary widely depending on a variety of factors. The cost values are presented here for comparing different TES application scenarios and should not be considered actual absolute costs. Currently IOUs offer a TES PLS incentive of $875 per kW of reduced peak period load (not to exceed 50% of project cost). TES system costs and payback periods were calculated with and without the incentive.

For TES applications in small to mid-sized commercial buildings such as retail stores, the number of deployments of thermal storage in conjunction with commercial direct expansion (DX) air-conditioning systems has been increasing over the previous decade[11]. It should be noted that this type of TES system isn't eligible for the current IOU PLS-TES program. Data from the DOE energy storage database indicates that this kind of TES system costs $2170/kW (the amount of electrical demand reduction during the on-peak hours) that includes rooftop units, storage and relevant installation cost[12]. The currently available incentive value, $875 per kW of reduced peak period load (not to exceed 50% of project cost) was also applied in calculating TES system costs and payback periods for small and medium retail buildings.

The following metrics in Table 6 are defined in this study to evaluate the TES value for utilities (e.g. demand savings) and customers (e.g. annual utility bill cost saving).

Table 6. TES system performance metrics.

[11] Ice Energy, http://www.ice-energy.com/

[12] DOE Global Energy Storage Database, http://www.energystorageexchange.org/

Parties	Metrics	Definition
Utilities	Peak Period Demand Savings	The reduction in the peak demand during the storage-discharged period from TES systems
Customers	Annual Electricity Cost	The total annual electric utility cost
	Annual Electricity Cost Savings	The annual energy bill savings between operation with and without TES
	Payback Period without Incentive	Length of time in years until cumulative electric utility cost savings from TES equal total initial cost of TES system
	Payback Period with Incentive	Length of time in years until cumulative electric utility cost savings from TES equal initial cost of TES system above available incentives

6.4.2 TES for Utilities and Grid Operators

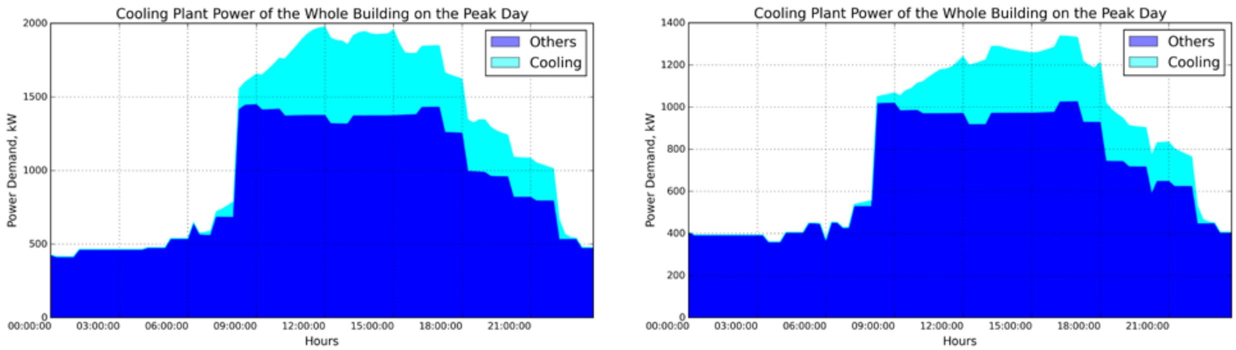
Utilities and grid operators are currently most interested in the amount of demand shed from summer afternoon on-peak hours (typically 12 pm – 6 pm). Full storage systems would provide greater on-peak demand shed potential than partial storage systems. Utilities and grid operators are increasingly interested in shifting loads at all hours to deal with intermittent renewable energy generators and the accompanying changes to the overall grid load pattern that will vary throughout the year. TES systems sized and operated for partial storage offer greater flexibility for load shifting compared to full storage systems.

6.5 Results

6.5.1 TES in PG&E Territory

6.5.1.1 TES in Office Buildings

Climate Zone 4 (CZ04) and Climate Zone 12 (CZ12) are representative of warm and hot climates in the PG&E territory, respectively. Figure 20 shows the electrical demand of the base case for “Pre1980” (Existing Buildings) and “New 2013” (New Buildings) without TES in CZ04. The peak demand of “Pre1980” existing buildings and “New2013” new buildings are 4.05 W/ft^2 and 2.82 W/ft^2, respectively. The cooling plant electrical demand accounts for about 32% of the whole building base load for both existing and new buildings. It can be seen that “New2013” buildings are more efficient than existing buildings, while the fraction of whole building demand that is cooling plant demand nearly the same for existing and new office buildings.



(a) Pre1980 (b) New 2013

Figure 20. Cooling plant power vs. whole building power for an office building in climate zone CZ04 on the peak demand day.

Table 7 summarizes the results of TES cost effectiveness for "Pre1980" existing buildings in CZ04. Under the PG&E tariff rates (TOU and PDP), full storage systems either deployed between 12pm to 6pm or 8 am to 6 pm are more attractive than partial storage systems for providing annual cost savings, which range from 13% to 17% for full storage systems and 7-8% for partial storage systems. The 9-hr full storage system provides the highest annual cost savings. Considering TES system cost, and assuming it scales with size (in tons), as the payback metric does, smaller systems—6-hr full and 9-hr partial—will have shorter payback periods (the inverse of the payback metric). Using TES alone as DR strategy for participating in PDP provides a modest 1-2% cost saving advantage. Older office building PG&E customers in CZ04 will have the lowest annual utility bills with tariff E19 PDP and a full storage 9-hr TES (see Table 7), but payback would be faster with a full storage 6-hr TES. Older buildings require larger cooling, and storage, systems than newer making the difference in cost between 6-hr and 9-hr systems greater for older office buildings compared to newer ones.

Table 7. TES cost effectiveness in "Pre1980" office building with PG&E tariffs in CZ04.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP
Base Chiller Capacity (Ton)	1,175						588	
Total cooling load (Ton.hr)	8,530							
Building peak power (W/ft2)	4.05		3.88		2.71		3.51	
TES Capacity (Ton.hr)	0		5561		8530		4265	
TES Portion of Cool Load	0		65%		100%		50%	
On-Peak Decrease (kW)	0		671				270	
Annual Utility Cost ($K)	1,404	1,378	1,217	1,200	1,186	1,169	1,311	1,288

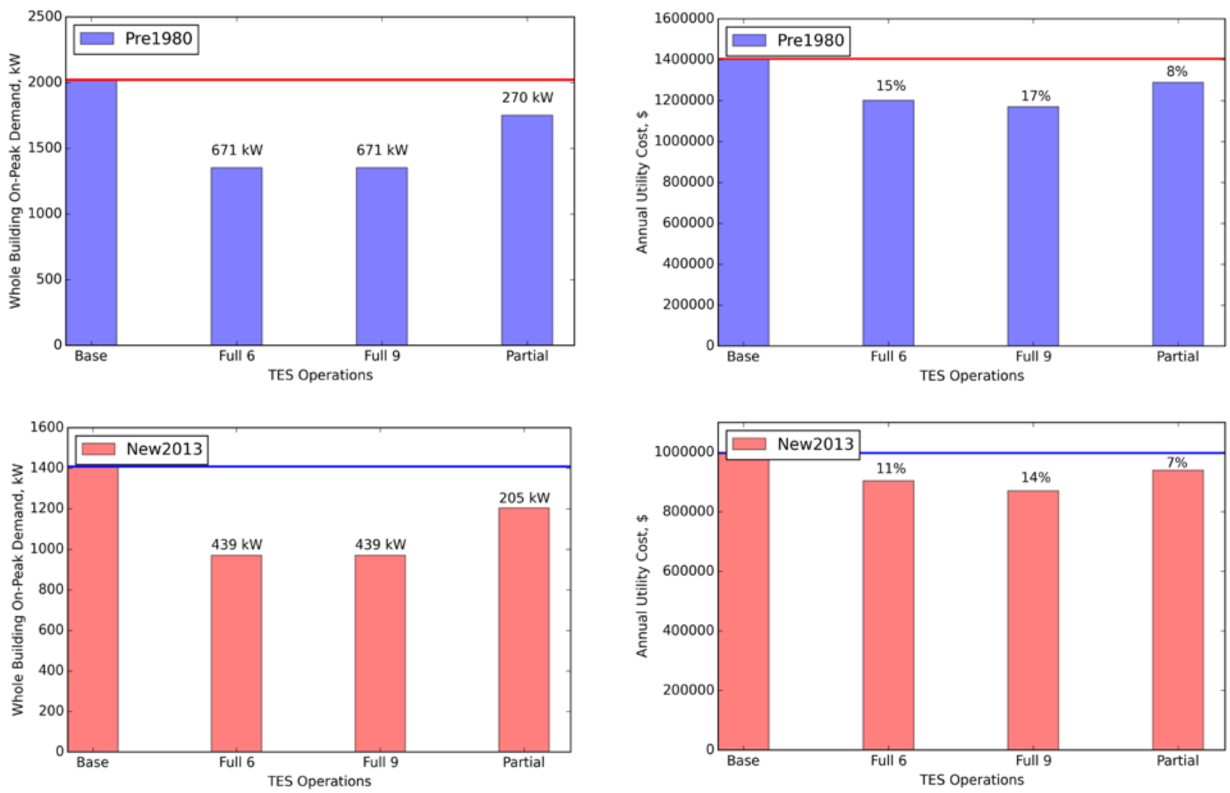
Annual Cost Savings ($)			187,482	204,021	218,556	234,980	93,054	115,862
Annual Cost Savings (%)			13%	15%	16%	17%	7%	8%
TES System Cost ($)			1,520,365		2,345,706		1,172,853	
TES Sys. Cost w/ Incent. ($)			933,240		1,758,581		936,603	
Payback Period (yr)			8.1	7.5	10.7	10.0	12.6	10.1
Payback Per. w/ Incent. (yr)			5.0	4.6	8.0	7.5	10.1	8.1

Similar to TES in "Pre1980" existing buildings, full storage TES systems provide greater annual utility bill cost savings than partial storage TES systems in new construction. As summarized in Table 8, the annual utility cost savings range from 10% to 14% for full storage TES systems. Due to the lower overall cooling load to be met in new construction, TES sizes are much smaller compared to older buildings. With the smaller TES system sizes, the cost differences between partial and full storage systems are smaller compared to those for older buildings. New office building PG&E customers in CZ04 will have the lowest annual utility bills with tariff E19 PDP and a full storage 9-hr TES (see Table 8) and payback is only slightly longer compared to a smaller full storage 6-hr TES.

Table 8. TES cost effectiveness in "New2013" office building with PG&E tariffs in CZ04.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP
Base Chiller Capacity (Ton)	762						381	
Total cooling load (Ton.hr)	4,786							
Building peak power (W/ft2)	2.83		2.57		1.96		2.41	
TES Capacity (Ton.hr)	0		3365		4786		2370	
TES Portion of Cool Load	0		70%		100%		50%	
On-Peak Decrease (kW)	0		439				205	
Annual Utility Cost ($)	1,013,569	997,244	915,495	903,939	881,844	870,288	953,596	939,117
Annual Cost Savings ($)			98,074	109,629	131,725	143,280	59,973	74,451
Annual Cost Savings (%)			10%	11%	13%	14%	6%	7%
TES System Cost ($)			933,939		1,324,890		651,585	
TES Sys. Cost w/ Incent. ($)			549,814		940,765		472,210	
Payback Period (yr)			9.5	8.5	10.1	9.2	10.9	8.8
Payback Per. w/ Incent. (yr)			5.6	5.0	7.1	6.6	7.9	6.3

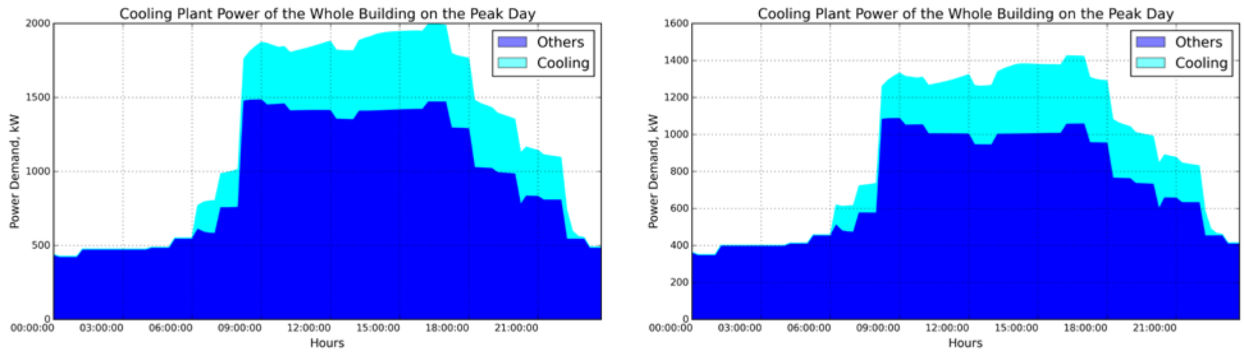
From the perspectives of the IOUs, the peak demand reduction is most attractive for TES applications in both existing and new buildings. Obviously, full TES systems deployed either on 8am~6pm or 12pm~6pm give the same demand reduction during the on-peak hours (12pm~6pm). As described in the section of TES system configurations, partial TES systems with storage-priority utilize the storage to the greatest extent rather than on the reduction of the peak demand. Figure 21 shows that full 9-hr storage TES systems are more attractive in the PG&E territory area.



(a) On-Peak Demand (kW) (b) Annual Utility Cost ($)

Figure 21. Value of TES for an office building in climate zone CZ04.

Figure 22 shows the electrical demand of the base case for "Pre1980" (Existing Buildings) and "New 2013" (New Buildings) without TES in CZ12. The peak demand of "Pre1980" existing buildings and "New2013" new buildings are 4.06 W/ft² and 2.83 W/ft², respectively. Compared with the building energy performance in CZ04, it can be seen that the peak demand of buildings in CZ04 and CZ12 is close, while the cooling load during the morning period is higher in CZ12.



(a) Pre1980

(b) New 2013

Figure 22. Cooling plant power vs. whole building power for an office building in climate zone CZ12 on the peak demand day.

As presented in Table 9 and Table 10, the TES performance of office buildings in CZ12 is similar as that in CZ04, but less attractive based on the payback metric. Notice that the office building in CZ12 has more cooling load in the morning period than that in CZ04, the results indicate that the shifting of the cooling load during the on-peak period is more effective for TES deployment rather than shifting the additional cooling load in the morning period. This finding also supports the deployment of the TES system during the on-peak hours rather than the full TES system on the entire day.

Table 9. TES cost effectiveness in "Pre1980" office building with PG&E tariffs in CZ12.

TES Cases	**Base Case**		**Full Storage 6-hr (12pm~6pm)**		**Full Storage 9-hr (8am~6pm)**		**Partial 9 Hours**	
Utility Tariffs	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP
Base Chiller Capacity (Ton)	1,266						633	
Total cooling load (Ton.hr)	9,004							
Building peak power (W/ft2)	4.00		3.77		2.96		3.47	
TES Capacity (Ton.hr)	0		73		114		57	
TES Portion of Cool Load	0		64%		100%		50%	
On-Peak Decrease (kW)	0		626				268	
Annual Utility Cost ($K)	1,394	1,381	1,253	1,221	1,194	1,182	1,313	1,300
Annual Cost Savings ($)			141,245	172,702	200,383	212,300	80,679	93,819
Annual Cost Savings (%)			10%	12%	14%	15%	6%	7%
TES System Cost ($)			1,585,524		2,476,023		1,238,012	
TES Sys. Cost w/ Incent. ($)			1,037,774		1,928,273		1,003,512	
Payback Period (yr)			11.2	9.2	12.4	11.7	15.3	13.2
Payback Per. w/ Incent.			7.3	6.0	9.6	9.1	12.4	10.7

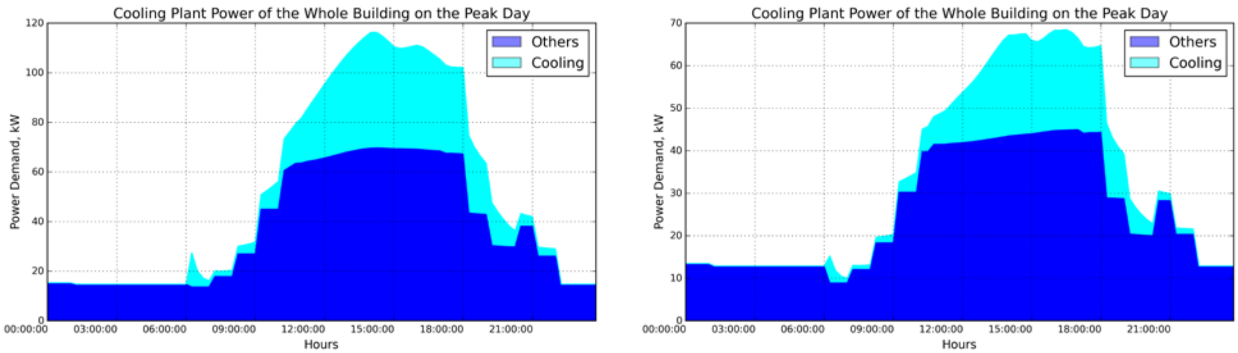
(yr)								

Table 10. TES cost effectiveness in "New2013" office building with PG&E tariffs in CZ12.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP	**E19**	E19 PDP
Base Chiller Capacity (Ton)	821						410	
Total cooling load (Ton.hr)	6,121							
Building peak power (W/ft2)	2.86		2.65		2.16		2.49	
TES Capacity (Ton.hr)	0		50		78		39	
TES Portion of Cool Load	0		65%		100%		50%	
On-Peak Decrease (kW)	0		436				183	
Annual Utility Cost ($)	1,011,972	1,002,869	919,794	911,274	888,451	879,932	955,369	946,349
Annual Cost Savings ($)			92,178	91,595	123,521	122,937	56,603	56,520
Annual Cost Savings (%)			9%	9%	12%	12%	6%	6%
TES System Cost ($)			1,085,975		1,694,121		847,061	
TES Sys. Cost w/ Incent. ($)			704,475		1,312,621		686,936	
Payback Period (yr)			11.8	11.9	13.7	13.8	15.0	15.0
Payback Per. w/ Incent. (yr)			7.6	7.7	10.6	10.7	12.1	12.2

6.5.1.2 TES in Retail Buildings

As shown in Figure 23, the peak demand of "Pre1980" and "New2013" retail stores is 5.08 W/ft^2 and 2.86 W/ft^2, respectively. The portion of the cooling plant electrical demand is 46% in "Pre1980" retail stores, 38% in "New2013" retail stores. On the peak day, the HVAC system operates from 6am to 10pm and the majority of the cooling plant electricity usage is consumed from 10am to 6pm. For the TES in retail stores, the following TES use cases are simulated: (1) full TES deployed from 10am to 9pm; (2) full TES deployed from 12am to 6pm; (3) partial TES in parallel deployed from 10am to 9pm and (4) partial TES with storage priority deployed from 12pm to 9pm.



(a) Pre1980 (b) New 2013

Figure 23. Cooling plant power vs. whole building power for a retail building in climate zone CZ04 on the peak demand day.

Table 11 and Table 12 present the summary of TES performance for "Pre1980" and "New2013" retail stores in CZ04. The annual utility cost savings range from 7% to 9% for full TES systems, 14~15% for partial TES systems. For full TES systems, the storage deployed between 12pm and 6pm is more attractive in comparison with full day storage. Partial TES systems receive much more energy cost savings due to the reduced chiller size. In addition, there are no time-related demand charges (e.g. on- or mid-peak demand charge) for PG&E's A10 rate schedule and the difference of electricity price between the on-peak period and the off-peak period is quite low.

Table 11. TES cost effectiveness in "Pre1980" retail building with PG&E tariffs in CZ04.

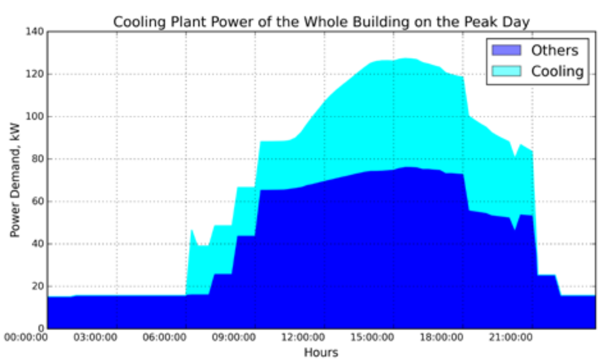
TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	**A10**	**A10 PDP**	**A10**	**A10 PDP**	**A10**	**A10**	**A10**	**A10 PDP**	**A10**	**A10 PDP**
Base Chiller Capacity (Ton)	61						31			
Total cooling load (Ton.hr)	411									
Building peak power (W/ft2)	5.11		4.11		3.33		3.95		3.92	
TES Capacity (Ton.hr)	0		292		411		205			
TES Portion of Cool Load	0		71%		100%		50%			
On-Peak Decrease (kW)	0		58				29			
Annual Utility Cost ($)	80,457	80,849	74,538	74,262	73,707	73,577	69,459	69,753	68,451	68,433
Annual Cost Savings ($)			5,919	6,586	6,750	7,272	10,999	11,095	12,006	12,415
Annual Cost Savings (%)			7%	8%	8%	9%	14%	14%	15%	15%
TES System Cost ($)			125,860		177,152		88,361		88,361	
TES Sys. Cost w/ Incent. ($)			21,460		72,752		36,161		36,161	
Payback Period (yr)			21.3	19.1	26.2	24.4	8.0	8.0	7.4	7.1
Payback Per. w/ Incent. (yr)			12.7	11.4	18.7	17.4	5.7	5.7	5.2	5.1

For TES applications in more efficient "New2013" retail, full 6-hr TES provides slightly lower annual utility bills than partial TES systems, but the difference is not significant, especially considering the much shorter payback of the partial TES using storage priority control.

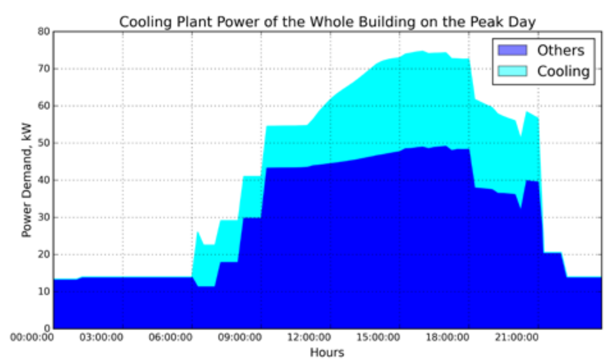
Table 12. TES cost effectiveness in "New2013" retail building with PG&E tariffs in CZ04.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	**A10**	**A10 PDP**	**A10**	**A10 PDP**	**A10**	**A10**	**A10**	**A10 PDP**	**A10**	**A10 PDP**
Base Chiller Capacity (Ton)	40						20			
Total cooling load (Ton.hr)	269									
Building peak power (W/ft2)	2.86		2.08		1.93		2.35		2.51	
TES Capacity (Ton.hr)	0		213		269		134			
TES Portion of Cool Load	0		79%		100%		50%			
On-Peak Decrease (kW)	0		26				12			
Annual Utility Cost ($)	50,122	50,335	43,406	43,402	43,473	43,494	44,416	44,602	43,562	43,581
Annual Cost Savings ($)			6,715	6,933	6,649	6,841	5,705	5,732	6,560	6,754
Annual Cost Savings (%)			13%	14%	13%	14%	11%	11%	13%	13%
TES System Cost ($)			56,420		71,253		35,494		35,494	
TES Sys. Cost w/ Incent. ($)			9,620		24,453		13,894		13,894	
Payback Period (yr)			8.4	8.1	10.7	10.4	6.2	6.2	5.4	5.3
Payback Per. w/ Incent. (yr)			5.0	4.9	7.3	7.1	4.4	4.4	3.8	3.7

Compared with the cooling load profiles in CZ04, retails in CZ12 have higher cooling loads in early morning (6am~10am) and evening (6pm~9pm) as shown in Figure 23. At the first glance, it indicates that there is more potential for full TES systems deployed from 9am to 9pm for retail buildings located in hotter climates.



(a) Pre1980



(b) New 2013

Figure 24. Cooling plant power vs. whole building power for a retail building in climate zone CZ12 on the peak demand day.

Table 13 and Table 14 present the summary of TES performances for "Pre1980" and "New2013" retail stores in CZ12. Same as TES system applications in CZ04, partial TES systems provide more energy cost savings than full TES systems. The results indicate that the reduced cost of electricity usage contributes to the majority of the total annual cost savings rather than the reduced demand does. Therefore, the most value that TES can provide for small and mid-sized retail buildings is enabling the use of a smaller chiller (lower cost) and overall improved system efficiency. Even though full TES systems can shed twice the peak demand as partial TES systems do, the decrease in demand charges is less than the reduced energy charges.

Table 13. TES cost effectiveness in "Pre1980" retail building with PG&E tariffs in CZ12.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	A10	A10 PDP	A10	A10 PDP	A10	A10	A10	A10 PDP	A10	A10 PDP
Base Chiller Capacity (Ton)	73						37			
Total cooling load (Ton.hr)	482									
Building peak power (W/ft2)	5.27		4.66		3.81		4.15		4.31	
TES Capacity (Ton.hr)	0		308		482		241			
TES Portion of Cool Load	0		64%		100%		50%			
On-Peak Decrease (kW)	0		59				28		24	
Annual Utility Cost ($)	85,504	86,458	80,341	80,182	79,723	79,664	72,667	73,400	71,812	72,054
Annual Cost Savings ($)			5,163	6,275	5,781	6,794	12,837	13,057	13,693	14,403
Annual Cost Savings (%)			6%	7%	7%	8%	15%	15%	16%	17%
TES System Cost ($)			128,030		200,359		100,179		100,179	
TES Sys. Cost w/ Incent. ($)			21,830		94,159		49,779		56,979	
Payback Period (yr)			24.8	20.4	34.7	29.5	7.8	7.7	7.3	7.0
Payback Per. w/ Incent. (yr)			14.8	12.2	25.7	21.9	5.9	5.8	5.8	5.5

Table 14. TES cost effectiveness in "New2013" retail building with PG&E tariffs in CZ12.

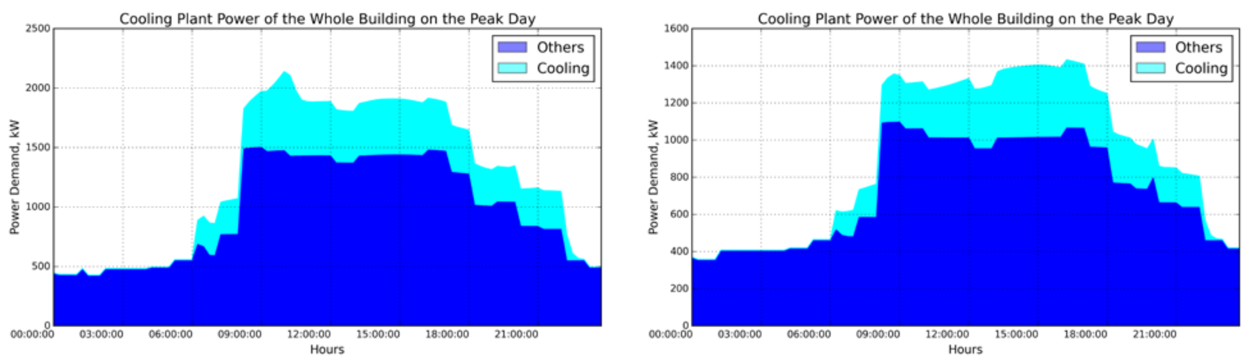
TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	A10	A10 PDP	A10	A10 PDP	A10	A10	A10	A10 PDP	A10	A10 PDP
Base Chiller Capacity (Ton)	52						26			
Total cooling load (Ton.hr)	348									
Building peak power (W/ft2)	3.05		2.74		2.25		2.49		2.78	
TES Capacity (Ton.hr)	0		211		348		174			
TES Portion of Cool Load	0		64%		100%		50%			

On-Peak Decrease (kW)	0		30				13		6	
Annual Utility Cost ($)	54,367	54,909	50,964	50,928	50,581	50,614	46,931	47,386	46,631	46,945
Annual Cost Savings ($)			3,403	3,981	3,787	4,295	7,436	7,523	7,736	7,964
Annual Cost Savings (%)			6%	7%	7%	8%	14%	14%	14%	15%
TES System Cost ($)			65,100		107,369		53,684		53,684	
TES Sys. Cost w/ Incent. ($)			11,100		53,369		30,284		42,884	
Payback Period (yr)			19.1	16.4	28.4	25.0	7.2	7.1	6.9	6.7
Payback Per. w/ Incent. (yr)			11.4	9.8	21.4	18.9	5.7	5.6	6.3	6.1

6.5.2 TES in SCE Territory

6.5.2.1 TES in Office Buildings

Figure 25 shows the electrical demand of the base case for "Pre1980" (Existing Buildings) and "New 2013" (New Buildings) without TES in CZ09. The peak demand of "Pre1980" existing buildings and "New2013" new buildings is 4.30 W/ft^2 and 2.89 W/ft^2, respectively. The cooling plant electrical demand accounts for about 31.5% of the whole building base load for both existing and new buildings, while existing buildings have more potential of peak demand savings than that of new buildings by over 40%.



(a) Pre1980 (b) New 2013

Figure 25. Cooling plant power vs. whole building power for an office building in climate zone CZ09 on the peak demand day.

Table 15 and Table 16 Summarize the simulation results of TES cost effectiveness for "Pre1980" existing buildings and "New2013" new buildings in California Climate Zone 09. Under SCE tariff rates, a full storage system either deployed between 12pm to 6pm or 8am to 6pm is more attractive than a partial storage system. The annual utility cost savings range from 9% to 18% in comparison with the base case without TES. Using the metric of the payback (annual utility savings per ton of TES installed) for comparison, full storage TES systems (8am~6pm) have slight advantage over full storage TES systems deployed from 12pm to 6pm.

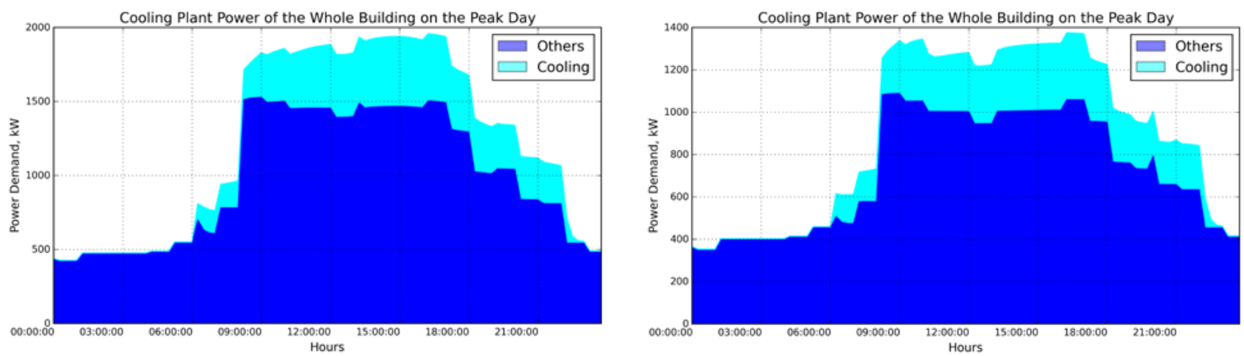
Table 15. TES cost effectiveness in "Pre1980" office building with SCE tariffs in CZ09.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**Option B**	CPP	**Option B**	CPP	**Option B**	CPP	**Option B**	CPP
Base Chiller Capacity (Ton)	1,175						588	
Total cooling load (Ton.hr)	8,530							
Building peak power (W/ft2)	4.30		4.27		2.74		3.55	
TES Capacity (Ton.hr)	0		5,561		8,530		4,265	
TES Portion of Cool Load	0		65%		100%		50%	
On-Peak Decrease (kW)	0		627				224	
Annual Utility Cost ($K)	1,327	1,288	1,206	1,177	1,114	1,085	1,276	1,241
Annual Cost Savings ($)			121,585	150,269	213,576	242,261	50,756	86,694
Annual Cost Savings (%)			9%	11%	16%	18%	4%	7%
TES System Cost ($)			1,529,275		2,345,750		1,172,875	
TES Sys. Cost w/ Incent. ($)			980,650		1,797,125		976,875	
Payback Period (yr)			12.6	10.2	11.0	9.7	23.1	13.5
Payback Per. w/ Incent. (yr)			8.1	6.5	8.4	7.4	19.2	11.3

Table 16. TES cost effectiveness in "New2013" office building with SCE tariffs in CZ09.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**Option B**	CPP	**Option B**	CPP	**Option B**	CPP	**Option B**	CPP
Base Chiller Capacity (Ton)	866						433	
Total cooling load (Ton.hr)	6,161							
Building peak power (W/ft2)	2.89		2.88		1.98		2.54	
TES Capacity (Ton.hr)	0		3,997		6,161		3,080	
TES Portion of Cool Load	0		65%		100%		50%	
On-Peak Decrease (kW)	0		443				164	
Annual Utility Cost ($)	965,072	937,069	875,966	855,301	828,630	807,965	900,832	872,835
Annual Cost Savings ($)			89,106	81,768	136,442	129,103	64,240	64,233
Annual Cost Savings (%)			9%	9%	14%	14%	7%	7%
TES System Cost ($)			1,099,175		1,694,275		847,000	
TES Sys. Cost w/ Incent. ($)			711,550		1,306,650		703,500	
Payback Period (yr)			12.3	13.4	12.4	13.1	13.2	13.2
Payback Per. w/ Incent. (yr)			8.0	8.7	9.6	10.1	11.0	11.0

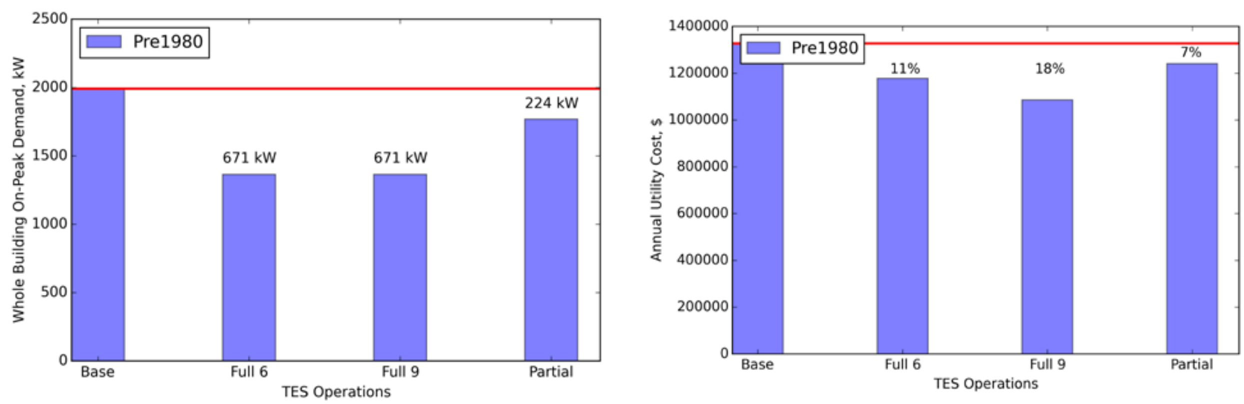
For TES applications in "Pre1980" existing buildings and "New2013" new buildings, the simulation results indicate that full storage TES systems with relative smaller storage capacity in new buildings are more attractive than in "Pre1980" existing buildings. As shown in Figure 26, the building energy performance in CZ09 and CZ10 are close because of the similar number of cooling degree-days.

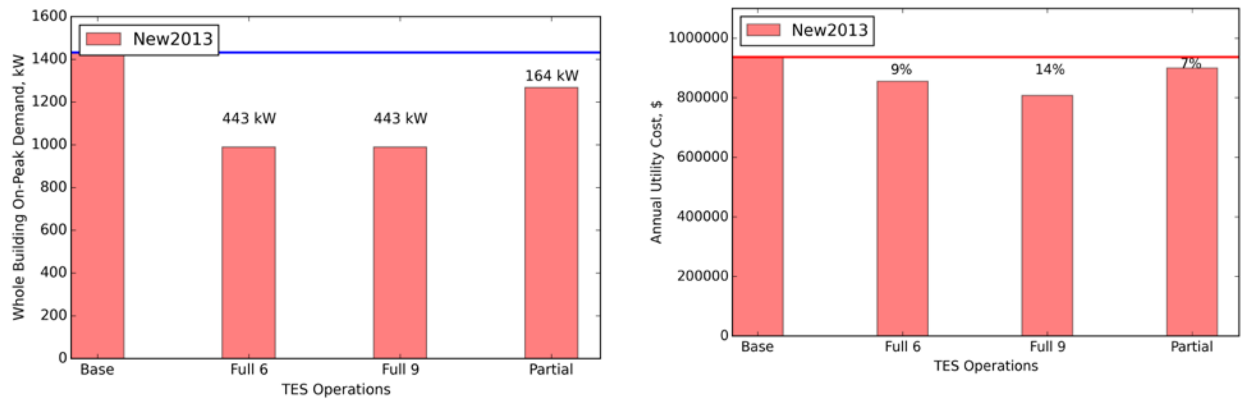


(a) Pre1980 (b) New 2013

Figure 26. Cooling plant power vs. whole building power for an office building in climate zone CZ10 on the peak demand day.

Figure 27 shows the effect of each TES use case on the on-peak demand reduction and the annual cost savings. Of all TES use cases, full storage TES systems provide the best values for both utilities and customers. The higher portion of electrical usage and cost during the on-peak hours encourages deploying the storage capacity as much as possible in this period rather than the partial deployment throughout the day.





(a) On-Peak Demand (kW) (b) Annual Utility Cost ($)

Figure 27. Value of TES for an office building in climate zone CZ09.

Option-A rate schedule is the default tariff for TES application under the PLS program. This rate schedule only has the monthly demand charge without the summer mid- and on-peak demand charges. For TES customers, the optimal solution is to reduce the monthly peak demand and run the TES during the on-peak hours to achieve both the energy and demand charge savings. As TES has flexible load capability by changing the storage charging and discharging operation mode with time of day, it can be possible to allow TES customers to enroll in the RTP tariff by operating the TES in a smart way.

For the TES applications under the tariffs of Option-A and RTP program in CZ10, the base case of conventional chiller system without TES, the annual utility cost under the RTP rate schedule is higher than that of the Option-A rate schedule by nearly 50%. Since an office customer in this climate zone would choose Option-A over RTP, we only consider the former for determining the best TES system for this customer using the simulation results. Under SCE tariff rate of Option-A, a full storage system either deployed between 12 pm to 6 pm or 8 am to 6 pm is more cost effective than a partial storage system. The annual utility cost savings range from 9% to 13% in comparison with the base case without TES. A full storage system (8 am~6 pm) saves only 4% more than a full storage deployed from 12pm to 6pm. In terms of the payback metric, a full storage system (8am~6pm) has the same value of TES as a full storage on the partial day (12pm~6pm).

Table 17. TES cost effectiveness in "Pre1980" office buildings with SCE tariffs in CZ10.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	Option A	RTP	Option A	RTP	Option A	RTP	Option A	RTP
Base Chiller Capacity (Ton)	2,231						634	
Total cooling load (Ton.hr)	8,736							
Building peak power (W/ft2)	3.97		3.97		3.09		3.55	
TES Capacity (Ton.hr)	0		5,545		8,736		4,368	

TES Portion of Cool Load	0		63%		100%		50%	
On-Peak Decrease (kW)	0		574				195	
Annual Utility Cost ($K)	1,270	2,454	1,164	2,107	1,090	2,009	1,185	2,269
Annual Cost Savings ($)			106,039	347,323	180,712	445,096	85,736	184,906
Annual Cost Savings (%)			8%	14%	14%	18%	7%	8%
TES System Cost ($)			1,524,875		2,402,400		1,201,200	
TES Sys. Cost w/ Incent. ($)			1,022,625		1,900,150		1,030,575	
Payback Period (yr)			14.4	4.4	13.3	5.4	14.0	6.5
Payback Per. w/ Incent. (yr)			9.6	2.9	10.5	4.3	12.0	5.6

Table 18. TES cost effectiveness in "New2013" office building with SCE tariffs in CZ10.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**Option A**	RTP	**Option A**	RTP	**Option A**	RTP	**Option A**	RTP
Base Chiller Capacity (Ton)	833						417	
Total cooling load (Ton.hr)	5,640							
Building peak power (W/ft2)	2.78		2.73		2.19		2.54	
TES Capacity (Ton.hr)	0		3,997		5,640		2,820	
TES Portion of Cool Load	0		71%		100%		50%	
On-Peak Decrease (kW)	0		383				127	
Annual Utility Cost ($K)	922	1,767	848	1,533	808	1,478	857	1,636
Annual Cost Savings ($)			74,266	233,437	114,372	288,272	65,414	130,133
Annual Cost Savings (%)			8%	13%	12%	16%	7%	7%
TES System Cost ($)			1,099,175		1,551,000		775,500	
TES Sys. Cost w/ Incent. ($)			764,050		1,215,875		664,375	
Payback Period (yr)			14.8	4.7	13.6	5.4	11.9	6.0
Payback Per. w/ Incent. (yr)			10.3	3.3	10.6	4.2	10.2	5.1

For TES applications in new construction in SCE territory, a full storage system (12pm~6pm) can save about 9% of the annual utility cost in comparison with the base case without TES. For a base case without TES, the annual utility cost under the RTP rate schedule is much higher than those of Option B, Option A and CPP rate schedules. For the building in CZ09 and CZ10, the cooling plant accounts for 25% of the whole building power on the peak day. Even though a full storage system can shift all the cooling plant power use to off-peak hours, the electricity price during the on-peak hours is about 10 times of the off-peak hours' price. On the other hand, notice that the number of extremely hot days in the climate zone of CZ09 and CZ10 is large. For the application of TES under the RTP tariff, there is a challenge for customer to switch from the

Option A or CPP rate to the RTP tariff, even though the TES can provide a flexible load management to the adoption of the RTP rate. If a customer is enrolling in the RTP rate schedule, the TES application can save 12.6% of the annual utility cost because of the high price during the on-peak hours. Also, interesting to note that annual utility costs are comparable for the large office simulations with tariffs CPP and Option A although they are structured quite differently with Option A having zero on- and mid-peak period demand charges in summer and roughly double the on- and mid-peak energy charges.

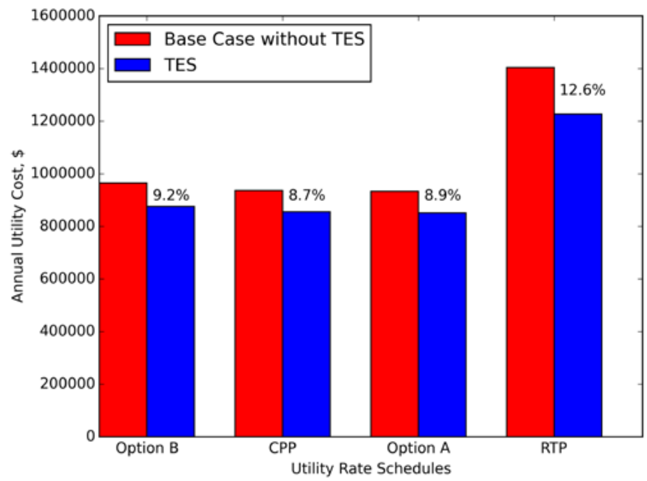
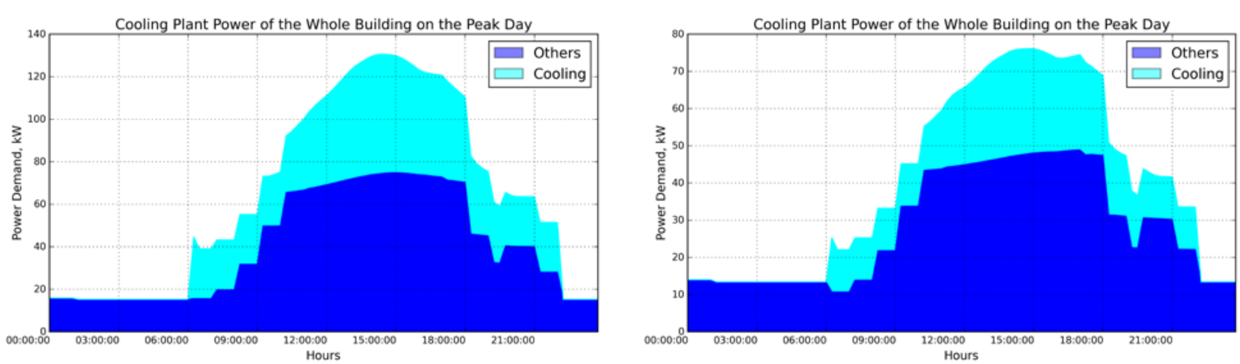


Figure 28. Office building annual utility cost under SCE Option A, Option B, and RTP rate schedules.

6.5.2.2 TES in Retail Buildings

As shown in Figure 28, the peak demand of "Pre1980" and "New2013" retail stores are 5.08 W/ft² and 2.86 W/ft², respectively. The portion of the cooling plant electrical demand is 46% in "Pre1980" retail stores, 38% in "New2013" retail stores. On the peak day, the HVAC system operates from 6am to 10pm and the majority of the cooling plant electricity usage is consumed from 10am to 6pm. For the TES in retail stores, the following TES use cases are simulated: (1) full TES deployed from 10am to 9pm; (2) full TES deployed from 12am to 6pm; (3) partial TES in parallel deployed from 10am to 9pm and (4) partial TES with storage priority deployed from 12pm to 9pm.



(a) Pre1980 (b) New 2013

Figure 29. Cooling plant power vs. whole building power for an retail building in climate zone CZ09 on the peak demand day.

Table 19 and Table 20 present the summary of TES performance for "Pre1980" and "New2013" retail stores in CZ09. The annual utility cost savings range from 13% to 15% for full TES systems, 12~14% for partial TES systems. For full TES systems, the storage deployed between 12pm and 6pm is more attractive in comparison with full day storage.

Table 19. TES cost effectiveness in "Pre1980" retail building with SCE tariffs in CZ09.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs (TOU)	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**
Base Chiller Capacity (Ton)	74						37			
Total cooling load (Ton.hr)	474									
Building peak power (W/ft2)	5.42		4.59		3.87		4.19		4.21	
TES Capacity (Ton.hr)	0		316		474		237		237	
TES Portion of Cool Load	0		67%		100%		50%		50%	
On-Peak Decrease (kW)	0		63				30		31	
Annual Utility Cost ($)	78,124	74,482	67,965	63,590	66,598	62,648	65,596	62,672	64,052	60,450
Annual Cost Savings ($)			10,159	10,892	11,526	11,834	12,528	11,810	14,071	14,032
Annual Cost Savings (%)			13%	14%	15%	15%	16%	15%	18%	18%
TES System Cost ($)			136,710		205,065		102,533		102,533	
TES Sys. Cost w/ Incent. ($)			23,310		91,665		48,533		46,733	
Payback Period (yr)			13.5	12.6	17.8	17.3	8.2	8.7	7.3	7.3
Payback Per. w/ Incent. (yr)			8.0	7.5	13.0	12.7	6.1	6.5	5.4	5.4
Utility Tariffs	**Option A**	**RTP**	**Option A**	**RTP**	**Option A**	**RTP**	**Option A**	**RTP**	**Option A**	**RTP**
Annual Utility Cost ($)	72,510	112,896	63,837	90,930	62,382	86,201	60,836	93,517	57,913	85,094
Annual Cost Savings ($)			8,672	21,966	10,127	26,696	11,673	19,380	14,596	27,802
Annual Cost Savings (%)			12%	19%	14%	24%	16%	17%	20%	25%
TES System Cost ($)			136,710		205,065		102,533		102,533	
TES Sys. Cost w/ Incent. ($)			23,310		91,665		48,533		46,733	
Payback Period (yr)			15.8	6.2	20.2	7.7	8.8	5.3	7.0	3.7
Payback Per. w/ Incent. (yr)			9.4	3.7	14.8	5.6	6.5	3.9	5.2	2.7

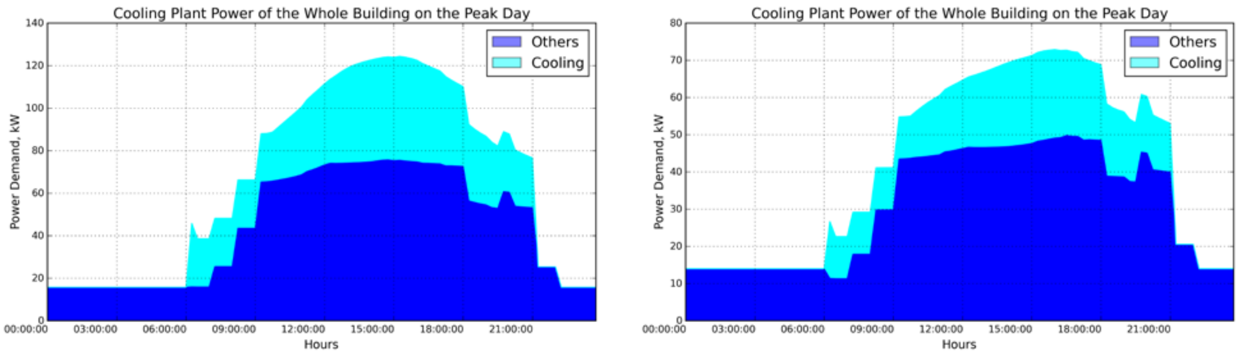
Table 20. TES cost effectiveness in "New2013" retail building with SCE tariffs in CZ09

TES Cases	Base Case	Full Storage 6-hr (12pm~6pm)	Full Storage 9-hr (8am~6pm)	Partial TES in Parallel	Partial TES with Storage Priority

Utility Tariffs	GS-2	CPP	GS-2	CPP	GS-2	CPP	GS-2	CPP	GS-2	CPP
Base Chiller Capacity (Ton)	52						26			
Total cooling load (Ton.hr)	348									
Building peak power (W/ft2)	3.12		2.75		2.26		2.53		2.60	
TES Capacity (Ton.hr)	0		237		348		174			
TES Portion of Cool Load	0		68%		100%		50%			
On-Peak Decrease (kW)	0		30				15		13	
Annual Utility Cost ($)	48,361	46,248	42,449	39,987	41,738	39,565	41,241	39,542	40,436	38,291
Annual Cost Savings ($)			5,912	6,262	6,623	6,684	7,120	6,707	7,924	7,957
Annual Cost Savings (%)			12%	13%	14%	14%	15%	14%	16%	16%
TES System Cost ($)			65,100		95,590		47,795		47,795	
TES Sys. Cost w/ Incent. ($)			11,100		41,590		20,795		24,395	
Payback Period (yr)			11.0	10.4	14.4	14.3	6.7	7.1	6.0	6.0
Payback Per. w/ Incent. (yr)			6.6	6.2	10.5	10.4	4.9	5.2	4.6	4.6

Utility Tariffs	Option A	RTP	Option A	RTP	Option A	RTP	Option A	RTP	Option A	RTP
Annual Utility Cost ($)	45,157	69,206	40,077	57,397	39,365	55,006	38,516	58,636	36,987	54,121
Annual Cost Savings ($)			5,079	11,809	5,792	14,200	6,641	10,570	8,169	15,085
Annual Cost Savings (%)			11%	17%	13%	21%	15%	15%	18%	22%
TES System Cost ($)			65,100		95,590		47,795		47,795	
TES Sys. Cost w/ Incent. ($)			11,100		41,590		20,795		24,395	
Payback Period (yr)			12.8	5.5	16.5	6.7	7.2	4.5	5.9	3.2
Payback Per. w/ Incent. (yr)			7.6	3.3	12.0	4.9	5.2	3.3	4.5	2.4

Compared with the cooling load profiles in CZ04, retail buildings in CZ12 have higher cooling loads in early morning (6am~10am) and evening (6pm~9pm), as shown in Figure 30, indicating more potential for full TES systems deployed from 9am to 9pm.



(a) Pre1980 (b) New 2013

Figure 30. Cooling plant power vs. whole building power for a retail building in climate zone CZ10 on the peak demand day.

Table 21 and Table 22 present the summary of TES performances for "Pre1980" and "New2013" retail buildings in CZ12. Same as TES system applications in CZ04, partial TES systems gives more energy cost savings than full TES systems. The results indicate that the reduced cost of electricity usage contributes the majority of the total annual cost savings rather than the reduced demand does. Therefore, the most value that TES can provide for small and mid-sized retails is the reduced chiller size and the improved system efficiency as well. Even though full TES systems can shed the peak demand twice as partial TES systems do, the reduced demand charges are still less than the reduced energy charges.

Table 21. TES cost effectiveness in "Pre1980" retail building in CZ10.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs (TOU)	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**
Base Chiller Capacity (Ton)	72						36			
Total cooling load (Ton.hr)	458									
Building peak power (W/ft2)	5.04		4.60		3.78		4.19		4.19	
TES Capacity (Ton.hr)	0		292		458		229			
TES Portion of Cool Load	0		64%		100%		50%			
On-Peak Decrease (kW)	0		52				21			
Annual Utility Cost ($)	77,148	73,952	67,838	63,430	66,170	62,373	66,338	63,512	64,212	60,848
Annual Cost Savings ($)			9,309	10,522	10,978	11,579	10,810	10,440	12,935	13,104
Annual Cost Savings (%)			12%	14%	14%	15%	14%	14%	17%	17%
TES System Cost ($)			112,840		176,989		88,494		88,494	
TES Sys. Cost w/ Incent. ($)			19,240		83,389		50,694		50,694	
Payback Period (yr)			12.1	10.7	16.1	15.3	8.2	8.5	6.8	6.8
Payback Per. w/ Incent. (yr)			7.2	6.4	12.0	11.4	6.5	6.7	5.4	5.4

Utility Tariffs	Option A	RTP	Option A	RTP	Option A	RTP	Option A	RTP	Option A	RTP
Annual Utility Cost ($)	72,323	145,851	63,930	113,988	62,206	106,605	61,668	121,748	58,432	109,143
Annual Cost Savings ($)			8,393	31,863	10,117	39,246	10,654	24,103	13,891	36,708
Annual Cost Savings (%)			12%	22%	14%	27%	15%	17%	19%	25%
TES System Cost ($)			112,840		176,989		88,494		88,494	
TES Sys. Cost w/ Incent. ($)			19,240		83,389		50,694		50,694	
Payback Period (yr)			13.4	3.5	17.5	4.5	8.3	3.7	6.4	2.4
Payback Per. w/ Incent. (yr)			8.0	2.1	13.0	3.4	6.6	2.9	5.0	1.9

For TES applications in more efficient "New2013" retail stores, full TES systems perform slightly better than partial TES systems, which are different from its effects in "Pre1980" existing retail stores.

Table 22. TES cost effectiveness in "New 2013" retail building CZ10.

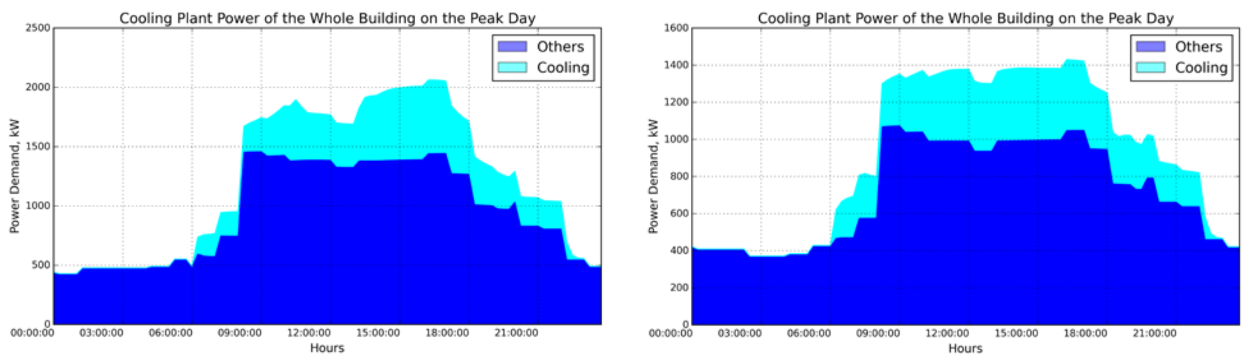
TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**	**GS-2**	**CPP**
Base Chiller Capacity (Ton)	52						26			
Total cooling load (Ton.hr)	332									
Building peak power (W/ft2)	2.97		2.69		2.26		2.60		2.59	
TES Capacity (Ton.hr)	0		205		332		166			
TES Portion of Cool Load	0		68%		100%		50%			
On-Peak Decrease (kW)	0		30				15		13	
Annual Utility Cost ($)	48,295	46,415	42,719	40,265	41,972	39,828	41,904	40,232	40,972	38,997
Annual Cost Savings ($)			5,576	6,150	6,323	6,587	6,391	6,182	7,323	7,418
Annual Cost Savings (%)			12%	13%	13%	14%	13%	13%	15%	15%
TES System Cost ($)			65,100		105,430		52,715		52,715	
TES Sys. Cost w/ Incent. ($)			11,100		51,430		25,715		29,315	
Payback Period (yr)			11.7	10.6	16.7	16.0	8.2	8.5	7.2	7.1
Payback Per. w/ Incent. (yr)			7.0	6.3	12.5	12.0	6.2	6.4	5.6	5.6
Utility Tariffs	**Option**	**RTP**	**Option**	**RTP**	**Option**	**RTP**	**Option**	**RTP**	**Option**	**RTP**

	A		A		A		A		A	
Annual Utility Cost ($)	45,454	89,570	40,430	72,534	39,657	68,755	39,218	76,283	37,568	69,541
Annual Cost Savings ($)			5,024	17,036	5,798	20,815	6,236	13,287	7,887	20,029
Annual Cost Savings (%)			11%	19%	13%	23%	14%	15%	17%	22%
TES System Cost ($)			65,100		105,430		52,715		52,715	
TES Sys. Cost w/ Incent. ($)			11,100		51,430		25,715		29,315	
Payback Period (yr)			13.0	3.8	18.2	5.1	8.5	4.0	6.7	2.6
Payback Per. w/ Incent. (yr)			7.7	2.3	13.7	3.8	6.3	3.0	5.2	2.1

6.5.3 TES in SDG&E Territory

6.5.3.1 TES in Office Buildings

Figure 31 shows the base load of "New 2013" (New Building) and "Pre1980" (Existing Building) on a peak day in CZ07. The peak demand of "Pre1980" is higher than that of the new building by about 600kW, nearly 30% of the base load's peak demand. The cooling plant power accounts for around 30% of the whole building for both the "New 2013" building and the existing "Pre1980" building.



(a) Pre1980 (b) New 2013

Figure 31. Cooling plant power vs. whole building power for an office building in climate zone CZ07 on the peak demand day.

Table 23 presents the summary of TES application values in "Pre1980" existing buildings. It can be seen that partial storage systems either deployed from 8am to 6pm are more effective than full storage systems under SDG&E's utility tariffs. The annual utility cost savings range from 8% to 16% in comparison with the base case without TES application. Using the metric of payback period for the comparison, partial storage (8am~6pm) systems give slight advantage over full storage systems (8am~6pm). The payback period is about 2 to 3 years for a partial storage system application.

Table 23. TES cost effectiveness in "Pre1980" office with SDG&E tariffs in CZ07.

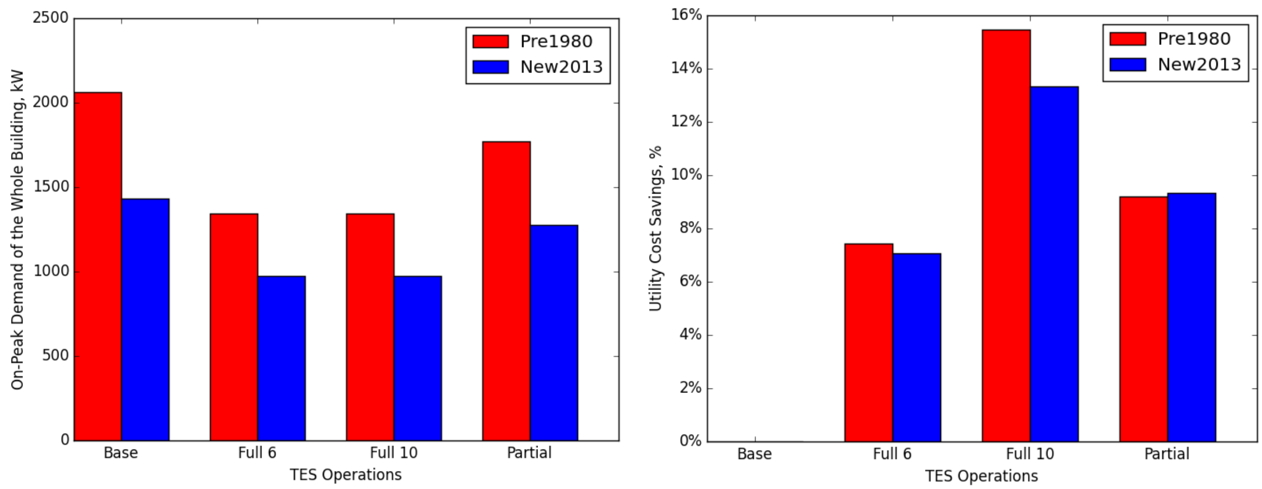
TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**AL-TOU**	CPP	**AL-TOU**	CPP	**AL-TOU**	CPP	**AL-TOU**	CPP
Base Chiller Capacity (Ton)	1,271						635	
Total cooling load (Ton.hr)	9,067							
Building peak power (W/ft2)	4.14		3.88		3.05		3.54	
TES Capacity (Ton.hr)	0		6,129		9,067		4,534	
TES Portion of Cool Load	0		68%		100%		50%	
On-Peak Decrease (kW)	0		721				294	
Annual Utility Cost ($K)	1,663	1,646	1,535	1,524	1,402	1,392	1,525	1,495
Annual Cost Savings ($)			128,459	122,085	260,722	254,348	138,565	151,189
Annual Cost Savings (%)			8%	7%	16%	15%	8%	9%
TES System Cost ($K)			1,685	2,493	1,246	1,685	2,493	1,246
TES Sys. Cost w/ Incent. ($K)			1,054	1,862	989	1,054	1,862	989
Payback Period (yr)			13.1	13.8	9.6	9.8	9.0	8.2
Payback Per. w/ Incent. (yr)			8.2	8.6	7.1	7.3	7.1	6.5

Table 24. TES cost effectiveness in "New2013" office with SDG&E tariffs in CZ07.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	**AL-TOU**	CPP	**AL-TOU**	CPP	**AL-TOU**	CPP	**AL-TOU**	CPP
Base Chiller Capacity (Ton)	878						439	
Total cooling load (Ton.hr)	6,524							
Building peak power (W/ft2)	2.87		2.76		2.20		2.55	
TES Capacity (Ton.hr)	0		4,076		6,524		3,262	
TES Portion of Cool Load	0		68%		100%		50%	
On-Peak Decrease (kW)	0		457				157	
Annual Utility Cost ($K)	1,209	1,199	1,123	1,115	1,048	1,040	1,103	1,087
Annual Cost Savings ($)			85,604	84,471	160,804	159,675	105,691	111,909
Annual Cost Savings (%)			7%	7%	13%	13%	9%	9%
TES System Cost ($)			1,120,900		1,794,100		897,050	
TES Sys. Cost w/ Incent. ($)			721,025		1,394,225		759,675	
Payback Period (yr)			13.1	13.3	11.2	11.2	8.5	8.0

Payback Per. w/ Incent. (yr)			8.4	8.5	8.7	8.7	7.2	6.8

Figure 32 shows the TES' effect on the peak demand reduction and the annual cost savings. Obviously the full storage TES deployed during the full day or the on-peak period can achieve the maximum demand savings during the on-peak period. For existing "Pre1980" and new constructed "New2013" buildings, the cooling plant demand accounts for 35% and 32% of the whole building peak demand, separately. Due to the high summer monthly demand charge, the full-day storage TES achieves about 13~16% of the annual utility bill savings, which is nearly double of cost savings from the full storage deployed during the on-peak period. A partial storage TES with less storage capacity can save more utility cost in comparison with a full storage TES deployed during the on-peak period.

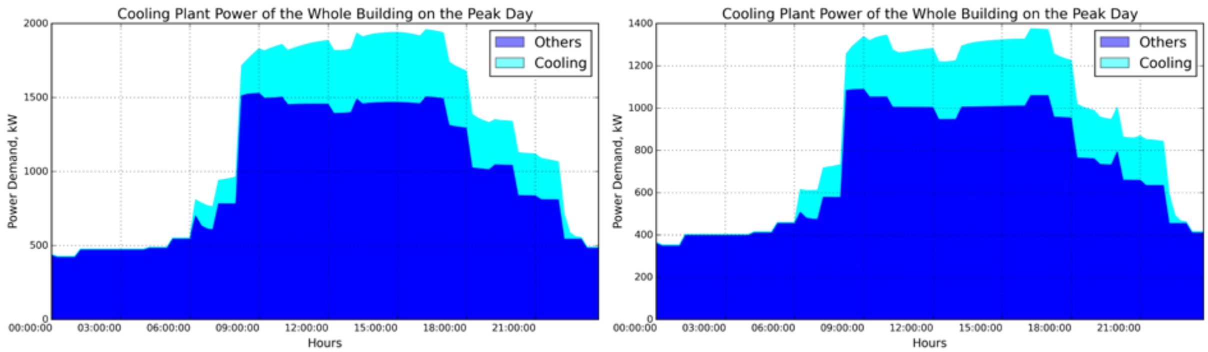


(a) On-Peak Demand (kW) (b) Annual Cost Savings (%)

Figure 32. Value of TES for an office building in climate zone CZ07

Climate zone CZ10 is located both in SCE and SDG&E's territory areas. The TES performance in "Pre1980" and "New2013" office buildings under SDG&E's territory area is same as that of buildings in SCE's territory area. However, the effect of TES deployment is different between those two scenarios due to different tariff rates of SCE and SDG&E.

Figure 33 shows the electrical demand of the base case for "Pre1980" (Existing Buildings) and "New 2013" (New Buildings) without TES in CZ10. The peak demand of "Pre1980" existing buildings and "New2013" new buildings are 3.97 W/ft^2 and 2.78 W/ft^2, respectively. The cooling plant electrical demand accounts for about 31.5% of the whole building base load for both existing and new buildings, while existing buildings have more potential of peak demand savings than that of new buildings by over 40%.



(a) Pre1980 (b) New 2013

Figure 33. Cooling plant power vs. whole building power for an office building in climate zone CZ10 on the peak demand day.

Table 25 and Table 26 present the summary of TES application values in "Pre1980" existing buildings and "New2013" new buildings in CZ10. It can be seen that full storage systems is most effective. On other hand, given the same amount of TES capacity, partial TES systems have advantage over the full TES systems. The annual utility cost savings range from 5% to 17% in comparison with the base case without TES application.

Table 25. TES cost effectiveness in "Pre1980" office building with SDG&E tariffs in CZ10.

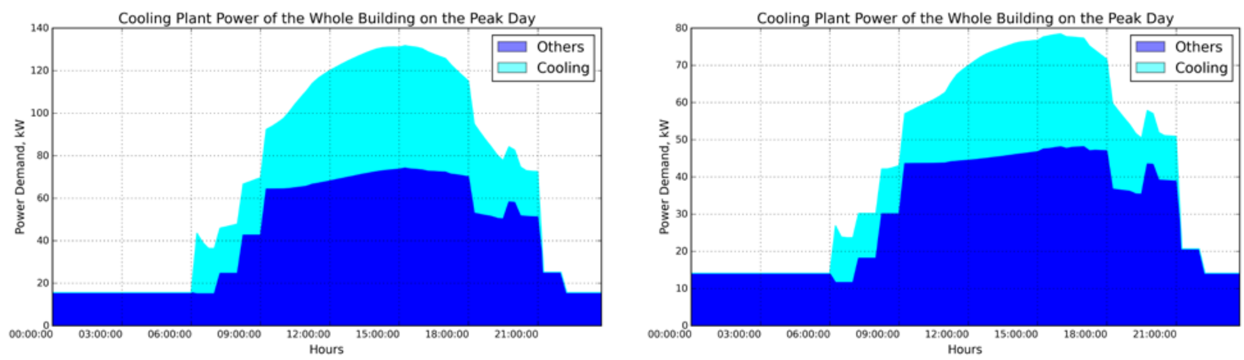
TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP
Base Chiller Capacity (Ton)	1,266						633	
Total cooling load (Ton.hr)	9,004							
Whole building peak power (W/ft2)	3.97		3.97		3.09		3.55	
TES Capacity (Ton.hr)	0		5,726		9,004		4,502	
Ratio of TES Capacity to total Cooling Load	0		64%		100%		50%	
Reduced On-Peak Electrical Demand (kW)	0		574				195	
Annual Utility Cost ($K)	1,311	1,275	1,205	1,179	1,109	1,083	1,249	1,216
Annual Cost Savings ($)			105,353	131,829	201,709	228,189	61,476	95,200
Annual Cost Savings (%)			8%	10%	15%	17%	5%	7%
TES System Cost ($)			1,574,650		2,476,100		1,238,050	
TES System Cost with Incentives ($)			1,072,400		1,973,850		1,067,425	
Payback Period (yr)			14.9	11.9	12.3	10.9	20.1	13.0
Payback Period with Incentives (yr)			10.2	8.1	9.8	8.7	17.4	11.2

Table 26. TES cost Effectiveness in "New2013" office building with SDG&E tariffs in CZ10.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial 9 Hours	
Utility Tariffs	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP
Base Chiller Capacity (Ton)	821						410	
Total cooling load (Ton.hr)	6,121							
Whole building peak power (W/ft2)	2.78		2.73		2.19		2.59	
TES Capacity (Ton.hr)	0		3,793		6,121		3,601	
Ratio of TES Capacity to total Cooling Load	0		65%		100%		50%	
Reduced On-Peak Electrical Demand (kW)	0		383				127	
Annual Utility Cost ($K)	1,208	1,191	1,130	1,116	1,047	1,034	1,142	1,119
Annual Cost Savings ($)			78,240	91,557	160,569	173,886	65,887	88,703
Annual Cost Savings (%)			6%	8%	13%	14%	5%	7%
TES System Cost ($)			1,043,075		1,683,275		990,275	
TES System Cost with Incentives ($)			707,950		1,348,150		879,150	
Payback Period (yr)			13.3	11.4	10.5	9.7	15.0	11.2
Payback Period with Incentives (yr)			9.0	7.7	8.4	7.8	13.3	9.9

6.5.3.2 TES in Retail Buildings

Figure 34 shows that the peak demand of "Pre1980" and "New2013" retail stores are 132 kW and 78 kW, respectively. The portion of the cooling plant electrical demand is 49% in "Pre1980" retail stores, 40% in "New2013" retail stores. On the peak day, the HVAC system operates from 6am to 10pm and the majority of the cooling plant electricity usage is consumed from 10am to 9pm.



(a) Pre1980 (b) New 2013

Figure 34. Cooling plant power vs. whole building power for a retail building in climate zone CZ07 on the peak demand day.

Table 27 and Table 28 present the summary of TES performance for "Pre1980" and "New2013" retail stores in CZ07. The annual utility cost savings range from 8% to 11% for full TES systems, 15~18% for partial TES systems. For full TES systems, the storage deployed between 12pm and 6pm is more attractive in comparison with full day storage. Partial TES systems receive more energy cost savings due to the reduced chiller size. Under the SDGE's TOU tariff, TES systems achieve almost equal cost savings from energy charges and demand charges.

Table 27. TES cost effectiveness in "Pre1980" retail building with SDG&E tariffs in CZ07.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs (TOU)	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP
Base Chiller Capacity (Ton)	68						39			
Total cooling load (Ton.hr)	545									
Building peak power (W/ft2)	5.34		4.86		3.69		4.13		4.37	
TES Capacity (Ton.hr)	0		348		545		272			
TES Portion of Cool Load	0		64%		100%		50%			
On-Peak Decrease (kW)	0		64				30		26	
Annual Utility Cost ($)	86,579	82,656	79,474	74,631	77,476	73,172	73,558	70,135	72,139	68,004
Annual Cost Savings ($)			7,104	8,025	9,103	9,484	13,021	12,521	14,440	14,652
Annual Cost Savings (%)			8%	10%	11%	11%	15%	15%	17%	18%
TES System Cost ($)			138,880		217,499		108,550		108,550	

TES Sys. Cost w/ Incent. ($)			23,680		102,299		54,550		61,750	
Payback Period (yr)			19.5	17.3	23.9	22.9	8.3	8.7	7.5	7.4
Payback Per. w/ Incent. (yr)			11.7	10.3	17.7	17.0	6.3	6.6	5.9	5.9

Table 28. TES cost effectiveness in "New2013" retail building with SDG&E tariffs in CZ07.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP	AL-TOU	CPP
Base Chiller Capacity (Ton)	55						28			
Total cooling load (Ton.hr)	403									
Building peak power (W/ft2)	3.18		2.87		2.35		2.52		2.59	
TES Capacity (Ton.hr)	0		261		403		201			
TES Portion of Cool Load	0		65%		100%		50%			
On-Peak Decrease (kW)	0		31				16		14	
Annual Utility Cost ($)	56,701	54,277	52,059	49,099	51,505	48,702	47,880	45,874	46,682	44,321
Annual Cost Savings ($)			4,642	5,177	5,195	5,575	8,821	8,402	10,019	9,956
Annual Cost Savings (%)			8%	10%	9%	10%	16%	15%	18%	18%
TES System Cost ($)			67,270		103,869		51,806		51,806	
TES Sys. Cost w/ Incent. ($)			11,470		48,069		23,006		26,606	
Payback Period (yr)			14.5	13.0	20.0	18.6	5.9	6.2	5.2	5.2
Payback Per. w/ Incent. (yr)			8.6	7.8	14.8	13.8	4.3	4.5	3.9	4.0

Table 29 and Table 30 present the summary of TES performance for "Pre1980" and "New2013" retail stores in CZ10. The annual utility cost savings range from 11% to 14% for full TES systems, 14~15% for partial TES systems. For full TES systems, the storage deployed between 12pm and 6pm is more attractive in comparison with full day storage. Partial TES systems receive more energy cost savings due to the reduced chiller size.

Table 29. TES cost effectiveness in "Pre1980" retail building with SDG&E tariffs in CZ10.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs (TOU)	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**
Base Chiller Capacity (Ton)	72						36			
Total cooling load (Ton.hr)	458									
Building peak power (W/ft2)	5.04		4.60		3.78		4.19			
TES Capacity (Ton.hr)	0		292		458		229			
TES Portion of Cool Load	0		64%		100%		50%			
On-Peak Decrease (kW)	0		53				21			
Annual Utility Cost ($)	90,981	86,888	83,744	78,561	81,147	76,643	78,708	75,131	77,691	73,577
Annual Cost Savings ($)			7,237	8,327	9,833	10,245	12,273	11,758	13,290	13,312
Annual Cost Savings (%)			8%	10%	11%	12%	13%	14%	15%	15%
TES System Cost ($)			115,010		180,392		90,196		90,196	
TES Sys. Cost w/ Incent. ($)			19,610		84,992		52,396		52,396	
Payback Period (yr)			15.9	13.8	18.3	17.6	7.3	7.7	6.8	6.8
Payback Per. w/ Incent. (yr)			9.5	8.2	13.6	13.1	5.9	6.1	5.4	5.4

Table 30. TES cost effectiveness in “New2013” retail building with SDG&E tariffs in CZ10.

TES Cases	Base Case		Full Storage 6-hr (12pm~6pm)		Full Storage 9-hr (8am~6pm)		Partial TES in Parallel		Partial TES with Storage Priority	
Utility Tariffs	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**	**AL-TOU**	**CPP**
Base Chiller Capacity (Ton)	52						26			
Total cooling load (Ton.hr)	332									
Building peak power (W/ft2)	2.97		2.69		2.26		2.60			
TES Capacity (Ton.hr)	0		205		332		166			
TES Portion of Cool Load	0		62%		100%		50%			
On-Peak Decrease (kW)	0		26				10			
Annual Utility Cost ($)	57,070	54,658	52,083	49,170	50,869	48,298	49,692	47,565	49,249	46,823

Annual Cost Savings ($)			4,987	5,488	6,201	6,360	7,378	7,094	7,821	7,836
Annual Cost Savings (%)			9%	10%	11%	12%	13%	13%	14%	14%
TES System Cost ($)			56,420		91,373		45,686		45,686	
TES Sys. Cost w/ Incent. ($)			9,620		44,573		27,686		27,686	
Payback Period (yr)			11.3	10.3	14.7	14.4	6.2	6.4	5.8	5.8
Payback Per. w/ Incent. (yr)			6.8	6.1	11.1	10.8	5.0	5.2	4.7	4.7

6.5.4 Summary

Table 31 summarizes different TES use cases' value in three territory areas of California. PG&E, SCE and SDG&E have similar TOU rate structures with totally different rate values, which have significant impacts on the TES design and operation. For the TES deployment in California, the annual utility cost savings range from 9% to 18% for TES deployment in large office buildings and 7% to 18% in retail stores, respectively. Full day (9a-6p) storage TES results in the lowest utility bills for office building customers in PG&E and SCE and full on-peak period (12p-6p) storage TES produces lowest annual utility bills for office building customers in SDG&E.

Table 31. Summary of TES value for office buildings in each utility territory.

Utilities		PG&E	SCE[1]	SDG&E
Demand Charge	Summer Monthly ($/kW)	13.67	15.57	24.43
	Summer Mid-, On-Peak ($/kW)	4.42, 19.03	6.49, 22.95	7.66, 10.37
Summer Off, Mid-, On-peak Energy Charge		0.077, 0.112, 0.165	0.062, 0.087, 0.142	0.080, 0.111, 0.121
Annual Utility Cost Savings		6~17%	4~16%	8~16%
TES Systems in Order of Performance		**Full Day Storage** > Full On-Peak Storage > Partial Storage	**Full Day Storage** > Full On-Peak Storage > Partial Storage	**Full On-Peak Storage** > Partial Storage > Full Day Storage

1. SCE tariffs CPP and Option B.

For TES deployment in small and mid-sized retail stores, partial TES systems perform better than full TES system as presented in Table 32. For full TES system applications, TES systems deployed between 12pm to 6pm achieve higher payback metrics in comparison to full day TES systems for all three IOUs' utility tariffs. Especially for the SCE's RTP program, TES systems provide as much as 25% of the annual utility cost savings.

Table 32. Summary of TES value for retail stores in each utility territory.

Utilities	PG&E	SCE[1]	SDG&E

Demand Charge	Summer Monthly ($/kW)	13.67	15.57	24.43
	Summer Mid-, On-Peak ($/kW)	4.42, 19.03	6.49, 22.95	7.66, 10.37
Summer Off, Mid-, On-peak Energy Charge		0.077, 0.112, 0.165	0.062, 0.087, 0.142	0.080, 0.111, 0.121
Annual Utility Cost Savings		7~15%	9~18%	8~18%
TES TES Systems in Order of Performance		**Partial Storage** > Full On-Peak Storage > Full Day Storage	**Partial Storage** > Full On-Peak Storage > Full Day Storage	**Partial Storage** > Full On-Peak Storage > Full Day Storage

1. SCE tariffs CPP and Option B.

CHAPTER 7: Conclusion and Future Work

In this study, we demonstrated the value of TES for demand response and various utility tariffs in California. A framework was developed to evaluate the cost effectiveness of various TES use cases, based on the commercial prototype building models. Beyond the value of TES for permanent load shifting from the on-peak hours to off-peak hours, the additional value of TES was analyzed specifically for demand response with fast response time and short event period. The code compliance of Title-24 of existing buildings (Pre 1980) and new buildings (2013) were used to modify the reference model to study the value of TES in California.

Simulations show that typical TES installations will have enough excess capacity to provide cooling demand shifting on most days. With current retail DR programs that have a relatively small number of "event" days, typically on the hottest days, the amount of excess is minimal, and, as is the benefit to customers of participating in DR with only TES. TES resources could be aggregated to participate in wholesale DR and/or ancillary services on days other than the hottest days, which are a vast majority of the days of the year. Field tests need to be performed that turn off compressors and reduce VFDs of chillers to determine if TES could be used to provide ancillary services that require fast response times (e.g. four seconds for CAISO).

In some cases, the TES configuration that provides the greatest reduction in the annual utility bill does not provide the shortest payback period. For older office buildings in PG&E territory, bill reduction is greatest with a full 9-h TES, but payback is faster with a full 6-h TES. Similarly, for old and new office buildings in SDG&E territory, a full 9-h TES provides the lowest annual utility costs, but payback is faster with a partial 9-h.

PDP or CPP with TES alone (without other measures such as increasing thermostat set points or reducing lighting) provides a very small cost savings, but if automated controls are in place, the effort to participate in DR event days with TES alone may be low enough to be beneficial.

Utilities currently look to TES to provide maximum peak period reduction. In most cases studied here, the TES configuration that provided the greatest economic benefit to the customer also provided the greatest peak period load reduction. However, small-to-medium retail customers will have the lowest utility costs with a partial storage system, which only provides a fraction, typically half, of peak period demand reduction compared to that of a full storage system.

Older less efficient buildings have higher peak period loads and present greater potential demand reductions that can be achieved with TES. Utilities should target older buildings with incentives to install TES to maximize demand reduction achieved with incentive programs. Incentives structured as dollar per kW of TES installed will achieve greater peak period reductions per dollar of incentive if targeted at new buildings, but, all other things being equal, the peak period load reduction provided by TES will be lower with a newer building.

CHAPTER 8: Case Studies

Two case studies were intended to provide insight into real-world TES operation for existing systems. They are not detailed equipment design studies, but rather intended to provide insight into TES operation of existing systems and how that operation will vary depending on utility tariff structure, utility metering, and building function.

8.1 Case Study—San Diego Office Building

8.1.1 Description of Facility

A 17-story office building located in San Diego County, California was studied to evaluate and optimize its TES system. Each floor of the ~300 ksqft office building is served by an air handling unit providing variable air volume supply. The basement central plant houses two chillers with variable chilled water flow controlled by 2-way valves. The main chiller (CH-1) is a nominal 500-ton centrifugal ice machine that can produce 385 tons in an ice-making mode. The TES system consists of a bank of 21 FAFCO Model 200 ice tanks with an effective storage capacity of 3847 ton-hours. In discharge mode, the TES circulates a glycol solution to a heat exchanger (HX). The building can also use a direct chiller cooling mode where the storage tanks are by-passed and chilled water is provided by the chiller to the HX..

The central plant also has a pony chiller that was originally a 170-ton capacity unit in series with the chilled water line coming from the HX. The pony chiller was replaced a few years ago with a 200-ton chiller (CH-2) and a new pump with larger flow capacity. The secondary pumps are equipped with variable speed drives.

The FAFCO tanks are still operational after over 25 years of service. However in recent years there has been a reduction in storage capacity. Also the original ice machine CH-1 will have to be phased out soon due to refrigerant regulations. There are certain flow discrepancies, which a recent test and balance (TAB) report also discovered. It would take some detailed examination of tank performance curves to determine if this had a significant influence on the TES performance (e.g. storge capacity).

8.1.2 Utility Electric Metering

In early TES incentive programs, it was SDG&E policy to demand separate metering for TES systems that received an incentive, which in those days amounted to between $250 to $300 per kW shifted during the on-peak period from 11 AM to 6 PM on weekdays from May 1 to September 30. This separate meter was a sub-meter which acted only as feedback to the operator to monitor the electric demand of the chiller and the TES operations.

The case study office building is metered and billed by two meters—one for the building electrical load (meter 024) to which CH-2 is connected and another meter (179) for the central plant and its equipment. In practice, loads on each meter seldom peak exactly at the same time. Therefore, the sum of the two or more individual peaks will not be the same, resulting in a reduced peak of the two or multiple loads combined.

8.1.3 Conjunctive Billing

Conjunctive billing means that the demand measured by each meter is summed and billed as if it was one meter. The advantage is that the two peaks of the meter practically never peak at the same time. This is of course accentuated by the fact that the TES system is shifting demand during the on peak period. Therefore the combined peak demand will always be lower than the demand charges of each individual peak.

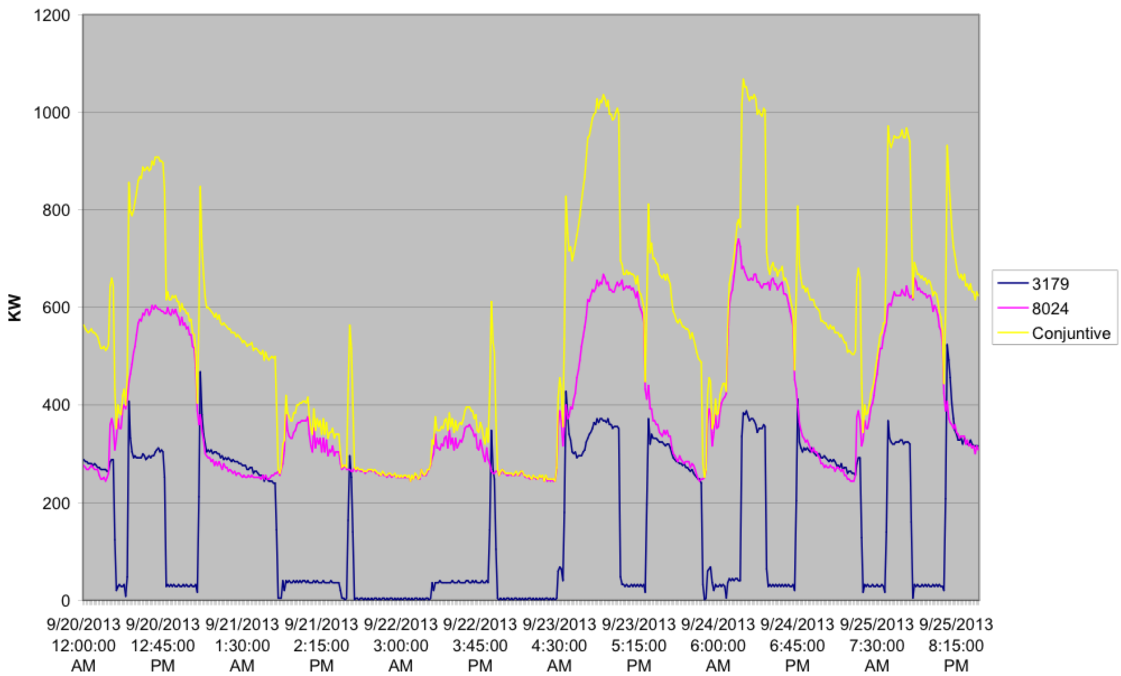


Figure 35. Electrical load profiles in a week from Sep 20th to Sep 25th, 2013

Figure 35 shows the electrical load curves for a period from Sep 20-25 in 2013 (a Friday to a Wednesday). The yellow line shows the combined load behind both meters, the blue line shows the central plant meter and the magenta line shows the building load. It can be seen that the building load meter (magenta) is pretty consistent and peaks around 630 kW. However, morning of 9/24 there is a spike that shows that chiller CH-2 started the morning cooling creating its own peak as well as the combined conjunctive peak.

Figure 36 below shows the load profiles for Friday September 20, 2013. The magenta colored line shows a typical electrical load profile for the building. Chiller CH-2 did not come on. The ice machine CH-1 charged the tanks until about 5:30 AM. Then around 7:30 AM CH-1 started in normal chilling mode using higher demand to bring down the temperature in the TES charging loop. The load then settled down to a constant load pattern until the TES was used to provide cooling starting at ~1:30 PM.

By using the chiller to provide cooling after 12p, an unnecessarily high demand peak is set during the 12-6p peak period. The highest demand for the central plant meter (3179 in Fig. 36) occurs at the startup of the charging cycle at ~7:30p. The spike at this time indicates that the tanks were down to zero latent storage capacity and sensible cooling was needed to reduce the tank loop temperature.

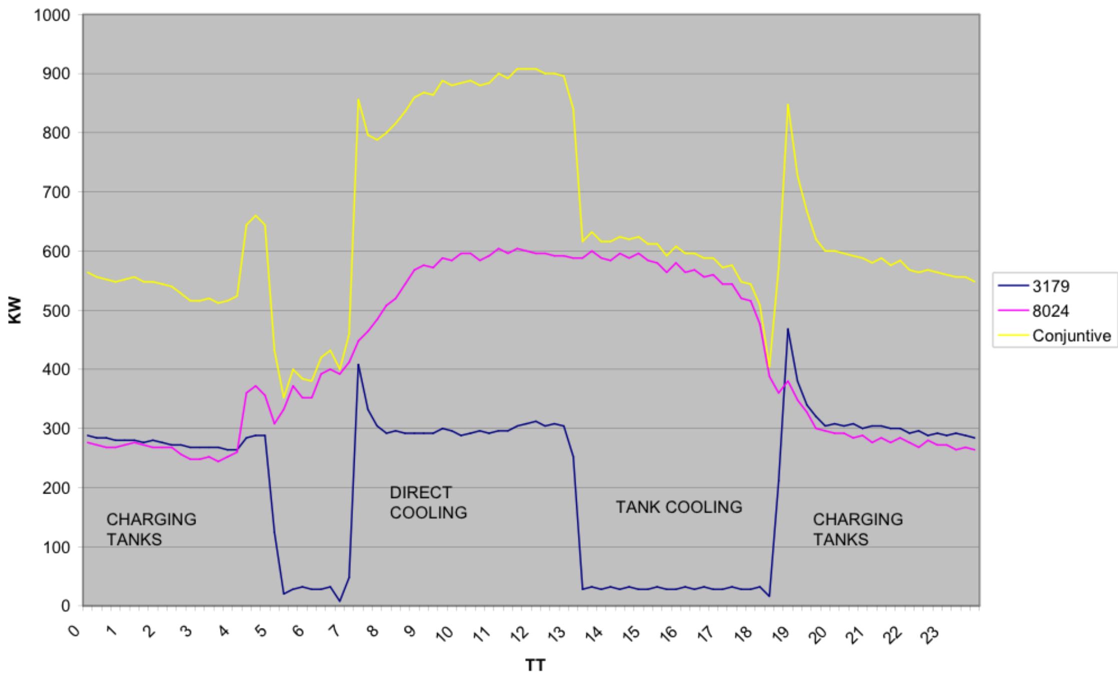


Figure 36. San Diego office building whole building meter (8024, magenta), central plant meter (3179, blue), and sum of both meters (Conjuctive, yellow) on Friday Sep 20, 2013.

Figure 36 illustrates the potential for reducing demand costs through conjunctive billing. For this example, assume peak demand for the month occurred on this day. The non-time related (NTR) peak demand occurred at 7:30 PM with a value of 460 kW for the central plant meter. The building meter peaked in the afternoon at 600 kW. With the meters considered individually, the NTR demand charges would be for 600 + 460 = 1,060 kW. The conjunctive meter has a peak demand of 905 kW. With the conjuctive meter, the NTR peak demand would be 155 kW lower than it was with the separate meters for the building and the central plant. An improved control sequence would provide further savings by turning the chiller off before 12p, which would have reduced the on-peak demand by another 300 kW.

Metering the central plant separately may have served its purpose initially for SDG&E to make sure that the demand shifting capabilities were implemented and to evaluate the incentive rebate program. When SDG&E introduced the NTR demand charge or also called non-coincidental demand charge, the economics for TES changed. Roughly 10 years ago the on-peak demand charge was approximately $12/kW and the NTR was approximately $4/kW. Now these rate values are reversed and normal TES control sequences that concentrate on shifting on-peak demand have had their potential to reduce electricity costs decreased.

Normally, with TES systems the night time chiller load is "hidden" in the nighttime demand "valley" when the building loads are low. With a separately metered central plant, there is no building load valley to hide the nighttime chiller load. This means that the TES system is now effectively only shifting the $4/kW on-peak demand if the chiller is not operated during the 11 AM to 6 PM on-peak period in summer. But the higher NTR demand charge applies now whether it occurs during the day or night.

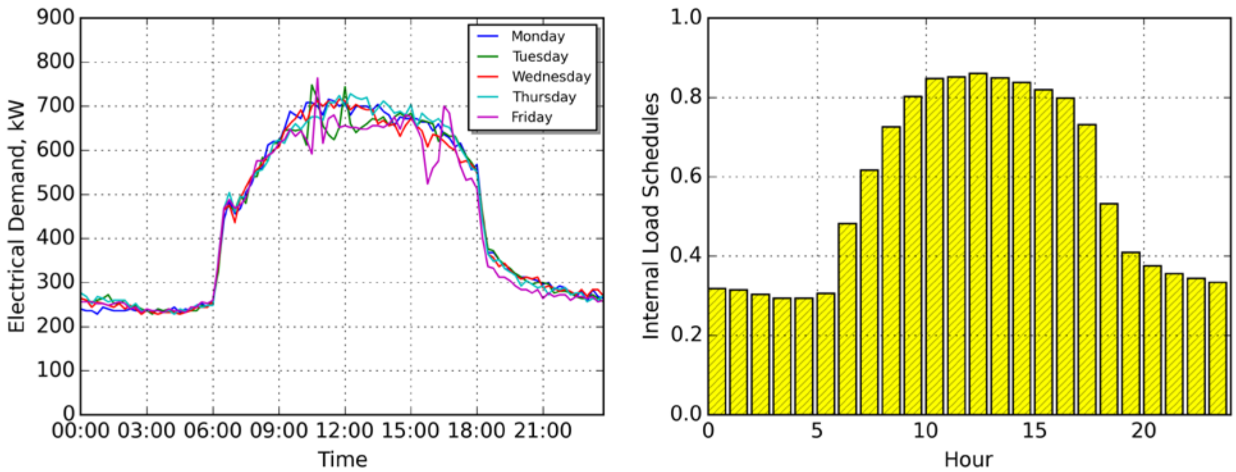
Decreased electricity costs can be achieved with the TES at this facility with relatively little effort and cost by taking the following actions:

1. Apply for conjunctive billing for its building and central plant electric meters.
2. Change the control sequences so that chillers do not run during the on-peak period from 11 AM to 6 PM during the summer months from May to October and from 5 PM to 8 PM during winter months from November to April.
3. If for some reason the conjunctive metering is not applied, then chiller CH-2 should be put on the central plant meter.
4. With the available storage capacity slowly diminishing the operational control strategy should be changed to a partial storage system. For this to be effective some troubleshooting work is required to determine the cause of the reduction of storage capacity and/or the reduced heat transfer rate, and find any possible remedy.
5. Adjust control sequence and schedule for charge and discharge of TES to maximize savings based on current SDG&E tariff for facility instead of for the rates that were in place when the current controls were configured. This may require some expert analysis of the facility load data.

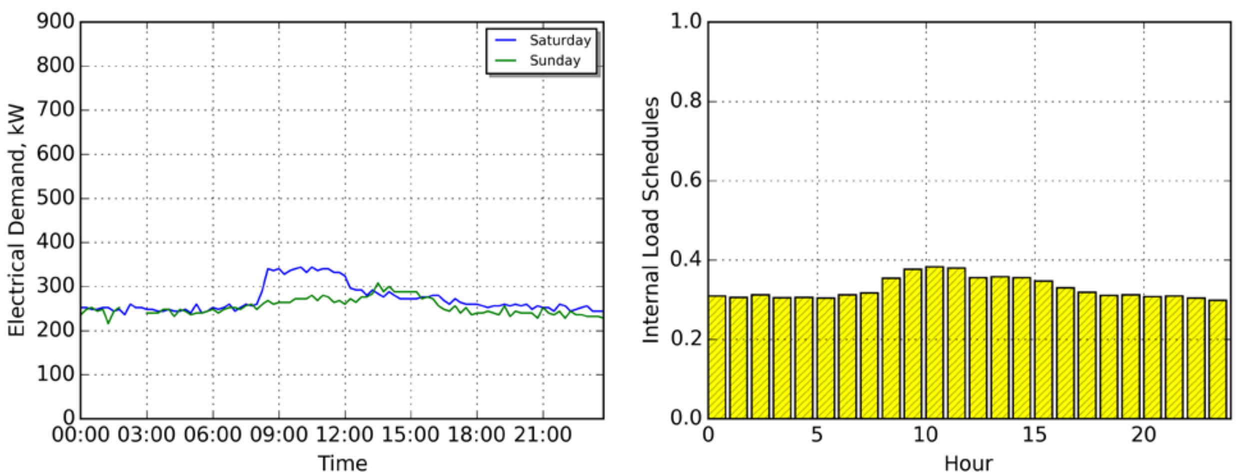
8.1.4 E+ Simulation Studies

An EnergyPlus model was created for the case study office building using the Demand Response Quick Assesment Tool (DRQAT) and then was modified to simulate the real TES configuration and operation. With the default inputs of space loads such as occupant, lighting and plug, energy usage results generated by the model differed significantly from actual building performance.

There are many reasons for the difference between predicted and actual energy performance. Weather is one of the most important factors in predicting a building's energy performance. Actual weather data are necessary for calibrating a simulation model with measured data from buildings. In this study, real weather data from July 2013 to July 2014 was downloaded from the National Climatic Data Center (NCDC) weather database, formatted into an EnergyPlus weather file, and used in the simulations. Power densities and operational schedules of lighting and plug loads was estimated from the sub-metered building electrical load (meter 024), as shown in Figure 37. The estimated power density of the lighting and plug loads was 2.5 W/ft^2. The actual operational schedules of the lighting and plug loads were fed into the model to replace the default inputs.



(a) Internal loads on weekdays



(b) Internal loads on weekend

Figure 37: Example of electrical power demand during a week in winter

As shown in Figure 38, the calibrated model results show good agreement with measured building data at the whole-building level from July 2013 to July 2014. The mean bias error between the measured and the simulated whole building power usage is 1.8%, which satisfies the model calibration tolerance for the monthly comparison.

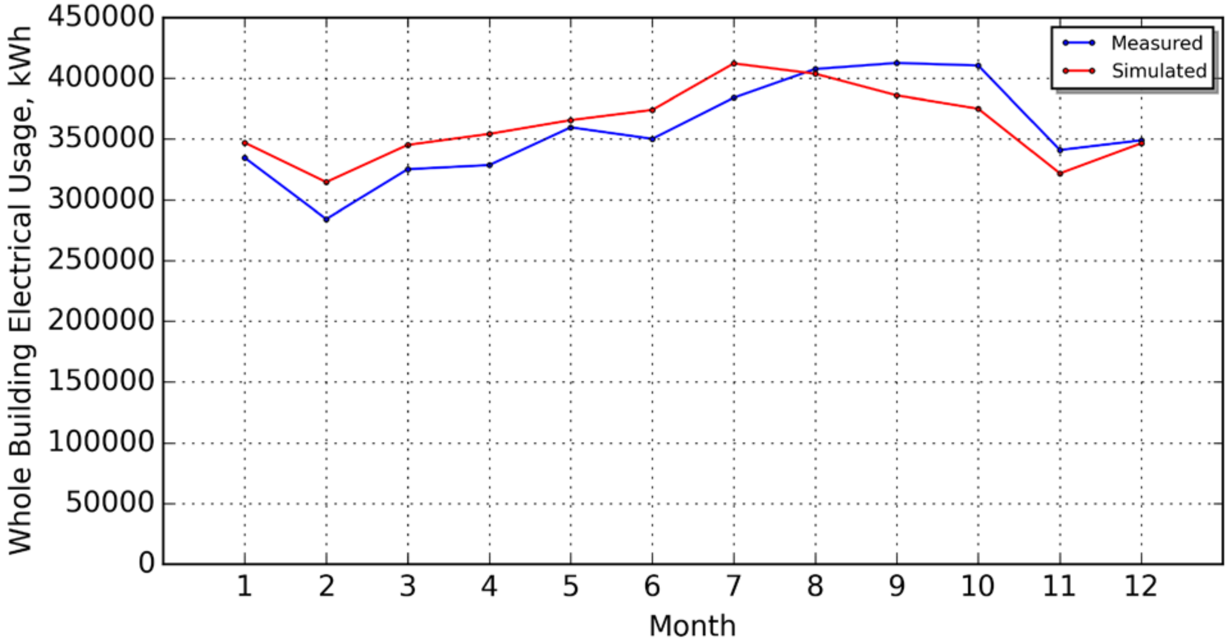


Figure 38: Comparison of the whole building electrical usage between the measured and the simulated

The purpose of calibrating the model was to evaluate the impact of the utility rate change on the TES performance over the recent years. This building has been running the same operations and controls of TES system while the rate schedule in SDG&E territory is changing every season. In SDG&E territory there are demand charges on both the T&D (Transmission and Distribution) side of the rate and the commodity side. As a DA (Direct Access) customer, this building doesn't pay all the demand charges as customers under the rate of Commodity Rates EECC. As presented in the section on utility tariffs, the utility rate of AL-TOU (DA) has a low and constant energy charge throughout the year, but high "non-coincident" demand charge at $24.43 and relatively high summer on-peak demand charge at $10.37 and summer mid-peak at $7.66. There is an opportunity to reduce the monthly "non-coincident" demand charge by changing full TES operations (11pm~6pm) to partial TES operations with the same TES system.

The calibrated model was used as the referenced base case and a new model with partial TES operations was proposed to evaluate the effort on the utility bills. Figure 39 shows the comparison of the whole building monthly peak demand between the current and the proposed TES operations. The average reduced demand is 204 kW in the summer season and 159 kW in the winter season. In total, the reduced annual utility bill is around $35,653, which is nearly 7.4% of the annual utility bill. The entire cost savings are from the rate difference between the monthly "non-coincident" demand charge and the monthly on-peak demand charge. Because the TES performance is significantly influenced by the utility rate tariff and structure, any change of the rate schedule should bring more attention to modify the TES operations and controls for utilizing the flexible load capability of the TES systems.

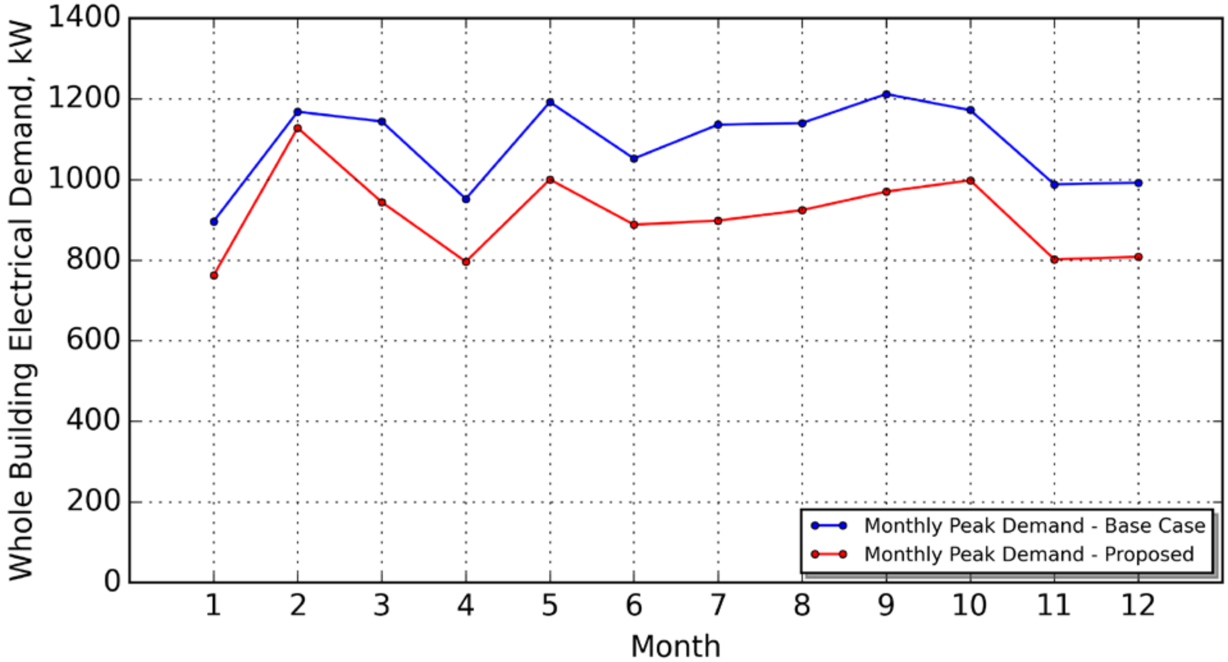


Figure 39: Comparison of the whole building monthly peak demand between the base case and the proposed

8.2 Case Study—San Diego Educational Buildings

Rancho Bernardo High School (RBHS) is part of the Poway Unified School District in San Diego, California. High school with multiple buildings as shown in Figure 40.

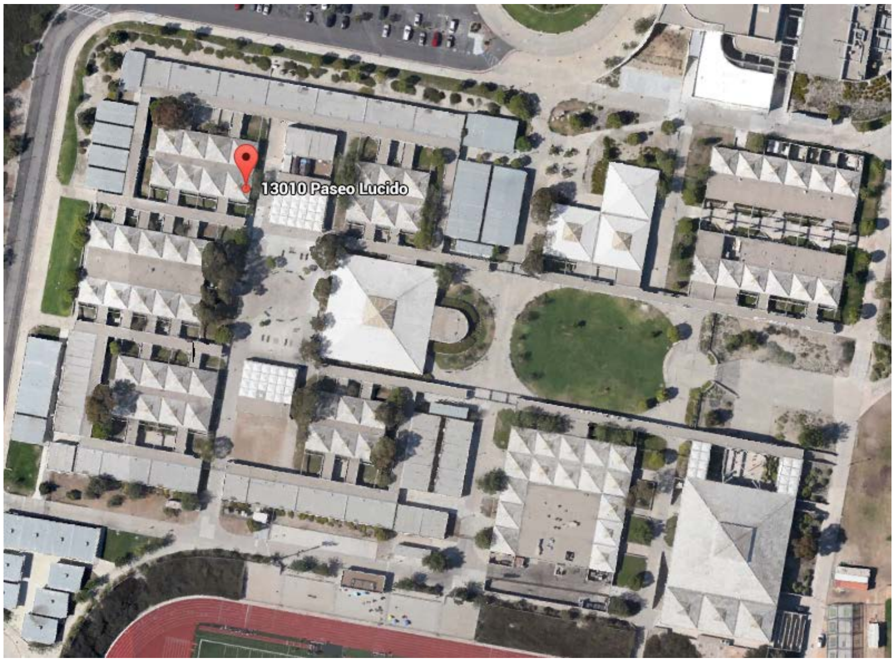


Figure 40. Rancho Bernardo High School (RBHS) campus buildings.

Bernardo Heights Middle School (BHMS) is a 113,503 square foot middle school serving students in Poway. The site is located right next to Rancho Bernardo High School with a large Performing Arts Center located between the two sites. The school features a multi purpose room (MPR), Library with computer labs, administration offices, classrooms, locker rooms and a gymnasium, along with two large squads.

8.2.1 RBHS HVAC

A central plant located at RBHS provides HVAC to buildings at RBHS and BHMS. The central plant, which was upgraded in 2011, is state-of-the-art equipped with water-cooled screw chillers, variable frequency drive (VFD) pumping and a 3,200 ton-hours TES ice system.. The plant charges the ice tank in the off-peak hours and then depletes the tanks during the portion of the school day that coincides with the utility (SDG&E) on-peak time period. During summer peak months the plant operates as a partial storage system. During the rest of the year the plant can operate as a full storage system.

The plant consists of two high efficiency York screw chillers. The primary chilled water loop is a glycol mix configuration for 21°F operation. The chilled water loop going to the load is a chilled water loop fed via the heat exchanger. When the TES is providing 100% of the cooling to both the RBHS and BHMS campuses, the chilled water temperature ranges between 40°F and 48°F based upon outside air conditions, actual cooling load and percent of tank charge. The primary side of the heat exchanger is fed by 50 horsepower (HP) pumps (1027 gpm / 115 ft-hd) with the secondary side of the heat exchanger fed by 100 HP pumps (1640 gpm / 160 ft-hd) chilled water pumps.

The cooling tower consists of a large BAC tower with two cells. Each cell is equipped with a 20 horsepower fan motor equipped with a VFD. The two 25 HP condenser water pumps are also variable speed. Each tower is equipped with a 7.5 HP filtration pump. All plant control is provided by an Alerton DDC system.

Ventilation is provided by 63 United Metal Product air handling units (AHUs) and fan coil units (FCUs) that range in size from 27 MBh to 214 MBh. A small portion of the facility is conditioned by four AAON packaged units.

8.2.2 Historical background

The original central plant was built in 1990 and consisted of an ice TES system utilizing FAFCO tanks. The storage capacity was 2,300 ton-hours. Two TRANE centrifugal chillers were used in ice making modes and normal chilled water operations. It was designed to operate as a partial storage system meaning that the tank would be assisted by a chiller during the summer on-peak period, which for SDG&E was 11 AM until 6 PM for May until September, at that time. In 2014 SDG&E changed October from a winter month to a summer month.

Initially the TES control sequences were relatively simple and included using the chiller(s) for cooling in the morning until shortly before 11 AM, and TES storage for cooling after that The schools closed down in mid-afternoon and the cooling load dropped off considerably after 4 PM. Figure 40 shows the hourly demand charges for the schools that were in place from when the TES system was installed to 2004. With this demand charge structure, the TES operation strategy was simply to minimize or avoid chiller use during the on-peak demand charge period of 12-6p, and it did not matter much if the load peaked in the morning as it did occasionally. In 2004, the tariff that the school was on changed such that the difference between demand charges during on-peak and off-peak hours became much smaller going from a difference of ~20 $/kW to ~6 $/kW (see Fig. 41). This decrease in the difference between on-peak and off-peak demand charges reduced the economic payback advantage of operating the school's TES. The difference between on-peak and off-peak demand charges for the school has increased to ~10 $/kW (see Fig. 42), somewhat improving the economic payment of operating the TES system for the school.

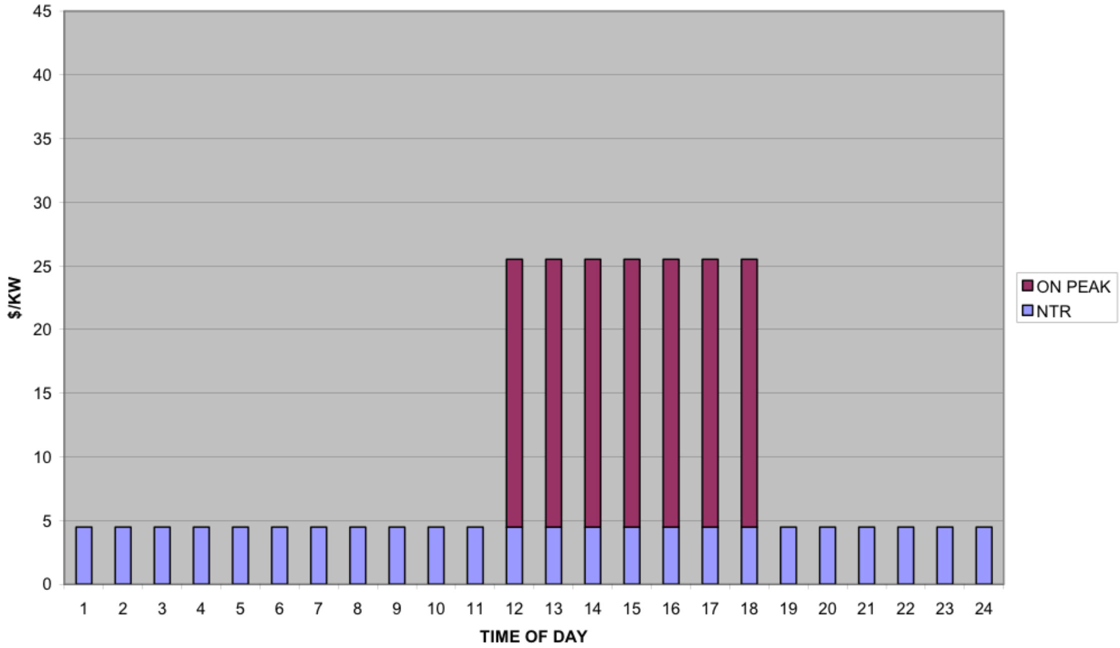


Figure 41. Summer monthly peak day demand charges SDG&E AL-TOU in 1999.

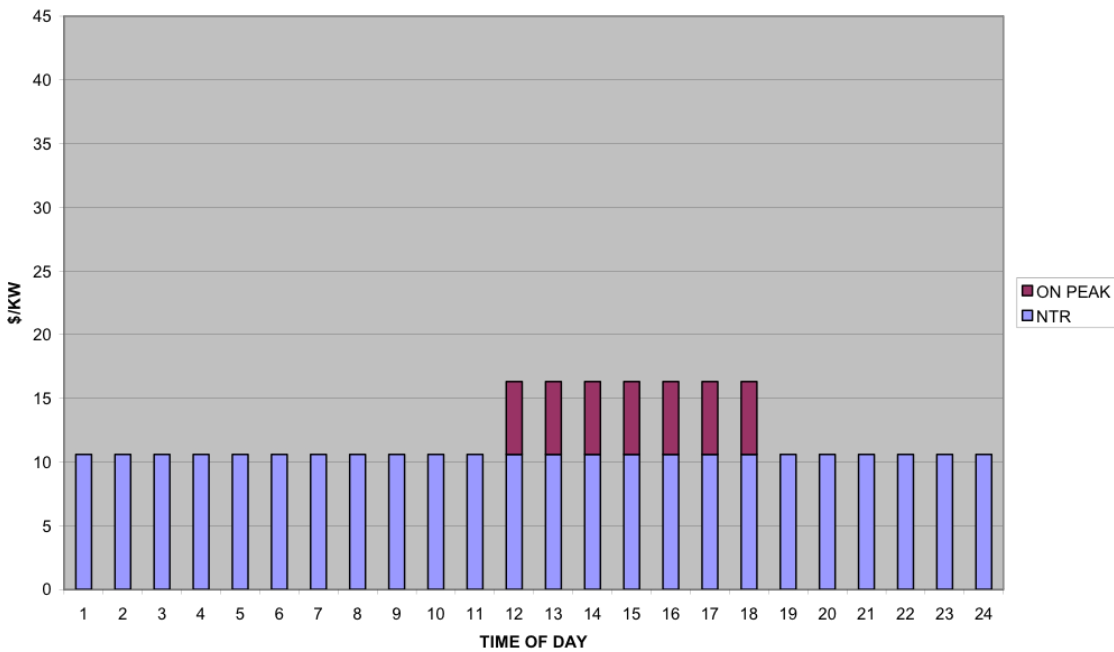


Figure 42. Summer monthly peak day demand charges SDG&E AL-TOU in 2004.

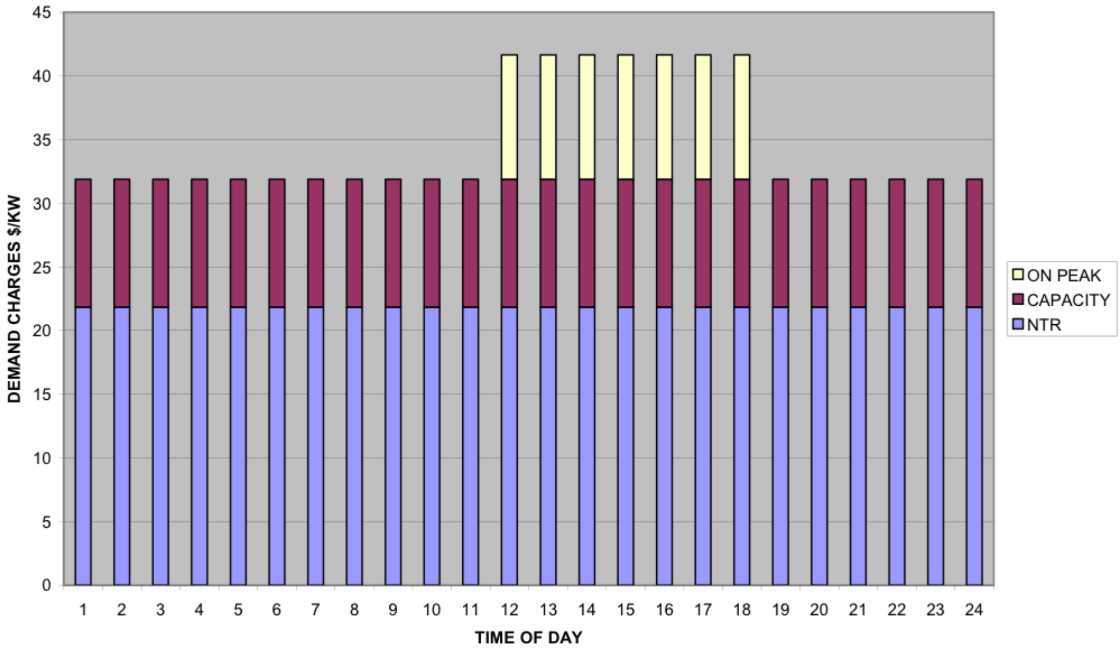


Figure 43. Summer months peak day demand charges SDG&E AL-TOU in 2014.

In 2005, the system was using basically the original control sequence that included operation of chillers alone for morning cooling as can be seen in the load profiles for September 2005 in Figure 44. The smaller difference between on-peak and off-peak demand tariffs after 2004 compared to before 2004 led to a need for more precise control of chiller operation and TES discharge to minimize overall demand charges.

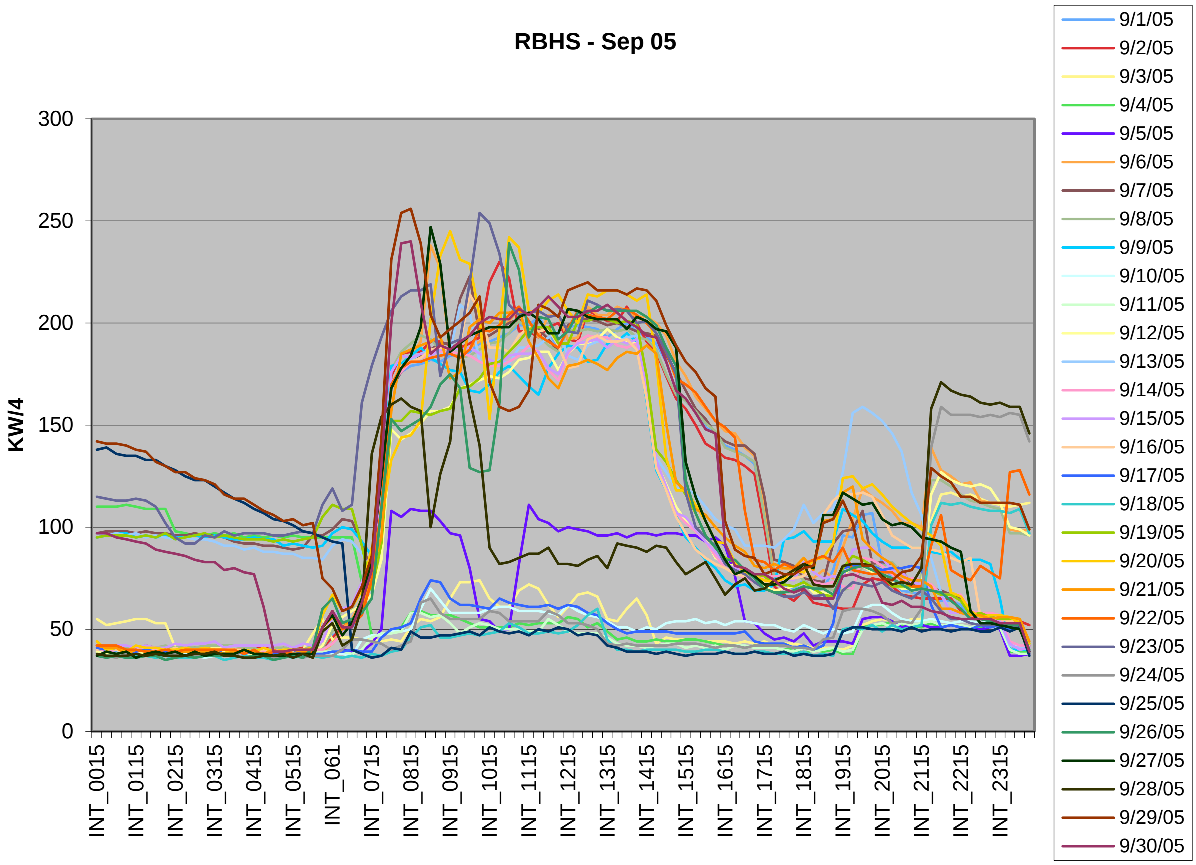


Figure 44. RBHS facility load on each day in September 2005. Actual load values are four times values shown.

In 2011 the chiller plant was upgraded with new chillers and an ice nodule storage system with a storage capacity increased from 2,300 ton-hours to 3,200 ton-hours. Also, with additional conditioned space, cooling load had also increased by ~150 tons. The TES operates as a partial storage system in summer months and a full storage system in winter months.

Facility load data collected during the chiller plant commissioning conducted in the month of September 2011 is shown in Figure 45. The control strategy implemented in 2011 was designed to keep peak demand during on-peak and off-peak periods about the same or slightly lower during on-peak periods due to the relatively small difference between on-peak and off-peak demand charges. In this control strategy, a maximum target demand during any 15-min period is set at 800 kW. Control strategies have become more complicated compared to when there were significant differences between on-peak and off-peak demand charges and no capacity charge and the control objective was to minimize or eliminate chiller operation during the afternoon on-peak period. To maximize the savings benefits that TES can provide, owners must keep current on their utility rate structures and adjust control of their TES when changes in tariffs warrant it.

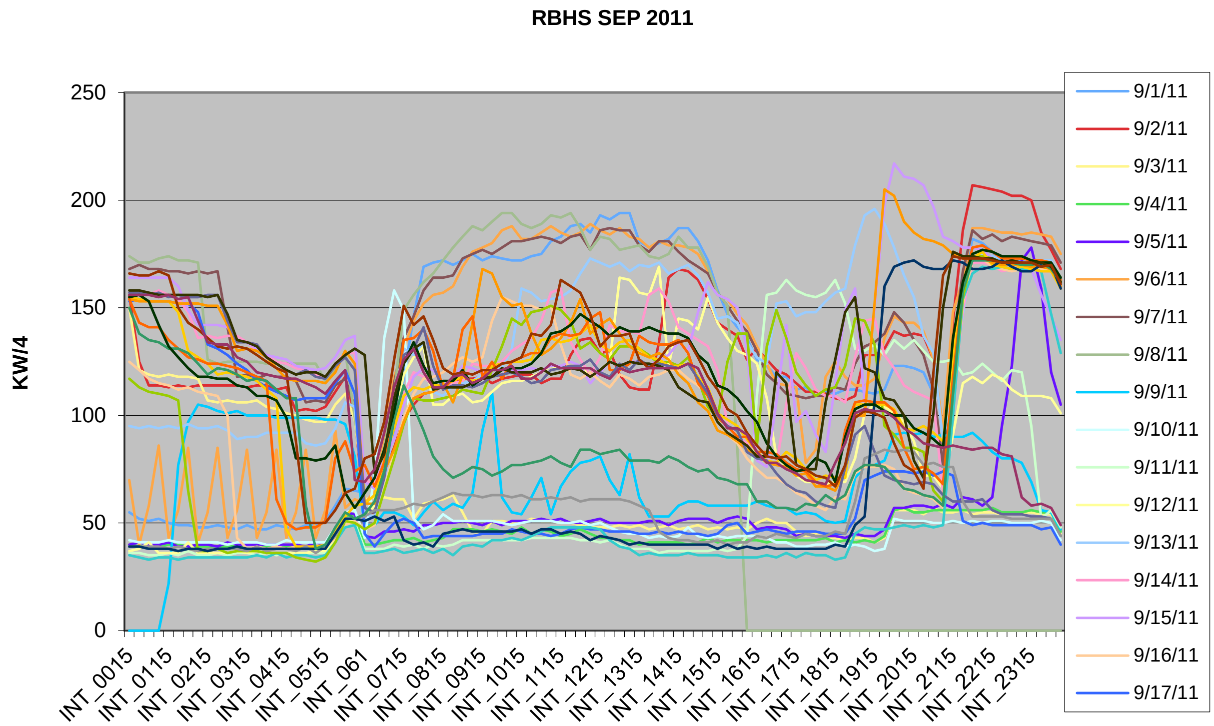


Figure 45. RBHS facility load on each day in September 2011. Actual load values are four times values shown.

During the summer of 2014, nearly all of the fan coil units at the RBHS high school campus were replaced. As is often the case when a chilled water system is subjected to a major renovation, rust particles get dislodged. When the system was resealed, it was found that there was decreased cooling capacity even though the main secondary circulation stand-by pump (100 HP) was also assisting and running at full speed. After installing filter screens at various locations in the chilled water loop and repeated cleaning, a trouble shooting process eventually showed that the heat exchanger had severely been clogged and that the flow was so reduced that only about 500 tons could be transferred to the secondary loop. In the 2011 central plant upgrade design process, a decision was made to eliminate the dirt screen. September 2011 was a particularly hot month and there were times when both chillers had to run during the on-peak period to keep complaints to a minimum (e.g. 9/17 in Figure 46). A properly operating TES has been shown to keep monthly peak demand to about 800 kW even in hot months and would have reduced September 2014 demand related charges by ~$13,000 compared to those incurred with the improperly operating system. The obvious take away here is for owners to correctly protect TES components at installation and to perform proper maintenance to maximize TES performance and economic payback.

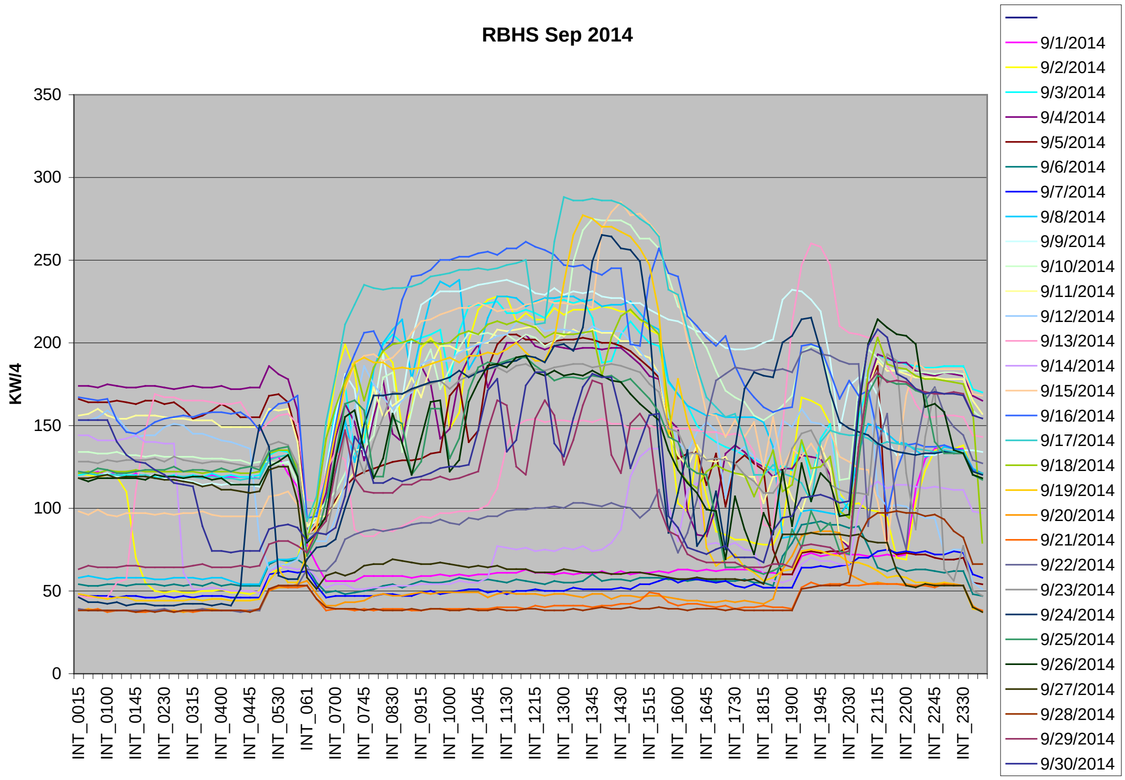


Figure 46. RBHS facility load on each day in September 2014. Actual load values are four times values shown.

CHAPTER 9: Conclusions

This study provided conclusions in the two key areas: (1) TES for demand response; (2) Cost effectiveness analysis of TES applications in three IOUs' territory areas. These results should aid utilities and regulators to identify improvements in the scaling of TES-related incentives programs and participation of TES systems in the DR market design.

9.1.1 TES for DR

Previous studies indicated that buildings can shed over 50% of HVAC related electric demand for both two-hour load shed events and 20-minute events by turning off chiller units. With the same control strategy, building with TES systems can provide a reliable and fast load shed by turning off chiller plants without any interruption on the building comfort service level. The value of TES systems was demonstrated in terms of two TES types: (1) full storage TES systems and (2) partial storage TES systems.

Full Storage TES systems: Of all the weekdays with TES operation, TES gets fully discharged for no more than 5% of the total number of weekdays. Unless DR events are called during the period when TES storage is not discharged, there is no room for full storage TES systems to participate DR programs.

Partial Storage TES systems: Compared with full storage TES systems, partial storage TES systems provide much more flexible load resources to participate various DR markets by switching the storage discharge mode between full and partial. For DR events called on the peak days, the integration of partial TES systems with typical DR control strategies (e.g. global temperature adjustment) can also provide one-hour or 20-minute load shed resource on the peak day by aggregating the cooling load reduction during the GTA deployment period. For an example of the BIP program in SCE, the BIP credit is much higher than the price paid for increased mid-peak demand charge. Therefore, buildings with partial TES systems can be good resource to participate DR programs with fast response time and less length of response.

9.1.2 Cost Effectiveness of TES in California

The TES suitability is greatly influenced by the following factors: (1) utility rate structures; (2) building load characteristics (e.g. load pattern, ratio of on-peak and off-peak cooling load); (3) climate; (4) retrofit of existing cooing system and available physical space for installation. In this study, a matrix of various TES use cases was simulated to evaluate the impact of building load, climate and utility rate schedules of three IOUs in California.

"Pre1980" existing buildings vs. "New2013" new buildings: Clearly, "New2013" new buildings are much more efficient that "Pre1980" existing buildings. It indicates that the potential of load shed during the on-peak hours is significantly higher in existing buildings, while the cooling portion of the whole building electrical demand is very close between existing and new buildings. Using the payback period as the comparison metric, TES applications are more attractive in new buildings. On the other hand, TES applications give more value in existing buildings based on the amount of demand savings (kW) and the annual utility bill savings ($).

Warm vs. Hot climate: In this study, the selected Climate Zone 4 (CZ04) and Climate Zone 12 (CZ12) represent the warm and hot climate in the PG&E territory area based on the number of cooling degree days. The whole building peak demand is higher in CZ04 and the annual electricity consumption is slight higher in CZ12. Under the PG&E's tariff rate, TES applications are relative attractive in the area of CZ04. In the SCE's territory area, TES applications are more attractive in the area of CZ09 than in CZ10, where are both hot climate areas.

Utility Rate Structures and Tariffs: Typically, utility rate structures include energy charges (time-of-use rates), coincident demand charges (on-peak, mid-peak), non-coincident demand charges (monthly maximum demand) and demand charge incentives of some tariffs (e.g. PDP, CPP). Because TES economics are highly dependent on favorable rates, each IOU' utility rate structure has its own favorable TES application in terms of system configuration and control operation. From the perspective of the payback and simple ROI, PG&E, SCE and SDG&E's favorable TES applications are full storage deployed from 12pm to 6pm, full storage deployed from 8am to 6pm and partial storage deployed from 8am to 6pm.

Office vs. Retail: The majority of the cooling load is distributed between 12pm to 6pm for small- and mid-sized retails. This kind of load pattern leads to more favorable TES deployment during the on-peak hours for all three IOUs' tariffs. On the other hand, the portion of the cooling load in retails (40~50%) is much higher than that in offices (30~32%). It provides additional potential for partial TES systems with smaller capacity of the chiller plant.

9.2 Future Work

Based on the framework in this study, future work will focus on the development of software or web-based tool to better understand the effect of TES applications in a user-specified environment. For audience like utility or regulators, the values that TES applications provide in the area of demand savings, integration of renewable generations and participation of DR market are of their interests. For customers, given the existing building load profile or simulated load profile of the new building, the tool can give an optimal system design and operation strategy by applying parametric analysis. In addition, better understanding of the utility rate evolution is quite necessary to evaluate the value of TES along with the change in grid because of more penetration of renewable generations and various DR products on the market.

GLOSSARY

Term	Definition
BIP	Base-Interruptible program
CAISO	California Independent System Operator
CEC	California Energy Commission
CZ	Climate Zone
CPUC	California Public Utilities Commission
CPP	Critical Peak Pricing
DA	Direct Access
DR	Demand Response
DOE	Department of Energy
DOE GESD	DOE Global Energy Storage Database
DX	Direct Expansion
EECC	Electric Energy Commodity Cost
FEMP	Federal Energy Management Program (DOE)
HP	Horse Power
HVAC	Heating, Ventilation and Air-Conditioning
IOU	Investor-owned utility
GTA	Global Temperature Adjustment
LBNL	Lawrence Berkeley National Laboratory
NREL	National Renewable Energy Laboratory
PG&E	Pacific Gas and Electric Company
PDP	Peak Day Pricing
PEC	Pacific Energy Center (PG&E)
PLS	Permanent Load Shifting
RBHS	Rancho Bernardo High School
RTP	Real-time Pricing

ROI	Return of Investment
SDG&E	San Diego Gas & Electric Company
SCE	Southern California Edison Company
TES	Thermal Energy Storage
TMY	Typical Meteorological Year
TOU	Time of Use
VFD	Variable Frequency Drive

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