Where the Heat Goes: Field Findings on Thermal Energy Storage in HVAC Systems

Final Project Report

February 2026

Code Readiness
RESEARCH THAT DRIVES PROGRESS

Project Number
CR24PGE0201-1

Code Readiness Project Team
This report was developed through the collaboration of a dedicated project team. Thomas Mertens of PG&E served as the Project Sponsor, providing guidance and oversight. Project management was led by Edie Taylor of West Monroe (formerly 2050 Partners), who also contributed as a Primary Author alongside Neil Bulger and Fatima Saeed of A2 Efficiency.

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Recommended Reference
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Introduction

About PG&E's Code Readiness Subprogram

PG&E's Code Readiness Subprogram supports the development, adoption, and implementation of California's building and appliance energy codes through long-range planning and data collection. Positioned between early-stage technology pilots and formal regulatory adoption, Code Readiness translates emerging ideas into actionable insights that support policymakers, regulators, and program implementers in making informed decisions. Code Readiness focuses on energy performance, cost-effectiveness, feasibility, and code compliance data to support regulatory advocacy. In addition to its primary focus on field data collection, Code Readiness works with trade allies to ensure that the market can meet key equipment capabilities that will be needed to achieve codes and standards goals and deliver statewide energy and carbon savings.

Collecting field data is a central strategy to support research, inform code development, and enable cost-effective energy savings. Field data improves energy model inputs to better represent actual building operations and HVAC equipment performance which is then used to inform the cost-effectiveness analysis that underpins the code development process. This Code Readiness project was developed and implemented by the team members shown in Table 1, referred to in this report as the "research team."

Table 1. Research Team

Company	Role
Pacific Gas & Electric (PG&E)	Project Sponsor, Program Administrator
2050 Partners	Project Manager, Program Implementer
A2 Efficiency	Technical Lead

Report Summary

Storing thermal energy - in tanks of water, ice, or other materials - is not a new technology for the built environment; there are many energy storage applications for domestic hot water. With the combined factors of increasing renewable penetration on the generation side and increasing loads on the demand side, grid managers are interested in optimizing "when" buildings consume energy. In addition to the domestic hot water applications, thermal energy storage (TES) technology can provide flexibility for HVAC loads to reduce demand during peak demand periods for most building types. TES for HVAC has significant potential to ease peak demand issues on the grid in a way that does not require occupants to sacrifice their thermal comfort. Prior Code Readiness modeling studies confirm that: (1) TES can have significant value for reducing peak demand in commercial buildings, and (2) TES can have a significant financial value for demand flexibility to both buildings and the grid.[1] This study provides real-world evidence to support these conclusions. The research team for this study identified active TES in HVAC applications in California, characterized their application in buildings, and analyzed their operation in reference to the electric grid.

[1] Gantley, Maya, Bulger, Neil, 2025. Energy Modeling Analysis: Peak Thermal Load Management Strategies https://www.etcc-ca.com/reports/energy-modeling-analysis-peak-thermal-load-management-strategies.

Purpose & Objectives

This report presents a survey and assessment of TES sites in California, focusing on systems that are in operation today. The following sections summarize the design details and operational data of several TES systems to describe the real-world operation of the systems and provide evidence of applications that are cost effective, have market penetration, and could be ready for Title 24 code requirements. The analysis demonstrates different deployment techniques, system sizes, and insights across multiple building types and California climate regions.

The research had the following objectives, intended to inform building codes and standards development, particularly CA Title 24:

- Understand market penetration of TES for HVAC in California.
- Identify use cases of TES that are cost-effective and functional for buildings today.
- Recommend code requirements or compliance options based on findings.
- Assess market readiness for heating-side TES and make any relevant codes and standard recommendations.

Regulatory Objectives

The research aimed to support the following regulatory objectives:

1. Include chilled water TES in CA Title 24 as a potential prescriptive requirement and expanded compliance option.
2. Define and recommend practical parameters and controls for code requirements and compliance options related to chilled water TES in non-residential HVAC.

Research Questions

The research aimed to address the following research questions:

- Where in California is TES being installed and used for demand flexibility?
- What are the configurations of TES systems in design and operation? What is consistent and different about the installations?
- How are the systems controlled? Does the control method vary by day or load?
- Do TES systems require operators to make discharge/charge decisions, or can they be automated to function consistently over the year?
- With the TES systems in operation today, what works and what does not? What lessons can we document for TES system designers and operators?
- What are the most cost-effective applications for TES in California today?
- With the TES systems in design today, what problems are they solving? What existing barriers are preventing TES designs from advancing to implementation and proper operation?

Scope of Study

The research team completed a multi-site study of applications of TES in HVAC in the state of California. All data represented in this report was provided by sites or gathered from publicly available sources.

Field Survey of TES in California

General Assessment

The research team combined stakeholder outreach with desk research to identify sites with TES in California. Stakeholders included architects, engineers, facilities managers, building owners, and TES system manufacturers. The research team asked these stakeholders to discuss their knowledge of TES in California, including novel applications and operationally proven TES based on known sites with TES. The team also asked for data on the systems, including design drawings, operational data and control sequence information. The team supplemented this data set with desk research from published reports and other public information on TES systems.

Figure 1 summarized the 39 sites by the type of thermal energy stored. Of the 39 sites, 32 sites were chilled water (CHW) and phase change (ice) storage, five sites were heating hot water (HHW), and two were condenser water (CW) storage in an ambient loop in two different residential high-rise buildings, one in San Francisco and one in San Jose.

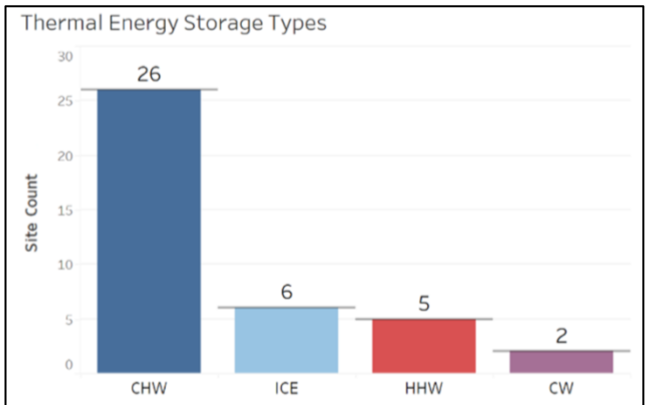


Figure 1. Summary of types of TES systems surveyed

Figure 2 shows a map of each location across California, with cooling applications (CHW and ice) on the left and heating applications (HHW and CW) on the right. Chilled water sites are present across California, while other forms of TES (CW, HHW, and ice) are primarily located in large urban areas and centers of progressive design. The team found that the chilled water storage adoption might be driven by a variability in utility rates that is found in most utility territories in California.

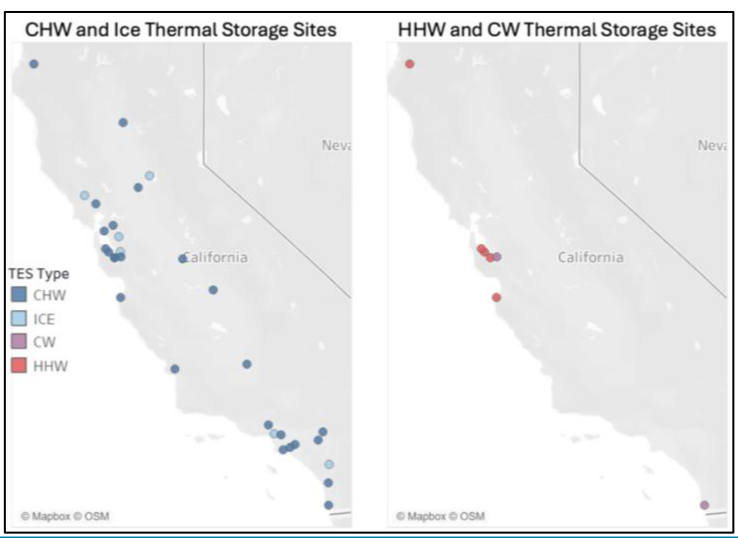
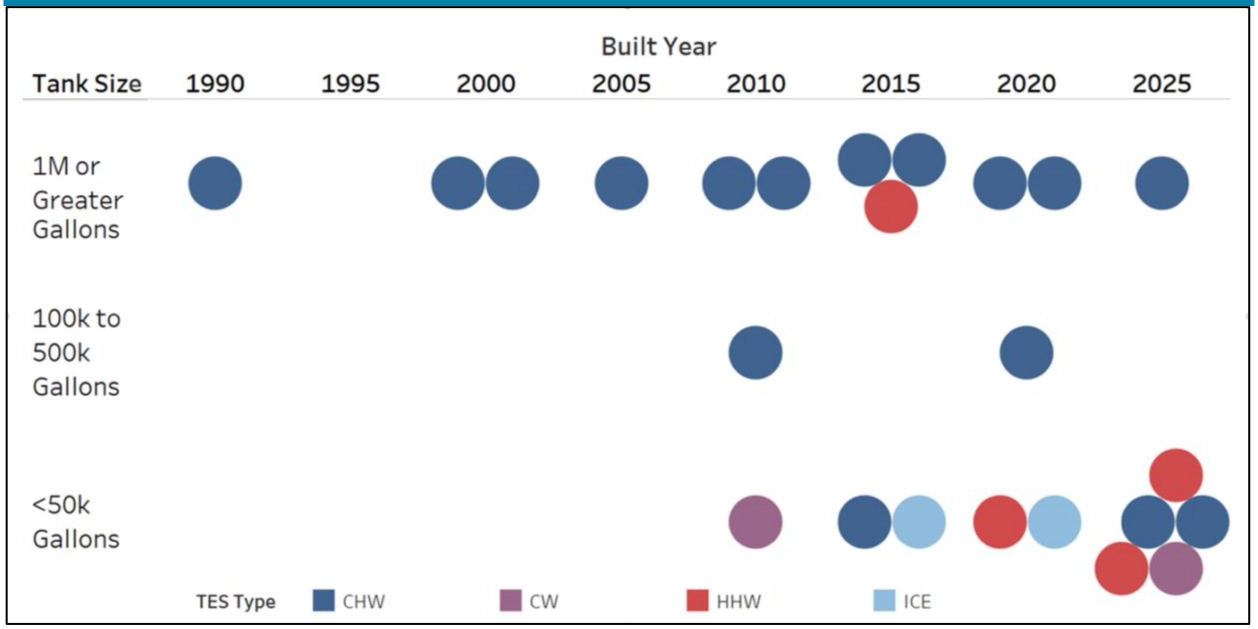


Figure 2. California TES sites Identified by Research Team

The team categorized the sites by system size (in gallons), year of construction, and type of storage in Table 2. The table organizes sites by construction year in 5-year bins from 1990 to 2025 and into three size categories: (1) under 50,000 gallons, (2) 100,000 gallons to 500,000 gallons, and (3) 1 million gallons or more. Table 2 shows that the past 10 years have seen an increase in the adoption of smaller and more diverse TES systems, including more HHW and CW.[2]

TABLE 2. TES SYSTEMS BY YEAR INSTALLED, SIZE OF TANK (GALLONS), AND THE TYPE OF THERMAL STORAGE



The distribution of TES across building types is as follows:

- College campuses: 24 sites (majority of dataset)
- Research Laboratories: 2
- Higher Education & Healthcare: 2
- Assembly Buildings: 2
- Highrise Residential Apartments: 1
- Highrise Hotel: 1
- Corporate Campus: 1
- Food Processing Facility: 1
- Multifamily Highrise: 1
- Winery: 1

Appendix B includes a table with more details on the TES systems the team identified. The team found that, for systems built before 2025, large building and campus chilled water storage hold the largest TES market share. There are emerging TES technologies that could have implications for market transformation of TES, including: (1) TES for space heating and (2) TES for packaged systems. The following sections describe these technologies and their grid flexibility implications.

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[2] The team gathered data and information on TES in design but focused on operational TES for this report. The trend towards HHW, CW, and smaller applications showed up in the future TES designs as well as operational TES.

TES for Space Heating

The Design: Of the sites identified by the team, five used TES for space heating functions, and all five were designed with hydronic heating systems. Three of the sites had relatively small thermal storage tanks (5,000 gallons or less) that were combined with air-to-water heat pumps (AWHPs). These small tanks are designed to enable electrification by reducing demand in specific ways. A heat pump has limitations on both sides of the capacity spectrum, meaning in both low demand and high demand scenarios. Similar to many other systems, performance is less ideal during peak capacity operation. To cover peak demand, heating systems are sized with substantial safety factors that are based on providing full ventilation in the coldest conditions and assume no internal gains. This situation rarely, if ever, occurs and sizing based on it can result in a heating system that does not perform well in typical operation. On the other end of the capacity spectrum, AWHPs can only function down to a minimum capacity that is not well suited for low demand situations. A small capacity heating TES can minimize energy penalties associated with performance on both sides of the capacity spectrum. See below for a visualization of this design theory.

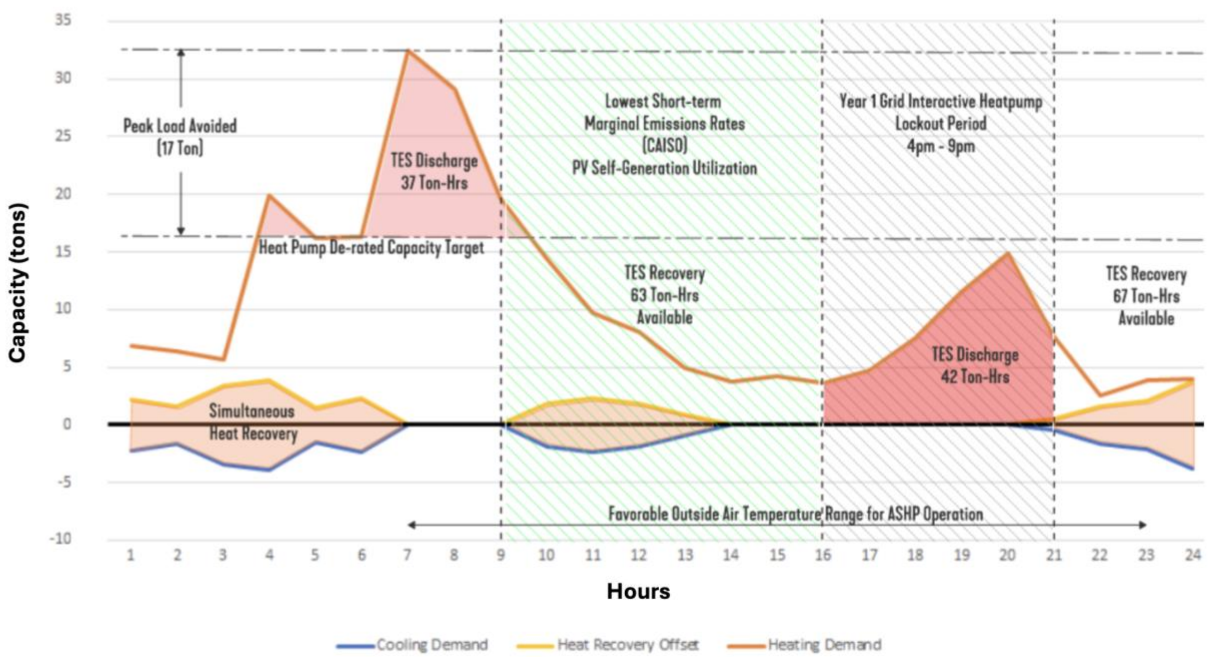


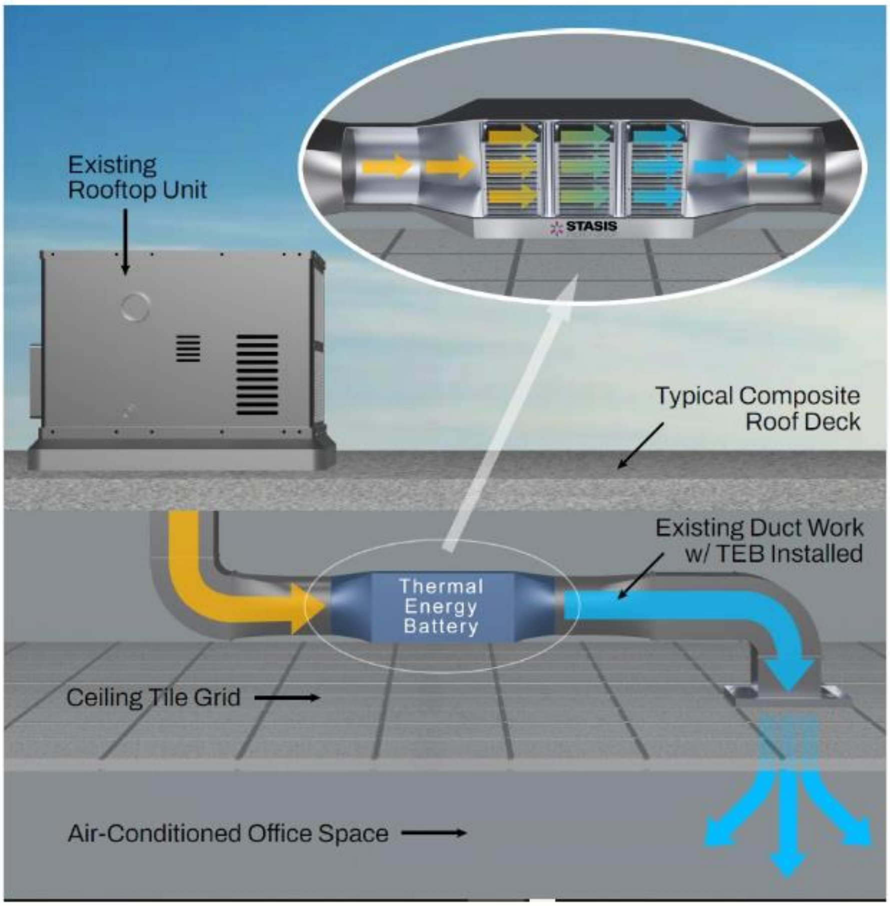
FIGURE 3. DESIGN CONCEPT FOR A SMALL HEATING TES TO SUPPORT HEAT PUMP FUNCTION

Two other sites with heating hot water storage used TES to reduce peak demand, which allowed a heating system design with smaller heat pumps than would be required without TES.

The Implications: The incorporation of TES into space heating design, particularly even small capacity storage for heating functions, can improve the cost effectiveness of commercial building electrification by decreasing the first cost of a heat pump installation. It also improves cost effectiveness of electrified systems allowing a building to benefit from time-of-use utility rate structures and programs and to maximize the performance of its heat pump at low

TES for Packaged Units

The Technology: In 2025, the California Energy Commission (CEC) completed a three-year study of phase change thermal storage devices used in small and medium non-residential buildings to improve the efficiency and shift the demand of rooftop packaged units for cooling. Stasis Energy Group (SEG) developed a TES solution made up of two primary components: (1) bio-based non-toxic organic phase-change material (PCM) within the ducting of the HVAC system and (2) a programmable thermostat controller, incorporating flexible schedules and smart algorithms. This technology integrates a 64°F phase-change material (PCM) "cooling brick" downstream of existing rooftop HVAC units to passively store and later release cool energy. The PCM is encapsulated in aluminum plates where the PCM solidifies at 64°F (18°C), which allows the material to charge or freeze at a much higher temperature setpoint compared to water.



Source: California Energy Commission, Report CEC-500-2025-015

FIGURE 4. PHASE CHANGE MATERIAL TES SYSTEM DIAGRAM

The system's primary function is to reduce peak electricity use during hot afternoons, lowering compressor runtime and shifting cooling loads to earlier, lower-cost, or renewable-rich hours without altering the airside system or adding mechanical complexity. During normal operation, the PCM charges by freezing when the RTU is running, then discharges as it melts to provide cooling when compressors cycle off—targeted specifically at reducing afternoon peak cooling demand.

The research team identified 10 project sites that participated in the CEC's project, and Table 3 shows the details of eight sites that the research team reviewed.

TABLE 3. SUMMARY OF EIGHT SITES WITH SEG'S PCM TES SOLUTION INSTALLED[3]

Location	IOU	SQFT Per Ton	Total Units' Tonnage for Project	% Max kW Reduced	Max kW Reduced	% Annual kWh Load Shifted	Annual kWh Load Shifted	% Annual kWh Saved	Annual kWh Saved
Thousand Oaks	SCE	330	10-tons	70%	6.4	53%	981	18%	2,309
Long Beach	SCE	234	3-tons	56%	1.8	44%	515	45%	2,799
Long Beach	SCE	367	3-tons	51%	1	55%	411	58%	2,174
El Monte	SCE	500	15-tons	50%	7.1	36%	1,013	27%	3,787
Orange	SCE	484	9.3-tons	63%	6.2	59%	656	12%	1,207
Sacramento	PGE	427	7.5-tons	50%	4.6	40%	324	4%	396
San Diego	SDGE	333	6-tons	79%	4	54%	818	25%	1,854
San Diego	SDGE	294	8.5-tons	67%	3.2	67%	1,582	22%	2,146

The project reported their results in terms of benefits to ratepayers, the public, and the environment. These results include:

- An average of 13% energy efficiency savings based on improving the rooftop units' operating efficiency.
- An average reduced peak demand (in kilowatts) of 57% from baseline conditions.
- A shift in energy consumption by nearly 46% from summer peak demand to summer off-peak demand periods.
- A reduction of 5.13 CO_2 metric tons of GHG emissions across all sites.

Figure 5 shows the electrical demand over a typical day at one of the sites before and after the retrofit of the phase change system. The TES operations focused on the afternoon cooling peak and can be observed in operation at 4 pm to 8 pm, where a significant reduction in peak demand energy can be seen in the post-retrofit data. This operational behavior aligns with typical TOU peak times in California rate structures, where 4 to 8 pm is the most expensive electricity of the day for most regions.

[3] Three of the ten sites had negative energy savings due to oversized storage with too much PCM causing unnecessary overcharging, which cut down on total efficiency benefit. The CEC project report notes that these sites were likely not the best locations for a demonstration.

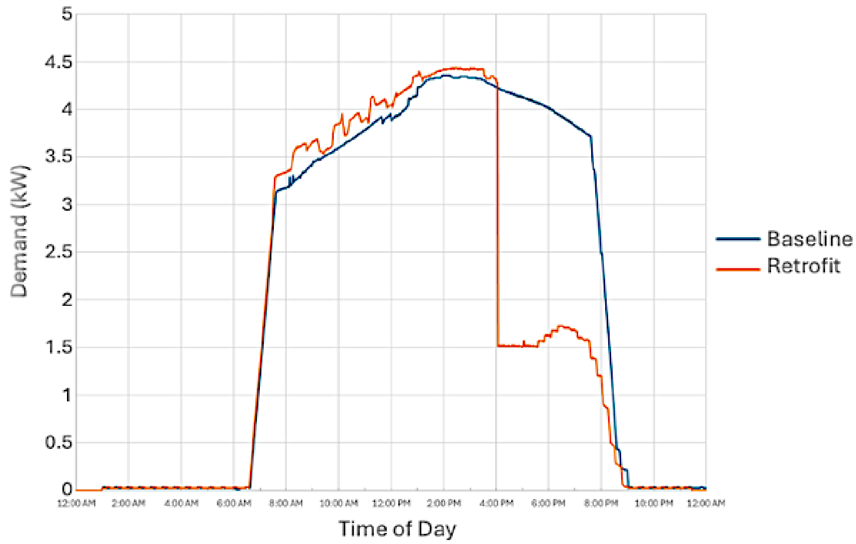


FIGURE 5. TYPICAL DAILY THERMAL ENERGY STORAGE PERFORMANCE FOR A FIELD SITE WITH PCM AIR-TO-AIR DEVICE SOURCE: CALIFORNIA ENERGY COMMISSION, REPORT CEC-500-2025-015

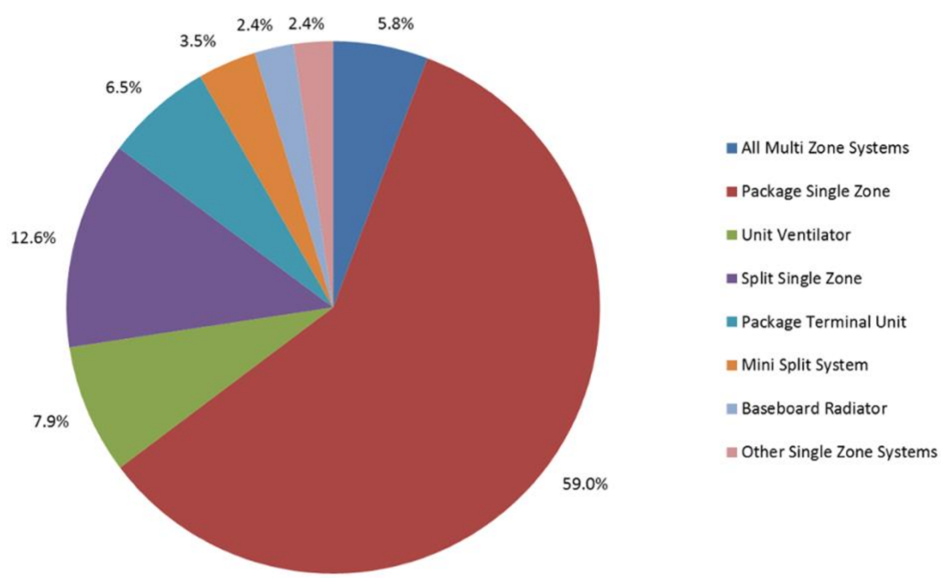


FIGURE 6. DISTRIBUTION OF HVAC SYSTEM TYPES FOR SMALL- TO MEDIUM-SIZE OFFICES IN CALIFORNIA SOURCE: CPUC COMMERCIAL SATURATION SURVEY

The Implications: Thermal storage technology that can be used in small- to medium-size packaged units would expand the TES market in California. For instance, about 70% of small to medium offices in California use packaged single-zone or split single-zone HVAC units. **Error! Reference source not found.** shows this distribution.[4] The dominance of single-zone HVAC system types suggests that TES technology compatible with them would maximize the grid potential for HVAC flexibility in California.

[4] CPUC. 2014. California Commercial Saturation Survey https://www.calmac.org/publications/california_commercial_saturation_study_report_finalv 2.pdf.

Multi-Site Study of Cooling TES

This section focuses on cooling TES, which the market characterization (above) identified as the largest portion of the TES market in California. The team obtained data from multiple sources, each providing distinct insights about TES operation in the real world.

The research team examined data provided by PG&E's Permanent Load Shift program. This data set included controls diagrams and sequence information, commissioning reports, and 1- to 2-week-long segments of hourly or sub-hourly data.[5] The research team examined the system design, control method, and performance of several participant sites, as described in the following sections.

Assessment of TES Control Methods

To conduct this investigation, the team leveraged data from PG&E's Permanent Load Shift program[6] to assess five (5) sites that successfully completed the program. From the data, three (3) sites included specifics of control sequences that could be analyzed:

- A research laboratory with ice TES and a glycol chiller.
- A large multifamily high-rise building with chilled water TES and AWHP producing CHW.
- A food processing facility with ice TES and a chiller.

Across all three sites, TES systems operated on a consistent daily schedule, set to charge in the evening and nighttime hours and discharge during the day. In addition to optimizing to charge/discharge cycles in these time windows, control systems made charging decisions based on outdoor air temperature and/ or temperature readings in the storage tank. The following subsections describe the systems and TES controls for each of these three sites.

Research Laboratory with Ice TES

System Description

The research laboratory used 16 CALMAC TES ice tank systems, charged from two water-cooled chillers through a heat exchanger, to serve the laboratory building. Each tank holds 4,965 gallons of fluid. The tanks are rated for approximately 392.7 tons of cooling at a rated 10°F temperature difference. The storage system holds approximately 6,000 ton-hours of cooling, 72 MMBtu of stored thermal energy. The Figure 7 schematic describes the site layout, and Figure 8 depicts the scale of the site's TES tanks relative to other HVAC equipment.

[5] The assessment provided here is based on the research team's review of engineering documentation that was provided by program applicants. While there were similarities in operation, the engineering language that applicants used to define that operation differed.

[6] The data set from the PG&E Permanent Load Shift program included at minimum 2 weeks of timeseries energy and load data for the storage systems, commissioning reports, sequence of operations and design drawings.

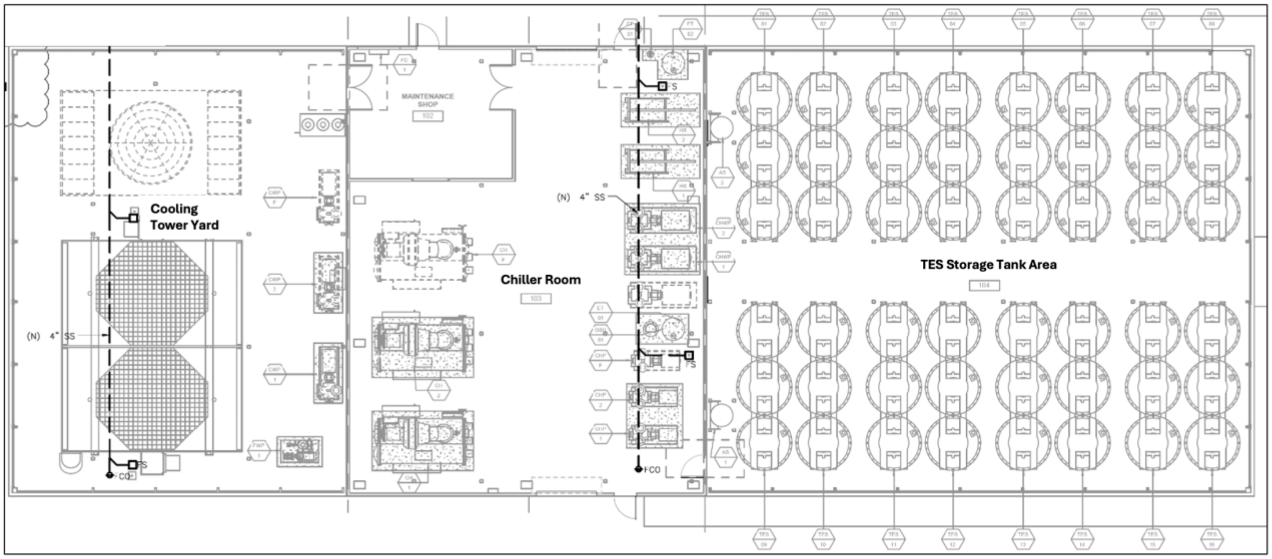


FIGURE 7. THERMAL ICE STORAGE IN SMALL OUTDOOR TANKS FOR A LABORATORY RESEARCH BUILDING

FIGURE 8. CALMAC THERMAL STORAGE TANKS ALONGSIDE AIR HANDLER SOURCE: TRANE, THERMAL BATTERY ICE-ENHANCED AIR-COOLED CHILLER PLANT

TES Control Method

For this site, ice freezes (charges) each evening from 11 pm to 7 am. From noon to 6 pm, the ice melts (discharges) into the chilled water loop. Ice can continue to melt until 11 pm if the tanks are not depleted.

TABLE 4. CONTROL SEQUENCE OF TES ICE STORAGE AT ESEARCH LABORATORY BY TIME OF DAY

Time	Chiller Operation	Thermal Ice Tank Operation
11 pm to 7 am	Ice mode: glycol chiller supply temp, 28°F	Charging
7 am to 12 pm	Normal operation: glycol chiller supply temp 41°F	Idle
12 pm to 6 pm	Off	Discharging
6 pm to 11 pm	Off *(or On*)*	Discharging *(or Idle*)*

**N.B.: Thermal ice storage will operate between 6 pm and 11 pm or until the storage tanks are depleted. The chillers, cooling towers and condenser will be activated once the tanks are depleted.*

Multifamily High-Rise Building with CHW TES

System Description

The multifamily building is a 271,594-sqft. twenty-three (23) story residential high-rise including 206 apartment units and three levels of above-grade parking. The design utilizes a 60,000-gallon underground firewater storage tank to store 42°F CHW. Two (2) rooftop air-source heat pumps (ASHPs) supply hot and chilled water to two-pipe fan coils in the residential units via change-over valves located at each unit. The AWHP plant serves two thermal zones – the North and South sides of the building – to provide either cooling or heating to each side. A dedicated outdoor air unit is served by the AWHPs and provides ventilation to the units and corridors.

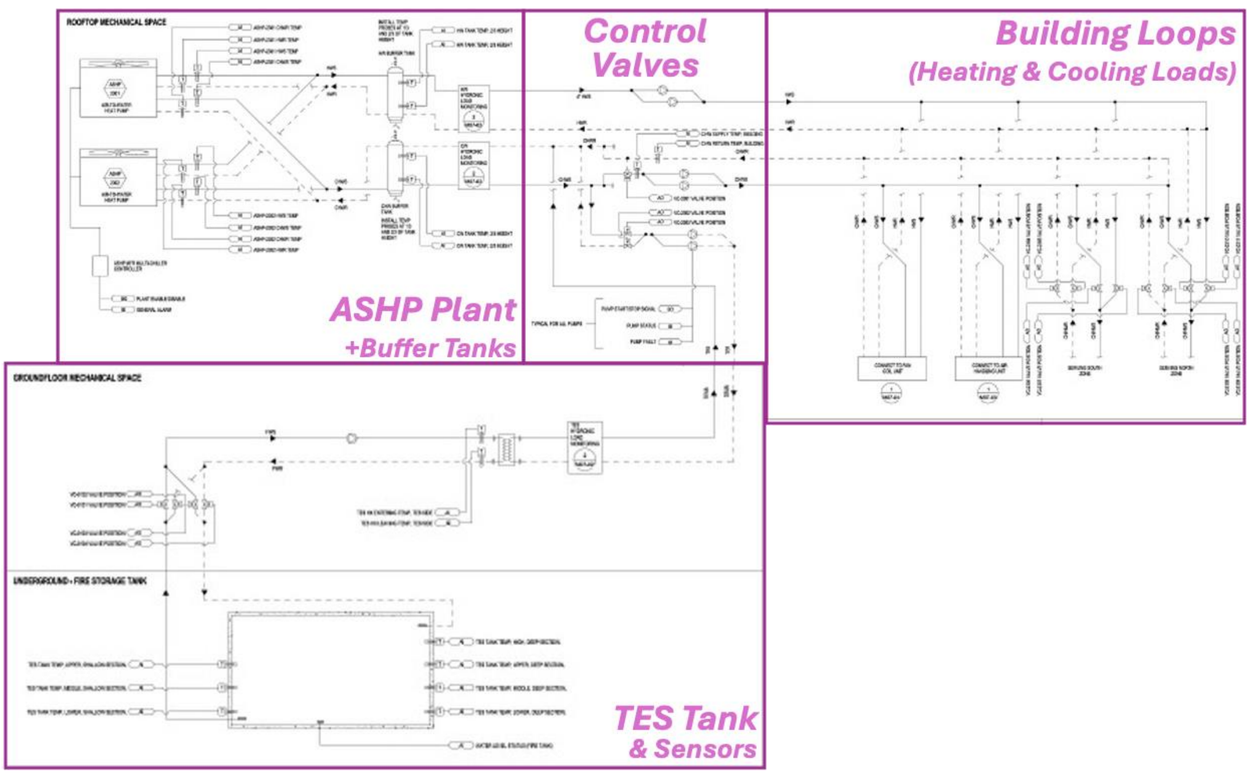
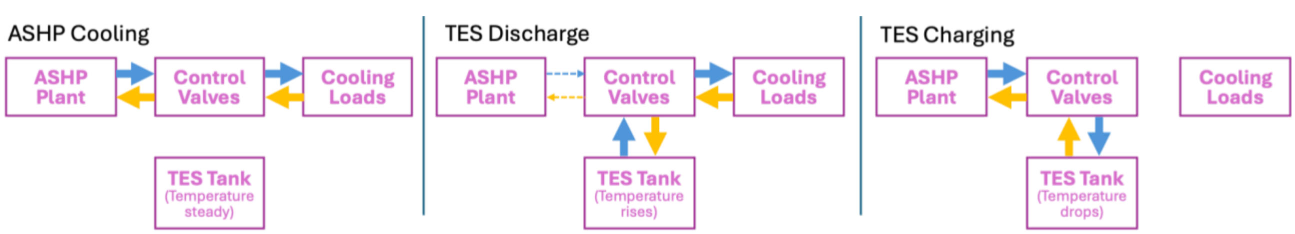


FIGURE 9. PLANS OF THE MULTIFAMILY BUILDING'S TES AND HVAC SYSTEM



These schematics show ASHP and TES system functions to meet building cooling loads.
Building heating loads are met by a separate (not depicted) ASHP loop.

FIGURE 10. SCHEMATIC OF THE MULTIFAMILY BUILDING'S TES AND HVAC COOLING OPERATIONS

TES Control Method

The logic for determining charge and discharge times for the CHW tank is based on the building automation system (BAS) timeclock, as well as predicted weather based on forecasts from the day before. Table 5 includes a description of the control sequences with the criteria used to charge and discharge the TES. **Error! Reference source not found.** shows a simplified graphic of the system with an overlay of the control sequences described above.

TABLE 5. CONTROL SEQUENCE BY TIME OF DAY AND PRIOR DAY CONDITIONS FOR HIGH-RISE RESIDENTIAL CHW TES

Time Period	Sequence of Operation
12 am to 8 am: Automatic Charging mode	TES tanks will charge the tank in this timeframe if the next day's predicted peak dry bulb outside air temperature is greater than 65°F. During TES charging mode, the chilled water supply temperature setpoint for the ASHP loop holds at 55°F
8 am to 12pm: ASHP Cooling Mode	With the TES neither charging or discharging, the ASHP loop supplies chilled water to the building based on a trim and respond logic that fluctuates between 55°F and 60°F
12 pm to 6 pm: Automatic Discharge mode	If the TES has been charged in the 12 am to 8am window, it will discharge in this timeframe. BMS commands the ASHP off while TES is discharging, assuming that the TES is meeting the building's supply water temperature. If the supply temperature is not being met, ASHP will turn on and mix its chilled water with TES to meet setpoint. The discharge occurs until the tank's top-most temperature sensors indicate a water temperature 2°F higher than the required supply water setpoint of 55°F.
6 pm to 12am: ASHP Cooling Mode and Weather Data Collection	With the TES neither charging or discharging, the ASHP loop supplies chilled water to the building based on a trim and respond logic that fluctuates between 55°F and 60°F At 8pm each day, the building management system (BMS) also downloads the weather forecast data from the internet. It gathers from multiple internet resources and averages the dry bulb highs and lows and dewpoint high and lows for the next three days.

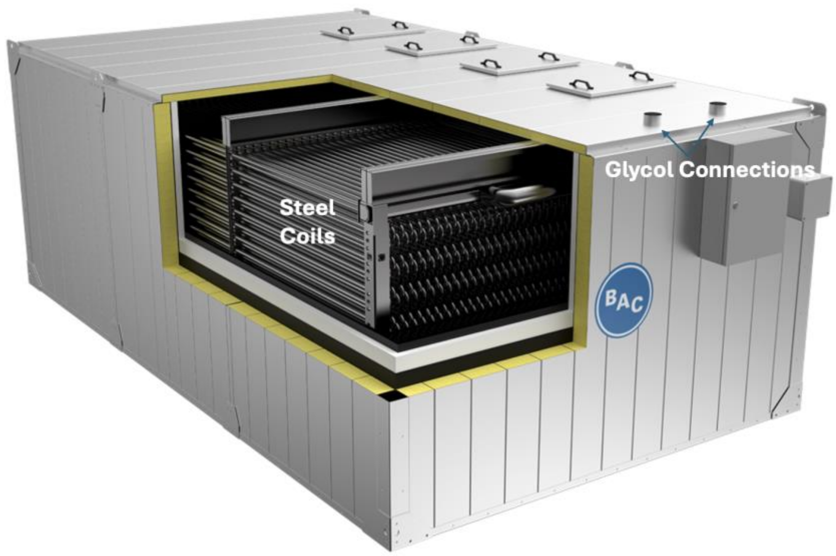
Key Takeaway: Integration of External Data

The multifamily site described above is an example of a control sequence that takes in external data on a more granular basis (references to external signal are bolded in the content above). Although not a utility rate or demand response signal, it is an external communication that optimizes the TES based on calculated demand peaks. The next day temperature forecast acts as an external supervisory signal available to the control logic, enabling anticipatory rather than purely reactive operation. This was the only site the research team assessed that incorporated an external signal into its control logic. Other sites used sequences of operations that run similarly throughout the year, optimized to a TOU rate that changes seasonally. This observation was notable to the research team because much of the financial value assessed to date for TES comes from integration with real-time or near real-time cost signals from a utility.

Food Processing Facility with Ice TES

System Description

The food processing facility used a Baltimore Air Coil ice storage system, as in Figure 11. This storage system was engineered to deliver 90 tons of cooling at peak (with 761 ton-hours of storage capacity from the TES) and 160 tons of chiller capacity for a total of 250 tons.



Source: Baltimore Air Coil

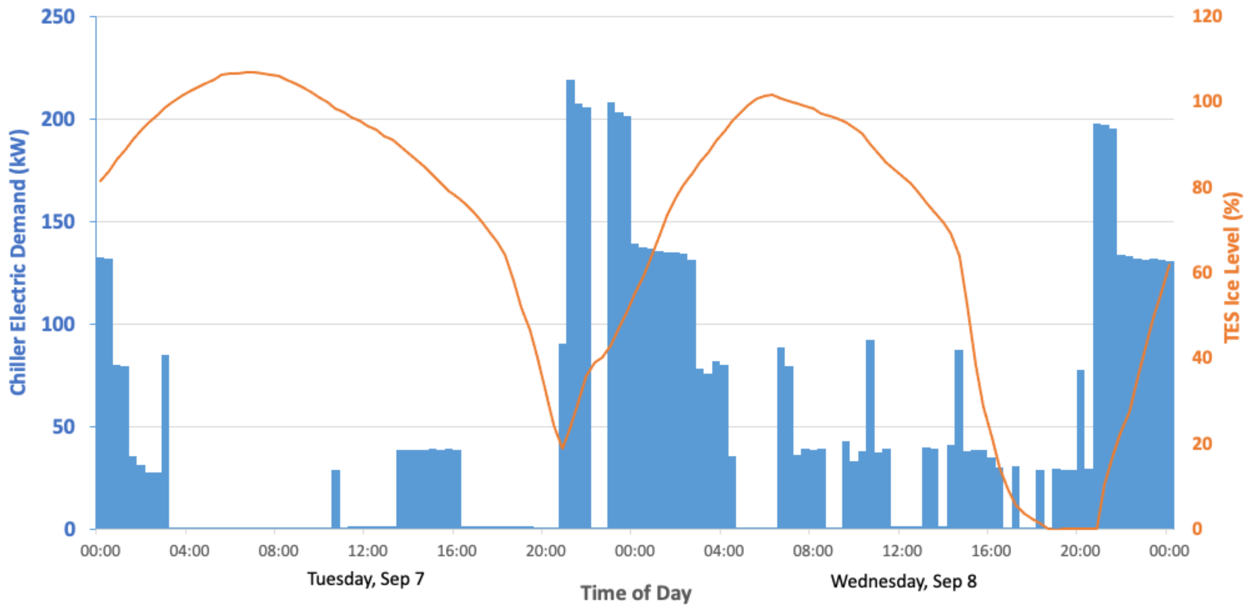
FIGURE 11. BAC TSU-M ICE CHILLER® ICE STORAGE SYSTEM.

TES Control Methods

The ice storage charges in the evening from 8 pm to 5 am and discharges throughout the day, from 5 am to 8 pm. On most days, the system completed this charge within a few hours (i.e., tank charging began at 8 pm and was complete by around 11 pm). The control sequence by time of day and an example of operations is shown in Table 6.

TABLE 6. CONTROL SEQUENCE FOR FOOD PROCESSING BUILDING TES

Time of Day and Typical Mode	Sequence of Operation
5 am to 8 pm TES Discharge	Ice is used as the primary cooling source with backup chillers for additional load.
8 pm to 5 am TES Charging, until full	Ice is charged from the chiller starting at 8 pm until the ice tank is fully charged. The chiller enters a standby mode once storage is charged.



Source: kW Engineering, Site Commissioning Report

FIGURE 12. TWO-DAY PERIOD OF ICE CHARGING AND DISCHARGING AT FOOD PROCESSING FACILITY TES

Figure 12 illustrates two days of the daily operating cycle of the food processing facility's TES system. Blue bars show the chiller electric demand over time, and an orange line shows the rising and falling charge level of the TES ice storage. Ice charging periods (8 pm to 5 am) show more electric demand as electricity is consumed to produce ice for the storage tank. The storage typically charges in less than 4 hours (shorter than the 9-hour period in which charging is allowed). As a result, the TES is in standby mode for a few hours every morning prior to initiating its discharging cycle at 5 am. The system consistently discharges in the expected time window (between 5 am and 8 pm), when chiller power is reduced (often to zero) since the system relies on stored cooling instead of running the chillers.

Assessment of TES Energy Use

This section describes other data sets that the research team received directly from sites with TES.[7] These sites had systems that have been in operation for multiple years with monitoring and controls that track the operation of the TES at intervals up to 15 minutes. The research team analyzed energy and load data from two sites:

- **Site A: Chilled Water Storage at a College Campus –** *A large water-cooled central plant with a chilled water storage tank as an integral part of the system operations. The site provided 12 months of detailed thermal load data for the campus, tank, and chillers, and electrical power of the chilled water plant.*
- **Site B: Large Hotel with Phase Change Ice Storage –** *A hotel with a water-cooled central plant using an ICE storage system with a small, dedicated, air-cooled chiller for peak reduction. The site provided information on the size of the system and the use of the ice storage for peak reduction and charging and discharging by a separate chiller.*

[7] The team gathered 6-12 months of field data for four sites but only conducted analysis for two sites. The two sites that were not analyzed had similar function to the analyzed sites but had less complete data.

The research team evaluated the operational energy of the sites to determine: (1) the decrease in thermal load on the chiller during TES discharging, (2) the increase in thermal load on the chiller during TES charging, (3) the electric energy reduction achieved during TES discharging and (4) the electric energy increase required during TES charging.

Insights from the analysis help to inform the Discussion section that follows these site descriptions. In that section, the research team anticipates how energy code compliance could designate thermal load shift capabilities and thermal load reduction capabilities, as well as how owners and operators should consider the value.

Site A: College Campus with CHW Storage

In 2011, this college campus installed a 1.6-million-gallon TES tank designed to store 40°F chilled water. The TES tank operates throughout the year and can store 19,000 ton-hours of cooling load. In 2012, the site's facilities manager used their electric rate structure (Figure 13) to develop a schedule for charging and discharging of the TES. The site has used the same schedule since 2012. Although the rates ($/kW) have changed over time, the relative relationships between max-peak, part-peak, and off-peak has remained steady enough that the schedule continues to serve the facility manager's goal of reducing operating costs.

The tank is approximately 70 feet tall and has a temperature sensor every two feet along its height. The mode of operation is determined based on the time of day and whether the temperature setpoint at each depth is being met. Figure 14 shows the rate periods and the temperature points at different tank depths that are evaluated to inform the system's decisions to recharge (Regen) or discharge (Deplete) the tank. The operations team may adjust times and setpoints to avoid the highest electrical energy cost rates and peak demand charges.

SEASON	TIME-OF-USE PERIOD	DEMAND CHARGES ($/KW)	ENERGY CHARGES ($/KWH)
SUMMER	Max-Peak	$16.74	$0.10132
	Part-Peak	$3.63	$0.08210
	Off-Peak	-	$0.06600
	Maximum	$6.08	-
WINTER	Part-Peak	-	$0.08354
	Off-Peak	-	$0.07020
	Maximum	$6.08	-

Summer Season (May – October)
Peak Hours: 12:00 noon to 6:00 pm, Monday–Friday (except holidays)
Partial-Peak Hours: 8:30 am to 12:00 noon AND 6:00 pm to 9:30 pm, Monday–Friday (except holidays)
Off-Peak Hours: 9:30 pm to 8:30 am, Monday–Friday (except holidays), All Day Saturdays, Sundays, and holidays
Winter Season (November – April)
Partial Peak Hours: 8:30 am to 9:30 pm, Monday–Friday (except holidays)
Off-Peak Hours: 9:30 pm to 8:30 am, Monday–Friday (except holidays), all day Saturday, Sunday, and holiday

Figure 13. Utility Rate Structure for Site A (PG&E rate E-20 from 2012, when Site A was Designed)

RATE PERIOD	TIME	SETPOINT
OFF-PEAK	9:30 pm – 8:30 am	Regen starts if 56-ft tank sensor is greater than 45°F
		Regen stops if 66-ft tank sensor is less than 45°F
PART-PEAK 1	8:30 am – 12:00 pm	Start chillers if 40-ft tank sensor is greater than 45°F
		OR Deplete tank if 60-ft tank sensor is less than 45°F
PEAK	12:00 pm – 6:00 pm	Deplete tank if available % is greater than 0%
		Start chillers if 2-ft tank sensor is greater than 42°F
PART-PEAK 2	6:00 pm – 9:30 pm	Deplete tank if available % is greater than 30%
		Start chillers if available % is less than 30%

Figure 14. Site A Charge (Regen) and Discharge (Deplete) Logic for the TES Tanks

Site Chilled Water Consumption

The college campus Site A uses chilled water for cooling and experiences cooling loads in all four seasons. To assess the value of TES across different load profiles, the research team determined first the average load patterns across the month then the average across each season, according to the site's California climate zone. The research team used these average seasonal profiles to understand typical operation. The average peak load is about 1,300 tons for summer months and 600 tons for winter months. Figure 15, below, shows an overlay of "typical" daily load profiles for each season. The research team identified "typical" days by examining all days in a month and selecting a one-day profile with a representative load shape for the month. The team then gathered the monthly load curves by season and chose the most extreme for the thermal load graph provided below.[8] The base cooling load (between midnight and 8 am) ranges throughout the year between 100 and 300 tons of cooling. Figure 15 shows that this building has year-round cooling load, which may not be true for other buildings or other climate zones.

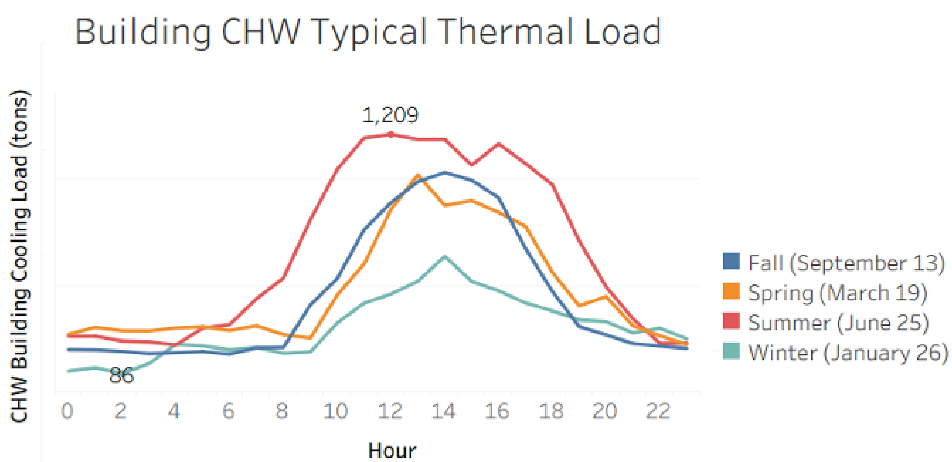


FIGURE 15. SITE A TYPICAL DAILY THERMAL LOAD, BY SEASON

Site Thermal Load Shift

The research team analyzed thermal load and TES load shift for a typical summer day when the site was fully occupied. Figure 16 illustrates how the TES shifts thermal loads in time. The left chart shows thermal storage shift, with charging (orange) in the morning and discharging (green) in the afternoon. The right chart compares the building chilled water load (light blue) to the chiller plant load (dark blue).

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[8] The team chose not to average data for all days in a month since an average daily load shape does not represent the true behavior of the plant or building.

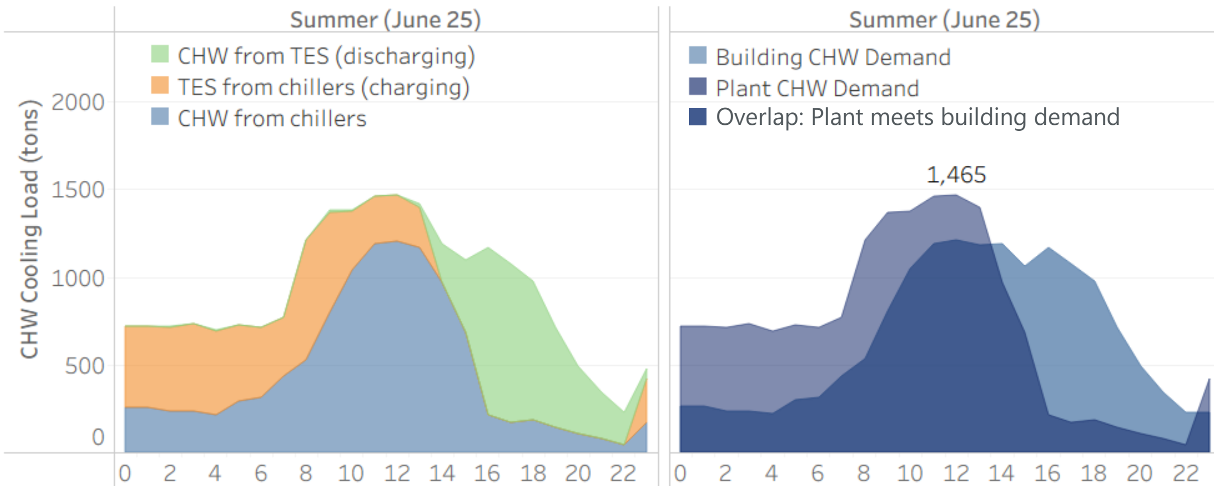

FIGURE 16. SITE A CHW THERMAL STORAGE CHARGING AND DISCHARGING ON A TYPICAL JUNE DAY

Electrical Power Shift

The research team estimated the reduction in peak period electric demand due to TES load shifting. To do this, the team estimated the electrical power that would be required for the central plant to meet the thermal load described above. The team calculated an average operational central plant efficiency for the site (in kW/ton) to determine a reference for what the plant would have consumed without TES.[9] The team compared this reference case with the actual plant electric demand and consumption to estimate the benefit achieved.

Figure 17 compares the actual electric demand of the central plant (left) with the estimated electric demand for a plant without TES (right). The figure on the right then shows the difference between these two, with negative energy use indicating an increase in electric consumption and a positive value indicating a decrease in electric consumption. Figure 17 shows that the peak demand of the chiller plant is amount 240 kW higher in a system with TES (953 kW) than the peak system demand without TES (713 kW). However, the benefit of the TES system is that the chiller plant demand is reduced to 0 kW during the electric grid peak period (4 pm to 10 pm).

[9] While the chillers are only a portion of the entire plant, this trend point was the only power data provided for the analysis and represents the greatest amount of energy which would be shifted.

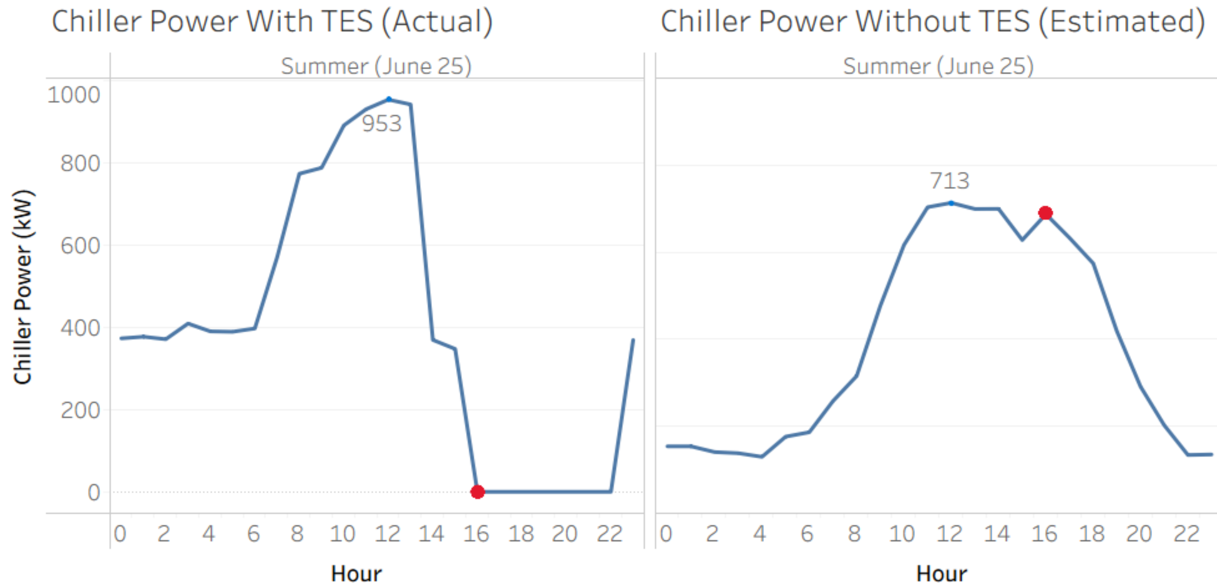

FIGURE 17. SITE A: ELECTRIC DEMAND PROFILE FOR TYPICAL JUNE DAY FOR CHILLER PLANT WITH TES (ACTUAL) AND CHILLER PLANT WITHOUT TES (ESTIMATED).

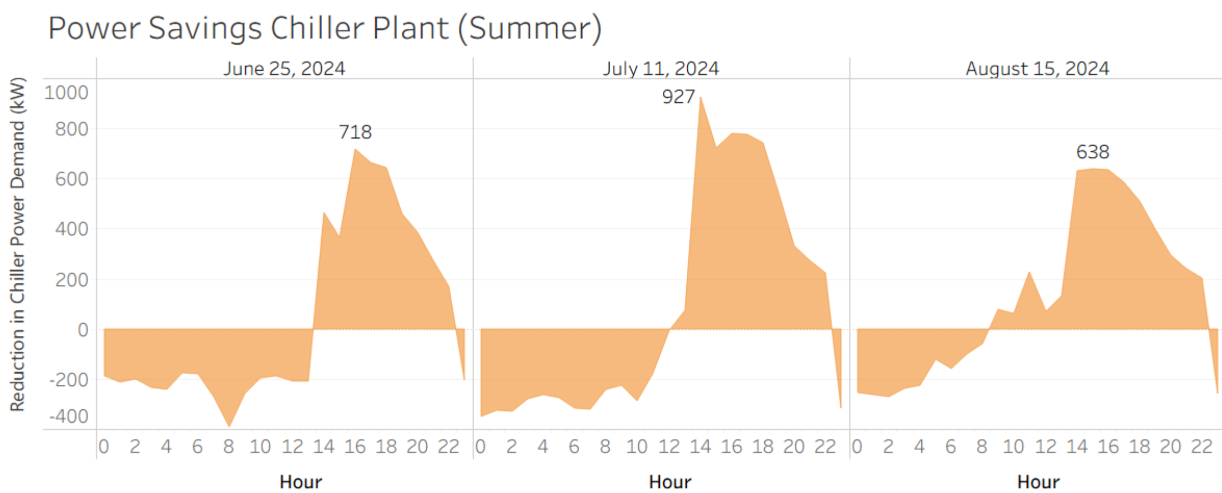

FIGURE 18. SITE A: CENTRAL PLANT ELECTRICAL POWER REDUCTION ON TYPICAL DAYS IN JUNE, JULY, AND AUGUST

This same load shifting pattern is evident in typical days for June, July and August, as shown in Figure 18. The figure shows that an average 200-300 kW increase in morning demand enables a demand reduction benefit of reducing afternoon peaks throughout the summer months between 600-900 kW.

Site B: Large Hotel Peak Thermal CHW Storage

Site Description

Site B is a large hotel in southern California with TES using ice. The installation was a retrofit, with the TES system added after the other HVAC equipment in the facility was constructed. The TES system was specifically designed to avoid peak demand and provide more thermal flexibility to the facility. Unlike Site A's large CHW tank, Site B provides a much smaller overall shift in thermal load and includes an air-cooled chiller dedicated to ice generation and an ice storage tank. With this configuration, the site provides a small, yet impactful peak thermal reduction during afternoon periods.

Unlike Site A, the TES equipment at Site B is owned and operated by an entity other than the building owner. This illustrates how third parties can provide TES as a service, simplifying the operational complexity for a building owner. Site B uses dedicated TES equipment that generates ice instead of chilled water, and Site B's system covers a smaller physical footprint than Site A. Because the Site B implementation uses a less efficient ice chiller, it comes with an overall energy consumption penalty (i.e., the system will consume more energy with TES than without TES).

Site Thermal Cooling Load and TES Shift

Site B uses chilled water for cooling, with TES to support that function during months with high cooling needs. Figure 19 compares thermal load profiles for typical days in May, June, August, and October. The research team used the same method discussed for Site A to develop "typical day" profiles. Peak load hovers around 900 tons in late summer, but averages about 575 tons in spring. The base cooling load throughout the year varies from 300-470 tons of cooling between midnight and 8 am.

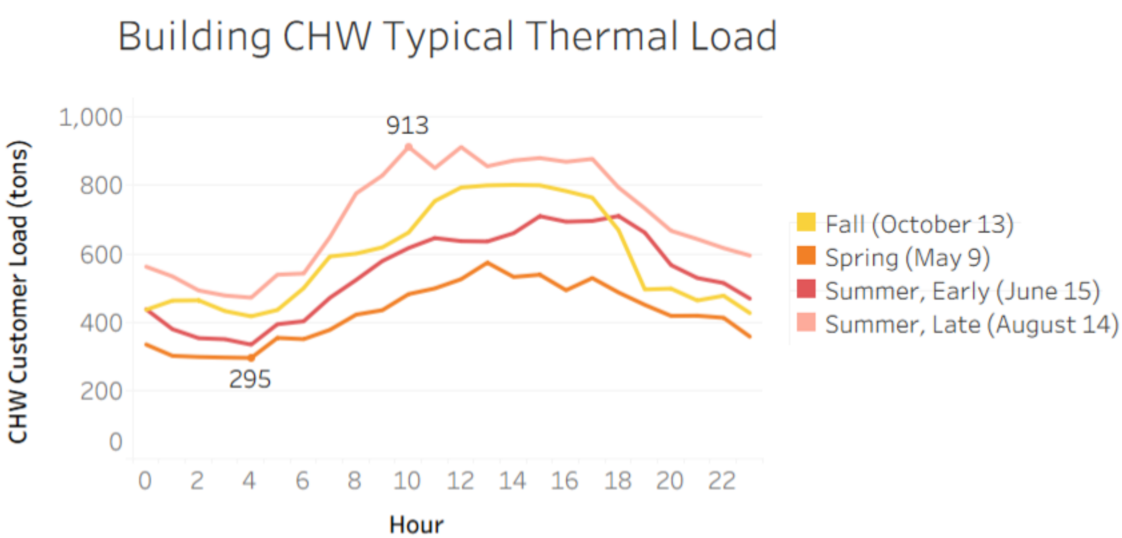

FIGURE 19. SITE B TYPICAL DAILY THERMAL LOAD (MAY, JUNE, AUGUST, OCTOBER)

Based on the assessment of typical system operation and performance, the research team selected August 14th to analyze and represent typical TES operation. **Error! Reference source not found.** shows the distinguishes the load by what is providing it, i.e. TES or chiller. On the right, the loads are simplified into building versus plant. Building demand describing what the load was met based on actual cooling needs in the building and plant demand describing what the systems actually generated over the day. From the figure, TES shifts a smaller load than the previous site, reducing thermal load in the afternoon by roughly 20 percent of the CHW thermal load of the building. The system then re-charged the TES following the event, from 9 pm to 9 am. when the thermal demand for CHW was the lowest.

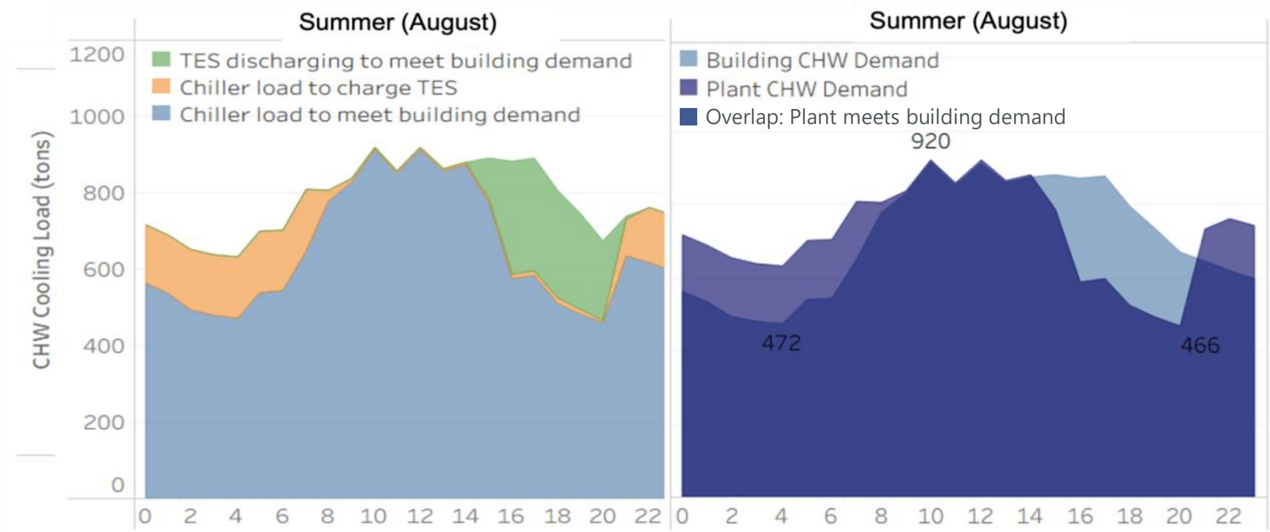

FIGURE 20. SITE B ICE THERMAL STORAGE CHARGING AND DISCHARGING ON A TYPICAL AUGUST DAY

Site CHW and TES Electric Power Shift

Figure 21 shows operational electric energy data for August 14th, summed for the plant chiller and the TES chiller. The building chiller, described in Figure 21 as chiller system without TES, operated on average at 200 to 400 kW, peaking at 414 kW at 10:00 in the morning. With the TES and the TES's associated chiller added to the equation, energy demand of the chilled water system increases 125 kW to support charging of the TES. While the thermal load on the chiller reduced by 20 percent, the electric power demand in the afternoon increased from 200 kW to 325 kW, or about a 63 percent increase compared to what the building would use at this time.

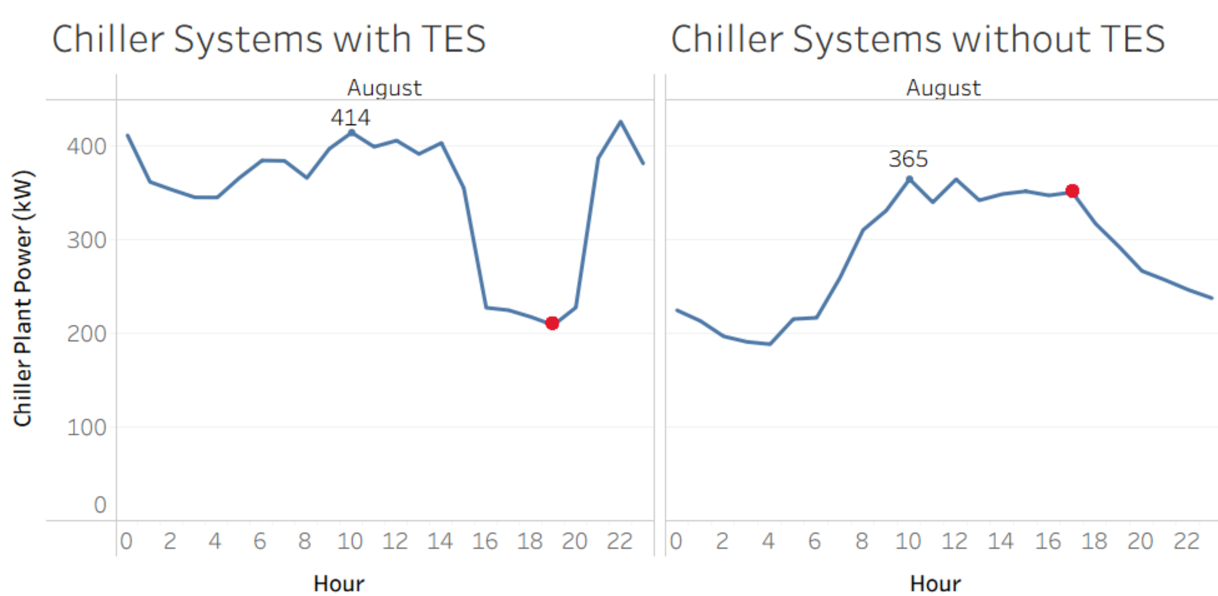

FIGURE 21. TOTAL ELECTRICAL POWER FOR CHILLER PLANT AND TES ICE CHILLER, WITH AND WITHOUT TES ACTIVE

To understand the potential benefit and avoided peak demand, the team analyzed the average operational efficiency of the CHW plant and estimated what the building peak demand would have been during afternoon peaks if it met building loads with the main chiller and no TES. The CHW plant, being a water-cooled modern CHW plant system, operates on average at 0.40 kW/ton or a COP of 8.8, reflecting a well-run efficient system. The ice chiller, however, ran on average at 1.0 kW/ton (COP of 2.5), requiring more energy per ton to freeze ice using a glycol solution and being an air-cooled device. From these plant efficiencies the team was then able to calculate the power savings for each hour that the TES was discharged.

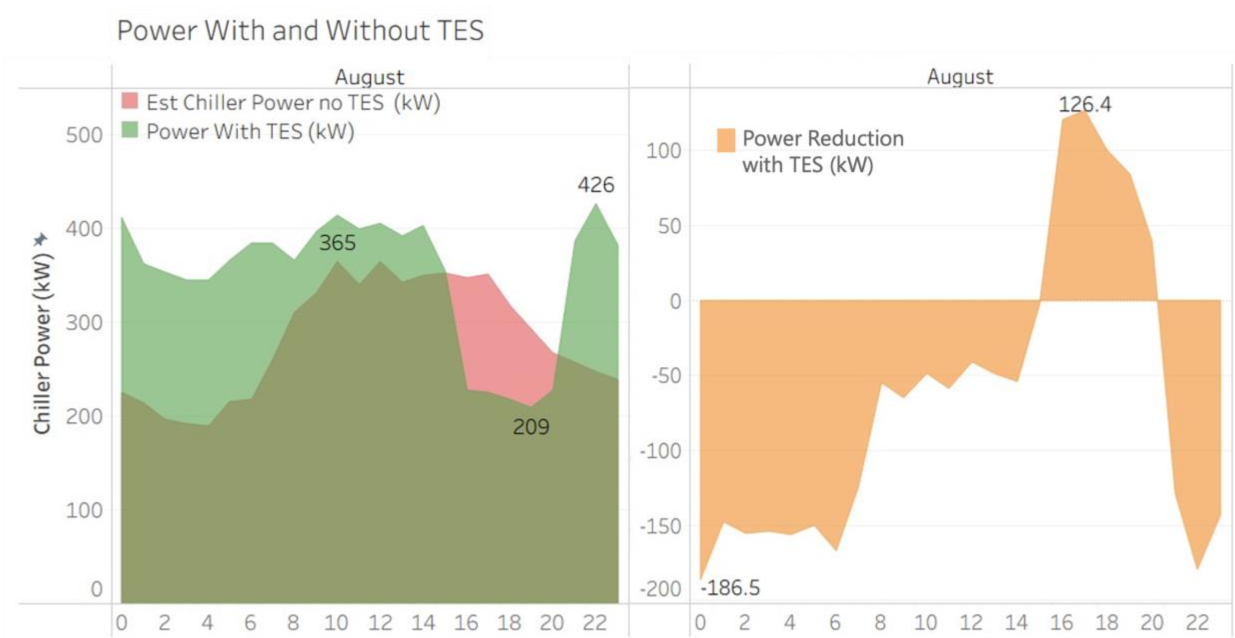

FIGURE 22. ELECTRICAL POWER USE OF CHILLER PLANT AND ICE CHILLER WITH AND WITHOUT TES

CHW Plant and TES Plant Operating Efficiency

The left side of Figure 21 (chiller with TES) shows a 50% drop in kW from the 2pm ("14" on the figure) hour to the 3pm hour, preparing the site for grid peak demand time periods. The site remains at this demand level until the end of the peak demand period, or 8pm. This trend of demand reduction was common at this site. Figure 22 shows an overlay of the demand on the left and a comparison of each hour of power demand compared to a system without TES. The peakiest hour of the pink area graph on the left (17:00) was reduced by 126.4 kW.
The ice chiller used to charge the TES proved to be lower efficiency and thus the highest kW reduction of 126.4 kW at 3pm was offset by 186.5 kW increase in electric demand in the morning (seen in figure 22).
This configuration used a physically smaller equipment, compared to a chilled water TES system with the same storage capacity. The compact footprint of ice storage systems is an advantage over chilled water storage, especially for buildings with limited space. The tradeoff for this design advantage is a higher electric demand in off-peak hours (because chillers for ice storage have lower efficiency compared to chilled water storage).

Discussion

From the outreach and site identification, the team observed that when TES is used for space conditioning, the most common application is space cooling in buildings. New sites are on the horizon for other applications such as space heating. The team expects that these sites will have a full year of operational data by 2027. Today, only chilled water storage sites have a full year of data to analyze, so the team prioritized analysis of TES systems used in chilled water applications in this phase of the study. The analysis framework presented above includes thermal load assessment, charging and discharging analysis, thermal reduction observations, and electric demand reductions in the context of utility cost. This framework could be replicated to assess the value of other forms of storage in the future.

Code Ready Solutions

While other types of systems are slowly making their way into the market, with many showing promising applications in design today. As of 1/1/2026, the team classifies TES applications as follows:

- Ready for prescriptive code:
    - Chilled water: Many sites in California have installed and are operating these systems in large buildings and district systems.
- Not ready for prescriptive code:
    - Packaged systems: These systems are in the early adoption phase and there are few manufacturers of them. Packaged TES systems would benefit from market transformation support.
    - Hydronic heating: These systems are in the early adoption phase with few designers. They would benefit from design assistance and clear compliance options.

Consistency of Operation

TES has a history of being used as a way for buildings to respond to demand response events called by the utility operator. Historically, these were infrequent events, thus it could be assumed that TES was used infrequently. The data analysis and controls assessment conducted for this project suggest that TOU rates in California have improved the cost-effectiveness of frequent TES operation. The controls sequences and energy data reviewed for this project, suggest that daily TES operation (depending on cooling load) is more common. The data displays consistent use of the storage in multiple seasons and load scenarios. In general, the behavior when aligned with utility rates suggests a reduction in cost is possible with differing TES configurations and in utility regions across California.

Notes on Control Methods

Review of TES design documents shows that designers specify TES to operate based on fixed time periods that are not intended to flex with ongoing operations or control signals from external sources. Most commonly, the systems are set to charge in the evening and nighttime hours and discharge during the day, correlating to TOU rate schedules. Energy data from operational TES supported this finding. Review of data over the course of a year for two sites showed consistent operation of TES. Although the research team did not calculate energy or cost savings for this study, this consistent operation suggests cost-effectiveness similarly based on sites TOU rate schedules. This common operational procedure indicates that most control methods are optimized to a site's TOU rate schedule.

TOU rate schedules across California are modified in rate cases that occur on multi-year cycles (generally, every three to four years). With the rapid growth of renewable electric generation in California, these rate cases do not always keep up with the current state of the electric grid. Many analyses and studies on grid flexibility assume demand side management will occur at the rate of grid decarbonization. This study found that, although TES systems could be designed to respond to frequent signals, many TES systems are not. This study observed that many recently installed TES systems are programmed based on slowly changing TOU rates, and systems are often not re-programmed when rates are updated. Only one system observed in this study took any daily external signals into account. None of the systems surveyed for this study used more granular real-time pricing or carbon data. For TES to contribute to grid flexibility, systems should have more functionality to respond to highly granular real-time data.

Limitations and Adaptations Required

Not all TES cooling applications are created equal. Some building types will require some cooling load year-round, which would mean an optimization of design capacity may differ from that of an HVAC system with little or no cooling load during heating season. Site A in the energy analysis shows a campus that has cooling load all year long, thus maximizing the tank capacity and flexing load every single day to the max functionality of this system makes sense. Also, systems with extra capacity can shift their peak from one hour to another. Optimization in systems without extra capacity might look different. Instead of shifting peak demand from one hour to another (cheaper) hour, these systems might distribute that shifted load over a longer time period, such that it does not set a new peak.

Conclusions & Recommendations

Conclusions

This study was conducted to compile and analyze real-world data on field applications of TES. The research provides evidence of TES installations that demonstrate consistent TES function and demand savings from load shifting and shedding. The results offer actionable insights for energy codes, standards, and programmatic initiatives, and provide a foundation for future research and development in this area.

Several sites in California use TES for cooling loads. This research project identified 39 sites with 19 of those sites being on campus contexts that used CHW with tanks ranging from 890,000 gallons to 6.9 million gallons.
Many sites used a large tank to store chilled water produced by the same chiller that services site loads.
Fewer sites, 6 out of the 39 surveyed sites, had ice storage, which uses ice and phase change slurry of material. These sites often used a separate chiller to produce colder temperatures (ice) than the building load and shifted load in a different way than those that stored chilled water. These sites typically shifted grid demand from late afternoon to a different time period, depending on the chiller performance and rate structures.
Field data in combination with data from acceptance testing and commissioning for large capacity chilled water suggests that BAS control strategies are automated, repetitive and that different sites use similar strategies designed around TOU periods. These strategies provide consistent patterns of operation on a day-to-day basis. Only one of the investigated sites included external signals in its control strategy.
Not all designs for chilled water storage are compatible with all sites. The research team identified a few discrepancies:
Some systems are designed such that separate chillers serve the TES system and regular building loads. In some cases, the chiller (or other mechanical system depending on the application) that charges the TES system is less efficient than the chiller that meets regular building loads. In these cases, buildings benefit from shifting their largest coincident peak demand to a non-grid-peak period (e.g., from the afternoon to the morning, for instance). However, using TES to shift load to less efficient systems is not an option for buildings that have electrical or cooling capacity limitations.
Chilled water tank storage works well for some applications. Ice storage and condenser water storage works well in others. A code requirement for cooling TES would give designers more options if it allowed flexibility in the storage media and mechanism.
There are fewer hot water storage systems in CA, but many high-performance design engineers are incorporating heating storage concepts into all-electric designs, because of the value they see in reducing potential winter morning peak demand. Previous Code Readiness research[10] has confirmed that 2025 long term system costs (LSC) peak significantly in winter mornings, creating value for heating thermal storage in compliance software.

- Novel designs for thermal storage systems are suggesting an opportunity to pair both heating and cooling storage in small capacities to tailor to very specific heating and cooling needs. Small capacity storage could alleviate exceptional design heating demands that are rarely realized in a building's real-world operation. Also, when paired with all-electric heat pump designs, even smaller capacity heating storage

[10] Gantley, Maya, Bulger, Neil, 2025. *Energy Modeling Analysis: Peak Thermal Load Management Strategies* https://www.etcc-ca.com/reports/energy-modeling-analysis-peak-thermal-load-management-strategies.

could support a reduction in what is projected to be high system costs on the grid on winter mornings in the future. Small capacity cooling storage could alleviate existing high peak demand charges in commercial buildings.

- Few packaged, plug-and-play options exist for TES, but those that exist have proven valuable for providing demand flexibility. To increase TES market saturation, the research team suggests more incentives and Emerging Technology (ET) projects be directed at this niche of the market.

Recommendations

Based on the findings from this data collection and analysis, the research team recommends the following actions:

1) Develop a chilled water TES metric to orient Title 24 language, prioritizing simplicity and actionable grid benefit.
2) Develop a prescriptive code requirement and a compliance option, with supportive guide, for chilled water TES in large non-residential buildings where hydronic HVAC is the standard HVAC system.
3) Add Title 24 permit submission requirements that include the type of thermal application (e.g., cooling, heating, or ambient condenser water), and details on equipment peak capacity and storage capacity, including any use of supplemental or backup devices for tank temperature maintenance such as electrical resistance. These details are essential to categorizing TES and gathering application data will help to document market trends and support additional regulation in the future.
4) Expand existing Title 24 acceptance tests for space conditioning TES of chilled water to include TES for hot water. Include additional requirements to document tank insulation, storage temperature, and any additional heating element utilized for hot water.
5) Conduct a study to evaluate the potential space savings and space requirements of using heating hot water thermal storage with heat pumps in existing building renovations to replace existing boilers versus a heat pump only solution.
6) Conduct a technology cost-estimation study of small TES chilled water and hot water systems to determine a range of incremental costs for non-residential buildings with hydronic HVAC.
7) Continue to encourage market adoption of packaged TES - either heating or cooling, with particular emphasis on heating storage- when paired with an all-electric heat pumps system through equipment standards, efficiency metrics, and testing.

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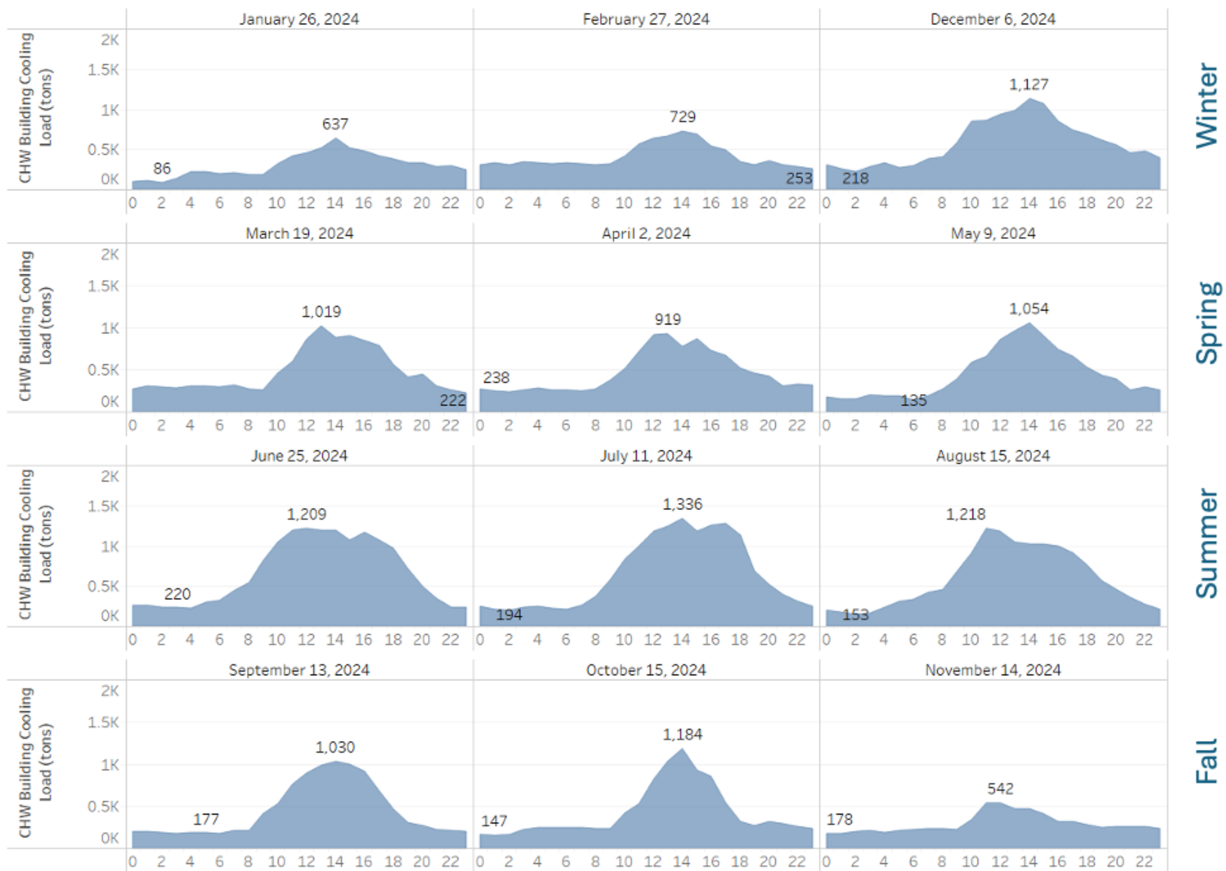
Appendices

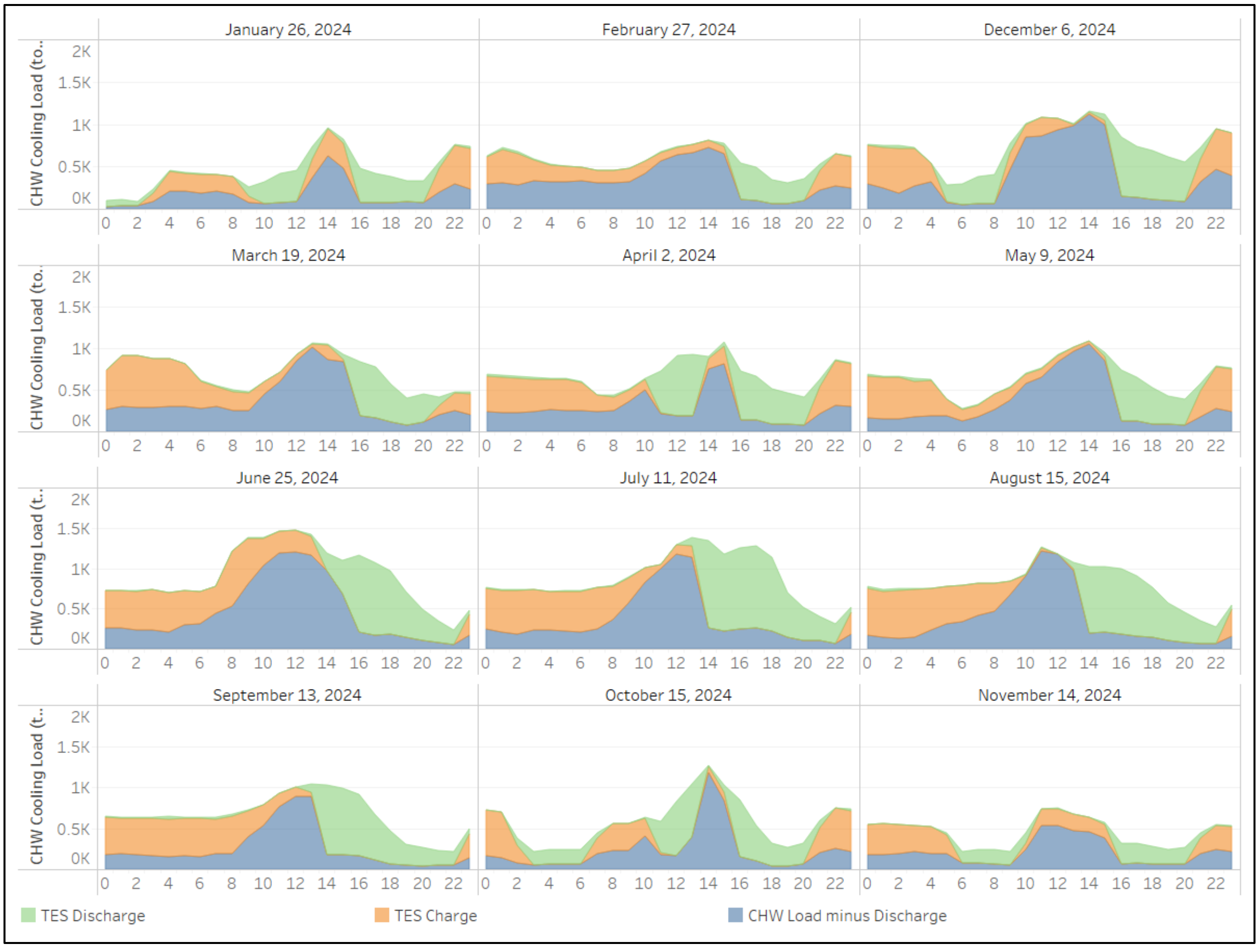
Appendix A: Additional Energy Analysis Data

Site A College Campus

The charts below show the median day for each month of chilled water use at Site A. The median day of each month was the quantity chosen because it is not swayed by the extremes. It is intended to represent a typical operational day in that month. Based on this data, the campus peak is set in summer into fall, June to October, coincident with warmer weather.

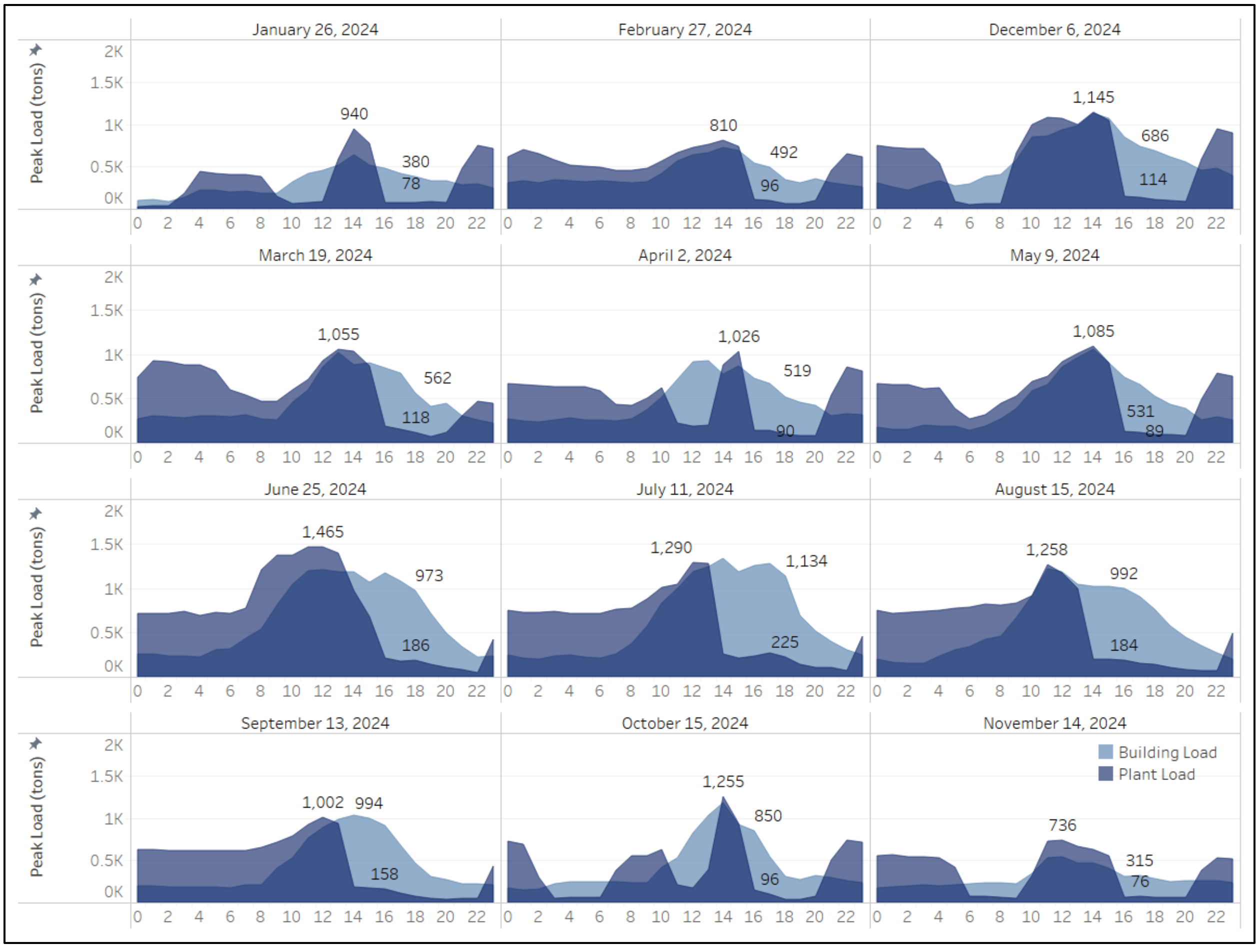


The figure below shows operations for each month on a typical day, representing the median of the data for the month, identified during the analysis process.



The charts show that the most significant and consistent discharge event occurs between 4 pm (16:00) and 10 pm (22:00) throughout the year. While the timeframe does not change significantly, the amount of load shifted does. The largest shifts occur in the summer and fall seasons when PM plant chilled water loads are highest. This indicates that load shift potential is highest when loads (driven by building use and outside air conditions) are highest.

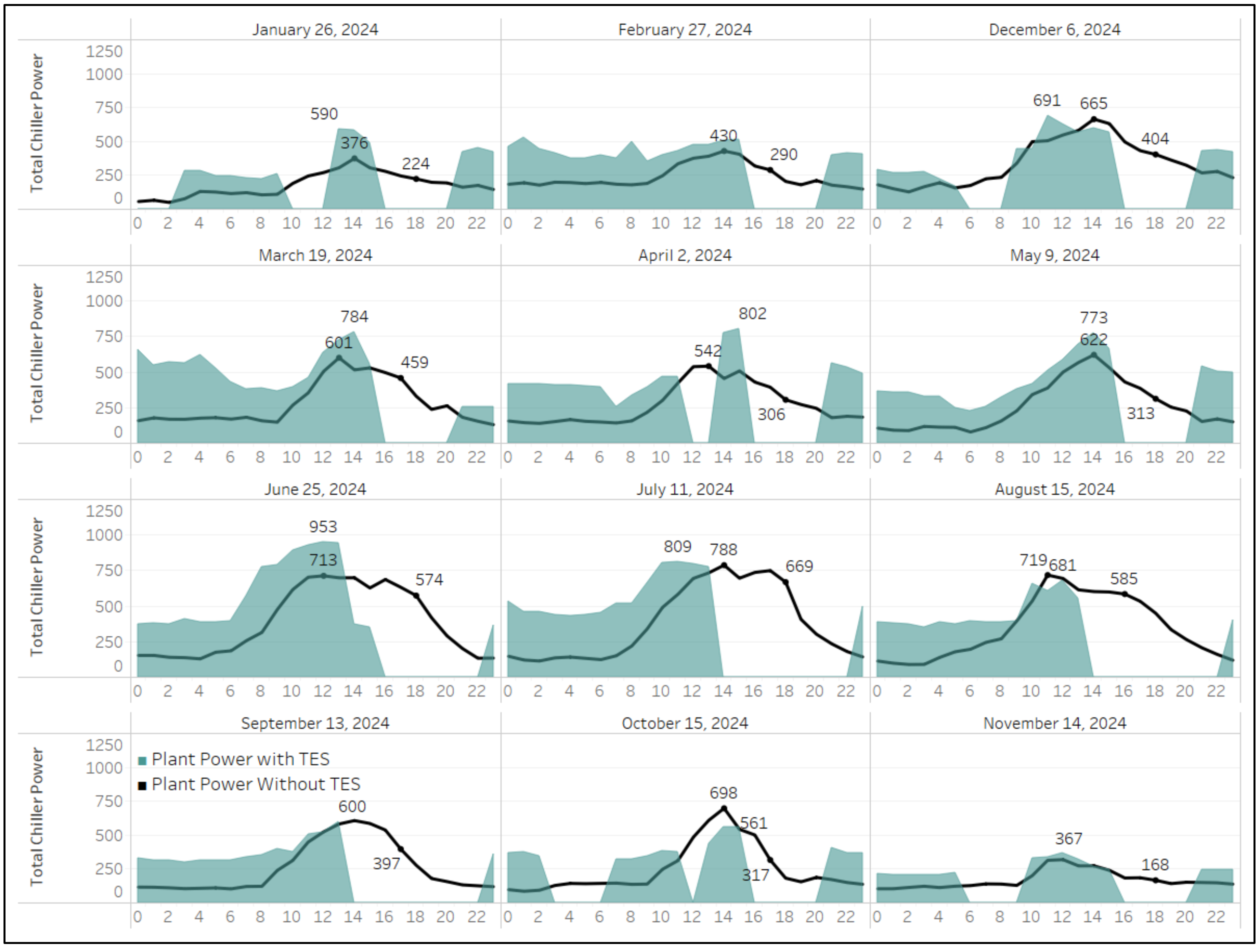
This section describes the optimization of thermal load at this site, combining the previous data sets to show the "before" and "after" of campus load. Combining the information from the previous chart of thermal load charge and discharge the following figure shows the net resulting thermal peak load on the central plant in dark blue and the building campus chilled water load in light blue or comparison.



The central plant shifts thermal load in the late afternoon (4 to 6 pm) using the chilled water tank the thermal load is shifted in summer months from 4 to 5 pm back five to six hours with the peak thermal load with TDs occurring between 10 am and 12 pm. The same shift can be observed in non-summer seasons, but with a lower overall demand reduction.

Peak Plant Power Savings kW

Using the provided data the research team analyzed the plant efficiency and kW per ton when the chilled water plant was operating and used the average efficiency to predict what the plant's total electric power would have been if the chillers were directly used to serve the campus chilled water load without thermal storage. The net result of this analysis is an estimated power savings of the chilled water TES shown below for a single median day for each month. The Gray area represents what the electric power demand was for the plant and the black line represents what the electric power demand would have been without TES.



From the data, we can see consistent reduction demand during TOU peak periods from the campus central chilled water loads across all seasons. On a peak summer day, that demand reduction is nearly 788 kW between 4 pm and 9 pm. In shoulder seasons can reduce peak demand associated with cooling by about 700 kW during the same window. In heating-dominant month in the winter, the system still reduces electric demand associated with cooling by about 250-300 kW.

Appendix B: Field Sites Surveyed (Full List)

The following is a complete list of the sites that the research team identified with TES. This list reflects only operational TES. The team also provided details of the location and system design for reference.

Site #	Building Type	TES Type	TES Size (gallons)	TES Energy (ton-hours)	CA Climate Zone	CA City	Built Year	Building Area Served (sf)
1	Research Laboratory	ICE	79,440	UN	4	Milpitas	2016	UN
2	Multifamily Highrise	CHW	60,000	730	4	Oakland	2018	275,000
3	Higher Ed and Healthcare	CHW	1,269,040	UN	3	Redwood City	2020	1,500,000
4	Higher Ed and Healthcare	HHW	69,870	12,700	3	Redwood City	2020	1,500,000
5	Food Processing Facility	ICE	9,150	7,776	2	Santa Rosa	2023	100,000
6	Corporate Campus	CHW	526,200	UN	4	Cupertino	2021	526,200
7	Highrise Residential Apartments	CW	110,000	UN	4	San Jose	2026	606,520
8	College Campus 1	CHW	2,300,000	30,000	9	Northridge	UN	7,362,074
9	College Campus 2	CHW	UN	16,800	4	San Jose	2012	6,000,000
10	College Campus 3	CHW	UN	13,000	12	Sacramento	UN	1,300,000
11	College Campus 4	CHW	UN	10,000	13	Bakersfield	UN	16,335,000
12	College Campus 5	CHW	1,350,704	20,000	11	Chico	1994	2,600,000
13	College Campus 6	CHW	1,660,000	28,000	13	Fresno	2024	3,100,000
14	College Campus 7	CHW	UN	37,000	8	Fullerton	2010	3,700,000
15	College Campus 8	CHW	UN	34,000	6	Long Beach	UN	UN
16	College Campus 9	CHW	UN	24,000	6	Los Angeles	UN	UN
17	College Campus 10	CHW	UN	30,000	10	San Bernadino	2016	1,240,700
18	College Campus 11	CHW	3,800,000	22,000	10	San Diego	2011	UN
19	College Campus 12	CHW	1,300,000	16,000	10	San Marcos	2001	13,329,360
20	College Campus 13	CHW	UN	6,500	2	Sonoma	2023	UN
21	College Campus 14	CHW	1,600,000	19,000	5	San Luis Obispo	2011	UN
22	College Campus 15	CHW	4,500	UN	1	Humbolt	2025	20,000
23	College Campus 15	HHW	4,500	UN	1	Humbolt	2025	20,000
24	College Campus 16	CHW	2,000,000	UN	13	Merced	2006	236,989
25	College Campus 17	CHW	6,900,000	UN	10	Riverside	2001	UN
26	College Campus 18	HHW	2,300,000	UN	4	Stanford	2015	UN
27	College Campus 18	CHW	4,300,000	90,000	4	Stanford	2015	UN
28	College Campus 20	CHW	890,000	10,000	8	Cypress	2012	UN
29	College Campus 21	ICE	UN	9,900	11	Rocklin	2012	UN
30	College Campus 22	ICE	UN	3,200	12	Dublin	1961	UN
31	College Campus 23	CHW	UN	2,905	4	Cupertino	2021	UN
32	College Campus 23	HHW	UN	1,946	4	Cupertino	2021	UN
33	College Campus 24	CHW	2,000,000	20,000	9	Walnut Creek	2018	UN
34	Highrise Hotel	ICE	UN	398	9	Beverly Hills	2023	UN
35	Assembly Building	HHW	5,000	75	3	Monterey	2026	65,000
36	Assembly Building	CHW	5,000	40	3	Monterey	2026	65,000
37	Research Laboratory	CW	25,000	UN	7	San Diego	2011	44,607
38	Winery	ICE	UN	UN	10	Temecula	2010	40,000