Store It While It's Hot: Thermal Energy in Commercial Buildings

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ABSTRACT

Thermal energy storage (TES) is a well-recognized solution to many of the grid issues that arise from building electrification and higher renewable energy penetration. It can provide much needed HVAC shifting for thermal loads in grid peak periods, where electric grid capacity is limited. PG&E's Code Readiness program has surveyed the California market to identify where TES installations are happening and analyze how those installations are functioning to shift load. Our research identified many sites using TES - most had thermal storage used for space cooling functions, but a few had heating storage combined with hydronic heat pumps. This paper will provide data from that survey as well as a deep data analysis of the load shifting activity in operation today. Two areas of note that this research will prioritize: (1) outreach identified few heating storage applications with all-electric heating systems. Most applications of thermal energy storage in the field, particularly in California were for the cooling side where rate arbitrage is lucrative. (2) The definition of thermal energy storage as far as controls, configuration and function were varied.

To both deal with the wide array of applications and begin to provide a framework for the value proposition of storage on the heating side, this research intends to provide a framework for assessing TES that can support its integration into energy codes, standards, and programs. This assessment will identify the potential roles for TES as a practical and scalable solution for electrification and grid flexibility, helping pave the way for broader implementation across California and beyond.

Introduction

As California's electric grid experiences higher coincident peaks from larger loads and greater variability driven by solar and wind generation, technologies capable of shifting electricity use offer a non-wires pathway to mitigate capacity constraints. Thermal energy storage is a relevant technology because it can shift cooling and heating loads that are typically significant contributors to coincident peak demand or building peak demand that occurs at the same time as grid peak demand. By decoupling thermal production from real-time electric demand, TES for HVAC can shift thermal loads that contribute to coincident peak demand to times of lower grid strain while still maintaining occupant comfort.

Pacific Gas and Electric Company's Code Readiness program conducted a statewide survey of TES in HVAC applications in California. Consistent with the program's mandate to analyze technologies for incorporation in code, this research examined where TES is being deployed, in what configurations, and to what extent systems are actively performing load shifting in practice. Outreach to the California building industry identified 38 total sites with TES installations, many of which provide cooling storage. This finding was consistent with today's economic drivers as time-of-use rate arbitrage and demand charge mitigation primarily support flexibility on the cooling side. Our research found few TES systems that support space heating functions. This imbalance highlights an important gap as building electrification policies increasingly shift winter heating loads onto the electric grid. This field study builds upon prior Code Readiness research examining TES modeling methodologies and the theoretical grid value of various storage configurations, particularly in high renewable scenarios.

In addition to a high-level survey of sites in California, this paper also provides a framework for value assessment and codification of TES and assesses several of the sites identified in the survey based on the recommended framework. The assessment reveals significant variability in how TES is defined, configured, and controlled across projects. Differences in system architecture, control strategies, and dispatch logic can affect the realized grid benefits, underscoring the value of codifying consistent performance criteria if TES is to be codified or incentivized at scale. From the assessment of sites, this research team provides policymaker direction to translate what is working and can be replicated today in code, particularly in jurisdictions with progressive approaches to code. The assessment through the framework also makes note of the complex criteria that are not ready for the primetime of code implementation, requiring more market movement to isolate definable and replicable language for code for various reasons discussed in the later sections.

Survey of TES Locations

The team first completed a high-level survey of TES systems in California to assess the scale of installations in the state. For this field survey, the research team identified TES systems through interviews of building industry professionals as well as general desk research. This outreach identified 38 sites in California with either operational TES or a system in design. The team then proceeded to gather basic details on the TES systems including location, year installed, type of storage, size of storage, and other general functions that could be gathered at the high level. Of those 38 sites, the most frequent application were storage systems that provide large capacity storage for cooling functions on campuses. The team did identify some exceptions to this most popular application. Nearly 10 sites had storage capacity that was less than 50,000 gallons. Starting in 2015, storage for space heating functions started to appear in commercial buildings. Half of those sites were installed in 2025, suggesting a potential market shift. The design community also confirmed this market shift, with many engineering consultants suggesting that design teams were proposing heating storage in combination with fully electrified buildings more frequently. The distribution of sites along key metrics of system type, tank size, and year built is provided in the diagram in Figure 1.

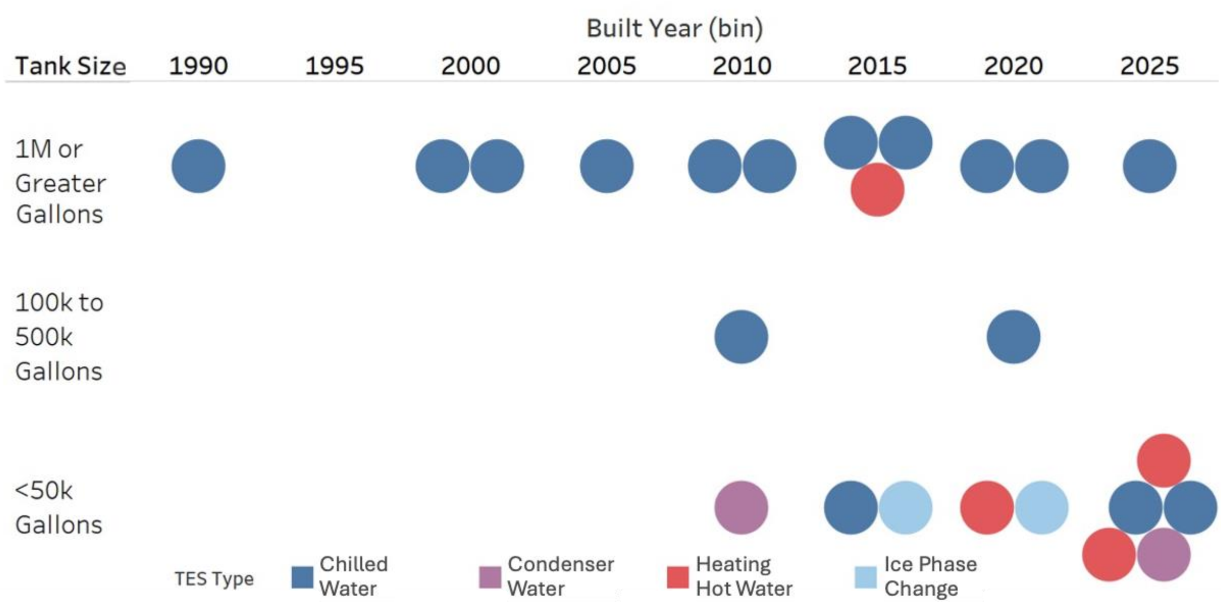


Figure 1. The distribution across 3 metrics: TES system type, tank size, and year built, for 38 sites surveyed for this study

Summary of TES Applications

Based on the survey of 38 TES installations, the research team attempted to abbreviate the list of sites to isolate key features and applications with high potential to provide demand flexibility and support reduction in coincident peak demand across the most buildings. The sections below isolate four key features determined to be valuable for this function from this research: small scale storage, storage that support heating end uses, storage integrated with waste heat recovery, multi-metric optimization.

Small Scale Storage

A common misconception of TES for designers and owners alike is that it requires a large amount of mechanical space in a building. This survey identified multiple systems with smaller storage mechanisms providing the thermal shift. Of the modern sites identified (after 2015), half the systems utilized smaller systems. In multiple cases the smaller scale storage did store for cooling end uses in a form that did not match the building's cooling distribution. Most frequently this was ice storage for chilled water-cooling functions. Storing as ice or other mixtures of water and phase change materials, can reduce the footprint of the system. Three examples of smaller TES applications include:

1. The research laboratory storing ice in 60 small tanks, charged from three chillers and a cooling tower, to serve the laboratory building.
2. A 23-story multifamily building utilizes a 60,000-gallon underground firewater storage tank for chilled water storage
3. A food processing facility, using storage in the form of ice to deliver 90 tons of cooling at peak alongside a 160-ton chiller plant for a total of 250 tons.

Heating Thermal Storage

Heating storage was less common than cooling storage, but the team did identify multiple instances of storage that supported space heating functions. The value of this TES application is that (1) it can improve the cost effectiveness of an electrified building design by reducing heat pump capacity and (2) it can improve an electrified site's operational cost effectiveness by reducing peak heating demand in the winter. While heating systems were a minority of the sites observed in California, two recently designed sites incorporated TES for storing hot water for HVAC in combination with hydronic heat pumps. In both instances, sites used two TES tanks, one for heating and one for cooling, enabling a shared hydronic heat pump plant to buffer thermal loads, reducing the size of the hydronic plant required. As was observed in an ACEEE HW/HA forum paper by Stet Sanborn, small HHW TES can provide a benefit for both mitigating the need to oversize heat pump plants by reducing the peak heating demand in the morning and again in the afternoon when the electric demand charges are highest.

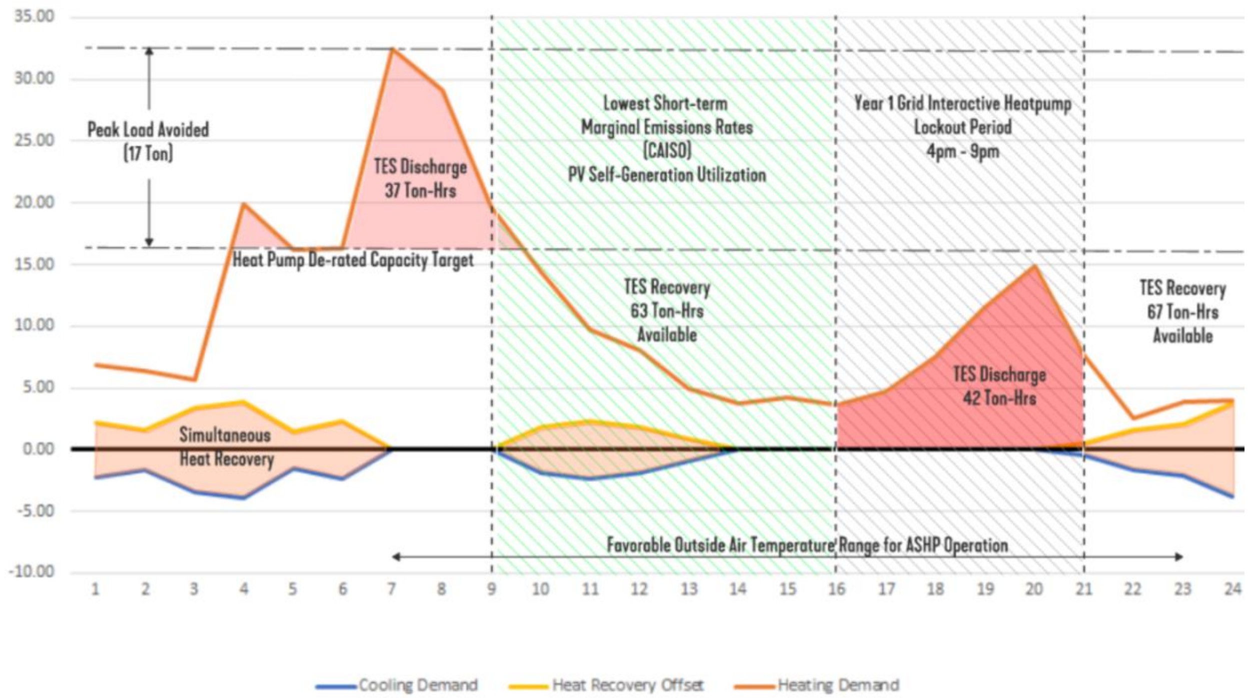
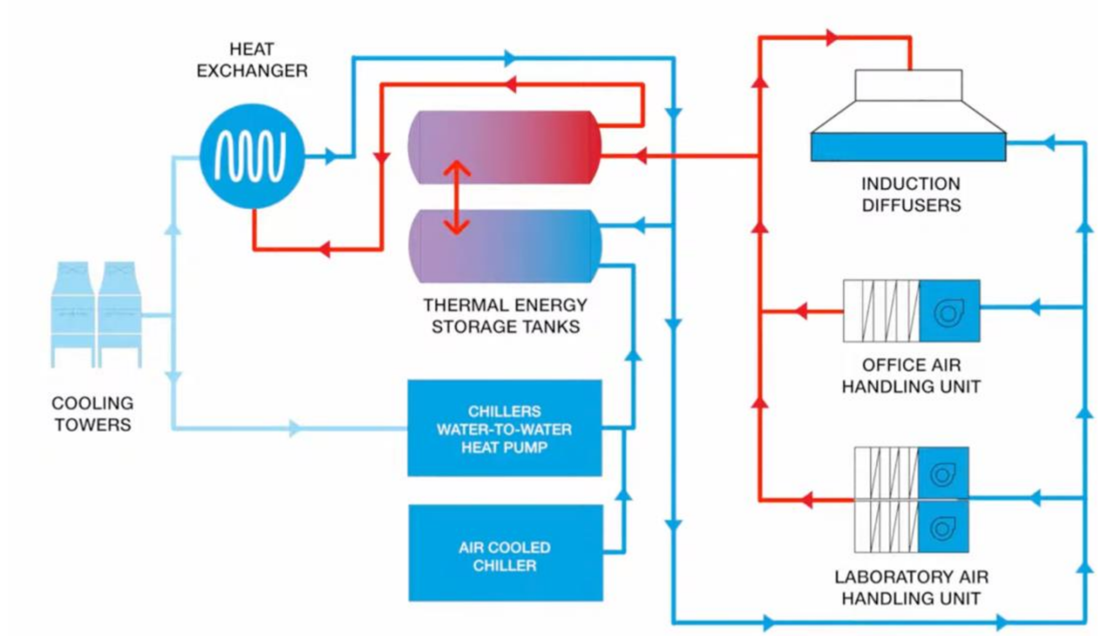


Figure 2. A graphic from Stet Sanborn's ACEEE paper that describes a heating storage design that avoids peak load and takes advantage of simultaneous heat recovery.

Heat Recovery and Thermal Energy Storage

The team identified two sites with TES configurations that leveraged waste heat for storage. Generally, the benefits of leveraging heat recovery to cover simultaneous heating and cooling loads in buildings are clear. TES that stores recovered heat has an added advantage of not requiring that that the heat rejection and heat use be simultaneous. Storage configurations that tapped into heat recovery for use in other places were rare, but the research team did identify two cases. These include three high-profile, high-performance building designs. One is the storage system designed for the Venter Institute and two other installations are Taylor Engineering’s Time Independent Energy Recovery (TIER) system.

The J. Craig Venter Institute’s research facility is an example of this heat recovery TES that is in operation in La Jolla, San Diego. The facility was completed in 2011 with a highly integrated



HVAC and TES system. The system (represented in the graphic above) utilizes TES between the heating and cooling water source heat pump system, capturing thermal energy when providing cooling or heating.

In current professional publications, including a 2024 ACEEE Summer Study paper (Stein and Gill 2024), TES with mechanical heat recovery has been presented as a method to completely electrify large commercial building HVAC. Taylor Engineers' TIER system uses the same principles of heat recovery seen in the Venter Institute on a larger scale. Heat recovery chillers, providing heating to the building, can generate an ambient source of condenser water which can then be utilized by electric chillers for cooling when needed.

Controls Feature: Multi-variable Optimization

In addition to the variation in configuration, the field study determined that optimization across multiple variables was not implemented across most sites. Typical TES operation is programmed around peak charge timeframes in primarily summer TOU rate structures. This means that, for most sites that were assessed in this survey, the primary optimization strategy was a single variable and that was cost oriented. In fact, many of the sites appeared to incorporate control strategies that were intended to be "set it and forget it." Fortunately, this method of operation does work for cooling TES because peak cooling demand in California in many commercial buildings coincides with peak charge windows in the summer. Also, these peak demand windows will most likely continue to be significant for cost effective load shifting and load shedding into the future.

The modeled potential for storage is typically evaluated by other variables, such as carbon emissions, real-time rates, or even estimates of future peak. The only site where the research team observed optimization of variables other than TOU rates was at UC Merced. Based on research conducted by LBNL in 2022 using model predictive controls (MPC) of the site, UC Merced optimizes charging to time periods with high on-site renewable electric generation, as well as optimizing for rates and high thermal loads (Kim et al. 2022).

Discussion

The Need for a Framework

TES is often conceptualized as relatively isolated, large storage tank. The survey conducted for this report observes that, in practice, TES is a diverse mechanism for flexibility and efficiency that is frequently integrated into system operation. Beyond a storage tank, successful implementation of TES requires considering the system as a whole. This system includes controls, central plant equipment, sequencing logic, and operational strategies that determine when and how stored energy is charged and discharged. Advancement of codes and standards requires that novel or hard to explain technology be condensed into a replicable, definable structure. The research team's field study concluded that some aspects of thermal energy storage are ready to be replicable and definable, and some are not. The framework provided in the following sections breaks down the elements that are code ready and the elements that are not.

Recommended Framework

Across the sites reviewed, TES installations varied widely in their degree of integration. While campus-scale systems occasionally treated TES as a relatively independent asset, most building-scale applications relied on a highly integrated design and controls approach. These systems commonly used TES in coordination with heat pumps or chillers, with storage charging and discharging governed by plant sequencing, operating temperature ranges, and constraints on compressor capacity. As a result, system performance was driven less by the physical characteristics of the storage tank and more by how TES was controlled, how it interacted with thermal loads, and how it was embedded within the overall plant architecture.

To compare systems consistently, TES installations were classified using a set of attributes that reflect these functional and operational distinctions. Key attributes used for system classification included:

- Primary TES application (heating, cooling, or condensing)
- Whether TES serves loads directly or operates in support of central equipment
- Relationship to central plant equipment (parallel, series, or pre-conditioning)
- Storage temperature conditions relative to normal operating setpoints
- Control strategy and control inputs governing charge and discharge
- Plant sequencing and staging logic
- Ability to charge and discharge without increasing installed compressor capacity
- Degree of integration within or outside the refrigerant loop

While these attributes above are useful for characterizing TES systems and comparing design approaches, many do not translate directly into criteria suitable for energy codes or efficiency programs. Energy codes and programs must focus on outcomes that are measurable, enforceable, and equitable across a wide range of building types and system configurations. Further, the ideal energy codes and program are best when setting efficiency criteria while enabling fixability and innovation.

Building on the system classification framework, a narrower set of evaluation criteria were identified to align with the objectives of energy codes and programs. These criteria emphasize how TES interacts with grid demand, system efficiency, and long-term performance rather than prescribing specific physical or design solutions. Each criteria includes a recommended requirement, the applicable energy code or efficiency programs, and stakeholders who would be most engaged. The energy code category considered the code from two perspectives, developing new requirements, code enhancements, and meeting and satisfying the energy code per project, code compliance. The resulting code-focused framework centers on the following metrics:

Criteria	**Recommended Criteria Structure**	**Code or Program Application**	**Required Stakeholders**
Peak demand benefit	The TES system consistently provides a reduction in a building's peak demand.	Code Compliance; Demand Response Programs	Utilities, Grid Operators, Program Administrators
Energy efficiency benefits	TES improve overall system efficiency by enabling operations at lower or higher temperature conditions that enhance equipment performance.	Code Compliance; Efficiency Programs	Designers, Engineers, Code Officials
HVAC equipment capacity	TES charging and discharging occurs without increasing installed plant or compressor capacity.	Code Enhancement	Owners, Developers
Robust Control of TES	System operation is sufficiently controllable and verifiable to support compliance and program administration.	Code Compliance; Efficiency Programs	Designers, Engineers, Commissioning
TES scalability	The system is broadly applicable using standardized components and control approaches.	Code Enhancement; Efficiency Programs	Program Administrators, Manufacturers

TES durability	The system maintains performance over the life of the building and supported by warranties, testing, or established standards.	Equipment and Appliance Standards	Manufacturers, Owners

The seven sites reviewed reveal meaningful patterns across the evaluation framework with implications for how energy code regulators and efficiency program administrators should proceed. The next section takes the recommended framework and applies them to these seven sites.

Applying the Framework

The first criteria in the framework is the peak demand benefit.

Site #	Site Peak Demand Benefit
1	Yes; Tariff-driven
2	Yes; Forecast-driven
3	Yes; Peak-Managed
4	Yes; Full-Shift
5	Yes; Specialty Tariff-driven
6	Yes; Forecast-Driven
7	Yes; Tariff-Driven

The research team observed, either with measured data or through operational survey, that all sites could consistently reduce their peak demand. The table above describes the sites shifting and the optimization method. Tariff-driven designates sites that leverage TOU rates to optimize. Specialty tariff driven is similarly optimized to a tariff, but the site's tariff is more dynamic than typical TOU rate. Designations that do not include tariff are driven by additional factors either within the building, such as peak load, or forecasted load.

The team observed that these criteria, while consistent, might be considered distinctly in design compared to operation. All of the systems have a maximum capacity that the storage can shift. This quantity could be designed based on the estimated peak demand of the building or site through energy modeling in design phases. The valuable distinction here is that designed capacity of shiftable load does not have to serve only in reducing peak demand in the operation of the building. That capacity of shiftable load can serve in multiple functions in building operation based on the optimization metric that the building opts to utilize. In other words, the designed capacity could serve to reduce peak demand based on a TOU or demand charge or based on a forecasted load for the next day or based on a dynamic rate or carbon signal. It is worth noting that the team did not observe any sites that were using dynamic rates or carbon signals to optimize although designers and operators were aware that it was possible to optimize with such signals. In fact, market research and industry interviews suggests that flexibility in choice of signal would allow for systems to transition along with grid needs as those progress.

These observed reductions were valuable in the context of utility rate structure today. Looking ahead, TES may also provide additional benefits by shifting load to periods of excess clean energy generation and supporting future utility rate structures that increasingly reward load flexibility and grid responsiveness. Today this is a supplemental benefit. In the future, this could be incorporated into codifiable metrics through the evolution of LSC or other potential structures that make clear the benefit of flexibility in code.

The concept of future-proofing storage is reliant on flexible controls that can be optimized to various metrics. At some sites, it seemed to be luck that sites saw demand reduction despite the limitations and rules of their optimization control sequence. This complexity is addressed by an additional criteria concerning robustness of control.

Site #	Robust Control of TES
1	Partial; Custom sequencing
2	Partial; Forecast-dependent
3	Partial; Sensor-intensive
4	Partial; Refrigeration-coupled
5	Partial; Supervisory logic
6	Partial; Legacy sequencing
7	Partial; SCADA*-specialist

**Note: SCADA (Supervisory Control and Data Acquisition) is an advanced supervisory controls and data acquisition platform with greater scale, customization, and integration capabilities than typical building management systems (BMS), commonly used in complex facilities, campuses, utilities, and industrial processes.*

The criteria for robustness of control offered a consistent message but a cautionary one because every site received only a partial rating. The specifics varied at each site, yet the underlying issue is the same. Current TES deployments rely on site-specific control architectures that are difficult to verify or replicate without deep operational knowledge. This argues for parallel investment in standards development around control verification and functional performance testing of TES, without which compliance pathways will likely remain difficult for designers and enforcement officials. Correlating this to the takeaways for peak demand benefit described above, the research suggests that any control verification for such systems should be signal agnostic.

Site #	Energy Efficiency Benefit
1	Yes; Load-shifting
2	Partial; Model-uncertain
3	Yes; Plant-optimized
4	Partial; Compression losses
5	Yes; Stabilized plant
6	Yes; Plant-optimized
7	No; Increased energy use

Benefits to energy efficiency from TES has inconsistent results. Several sites improved efficiency by reducing load. Others, however, show uncertain benefits or net negatives in efficiency, i.e. an increase in energy use, specifically peak demand. For instance, some sites moved so much demand from peak hours in the afternoon that the building established a new peak demand in the morning. This has implications for equipment sizing and thus first cost that are not a good fit for many sites. This variance reflects the real difficulties in system design and control for charging and discharging integration within a central plant to be optimized. A near-term solution to this variance could be to provide system performance standards in efficiency programs. Based on the data that the team has gathered, a recommended performance standard would be to require that all equipment used for storage functions (e.g. an ice chiller) be within an efficiency range, 0% to 30% for example, of the equipment used for regular HVAC operation of directly meeting thermal loads (e.g. the chiller providing normal space comfort cooling). Another option would be to cap shiftable demand at a percentage of peak demand relative to average daily demand.

It is worth noting that this finding is applicable to the function of TES in the scope of codes and policy today. In a future scenario where the primary driving metric is a dynamic price or carbon signal, boundaries on the maximum demand shifted or the efficiency of the storage mechanisms might not be necessary because cost or carbon could tradeoff differently.

Site #	HVAC Equip Capacity Change
1	No Change
2	No Change
3	No Change
4	No Change
5	No Change
6	Downsized; Storage-dependent
7	Upsized; Recharge capacity

Findings on the equipment capacity criteria are more straightforward. Most sites demonstrated that TES could operate without requiring additional system capacity to deliver the storage. In fact, one site proved that TES could translate to a downsized primary plant or system. The single exception was one site where additional recharge capacity was added to the facility[1]. A code provision establishing that TES installations shall not increase capacity above what load would otherwise be an enforceable way to define a cost-effective solution.

Site #	Scalability	Durability
1	Partial; Campus-only	High; Productized
2	No; Non-repeatable	Low; Integration-fragile
3	Partial; Central plant	Medium; Engineered system
4	Partial; Vendor-specialist	Medium; Engineered system
5	Partial; Custom-engineered	Medium; Engineered system
6	Partial; Campus-scale	Medium; Engineered system
7	No; Market-dependent	Medium; Operator-dependent

Scalability and durability showed the widest range of outcomes. These categories matter not only as performance criteria but as prerequisites for code adoption itself: without demonstrated market availability of reliable, repeatable systems, code enhancement and adoption agencies lack sufficient evidence to define requirements. These findings would be best addressed through equipment standards and manufacturer certification programs or qualified configuration lists to build a foundation of confidence over time.

Site #	Building Peak Demand	Robust Control of	Energy Efficiency	HVAC Equip Capacity	Scalability	Durability

[1] This site required a stand-alone system based on the owner's requirements for autonomy between the general chilled water system and the TES system. This criterion was unique to this design and project and not inherently due to the TES system

	Benefit	TES	Benefit	Change		
1	Yes	Partial	Yes	No Change	Partial	High
2	Yes	Partial	Partial	No Change	No	Low
3	Yes	Partial	Yes	No Change	Partial	Medium
4	Yes	Partial	Partial	No Change	Partial	Medium
5	Yes	Partial	Yes	No Change	Partial	Medium
6	Yes	Partial	Yes	Downsized	Partial	Medium
7	Yes	Partial	No	Upsized	No	Medium

Figure 4 A compilation of the tables describing individual criteria above to show the holistic view of an evaluation using the recommended framework for TES assessment.

Taken together, the site data supports a differentiated regulatory strategy. Peak demand benefit and equipment capacity benefits may be mature enough to consider in near-term energy code language. Criteria for energy efficiency and controls verification are better suited to efficiency programs and standards development in the intermediate term. Scalability and durability belong primarily to programs which directly work with manufacturers and certification agencies such as market transformation efforts which can lay the groundwork for broader market confidence.

Conclusions

Thermal energy storage (TES) is no longer an emerging technology. Instead, it is a proven strategy with successful installations across diverse building types and HVAC configurations in California. Yet current regulations, codes and standards, do not fully capture its demonstrated value. Policymakers now have an opportunity to modernize energy policy so that codes, programs, and market initiatives each support the aspects of TES they are best positioned to advance.

It is clear that a near-term priority for policymakers can be chilled water TES. Cooling applications already demonstrate a reliable source of load flexibility, particularly in utility regions where TOU rates provide the appropriate signal to shift. Because of this, TES for HVAC cooling is ready for regions with progressive codes.

In structuring criteria for TES in buildings and central plants, policymakers should focus on peak demand reduction. Evidence from sites with operational TES suggest that the systems can be designed around peak demand reduction to be utilized for peak demand reduction as well as additional grid benefits as they become available during the lifetime of the site. Codifying around peak demand reduction also has the benefit of smooth integration into the design process to tap the potential of a TES market that is highly mature, particularly in California. Further study could be leveraged to determine the compliance structure required to defend a required peak demand reduction code measure as it would require assumptions on operation that might need to shift based on the metric of analysis (LSC, cost, carbon, etc.).

Other criteria from the framework needs more development before being incorporated into code. Program administrators should support energy efficiency and controls verification through utility programs and performance standards**.** While TES can deliver efficiency gains, these outcomes depend on proper system integration and control strategies. Incentive programs and measurement-and-verification frameworks are better suited than codes to ensure these operational benefits are realized.

Beyond programs and incentives, policymakers should invest in market transformation efforts that advance scalability, durability, and product standardization**.** Partnerships with manufacturers, certification bodies, and market development initiatives can accelerate product consistency and performance transparency. These efforts will build the market confidence and data foundation needed for broader regulatory adoption.

All the following recommendations are intended for cooling TES as noted above. For heating side TES, while there is a clear motivating factor to reduce grid strain in the context of electrification, the technology is less developed. This technology represents a significant but underdeveloped opportunity that requires targeted incentives, demonstration projects, and industry collaboration before code adoption.

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