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Title 24, Part 11 (CALGreen) Proposal for Thermal Energy Storage

Additional submitted attachment is included below.

CALIFORNIA ENERGY
CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

To: **California Energy Commission**

From: Sean Steffensen and Bryan Boyce, Energy Solutions on behalf of the California Statewide Utility Code and Standards Enhancement (CASE) Team

Date: June 20, 2024

Subject: **Title 24, Part 11 (CALGreen) Proposal for Thermal Energy Storage**

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1. Background

The California Energy Commission has documented that of all the policy scenarios considered only the aggressive electrification scenario was capable of achieving the trajectory to carbon neutrality by 2045 (California Energy Commission 2021). Interest in all-electric HVAC systems for commercial new construction has been growing sharply in recent years. Evidence of this trend can be found in the adoption of all-electric reach codes by local jurisdictions. Based on localenergycodes.com, between 2019 and early 2023, jurisdictions representing roughly 11 million Californians, or 28 percent of the state population have enacted all-electric reach codes. Most of this activity is centered around the Bay Area (including San Francisco) and southern California (including Los Angeles), making this a statewide trend. In addition, indications from government agencies such as the California Air Resources Board (CARB) have signaled potential upcoming regulations to set emissions-based standards for residential space heating appliances by 2030 (i.e., a zero on-site emissions limit, which would only be achievable with electric-powered equipment), with similar emissions-based regulations on commercial HVAC equipment likely following later. The underlying message is clear: all-electric space heating systems are poised to become prevalent in California in the coming years.

Large buildings face unique challenges when pursuing all-electric space heating due to the need for significant space requirements of air-to-water heat pumps (when serving hydronic heating) or other types of air source heat pumps (ASHP) if other systems are used. System configurations that include heat recovery and thermal energy storage can effectively shrink the capacity of air source equipment. This can save significant roof space and reduce upfront costs due to reduced ASHP equipment capacity needs. In addition, the plant efficiency (including chillers, heaters, heat rejection, and pumping) can increase by 20-40 percent relative to a two-pipe air to water heat pump (AWHP) and water-cooled chiller (WCC) system. The result is that Title 24, Part 11 has a unique opportunity to steer designers and installers toward the most efficient and cost-effective options available on the market, as this new, all-electric commercial building stock is starting to be constructed.

This memo leverages information from the 2025 Nonresidential HVAC Space Heating – Final CASE Report available at https://title24stakeholders.com/measures/cycle-2025/nonresidential-hvac-space-heating/.

2. Proposed Code Change

2.1 Code Change Description

The measure is being pursued as a prerequisite option within Appendix A5 Nonresidential Voluntary Measures Division A5.2 Energy Efficiency of Title 24, Part 11, and would apply to newly constructed large buildings with large simultaneous or diurnal heating and cooling loads. The new voluntary requirement is needed to encourage designers of large buildings to pursue all-electric space heating in an efficient manner, with the specific goal of ensuring that building waste heat is leveraged in a way to minimize the installed capacity of ASHP equipment. Large buildings would have challenges meeting their space heating needs solely with ASHP due to space, cost, and efficiency barriers. Figure 1 demonstrates two types of systems that leverage thermal energy storage as part of the design, with the schematic on the left of the figure showing hot water thermal energy storage and the one on the right showing condenser water thermal energy storage. The figures show two versions of the same underlying concept, namely, that building waste heat is captured in a thermal energy storage tank for later usage rather than rejected to the ambient environment.

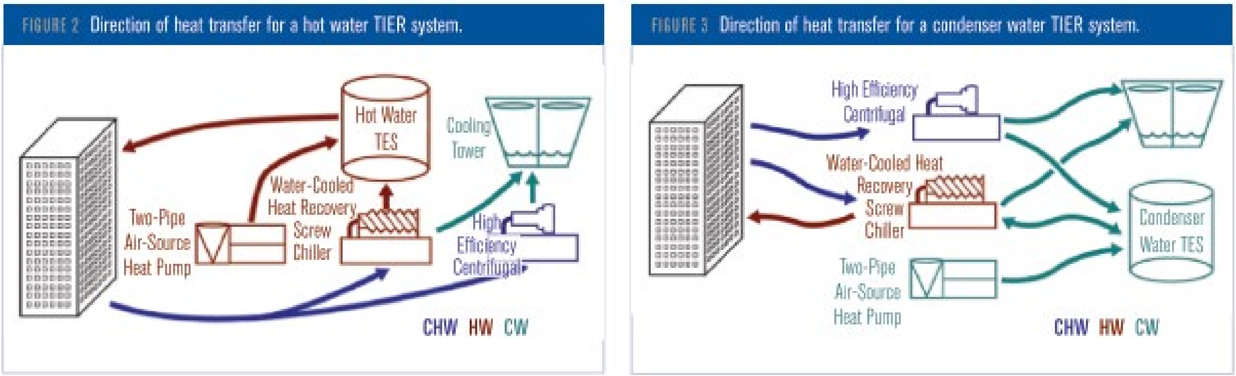
FIGURE 2 Direction of heat transfer for a hot water TIER system.

FIGURE 3 Direction of heat transfer for a condenser water TIER system.

Figure 1: Schematic of heat recovery and thermal storage systems.
Source: (Gill 2021)

The arrows in Figure 1 show the direction of energy movement, and the color gives an indication of the relative temperature band of the heat. The cooling tower and air source heat pumps are needed for the system to stay balanced throughout the year - adding or removing heat from the system as needed - but with the addition of thermal energy storage, their runtime hours should decrease, improving the overall system efficiency. The systems are known as time independent energy recovery (TIER) systems.

This proposal specifies thermal energy storage in addition to heat recovery equipment, which makes heat recovery more viable for sites without significant overlapping cooling and heating load profiles. For buildings with low overlapping loads, the thermal energy storage voluntary requirement is intended to store waste heat from when the building is in cooling mode so that it can be re-used later when the building is in heating mode. When applied to buildings using gas for space heating, the measure can be considered “electric readiness.” This is because thermal energy storage (along with a trim gas boiler used to provide heating when recovered heat is insufficient to meet space heating loads) will reduce the amount of ASHP equipment needed for when the building eventually electrifies its space heating by replacing its gas boiler with ASHP equipment.

2.2 Proposed Code Language

The proposed changes to the voluntary requirements are provided below. Changes to the 2022 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

California Green Building Standards Code

APPEMDIX A5 NONRESIDENTIAL VOLUNTARY MEASURES

Division A5.2 – Energy Efficiency

…

SECTION A5.203

PERFORMANCE APPROACH

A5.203.1 Energy efficiency.

Nonresidential, high-rise residential and hotel/motel buildings that include lighting and/or mechanical systems shall comply with Sections A5.203.1.1 and A5.203.1.2. Newly constructed buildings and additions are included in the scope of these sections. Buildings permitted without lighting or mechanical systems shall comply with Section A5.203.1.1 but are not required to comply with Section A5.203.1.2.

A5.203.1.1 Tier 1 and Tier 2 prerequisites.

To comply with Tier 1, ONE of the following efficiency measures is required for all applicable components of the building project. To comply with Tier 2, TWO of the following efficiency measures are required.

…

A5.203.1.1.6 Thermal Energy Storage.

Thermal energy storage intended to reduce the heating equipment full-load capacity needs is required for new buildings that meet both A and B:

A. $Cooling_{cap} \geq 800$ tons

B. $SWH_{cap} + Heating_{cap} \geq 4{,}000$ kBtuh

Where,

$Cooling_{cap}$ = design capacity of all mechanical cooling systems

SWH_{cap} = design capacity of all service water heating (SWH) systems, excluding systems expected to operate less than 5 hours/week, such as instant-hot for emergency eyewash.

$Heating_{cap}$ = design capacity of all space heating systems

If the building meets A and B above, then the thermal energy storage system shall include both:

1. Thermal energy storage capacity not less than 2 hours multiplied by ($SWH_{cap} + Heating_{cap}$) (e.g., 8,000 kBtu or greater), and
2. Water-to-water heat pumps or other means of heat recovery to extract heat from the storage system while heating, and rejecting heat to the storage system while cooling.

3. Justification

For small and medium size commercial buildings, a variety of existing heat pump-based electrification solutions exist on the market. These options include unitary single zone ASHPs and variable refrigerant flow systems. However, large commercial buildings have been considered harder to electrify due to space and equipment capacity issues. A simple but relatively inefficient all-electric hydronic system that is currently allowed by code consists of AWHP supplying hot water sized to meet the building's peak heating load. Even if legacy design practices around space heating – including designing to ultra-hot water temperatures (e.g., 140 °F or higher) and oversizing the system design capacity, as was commonly done with natural gas boilers – are overcome, the resulting system is still unattractive for several reasons:

- First, the space requirement for ASHPs (of which AWHPs are a subcategory) is typically significant and may be hard to achieve in dense urban areas.

- Second, the efficiency of an AWHP delivering a hot water supply temperature (HWST) of 120 °F is in the 2.0 to 2.5 coefficient of performance range at a heating design temperature of 30 °F ambient air temperature.
- Third, an AWHP system sized to meet heating demand is expensive.

Despite its drawbacks, AWHP systems serving hydronic reheat are being promoted as an all-electric option for large buildings because they have a lower carbon emissions impact than gas heating systems. The Code Readiness Electrification Designer Interview report found that multiple design engineers use configurations of multi-zone VAV systems with AWHPs supplying zone heating and reheat coils (Bulger 2023). This measure seeks to improve upon the default AWHP system that is typically installed in large buildings when all-electric solutions are pursued. The Statewide CASE Team surveyed the literature and market of available designs and have concluded that the inclusion of thermal energy storage and dedicated heat recovery chillers are critical components of an efficient and cost-effective hydronic system design. Determining the specific requirements and triggers around heat recovery chiller sizing and when a thermal energy storage tank should be specified was the focus of this measure.

3.1 Market Readiness

All-electric hydronic space heating with condenser water storage is growing but is not yet widespread. Other types of commonly used thermal energy storage systems include ice storage, chilled water storage and hot water storage. Trane/CALMAC produces a commercially available ice storage option that has been available for decades, with thousands of successful installations. Ice thermal storage has the advantage of a lower footprint due to the latent capacity boost from freezing water. Condenser water storage is an appealing option in the mild California climate. Condenser water storage, ice storage and chilled water/hot water storage systems would all meet the proposed requirement.

The principle is that large office buildings tend to generate reasonable to significant amounts of heat year-round, even in the winter. This internal building load generation in commercial buildings tends to be high. Daytime heating loads from people, data centers, and other processes can be stored overnight to be used for the next morning warm-up period. This diurnal trend should suffice to provide most of the heating loads in many California nonresidential buildings, with some ASHP capacity being made available to meet supplemental heating loads during peak periods. shows the different operating modes in one graphic. Several key operating modes are summarized here:

1. The building is in heating mode. In this mode, the condenser water thermal energy storage tank supplies energy to the heat recovery chiller to satisfy the building’s heating needs. The 2-pipe ASHPs may or may not be needed,

depending on if the storage capacity of the thermal energy storage tank is sufficient for the given weather conditions. During peak heating periods, it is expected that the ASHP will be needed, but there are milder periods when the ASHP can remain off.

2. The building is in cooling mode. In this mode, there is more heat in the building than is needed, so heat must be removed from the building on balance. The preference will be to use that waste heat to charge the thermal energy storage tank with energy. At a certain point, the thermal energy storage tank will become “full” and the cooling tower will be called upon to reject the excess energy from the building.

4. Energy Savings

4.1 Objective and Methodology

Title 24, Part 6 Section 10-106 requires local jurisdictions that adopt local energy code ordinances to submit “findings and supporting analyses on the energy savings and cost effectiveness of the proposed energy standards” to the CEC. While jurisdictions may quantify energy savings and cost effectiveness by any method determined appropriate, the analyses in this memo use the procedures established by the CEC to evaluate proposed revisions to Title 24, Part 6.

The Statewide CASE Team measured per unit energy savings expected from the proposed code changes in several ways to quantify key impacts. First, savings are calculated by fuel type. Electricity savings are measured in terms of both energy usage and peak demand reduction. Natural gas savings are quantified in terms of energy usage. Second, the Statewide CASE Team calculated source energy savings. Source energy represents the total amount of raw fuel required to operate a building. In addition to all energy used from on-site production, source energy incorporates all transmission, delivery, and production losses. The hourly Source Energy values provided by CEC are proportional to GHG emissions. Finally, the Statewide CASE Team calculated Long-term Systemwide Cost (LSC) savings, formerly known as Time Dependent Value (TDV) Energy Cost Savings. LSC savings are calculated using hourly energy cost metrics for both electricity and natural gas provided by the CEC. These LSC hourly factors are projected over the 30-year life of the building. The LSC hourly factors incorporate the hourly marginal cost of generation, transmission and distribution, fuel, capacity, losses, and cap-and-trade-based CO2 emissions. More information on source energy and LSC hourly factors is available in the March 2020 CEC Staff Workshop on Energy Code Compliance Metrics (California Energy Commission 2022) and the July 2022 CEC Staff Workshop on Energy Code Accounting for the 2025 Building Energy Efficiency

Standards (California Energy Commission 2022). The CEC directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings (California Energy Commission 2022). The prototype building that the Statewide CASE Team used in the analysis is presented in Table 1.

Table 1: Prototype Buildings Used for Energy, Demand, Cost Analysis

Prototype Name	Number of Stories	Floor Area (Square Feet)	Description
OfficeLarge	12	498,589	12 story + 1 basement office building with 5 zones and a ceiling plenum on each floor. WWR-0.40.

The Statewide CASE Team estimated LSC energy, source energy, electricity, natural gas, peak demand, and GHG impacts by simulating the proposed code change in EnergyPlus using prototypical buildings and rulesets from the 2025 Research Version of the California Building Energy Code Compliance (CBECC) software. CBECC generates two models based on user inputs: the Standard Design and the Proposed Design. The Standard Design represents the geometry of the prototypical building and a design that uses a set of features that result in a lifecycle energy budget and Source energy budget that is minimally compliant with 2022 Title 24, Part 6 code requirements. Features used in the Standard Design are described in the 2022 Nonresidential ACM Reference Manual. The Proposed Design represents the same geometry as the Standard Design, but it assumes the energy features that the software user describes.

To develop savings estimates resulting from the proposed code changes using an “all electric” base case, Statewide CASE Team created a Standard Design for each prototypical building representing compliance with 2022 Code and then modified the space heating system to convert it from a natural gas boiler to an electric AWHP sized to meet peak design loads. This system represents the baseline conditions against which the measures were compared. For this measure, the standard design uses a 2-pipe AWHP because our baseline condition is assumed to be a design minimally complying with the code in a local jurisdiction that has adopted an all-electric energy code. The Proposed Design was identical to the Standard Design in all ways except for the revisions that represent the proposed changes to the code. Large office is the prototype that represents buildings most likely to be triggered by this measure, so their proposed design configurations include heat recovery and thermal energy storage elements. The changes between the standard and proposed designs are further described in the scenario analysis section below.

CBECC calculates whole-building energy consumption for every hour of the year in every climate zone and applied the climate-zone specific LSC hourly factors when calculating energy and energy cost impacts. Per unit energy impacts for nonresidential buildings are presented in savings per square foot. Annual energy, greenhouse gas, and peak demand impacts for each prototype building were translated into impacts per square foot by dividing by the floor area of the prototype building. This step allows for an easier comparison of savings across different building types and enables a calculation of statewide savings using the construction forecast that is published in terms of floor area by building type.

4.2 Scenario Analysis

This measure's base case consists of an all-electric building fully satisfied with AWHPs supplying hot water. The impacted prototype is a large office.

The Statewide CASE Team modeled the proposed measure using condenser water (CW) thermal energy storage (in essence, the TIER system), which provides several energy efficiency benefits. CW thermal energy storage systems operate the AWHP and HRC in low-lift conditions. The AWHP is configured to deliver CW temperatures (drawing heat from ambient air at design heating conditions, typically 30°F in most California climates) and the heat recovery chiller operates between CW and HW temperatures. The more limited operating envelopes increase efficiency due to the compressor not working as hard as it would if the AWHP were delivering HW temperatures.

The measure case was modeled outside of CBECC (and EnergyPlus) according to detailed specification prepared by Taylor Engineers in a memo to the Oakland Building Department (Energy Solutions 2023). The all-electric baseline prototype IDF files were exported from CBECC and then post-processed according to the Taylor Engineers specification.

The results include energy savings from the addition of thermal energy storage and heat recovery to the large office prototype. This represents energy savings achieved from the thermal energy storage+HR measure targeted at buildings with low overlapping space cooling and heating loads.

Table 2: Lookup Table for Thermal Energy Storage

Measure Name	Measure ID
Thermal Energy Storage (AWHP Baseline)	A
Thermal Energy Storage (Gas Baseline)	B

Table 3: First Year Electricity Savings (kWh) Per Square Foot

Measure ID	Prototype	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16
A	OfficeLarge	0.34	0.47	0.17	0.49	0.27	0.26	0.28	0.31	0.27	0.28	0.46	0.46	0.41	0.68	0.31	0.94
B	OfficeLarge	(0.10)	0.06	0.02	0.10	0.04	0.22	0.26	0.24	0.20	0.18	0.12	0.11	0.15	0.10	0.27	0.03

Table 4: First Year Peak Demand Reduction (W) Per Square Foot

Measure ID	Prototype	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16
A	OfficeLarge	0.09	0.10	0.04	0.11	0.07	0.01	0.00	0.02	0.02	0.04	0.14	0.12	0.09	0.21	0.02	0.23
B	OfficeLarge	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	0.00	(0.00)	(0.00)

Table 5: First Year Natural Gas Savings (kBtu) Per Square Foot

Measure ID	Prototype	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16
A	OfficeLarge	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
B	OfficeLarge	6.67	4.94	4.33	3.46	4.44	1.68	1.37	1.88	2.04	2.43	3.78	4.29	3.49	4.23	1.35	3.75

Table 6: First Year Source Energy Savings (kBtu) Per Square Foot

Measure ID	Prototype	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16
A	OfficeLarge	1.04	1.31	0.45	1.32	0.68	0.21	0.19	0.31	0.33	0.39	1.37	1.17	0.94	2.03	0.41	2.59
B	OfficeLarge	5.87	4.43	3.81	3.15	3.94	1.60	1.34	1.77	1.91	2.23	3.42	3.86	3.17	3.82	1.42	3.33

Table 7: First Year LSC Energy Savings ($) Per Square Foot

Measure ID	Prototype	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16
A	OfficeLarge	2.39	3.04	1.02	3.08	1.69	1.21	1.24	1.46	1.35	1.47	3.02	2.82	2.45	4.55	1.67	6.43
B	OfficeLarge	3.11	2.91	2.38	2.31	2.56	1.93	1.91	2.15	2.07	2.21	2.68	2.85	2.63	2.97	2.14	2.23

5. Cost Effectiveness

Cost effectiveness is presented in terms of long-term system cost (LSC). Per-unit energy cost savings for newly constructed buildings, additions, and alterations in terms of LSC savings realized over the 30-year period of analysis are presented 2026 present value dollars (2026 PV$) in the tables below.

The incremental first cost and incremental replacement and maintenance costs over the period of analysis are also included. A measure is cost effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the total cost benefits realized over the analysis period by the total incremental costs. The B/C ratio was calculated using 2026 PV$ costs and cost savings.

The cost-effectiveness analysis must show that there is a pathway to comply with the code that is cost effective, but it is not necessary to demonstrate that every possible compliance pathway is cost effective. We analyzed the system with CW thermal energy storage and expect all configurations featuring thermal energy storage to be both cost effective and allowable for compliance. This memo presents the cost effectiveness of the recommended prerequisite option for thermal energy storage.

5.1 Energy Cost Savings Results

Per unit energy cost savings for newly constructed buildings that are realized over the 30-year period of analysis are presented 2026 precent value dollars (2026 PV$) in Table 8 through Table 9.

The LSC hourly factors methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods. This measure is expected to have an impact on heating peak demand, as well as potentially on cooling peak demand depending on how the thermal energy storage tank is configured.

Table 8: 2026 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – New Construction and Additions – Large Office (Thermal Energy Storage – AWHP Baseline)

Climate Zone	30-Year LSC Electricity Savings (2026 PV$)	30-Year LSC Natural Gas Savings (2026 PV$)	Total 30-Year LSC Savings (2026 PV$)
1	2.39	0.00	2.39
2	3.04	0.00	3.04
3	1.02	0.00	1.02
4	3.08	0.00	3.08
5	1.69	0.00	1.69
6	1.21	0.00	1.21
7	1.24	0.00	1.24
8	1.46	0.00	1.46
9	1.35	0.00	1.35
10	1.47	0.00	1.47
11	3.02	0.00	3.02
12	2.82	0.00	2.82
13	2.45	0.00	2.45
14	4.55	0.00	4.55
15	1.67	0.00	1.67
16	6.43	0.00	6.43

Table 9: 2026 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – New Construction and Additions – Large Office (Thermal Energy Storage – Gas Baseline)

Climate Zone	30-Year LSC Electricity Savings (2026 PV$)	30-Year LSC Natural Gas Savings (2026 PV$)	Total 30-Year LSC Savings (2026 PV$)
1	-0.57	3.68	3.11
2	0.14	2.77	2.91
3	-0.09	2.47	2.38
4	0.36	1.95	2.31
5	0.07	2.49	2.56
6	0.94	1.00	1.93
7	1.08	0.83	1.91
8	1.00	1.15	2.15
9	0.84	1.23	2.07
10	0.75	1.46	2.21
11	0.43	2.25	2.68
12	0.34	2.51	2.85
13	0.54	2.09	2.63
14	0.43	2.54	2.97
15	1.30	0.84	2.14
16	0.07	2.17	2.23

5.2 Incremental First Cost

5.2.1 Thermal Energy Storage – Electric Baseline

Condenser water Time Independent Energy Recovery (TIER) is a form of thermal energy storage that uses condenser water for thermal storage. It was bid as an alternate system design option versus AWHPs on four recent Bay Area new construction projects. See Table 10 for incremental costs developed by Taylor Engineers comparing several all-electric hydronic design options, including TIER. Pricing was provided by each individual project’s General Contractor and thus represents the total net cost to the owner. In all cases TIER costs less than the base case all-electric design.

Table 10: TIER Plant Incremental Cost Savings

Location	Santa Clara	Sunnyvale	San Jose	Oakland	Average
Stories	3	3	6	27	
Building area (ft^2)	314,000	1,100,000	1,022,981	718,000	
CHWcap (tons)	780	2,660	1,800	1,200	
SWHcap (kBtuh)	307	N/A	553	N/A	
Hwcap (kBtuh)	5,000	18,986	11,896	10,215	
Tank capacity (kBtu)	12,125	45,807	**	34,436	
Tank capacity (gallons)	35,000	141,000	**	53,000	
Tank doubles as fire water storage?	No	Yes	Yes	Yes	
First Cost Savings ($)	*	$1,500,000	$6,725,003	$2,200,000	
First cost savings ($/ft^2)	*	$ 1.36/ ft^2	$ 6.57/ ft^2	$ 3.06/ ft^2	$3.67/ ft^2

*For the Santa Clara site, TIER was the base bid. The General Contractor indicated that AWHPs was a net cost add but did not provide a hard bid, i.e., TIER was lower cost. The owner opted for TIER since it was lower cost, lower energy use, and lower maintenance.

**Tank size TBD.

Table 11: Detailed Pricing for TIER vs AWHP - San Jose Site

All-In System Costs (options)	***ASHP/ Chilled Water*** **$**	***ASHP/ Chilled Water*** **$/sf**	***TIER Plant*** **$**	***TIER Plant*** **$/sf**
General Conditions	481,226	$0.47	481,226	$0.47
Staking	5,000	$0.00	5,000	$0.00
Concrete	0	$0.00	156,741	$0.15
Rebar	0	$0.00	37,425	$0.04
Structural Steel	500,000	$0.49	210,000	$0.21
Misc. Metal	75,000	$0.07	32,000	$0.03
Below Grade Waterproofing	0	$0.00	5,000	$0.00
Signage	1,000	$0.00	1,000	$0.00
Fire Sprinklers	0	$0.00	26,600	$0.03
Plumbing	320,000	$0.31	320,000	$0.31
HVAC[a]	17,199,508	$16.81	11,118,477	$10.87
Electrical	3,000,000	$2.93	3,028,623	$2.96
Design	320,327	$0.31	320,327	$0.31
Subtotal	21,902,061	$21.41	15,742,419	$15.39
Contingency	1,095,103	$1.07	787,121	$0.77
SDI	229,972	$0.22	165,295	$0.16
Fee	685,201	$0.67	492,498	$0.48
Total	23,912,336	$23.38	17,187,333	$16.80

[a] HVAC cost savings from Table 10

The incremental cost of the proposed system compared to the all-electric baseline is negative $3.67/sf.

5.2.2 Thermal Energy Storage – Gas Baseline

Because of the indirect manner by which incremental costs were calculated for the four efficiency cases of this analysis, we are showing the relationship between the costs in Figure 2 for clarity. The incremental cost of the proposed thermal energy storage system compared to the gas baseline is $0.85/sf.

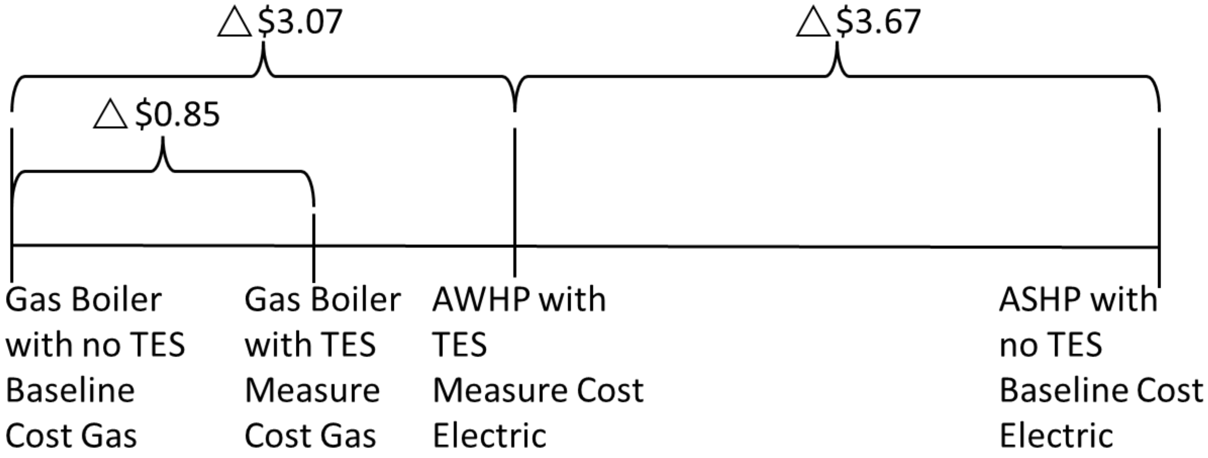

Figure 2: Schematic comparison of Incremental Costs for Different Modeling Cases (all units $/sf)

The incremental cost for thermal energy storage with a gas baseline was determined via the following steps.

1. First starting with the incremental cost of a TIER system versus an all-electric all-2-pipe ASHP baseline. This pricing averages negative $3.67/sf and is described above in Table 10: TIER Plant Incremental Cost Savings (i.e., TIER costs less than all 2-pipe ASHPs).
2. We then worked with a mechanical contractor to redesign/reprice the all-electric ASHP baseline for one of the TIER sites to a conventional gas boiler system (basically CEC Alternative Compliance Manual (ACM) System 6). This included deleting ASHPs, deleting primary HWPs, deleting buffer tanks, adding boilers, and adding new gas service to boilers on the roof. These changes are summarized in Table 12. This exercise indicated that the cost to upgrade from gas boilers to all-electric ASHPs is $6.74/sf and $575/kbtuh (or $0.575/Btuh).
3. $6.74/sf - $3.67/sf = $3.07/sf = cost to go from the ACM System 6 (gas boiler baseline to TIER w/ AWHP.
4. We then averaged the heating capacity of the 4 TIER sites to arrive at 3.86 btuh/sf of boiler/ASHP heating capacity for TIER plants (compared to about 12 btuh/sf without TIER thermal energy storage).
5. Multiplying the ($0.575/Btuh) times 3.86 btuh/sf, yields a cost $2.22/sf which indicates that a TIER plant with ASHP costs $2.22/sf more than a TIER plant with gas boilers.
6. $3.07/sf - $2.22/sf = $0.85/sf = cost to go from the ACM System 6 (gas boiler baseline to TIER w/ gas boilers.

Table 12: Incremental Cost for Conversion of All-Electric HW Plant to Gas Heat

Description	Equipment Cost	Other Mechanical Contractor Cost	Plumbing Contractor Cost	Electrical Contractor Cost	Controls Contractor Cost	Total
Delete (2) 420-ton Climacool ASHP (6 modules each)	($3,187,800)	($24,000)	$0	($100,000)	($39,600)	($3,351,400)
Delete (2) 490-ton Climacool ASHP (7 modules each)	($3,719,100)	($24,000)	$0	($100,000)	($39,600)	($3,882,700)
Add (2) 6,000 MBH condensing boilers such as Aerco Benchmark 6000 or Lochinvar Crest FB6001	$379,500	$60,000	0	$0	$55,000	$494,500
Delete (4) primary hot water pumps	($48,576)	($16,000)	$0	($10,000)	($35,200)	($109,776)
Delete HHW buffer tank	($12,650)	($2,000)	$0	$0	$0	($14,650)
Add new gas service to boilers on roof	$0	$0	$100,000	$0	$0	$100,000
Add/deduct for HW piping changes (boiler control valves, min flow bypass valve, etc.)	$0	($130,000)	$0	$0	$0	($130,000)
Total Costs	($6,588,626)	($136,000)	$100,000	($210,000)	($59,400)	($6,894,026)
Building Area (sf)	N/A	N/A	N/A	N/A	N/A	1,022,981
Normalized Total ($/sf)	N/A	N/A	N/A	N/A	N/A	($6.74)

5.3 Incremental Maintenance Costs

Incremental maintenance cost is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the 30-year period of analysis. The present value of equipment maintenance costs (or savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2025 LSC hourly factors. The present value of maintenance costs that occurs in the n^{th} year is calculated as follows:

$$Present\ Value\ of\ Maintenance\ Cost\ =\ Maintenance\ Cost\ \times \left\lfloor \frac{1}{1+d} \right\rfloor^{n}$$

For heat recovery with thermal energy storage, maintenance and replacement costs are expected to be lower for the proposed case because there are fewer AWHPs or boilers to maintain and replace. Incremental maintenance costs for this measure were not quantified. This aspect is not needed to demonstrate cost effectiveness since in the electric scenario, the proposed case has lower first costs (in the electric-to-electric scenario), lower energy costs and lower maintenance/replacement costs than the base case. In the gas scenario, the measure is lifecycle cost effective, and the measure case maintenance costs are lower than its base case, which would improve the cost effectiveness if quantified.

5.4 Cost Effectiveness

Results of the per unit cost-effectiveness analyses are presented in Table 13 for new construction/addition for the condition of heat recovery with thermal energy storage (represented by the large office prototype) with an electric baseline and Table 14 for the gas baseline case. The B/C ratio is infinite (implying immediate payback) due to the fact that the incremental first cost is negative relative to the baseline design without heat recovery and thermal energy storage.

Benefits and costs are defined as follows:

- **Benefits: LSC Savings + Other PV Savings:** Benefits include LSC Savings over the period of analysis. Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost, incremental PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs, and incremental residual value if proposed residual value is greater than current residual value at end of the CASE analysis period.

- **Costs:** Total Incremental Present Valued Costs: Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation-adjusted) three percent rate and if PV of proposed maintenance costs is greater than PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the benefit-to-cost ratio is infinite.

Table 13: 30-Year Cost-Effectiveness Summary Per Square Foot – New Construction/Additions – Large Office (Thermal Energy Storage - AWHP Baseline)

Climate Zone	Benefits LSC Savings + Other PV Savings (2026 PV$)	Costs Total Incremental PV Costs (2026 PV$)	Benefit-to-Cost Ratio
1	2.39	(3.67)	Infinite
2	3.04	(3.67)	Infinite
3	1.02	(3.67)	Infinite
4	3.08	(3.67)	Infinite
5	1.69	(3.67)	Infinite
6	1.21	(3.67)	Infinite
7	1.24	(3.67)	Infinite
8	1.46	(3.67)	Infinite
9	1.35	(3.67)	Infinite
10	1.47	(3.67)	Infinite
11	3.02	(3.67)	Infinite
12	2.82	(3.67)	Infinite
13	2.45	(3.67)	Infinite
14	4.55	(3.67)	Infinite
15	1.67	(3.67)	Infinite
16	6.43	(3.67)	Infinite
Total	1.59	(3.67)	Infinite

Table 14: 30-Year Cost-Effectiveness Summary Per Square Foot – New Construction/Additions – Large Office (Gas Boiler with Thermal Energy Storage - Gas Baseline)

Climate Zone	Benefits LSC Savings + Other PV Savings (2026 PV$)	Costs Total Incremental PV Costs (2026 PV$)	Benefit-to-Cost Ratio
1	3.11	0.85	3.65
2	2.91	0.85	3.42
3	2.38	0.85	2.80
4	2.31	0.85	2.72
5	2.56	0.85	3.01
6	1.93	0.85	2.27
7	1.91	0.85	2.25
8	2.15	0.85	2.53
9	2.07	0.85	2.44
10	2.21	0.85	2.60
11	2.68	0.85	3.15
12	2.85	0.85	3.35
13	2.63	0.85	3.09
14	2.97	0.85	3.49
15	2.14	0.85	2.52
16	2.23	0.85	2.62
Total	2.20	0.85	2.59

6. On Bill Savings

For local jurisdictions looking for more information regarding how implementing this requirement may impact customer utility bills and energy usage, please contact the Reach Codes program at info@localenergycodes.com. The program provides technical support to facilitate adoption of local green building and energy efficiency ordinances that reach beyond California's minimum requirements.

7. Enforcement

Our proposal for enforcement of this measure is for there to be an update to the compliance forms to capture key parameters that are necessary to describe the thermal capacity of the thermal energy storage system. For custom-built sensible water storage tanks, there are three critical parameters that can describe capacity. Those are the tank's usable volume of water (in gallons) and the tank's minimum and maximum operating setpoints (in degrees Fahrenheit). Additional fields could include: heat recovery chiller minimum and maximum evaporator and condenser temperatures and air to water heat pump minimum and maximum entering and leaving water temperatures would capture the variation in the system. These parameters would be stated on the building's design drawings, and this is how the code compliance official can verify the information. Based on parameters such as those stated above, the thermal energy storage tank capacity can be readily calculated based on conservation of energy principles. For any manufactured or packaged thermal energy storage solution (which is likely how ice and other phase change material-based storage solutions will be marketed), we propose that the enforcement approach rely upon the unit's rated storage capacity (generally in units of ton-hours or Btus). AHRI-900 is a test standard that could be referenced, though it was developed for cooling-oriented thermal energy storage use cases in mind, its method for determining capacity is valid for heating-oriented thermal energy storage.

8. References

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