Thermal Energy Storage

Compliance Option

STAFF DRAFT REPORT

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ABSTRACT

This Staff Report on *Thermal Energy Storage Systems* describes the impacts that were evaluated by the Energy Commission in determining whether compliance credit with the *2005 Building Energy Efficiency Standards* should be approved. The impacts that are addressed include energy use, emissions, and compliance credit. The report also includes eligibility criteria and acceptance requirements that must be met by contractors to qualify these systems for compliance credit and the compliance forms that must be used for reporting to the building departments. Finally this report includes the comments expressed by the public and staff response to those comments.

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EXECUTIVE SUMMARY

Staff has prepared this report evaluating an application for approval of a compliance option for thermal energy storage systems used for nonresidential buildings. This application was submitted by Energysoft, LLC, of Novato, California.

The proposed compliance option would provide compliance credit under the *2005 Building Energy Efficiency Standards* (Standards) for nonresidential buildings when a TES system is installed.

TES systems reduce energy consumption during peak demand periods by shifting energy consumption to nighttime. Operation of the thermal energy storage compressor during the night produces cooling energy which is stored in the form of cooled fluid or ice in tanks. The stored energy is then used during the following peak load daytime hours. Performance efficiency of the compressor is more efficient due to lower nighttime ambient temperatures. This efficiency improvement is partially offset by the system's reduced ability to store energy as the storage approaches full charge due to the reduced temperature differential (lower heat transfer).

Staff supports approval of this compliance option on the condition that thermal energy storage systems meet the acceptance testing and eligibility criteria specified in this report. Compliance software including this compliance option to model thermal energy storage systems as specified in this report shall be subject to approval by the California Energy Commission.

SUMMARY OF APPLICANT'S REQUEST

The applicant proposed that compliance credit for thermal Energy storage (TES) systems be approved based on the reductions of energy use during peak demand periods. The applicant documentation to support this claim included projected performance data of TES systems generated by building compliance simulations using a research version of EnergyPro. The simulations showed that TES systems (where designed to meet full and partial loads) compared favorably against the base case requirements of the *2005 Building Energy Efficiency Standards*.

The applicant's application also proposed eligibility criteria and acceptance testing requirements that must be met for a TES system to qualify for compliance credit. The eligibility criteria address verification of specific measures that affect performance and reliability of the equipment. The acceptance requirements call for installer verification of control functions and the presence of required features. The eligibility criteria and acceptance requirements are discussed on page 7 of this report.

EVALUATION OF PROPOSAL

Staff evaluated the thermal energy storage compliance option and found the reports content to be comprehensive and technically correct. The evaluation included: verification of performance data, determining the applicability of acceptance testing, and determining if the eligibility requirements were complete. Staff proposed a number of amendments that were need to address concerns raised through public comments, including adding data for partial load operation and clarifying language in the proposed acceptance and eligibility requirements.

Staff’s review of the technical content of the application found that the report contained reasonable justifications. The key issue is what modeling rules are used to simulate the TES systems performance. The TES compliance options propose using the modeling rules contained in DOE 2.1E which have been demonstrated to accurately model all of the attributes associated with TES systems. Staff’s review of the input files used to generate the comparisons found no errors and sample runs of those files generated identical results to that claimed by the applicant. Staff did ask for additional runs and some modification in the simulation assumptions. The applicant complies with all staff requests for changes in the simulation assumptions.

Staff also evaluated and commented on the acceptance and eligibility requirements specified in the application. Staff had proposed a number of additional tests and checks to be added to the acceptance and eligibility requirements and after reviewing the public comments staff made additional changes to these requirements. Staff’s position is that the proper implementation of the acceptance and eligibility criteria is critical to the insurance of a TES systems reliability to provide energy savings over the life of the equipment. As part of the changes made to address this concern staff made requested modifications of the MECH-9-A which must be filled out and signed by the installer before it is submitted to the building department.

Staff’s final evaluation comments are directed toward the concern that TES systems will require some additional routine maintenance checks (for example, periodic inspection and calibration of controls, and visual inspection to check for leakages, overflow, and proper fluid level in the tank) beyond what might be necessary for a conventional system. Lack of maintenance is an issue and a factor that affects the efficiency of all equipment. While TES may need somewhat higher maintenance, the added cost of the equipment may help to promote better servicing. Therefore staff believes that a lack of maintenance will not be a pervasive problem with TES systems.

COMPLIANCE CREDIT ANALYSIS

Table 1 compares the standard energy budget of a minimally compliant building with a standard chiller to a building with the same features and a full capacity Ice storage TES system for all climate zones.

Table 1

Energy saving based on a full load ice storage system

Climate Zone	Standard Design Total Energy KTDV[1]/ sq ft-yr	Total Energy with TES KTDV/ sq ft-yr	Percent Savings Total	Standard Design Cooling Energy KTDV/yr	Cooling Energy with TES KTDV/yr	Percent Savings Cooling
1	159.3	156.9	2.9%	2,508,922	2,466,264	1.7%
2	173.6	167.4	4.9%	2,703,799	2,646,860	2.1%
3	167.9	162.5	4.9%	2,657,511	2,603,222	2.0%
4	178.3	169.0	6.7%	2,803,167	2,714,622	3.2%
5	170.0	165.8	3.6%	2,701,192	2,653,550	1.8%
6	196.5	188.8	4.5%	2,811,097	2,748,674	2.2%
7	183.4	174.7	5.9%	2,867,078	2,786,152	2.8%
8	203.8	192.8	6.4%	2,915,815	2,825,029	3.1%
9	203.9	192.8	7.1%	2,920,344	2,823,482	3.3%
10	204.3	194.8	6.7%	2,939,046	2,844,113	3.2%
11	181.9	174.3	6.0%	2,831,437	2,742,982	3.1%
12	180.2	171.8	6.2%	2,800,332	2,716,144	3.0%
13	187.0	176.2	7.6%	2,973,796	2,832,051	4.8%
14	205.8	195.4	6.9%	2,899,129	2,784,421	4.0%
15	225.5	208.7	9.5%	3,302,782	3,101,515	6.1%
16	174.4	171.2	4.2%	2,577,746	2,534,021	1.7%

Source: EnergySoft, LLC – data generated using sample building and proposed modeling rules.

A sample building with the following characteristics was used in the analysis:

- Building area: 315,000 square feet
- Occupancy type: Medical office
- Five single duct VAV[2] systems with heating provided by 30 percent VAV terminal boxes
- Lighting Power Density = 1.10 watts per square foot
- Window-to-Wall Ratio: 23 percent

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[1] Thousands of Time Dependent Value
[2] Variable air volume

- Two 300-ton centrifugal chillers using 0.576 kilowatts per ton
- Two 300-ton cooling towers with two speed fans

A 2,400 ton-hour Ice-on-Coil TES system was modeled for the building with a 6 hour (full capacity) TES system. When ice produced by the TES system was melted to meet the building cooling load, one chiller and one cooling tower were modeled as not operating in the simulation.

The percentage savings shown in Table 1 represent the impacts to the total and cooling portion of the building energy use resulting from installation of TES. The amount of compliance credit depends on the climate zone, cooling load and the capacity (ton-hour) of the TES system. Compliance credits for Climate Zone 4 and for Climate Zones 7 through 15 are substantial due to the large cooling loads in those climates.

Energy compliance credit for the use of a TES system may be traded off by reducing the efficiency of other building features. Table 2 shows the impact of trading compliance credit for increased lighting power density.

Table 2

Impact on lighting power density if the entire TES compliance credit is traded for increased lighting power density
(Relative to a Standard lighting requirement of 1.1 watts per square foot)

Climate Zone	Allowed Lighting Power (W/sq ft) with TES compliance credit	Increase in Lighting Power over Standard lighting requirement (W/sq ft)
1	1.20	0.10
2	1.28	0.18
3	1.26	0.16
4	1.35	0.25
5	1.22	0.12
6	1.25	0.15
7	1.30	0.20
8	1.30	0.20
9	1.33	0.23
10	1.35	0.25
11	1.33	0.23
12	1.33	0.23
13	1.38	0.28
14	1.33	0.23
15	1.44	0.34
16	1.30	0.20

Source: EnergySoft, LLC – data generated using sample building and proposed modeling rules.

Table 2 shows that the TES compliance credit allows the lighting power density to be increased from 0.1 to 0.34 watts per square foot depending on the climate zone, resulting in a percentage increase in lighting power of up to 30 percent.

Table 3 shows the impact to natural gas consumption when compliance credit is completely traded off by reducing building envelope energy efficiency features. The projected statewide increase in therms/yr is based on construction activity in 2003.

Table 3

Impact on natural gas use if compliance credit is completely traded for reduction in building envelope energy efficiency features

Climate Zone	Baseline Therms/yr	Therms/yr with TES if credit is completely traded off	Increase in Therms/yr
1	30,573	43,354	12,781
2	33,167	51,277	18,110
3	24,622	45,648	21,026
4	24,869	50,663	25,794
5	21,681	36,167	14,486
6	13,808	31,823	18,015
7	15,887	32,288	16,401
8	14,256	36,387	22,131
9	15,804	40,313	24,509
10	17,805	41,126	23,321
11	36,036	60,351	24,315
12	33,738	57,159	23,421
13	24,951	53,254	28,303
14	32,727	61,774	29,047
15	13,277	37,239	23,962
16	59,583	78,029	18,446

Source: EnergySoft, LLC – data generated using sample building and proposed modeling rules.

As shown in the Tables 2 and 3, compliance credit tradeoffs may result in increased electricity and natural gas use. Environmental impacts resulting from compliance credit tradeoffs are addressed on page 20 of this report.

Table 4 demonstrates the impacts that will result when a TES is sized to provide only a portion of the load. In this analysis the impact of a chilled water system that is sized to serve approximately half the demand period (running 3 hours from 12 to 3) is compared to a building with base case assumptions in all climate zones.

Table 4

Energy saving based on a partial load chilled water system

Climate Zone	Standard Design Total Energy KTDV/ sq ft-yr	Total Energy with TES KTDV/ sq ft-yr	Percent Savings	Standard Design Cooling Energy KTDV/yr	Cooling Energy with TES KTDV/yr	Percent Savings
1	161.5	156.5	3.1%	2,508,922	2,469,648	1.6%
2	176.0	171.6	2.5%	2,703,799	2,684,008	0.7%
3	170.9	164.9	3.6%	2,657,511	2,627,924	1.1%
4	181.1	174.5	3.6%	2,803,167	2,772,113	1.1%
5	172.0	166.7	3.1%	2,701,192	2,676,264	0.9%
6	197.7	191.6	3.1%	2,811,097	2,793,552	0.6%
7	185.6	179.4	3.3%	2,867,078	2,848,971	0.6%
8	205.9	198.9	3.4%	2,915,815	2,895,214	0.7%
9	207.5	199.8	3.7%	2,920,344	2,895,772	0.8%
10	208.9	201.4	3.6%	2,939,046	2,914,552	0.8%
11	185.4	180.6	2.6%	2,831,437	2,808,456	0.8%
12	183.2	177.1	3.3%	2,800,332	2,772,915	1.0%
13	190.7	185.6	2.7%	2,973,796	2,943,974	1.0%
14	209.9	203.4	3.1%	2,899,129	2,867,810	1.1%
15	230.6	223.6	3.0%	3,302,782	3,252,551	1.5%
16	178.7	174.6	2.3%	2,577,746	2,562,966	0.6%

Source: EnergySoft, LLC – data generated using sample building and proposed modeling rules.

Table 4 demonstrates that when TES is designed to operate for reduced hours that Time Dependent Valve (TDV) energy savings are still provided in all 16 climate zones. One clear result shown by the data is that reducing capacity by half significantly reduces savings, particularly in cooling predominated climate zones. A portion of this impact may be caused by the 12 Noon start time (which is a required assumption for TES modeling).

See the instructions in Appendix C on how to obtain the DOE run files which can be used to evaluate the data presented in Tables 1 through 4.

ELIGIBILITY CRITERIA AND ACCEPTANCE TESTING

To ensure reliable energy savings and proper operation and control, the applicant worked with staff to develop eligibility criteria and acceptance testing requirements.

Eligibility Criteria

The following types of TES systems are eligible for compliance credit:

- Chilled Water Storage
- Ice-on-Coil
- Ice Harvester
- Brine
- Ice-Slurry
- Eutectic Salt
- Clathrate Hydrate Slurry (CHS)

The following Certificate of Compliance information for both the chiller and the storage tank shall be provided on the plans, using the MEC-2-C (TES) form shown in Appendix A, to document the key TES System parameters and allow plan check comparison to the inputs used in the DOE-2 simulation. DOE-2 Keywords are shown in ALL CAPITALS in parentheses.

Chiller:

- Brand and Model
- Type (Centrifugal, Reciprocating, Other)
- Capacity (tons) (SIZE)
- Starting Efficiency (kilowatts per ton) at beginning of ice production (COMP - KW/TON - START)
- Ending Efficiency (kilowatts per ton) at end of ice production (COMP - KW/TON/END)
- Capacity Reduction (% / ^{o} F) (PER – COMP - REDUCT/F)

Storage Tank:

- Storage Type (TES-TYPE)
- Number of Tanks (SIZE)
- Storage Capacity per Tank (ton-hours) (SIZE)
- Storage Rate (tons) (COOL – STORE - RATE)
- Discharge Rate (tons) (COOL – SUPPLY - RATE)
- Auxiliary Power (watts) (PUMPS + AUX - KW)
- Tank Area (CTANK – LOSS - COEFF)
- Tank Insulation (R - Value) (CTANK – LOSS - COEFF)

Acceptance Testing

Acceptance testing also shall be conducted and documented on the MECH-9-A form shown in Appendix B. The installing contractor shall complete the following acceptance tests and certify to ensure the TES System is controlled and operated consistent with the compliance simulation. The results shall be submitted to the Building Department using form MECH-9-A (TES) shown in Appendix B.

1. Verify that the TES system and the chilled water plant is controlled and monitored by an energy management system (EMS).
2. Force the time for TES operation to be between 9 p.m. and 9 a.m. and simulate a partial or no charge of the tank and simulate no cooling load by setting the indoor temperature set point higher than the ambient temperature. Verify that the TES system starts charging (storing energy).
3. Force the time for TES operation to be between 6 p.m. and 9 p.m. and simulate a partial charge on the tank and simulate a cooling load by setting the indoor temperature set point lower than the ambient temperature. Verify that the TES system starts discharging.
4. Force the time for TES operation to be between noon and 6 p.m. and simulate a cooling load by lowering the indoor air temperature set point below the ambient temperature. Verify that the tank starts discharging and the compressor is off. For systems designed to meet partial loads the system should be run until the TES storage is fully depleted. The number of hours of operation before the system depletes its storage must meet or exceed the designed operational hours for the system.
5. Force the time for TES operation to be between 9 a.m. to noon, and simulate a cooling load by lowering the indoor air temperature set point below the ambient temperature. Verify that the tank does not discharge and the cooling load is met by the compressor only.
6. Force the time for TES operation to be between 9 p.m. and 9 a.m. and simulate a full tank charge by changing the sensor that indicates tank capacity to the Energy Management System so that it indicates a full tank capacity. Verify that the tank charging is stopped.
7. Force the time for TES operation to be between noon and 6 p.m. and simulate no cooling load by setting the indoor temperature set point above the ambient temperature. Verify that the tank does not discharge and the compressor is off.
8. Verify that the chiller's efficiency is equal to or greater than the requirements listed in Section 112 of the Building Energy Efficiency Standards.
9. Verify that if the design of the TES equipment includes a bypass that allows for direct chiller operation that it is designed so that if the bypass is used, the efficiency of the system will not be significantly reduced in comparison to a central chiller system with no TES.

ALTERNATIVE CALCULATION METHODS (ACM) APPROVAL MANUAL SECTION

ACM Chapter 3 Optional Capabilities

This section provides recommended language for the *Nonresidential ACM Manual*, Section 3.3, HVAC Systems and Plant under the Subsection 3.3.16, Thermal Energy Storage (TES) Systems.

3.3.16 Thermal Energy Storage (TES) Systems

To prevent the user from specifying a TES system that has insufficient capacity to meet the load, the ACM shall ensure that the cooling load is met. This shall be accomplished by switching to compressor direct efficiency.

Description: The TDV energy savings associated with storing cooling energy during off-peak periods for use during high demand periods may be modeled by the ACM. The ACM shall simulate the TES system according to the following rules, criteria, inputs, and outputs:

1. The system includes a storage tank for storing cooling energy on-site.
2. The storage of cooling energy (charging) is accomplished through an active mechanism such as the pumping of chilled water and not a passive mechanism such as the storage of energy through the thermal mass of the building.
3. Charging is accomplished through an onsite chilled medium such as water or a eutectic solution but not by a direct expansion cooling system.
4. The system includes automatic controls that allow energy storage to occur during off-peak hours.
5. The system (TES-TYPE) is one of the following:

   - Chilled Water Storage
   - Ice-on-Coil
   - Ice Harvester
   - Brine
   - Ice-Slurry
   - Eutectic Salt
   - CHS

DOE Keyword: TES-TYPE
SIZE

COOL-STORE-RATE
COOL-SUPPLY-RATE
COOL-STORE-SCH
CTANK-BASE-T
CTANK-T-RANGE
CTANK-LOSS-COEF
COMP-KW/TON-START
COMP-KW/TON-END
EVAP-DELTA-T
REFRIG-T-AT-PC
PER-COMP-REDUCT/F
PUMP+AUX-KW

The evaporator delta T (EVAP-DELTA-T) shall specify the drop in refrigerant temperature as the system begins to charge. Values shall be set by the ACM as follows:

- Chilled Water - n/a
- Ice-on-Coil Systems - 4º F
- Ice Harvester 4º F
- Brine (Encapsulated Ice) - 4º F
- Ice Slurry - 4º F
- Eutectic Salt - 0º F
- CHS - n/a

The refrigerant temperature (REFRIG-T-AT-PC) shall specify the refrigerant temperature at the start of the storage phase change. Values shall be set by the ACM as follows:

- Chilled Water - n/a
- Ice-on-Coil Systems - 22º F
- Ice Harvester - 22º F
- Brine (Encapsulated Ice) - 22º F
- Ice Slurry - 22º F
- Eutectic Salt - 41º F
- Clathrate Hydrate Slurry (CHS) - n/a

For TES systems that use ice as the storage medium, additional parameters shall specify the efficiency of the chiller when it begins the charging process to make ice (COMP-KW/TON-START) and the efficiency of the chiller at the end of the charging process when ice making is complete (COMP-KW/TON-END). In addition, the reduction in chiller capacity that occurs as the temperature of the refrigerant is reduced during the ice making process (PER-COMP-REDUCT/F) shall be specified.

The thermal energy storage tank shall be simulated through the following additional ACM inputs:

- Storage capacity (SIZE) shall specify the total storage capacity of the system.
- Storage rate (COOL-STORE-RATE) shall specify the maximum rate at which the chiller can add cooling into the storage tank.
- Discharge rate (COOL-SUPPLY-RATE) shall specify the maximum rate at which cooling energy can be extracted from the storage tank.
- Base temperature (CTANK-BASE-T) shall specify the highest temperature of the storage medium delivered. This shall be fixed at 50º F.
- Temperature range (CTANK-T-RANGE) shall specify the temperature difference between the Base temperature and the coldest storage temperature of the system. Values shall be set by the ACM as follows:

    - Chilled Water - 10º F
    - Ice-on-Coil Systems - 18º F
    - Ice Harvester - 18º F
    - Brine (Encapsulated Ice) - 18º F
    - Ice Slurry - 18º F
    - Eutectic Salt - 6º F
    - CHS - 6º F

- Storage tank heat loss Coefficient (CTANK-LOSS-COEF) shall specify the product of the U-Value and area of the storage tank for determining the heat transfer loss between the storage tank and ambient conditions.

The ACM shall use a non-varying charging and discharging schedule for all TES systems (COOL-STORE-SCH). Charging will occur starting at 9 p.m. and ending at 9 a.m. Discharging will begin at noon and end at 6 p.m. The cooling load between 6 p.m. and 9 p.m. is met by the TES system (when the stored energy is available) or by the compressor (when the stored energy is not available). Between 9 a.m. and noon the tank does not discharge, and the cooling load is met by the compressor only.

Auxiliary energy use (PUMP+AUX-KW) shall specify any pumping or energy usage from devices such as air blowers used in the TES system.

Special requirements for ACM developers:

- The PERF-1, Special Features and Modeling section must have a note to alert the building department to inspect the TES system using the MECH-2-C (TES) form.
- The PERF-1 must alert the building department to the need for a Certificate of Acceptance for TES systems, MECH-9-A.

Input Type: Required

Tradeoffs: Yes

Modeling Rules for Proposed Design: Modeling software shall model features of TES systems as input by the user according to plans and specifications for the building.

Modeling Rules for Standard design: Modeling software shall model the system without TES systems according to the required systems and plant capabilities and Table N2-10.

Modeling Rules for Standard Design (Existing, Unchanged & Altered Existing): Modeling software shall model the existing system as it occurs in the existing standard design building. If the permit involves alterations, modeling software shall model the standard design as the existing, unchanged building with the systems that existed before alterations.

ACM Chapter 4 User's Manual and Help System Requirements

This section provides recommended language for inclusion in the *Nonresidential ACM Manual*, Section 4.4.3, HVAC systems and plant, related to the user documentation requirements. The language provided here is similar to that in the current ACM manual.

Thermal Energy Storage (TES) Systems

The ACM user's manual and help system shall describe the types of thermal energy storage (TES) systems that can be modeled. Describe all of the input parameters associated with the storage medium, and special inputs associated with the chiller operation, including when the system is charging the storage medium, meeting the cooling load with the compressor only, meeting the cooling load by discharging the storage medium only, and meeting the cooling load by either discharging the storage medium or with the compressor. Explain that this compliance option requires a special certificate of acceptance that must be filled out in the field, documenting acceptance testing of the TES system. Explain that this compliance option requires a special certificate of compliance to be included on the plans documenting specific TES system parameters.

ACM Chapter 5 Reference Method Comparison Tests

This section provides recommended language for inclusion in the *Nonresidential ACM Manual*, Section 5.3 optional capabilities tests.

5.3.9 O10 Test Series - Thermal Energy Storage (TES) Systems

This series tests thermal energy storage (TES) systems. This test uses the 10-zone version of Building Prototype B with the same features used (except as noted) in test C22C16.

Test O101C3: Building Prototype C - Climate Zone 3 – San Francisco.

This test uses a chilled water storage system to shift cooling load off-peak.

System parameters are identical to Prototype C, except as follows:

Chiller Type:	Water Cooled Centrifugal
Capacity:	25 tons
Efficiency:	0.6 kilowatts per ton
TES Starting Efficiency:	0.7 kilowatts per ton
TES Ending Efficiency:	0.8 kilowatts per ton
Capacity Reduction:	2%

Storage Tank Parameters:

Type:	Chilled Water
Storage Capacity:	150 ton-hrs
Storage Rate:	25 tons
Discharge Rate:	25 tons
Storage Tank Area:	220 square feet
Storage Tank Insulation:	R-10

Test O102C12: Building Prototype C - Climate Zone 12 – Roseville.

This test is the same system that was used for Test 0101C3. However, when used in Roseville, the TES system will have insufficient capacity. The ACM must assure that the additional load is met by backup chillers, or the system must fail.

Test O103C12: Building Prototype C - Climate Zone 12 – Roseville.

This test uses a chilled water storage tank to shift cooling load off-peak.

System parameters are identical to Prototype C, except as follows:

Chiller Type:	Water Cooled Centrifugal
Capacity:	25 tons
Efficiency:	0.6 kilowatts per ton

Storage Tank Parameters:

Type:	Chilled Water
Storage Capacity:	250 ton-hrs
Storage Rate:	40 tons
Discharge Rate:	40 tons
Storage Tank Area:	400 square feet
Storage Tank Insulation:	R-20

Test O104C12: Building Prototype C - Climate Zone 12 – Roseville.

This test uses an ice harvester storage system to shift cooling load off-peak.

System parameters are identical to Prototype C, except as follows:

Chiller Type:	Water Cooled Centrifugal
Capacity:	25 tons
Efficiency:	0.6 kilowatts per ton
TES Starting Efficiency:	0.7 kilowatts per ton
TES Ending Efficiency:	0.8 kilowatts per ton
Capacity Reduction:	2%

Storage Tank Parameters:

Type:	Ice-Harvester
Storage Capacity:	250 ton-hrs
Storage Rate:	40 tons
Discharge Rate:	40 tons
Storage Tank Area:	250 square feet

Storage Tank Insulation:	R-20

Test O105C12: Building Prototype C - Climate Zone 12 – Roseville.

This test uses a brine storage system to shift cooling load off-peak.

System parameters are identical to Prototype C, except as follows:

Chiller Type:	Water Cooled Centrifugal
Capacity:	25 tons
Efficiency:	0.6 kilowatts per ton
TES Starting Efficiency:	0.7 kilowatts per ton
TES Ending Efficiency:	0.8 kilowatts per ton
Capacity Reduction:	2%

Storage Tank Parameters:

Type:	Brine
Storage Capacity:	250 ton-hrs
Storage Rate:	40 tons
Discharge Rate:	40 tons
Storage Tank Area:	250 square feet
Storage Tank Insulation:	R-20

Test O106C12: Building Prototype C - Climate Zone 12 – Roseville.

This test uses an ice-slurry storage system to shift cooling load off-peak.

System parameters are identical to Prototype C, except as follows:

Chiller Type:	Water Cooled Centrifugal
Capacity:	25 tons
Efficiency:	0.6 kilowatts per ton
TES Starting Efficiency:	0.7 kilowatts per ton
TES Ending Efficiency:	0.8 kilowatts per ton
Capacity Reduction:	2%

Storage Tank Parameters:

Type:	Ice-Slurry
Storage Capacity:	250 ton-hrs
Storage Rate:	40 tons
Discharge Rate:	40 tons
Storage Tank Area:	250 square feet
Storage Tank Insulation:	R-20

Test O107C12: Building Prototype C - Climate Zone 12 – Roseville.

This test uses a Clathrate Hydrate Slurry storage system to shift cooling load off-peak.

System parameters are identical to Prototype C, except as follows:

Chiller Type:	Water Cooled Centrifugal
Capacity:	25 tons
Efficiency:	0.6 kilowatts per ton

Storage Tank Parameters:

Type:	CHS
Storage Capacity:	250 ton-hrs
Storage Rate:	40 tons
Discharge Rate:	40 tons
Storage Tank Area:	250 square feet
Storage Tank Insulation:	R-20

Test Run Results:

The sample output below provides an example of the test run results that shall be reported for the ACM Tests.

Test	O101C3	O102C12	O103C12	O104C12	O105C12	O106C12	O107C12
Heating	27.12	31.23	31.23	31.23	31.23	31.23	31.23
Cooling	40.07	61.94	51.8	53.78	53.78	53.78	51.71
Lighting	54.78	54.86	54.86	54.86	54.86	54.86	54.86
Receptacles	34.44	34.53	34.53	34.53	34.53	34.53	34.53
Fans	70.59	78.57	78.57	78.57	78.57	78.57	78.57
Heat Rejection	16.29	22.49	18	18	18	18	18
Pumps/Misc	24.73	27.9	27.9	27.9	27.9	27.9	27.9
Process	0	0	0	0	0	0	0
DHW	40.17	40.17	40.17	40.17	40.17	40.17	40.17
Total	308.19	351.69	337.06	339.04	339.04	339.04	336.97

ENVIRONMENTAL IMPACT

Air Quality

Approval of this compliance option for TES systems will provide substantial cooling compliance credit. The credit may be traded off to allow other less efficient equipment and building envelope features which may result in increased building space heating and/or cooling energy use. For example, this compliance credit may be traded off for measures such as more lighting power or reduced wall and ceiling insulation. Reduction in envelope efficiency features may increase space heating energy use, resulting in increased emissions of NO_x, CO, and PM_{10} at the building site.

It is hard to predict the expected market penetration of TES systems. To assess air quality impacts that could occur as a result of Energy Commission approval of the compliance option, staff evaluated a worst case scenario assuming 100 percent statewide market penetration. Minimally compliant buildings with standard design features in all the climate zones were used as the base case. For the proposed case, a TES system was added to the minimally compliant building, and the building lighting power density was increased until the building again became minimally compliant with the energy budget. In another scenario, the building envelope insulation was degraded until the building became minimally compliant. The onsite electricity and heating energy usage of the proposed building was compared to the base case. The increase in electric and natural gas energy usage were multiplied by emission factors that are applicable to power plant and natural gas furnaces, respectively, for each primary pollutant to estimate the potential worst case incremental emissions that could result from approval of the compliance option.[3]

Tables 5 and 6 show the estimated increase in emissions based on Table 1 data in comparison to total statewide emissions. The emission factors are based on California's statewide average furnace emissions factors developed by Energy Commission staff.

Table 5

Worst case increased emissions from approval of this compliance option when compliance credits are completely traded off for increased lighting power

	NO_x	**CO**	**PM_{10}**
Statewide worst case increased emissions from this compliance option (Tons/yr)	4.09	2.48	.65
Statewide total emissions (Tons/yr)	1,244,449	6,376,204	1,174,229
Worst case percent increase	0.00032%	0.0000388%	0.0000553%

Table 6

Worst case increased emissions from approval of this compliance option when compliance credits are completely traded off for reduced building insulation

	NO_x	**CO**	**PM_{10}**
Statewide worst case increased emissions from this compliance option (Tons/yr)	56.03	16.81	5.6
Statewide total emissions (Tons/yr)	1,244,449	6,376,204	1,174,229
Worst case percent increase	0.0045%	0.000263%	0.000476%

Table 7 shows the average emission factors for furnaces in California that were used in the analysis.

Table 7

Emission factors (Lb. per MMBtu)

Pollutants	NO_X	CO	PM_{10}
Emission factor	0.05	0.03	0.01

[3] Note that reduced electricity consumption would reduce emissions at the power plant that generated the electricity (whether in California or at an out-of-state power plant that supplies electricity to California). These reduced emissions are not a negative environmental impact, and thus are outside this analysis. The location of the reduced emissions at the power plant is indeterminable.

Table 8 shows the average emission factors for power plants in California that were used in the analysis.

Table 8

Emission factors (Lb. per kWh)

Pollutants	NO_X	CO	PM_{10}
Emission factor	0.00038	0.00023	0.00006

Staff finds no significant increase in emissions resulting from the approval of this compliance option.

STAFF CONCLUSIONS

Staff supports the approval of this compliance option with the amendments that have been proposed. Staff believes that TES systems will provide significant and reliable savings during peak periods and that the testing at installation and inspection will provide reasonable quality control. In holding this belief, staff realizes that even with proper installation and inspection there are inherent risks in potentially not achieving the presumed savings. While this concern exists it must be realized that many of the systems already used in the standards have inherent performance issues that may result in substantially lower performance than as modeled.

Staff received several comments on the content of the TES draft report. Staff has given careful consideration to all comments, amending this report where modifications were considered appropriate. Staff has provided responses to each comment in Appendix C of this report.

Prior to the approval of this report by the Energy Commission additional comments must be submitted by July 9th to be considered. Comments should be directed to Rob Hudler at (916) 654-4072 or by email at [rhudler@energy.state.ca.us].

APPENDIX A - CERTIFICATE OF COMPLIANCE FORM

MECH-2-C (TES)

CERTIFICATE OF COMPLIANCE		**MECH-2-C (TES)**
Thermal Energy Storage (TES) Systems		
Project Name		Date
Component	**Parameter** (DOE-2 Keyword)	
Chiller	Brand and Model:	
	Type (Centrifugal, Reciprocating, etc):	
	Capacity (tons): (SIZE)	
	Starting Efficiency (kW/ton): (at beginning of ice production) (COMP-KW/TON-START)	
	Ending Efficiency (kW/ton): (at end of ice production) (COMP-KW/TON-END)	
	Capacity Reduction (% / F): (PER-COMP-REDUCT/F)	
Storage Tank	Storage Type (Check): (TES-TYPE)	☐ Chilled Water Storage ☐ Ice Harvester ☐ Brine ☐ Ice-Slurry ☐ Eutectic Salt ☐ Clathrate Hydrate Slurry
	Number of Tanks: (SIZE)	
	Storage Capacity per Tank (ton-hours): (SIZE)	
	Storage Rate (tons): (COOL-STORE-RATE)	
	Discharge Rate (tons): (COOL-SUPPLY-RATE)	
	Auxiliary Power (watts): (PUMP+AUX-KW)	
	Tank Area (sq ft): (CTANK-LOSS-COEFF)	
	Tank Insulation (R-Value): (CTANK-LOSS-COEFF)	

APPENDIX B - CERTIFICATE OF ACCEPTANCE FORM

Mech-9-A

2005 ACCEPTANCE REQUIREMENTS FOR CODE COMPLIANCE

Thermal Energy Storage (TES) System Acceptance Document MECH-9-A

Project Name	Date
Project Address	

TES System Controls and Operation Verification

1	The TES system and the chilled water plant is controlled and monitored by an EMS.	☐ Pass ☐ Fail
2	Force the time to be between 9 p.m. and 9 a.m. and simulate a partial or no charge of the tank and simulate no cooling load by setting the indoor temperature set point higher than the ambient temperature. Verify that the TES system starts charging (storing energy).	☐ Pass ☐ Fail
3	Force the time to be between 6 p.m. and 9 p.m. and simulate a partial charge on the tank and simulate a cooling load by setting the indoor temperature set point lower than the ambient temperature. Verify that the TES system starts discharging.	☐ Pass ☐ Fail
4	Force the time to be between noon and 6 p.m. and simulate a cooling load by lowering the indoor air temperature set point below the ambient temperature. Verify that the tank starts discharging and the compressor is off. For systems designed to meet partial loads the system should be run until the TES storage is fully depleted. The number of hours of operation must meet or exceed the designed operational hours for the system.	☐ Pass ☐ Fail
5	Force the time to be between 9 a.m. to noon, and simulate a cooling load by lowering the indoor air temperature set point below the ambient temperature. Verify that the tank does not discharge and the cooling load is met by the compressor only.	☐ Pass ☐ Fail
6	Force the time to be between 9 p.m. and 9 a.m. and simulate a full tank charge by changing the output of the sensor to the EMS. Verify that the tank charging is stopped.	☐ Pass ☐ Fail
7	Force the time to be between noon and 6 p.m. and simulate no cooling load by setting the indoor temperature set point above the ambient temperature. Verify that the tank does not discharge and the compressor is off.	☐ Pass ☐ Fail

Certification Statement

I certify that all statements are true on this MECH-9-A form, including the PASS/FAIL Evaluation. I affirm I am eligible to sign this form under the provisions described in the Statement of Acceptance on form MECH-1-A

Name:		
Company:		
Signature:		Date:

APPENDIX C - DOE INPUT FILES

If you desire to review the input file contact Rob Hudler by email at [rhudler@energy.state.ca.us] or by telephone at (916) 654-4072.

APPENDIX D - RESPONSE TO COMMENTS

A concern was raised that direct contact refrigeration ice storage was excluded. Staff assumes the comment is directed to Distributed Ice Energy Systems. This compliance option does not include Distributed Ice Energy Systems which were included in a separate compliance option. This compliance option does include ice on coil systems.

Comments were received that the compliance option did not include an allowance for modeling partial storage TES systems. Staff believes partial storage TES are beneficial and modifications have been made to allow for partial storage. The start time for all TES equipment will remain at 12 p.m. with partial storage systems allowed to run out of ice and then switch to compressor mode.

A proposal was made to include monitoring of equipment. While monitoring may be beneficial for utility monitoring it is inappropriate to be included as part of acceptance testing for the building standards. There are no available resources to check this type of data within the current inspection process.

A comment was made suggesting a change in terminology related to brine system type. The terms are built into DOE and making changes in the interface may create more confusion. Staff believes that the terminology should remain as is.

Staff is in agreement that the analysis may need a more conservative perspective. Staff has added additional analysis to include two additional types of equipment. The first is a chiller with a minimal efficiency of 2.5 COP and an IPLV of 2.8. This will include those chillers designed for operating at lower temperature that may be required to operate in compressor mode.

Concerns were raised that TES systems may not deliver projected savings. Staff understands this concern and historically we have required conservative estimates of savings for all equipment. While reliability of savings will always be an issue, a technology cannot be rejected solely on the concern of potential problems with meeting expected energy savings. The concern over reliability and delivered savings could be applied to high efficiency equipment of all types. Staff believes that additional analysis will address the concerns raised and has also included analysis of lower efficiency TES systems.

An issue was raised that source energy should be used to compare TES performance. The reason for development of the Time Dependent Variables (TDV) was to provide recognition that energy generated during peak periods is provided by lower efficiency electricity generation plants. If source energy was used to compare TES then the entire intent of what TDV was intended to support would be invalid.

One comment received noted that the building type was a high-rise hotel. The files were in fact for a medical office building.