

## DOCKETED

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## CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

# Comments on Draft Title 24 Nonresidential Alternative Calculation Method (ACM) Reference Manual

## 2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team

August 20, 2015



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# TABLE OF CONTENTS

---

|                                                                                         |           |
|-----------------------------------------------------------------------------------------|-----------|
| <b>1. Introduction.....</b>                                                             | <b>2</b>  |
| <b>2. Operable Window/Door Interlocks.....</b>                                          | <b>2</b>  |
| 2.1 Recommended Language for ACM Reference Manual –Window/Door Switch<br>Controls ..... | 2         |
| 2.2 Evaluation of Integrated Window/Door Switch Measure .....                           | 3         |
| <b>3. Thermally Driven Cooling .....</b>                                                | <b>10</b> |
| <b>4. Equipment Efficiency .....</b>                                                    | <b>11</b> |
| <b>Appendix A: Thermally Driven Cooling CASE Report.....</b>                            | <b>12</b> |

# 1. INTRODUCTION

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The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE) and Southern California Gas Company (SoCalGas) – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings.

This document presents the Statewide CASE Team's comments on the Draft Nonresidential Alternate Calculation Method (ACM) Reference Manual, which CEC posted for public review on August 8, 2015. The Statewide CASE Team has advocated for several revisions to the ACM Reference Manual since early 2014 that have not yet been incorporated into the draft that CEC released for public review. Specifically, rulesets for thermally driven cooling and operable door/window switch controls have not been fully addressed. This document provides the recommendations that the Statewide CASE Team has provided CEC in previous communications, including in CASE Reports that were submitted in fall 2014.

We look forward to working with CEC in the coming months to add these important rulesets to the Nonresidential ACM Reference Manual.

## 2. OPERABLE WINDOW/DOOR INTERLOCKS

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The Draft Nonresidential ACM Reference Manual does not include a strategy for modeling the operable window/door interlock measure. The adopted Standards for operable windows/doors exempt doors that have automatic closing mechanisms. The measure only applies to doors that, by default, remain open once they are manually opened by a user.

The Statewide CASE Team presented proposed language for the ACM Reference Manual in the Proposals Based on ASHRAE 90.1-2013 CASE Report. We provided CEC staff with an updated version of the proposed language for the ACM Reference Manual on July 17, 2015. For reference, the updated language is provided below.

Section 2.2 of this document presents a summary of the analysis used to generate the proposed ACM language. When compared to the baseline model, which does not include window/door switch controls, the recommended modeling rules will result in about a 1 percent increase in HVAC energy cost if operable windows/doors do not have switches and about a 1 percent decrease in HVAC energy cost if operable windows/doors do have switches.

### 2.1 Recommended Language for ACM Reference Manual – Window/Door Switch Controls

The Statewide CASE Team recommends that the following language be added to the ACM Reference Manual. Proposed additions to the 2013 ACM Reference Manual are underlined and

proposed deletions are ~~stuck~~. All proposed language would be new for the 2016 ACM Reference Manual.

The baseline model will not have operable windows.

If the proposed design includes operable windows or doors that do not meet the exceptions and do not have switches and the operable area of such windows/doors exceeds 1% of the wall area then the design infiltration rate (Ides) for the affected zones in the proposed model is increased from the default value of 0.000228 m<sup>3</sup>/s-m<sup>2</sup> (0.0448 cfm/ft<sup>2</sup> extwall) to 0.00822 m<sup>3</sup>/s-m<sup>2</sup> (1.619 cfm/ft<sup>2</sup> extwall) if:

- Zone is scheduled to be occupied, and either:
  - Outside air temperature is  $\geq 62^{\circ}\text{F}$  and  $\leq 70^{\circ}\text{F}$  and zone is in heating, or.
  - Outside air temperature is  $\geq 75^{\circ}\text{F}$  and  $\leq 80^{\circ}\text{F}$ .

If the proposed design includes operable windows or operable doors that do not meet one of the exceptions and all such windows/doors have window switches then the design infiltration rate (Ides) for the affected zones in the proposed model is increased from the default value of 0.000228 m<sup>3</sup>/s-m<sup>2</sup> (0.0448 cfm/ft<sup>2</sup> extwall) to 0.00382 m<sup>3</sup>/s-m<sup>2</sup> (0. 0.753 cfm/ft<sup>2</sup> extwall) if:

- Zone is scheduled to be occupied, and
- Outside air temperature is  $\geq 62^{\circ}\text{F}$  and below cooling setpoint, and
- Zone is in cooling (Room temperature  $\geq$  cooling setpoint – 1.0°F).

## 2.2 Evaluation of Integrated Window/Door Switch Measure

### 2.2.1 Introduction

When a building has both mechanical heating/cooling and operable windows/doors, it is likely that annual heating/cooling energy will be higher than if the building did not have operable windows. This is because operable windows/doors are often left open when exterior conditions are not favorable for using outside air for cooling/heating, resulting in high infiltration loads on the mechanical system. There are many reasons why windows or doors end up open when conditions are not favorable, including:

1. Occupant wants more fresh air and does not know or care about heating/cooling energy penalty. This is particularly true when the space temperature can be maintained at setpoint despite the extra infiltration load.
2. Occupant does not know the zone mode (heating/cooling) or outside temperature so cannot gauge if opening the window will reduce or increase energy use.
3. Occupant opened the window under favorable conditions, but left the room (with the window open) and conditions changed to unfavorable.
4. Occupant A's office has the thermostat for a zone that includes Occupant B's office. Occupant A opens the window on a brisk day causing the zone to go to full heating. Occupant B is then forced to open the window to prevent from overheating.

The intent of using integrated operable window/door switches is to prevent unnecessary energy use for heating or cooling additional un-tempered air if an operable window is left open. This is accomplished by integrating a simple mechanical interlock into the HVAC system operation with respect to operable window position. One example of this would be an HVAC system that disables heating when any window in the room with the thermostat is left open. Note that

mechanical ventilation would not be required to be disabled. For example, this requirement could be met by resetting the active heating setpoint to 60°F while still providing minimum ventilation to a zone with open windows.

## **2.2.2 Summary of Modeling Methodology and Results**

To evaluate both the penalty and the benefits of window switch, a reference medium office building was simulated for both Sacramento and Oakland, California.

The simulation results show the total HVAC Time Depending Valuation (TDV) energy consumption increases by 0.67 percent to 2.64 percent in Sacramento for a mixed mode building without window switch when compared to a well-sealed building with Title 24-2013 specified infiltration rate. In Oakland, the penalty is 0.54 to 1.97 percent. For buildings with window switch, the HVAC TDV energy decreased by 0.42 percent to 1.13 percent for Sacramento, and 2.46 percent to 6.11 percent for Oakland.

## **2.2.3 Methodology**

To evaluate both the penalty and the benefits of window switches, a reference medium office building was simulated using EnergyPlus V 8.1. EnergyPlus was selected because of its capability to model thermal mass effect, and it allows easy implementation of various window operation strategies. Developers of CBECC-Com (California Building Energy Code Compliance for Commercial/Nonresidential Buildings) software provided the prototype office building model. The CBECC-Com prototypes is a subset of the DOE Prototype Buildings Models developed by Pacific Northwest National Laboratory for analysis of ASHRAE Standard 90.1. The models are modified to comply with the requirements of Title 24-2013, and they are available from the California Energy Commission's Building Energy Efficiency Software Consortium webpage.

Buildings under the following conditions were modeled (see Table 1):

- Model 0: Sealed building with conventional HVAC and non-operable windows
- Model 1: Building with conventional HVAC and unfavorable operable window open during occupied hours
- Model 2: Building with window switch integrated HVAC and operable window open during occupied hours

**Table 1: Simulation Models**

| Model | Descriptions    | Window/Door Open/Close*                                                                                                                                                                                                                          |
|-------|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0     | Baseline sealed | Closed all the time                                                                                                                                                                                                                              |
| 1     | Without switch  | Open only when: <ul style="list-style-type: none"> <li>▪ Space is occupied; and</li> <li>▪ OAT is between 62 and 70 °F and the space is in heating; or</li> <li>▪ OAT is between 75 and 80 °F.</li> </ul>                                        |
| 2     | With switch     | Open only when: <ul style="list-style-type: none"> <li>▪ Space is occupied; and</li> <li>▪ OAT is between 62 and cooling setpoint; and,</li> <li>▪ Space is in cooling (Room temperature <math>\geq</math> cooling setpoint – 1.0°F).</li> </ul> |

\*See Section 2.2.6 for 2013 Title 24 HVAC setpoint and operation schedule

## 2.2.4 Modeling of Infiltration

Window operation (open/close) is simulated by changing of the infiltration rate in buildings, i.e. infiltration rate is at baseline level when windows are closed and at higher level (to be determined) when they are open.

### **Baseline Design Infiltration Rate**

The baseline building is a sealed building with infiltration rate specified by the 2013 Title 24 Nonresidential ACM method. This method requires modeling software to calculate the infiltration rate into the building based on design infiltration rate ( $I_{des}$ ), schedule fraction ( $F_{schedule}$ ), temperature difference between zone and outdoor air, and wind speed, using the following equation:

$$Infiltration = I_{des} \cdot F_{schedule} (A + (B \cdot |t_{zone} - t_{odb}|) + (C \cdot ws) + (D \cdot ws^2))$$

Where:

|                |                                                                         |
|----------------|-------------------------------------------------------------------------|
| Infiltration   | = zone infiltration airflow (m <sup>3</sup> /s –m <sup>2</sup> )        |
| $I_{des}$      | = design zone infiltration airflow (m <sup>3</sup> /s –m <sup>2</sup> ) |
| $F_{schedule}$ | = fraction adjustment from a user input schedule                        |
| $t_{zone}$     | = zone air temperature (°C)                                             |
| $t_{odb}$      | = outdoor drybulb temperature (°C)                                      |
| ws             | = wind speed (m/s)                                                      |
| A              | = overall coefficient                                                   |
| B              | = temperature coefficient (1/°C)                                        |
| C              | = wind speed coefficient (s/m)                                          |
| D              | = wind speed square coefficient (s <sup>2</sup> /m <sup>2</sup> )       |

For the baseline design,  $I_{des}$  have a default of 0.0448 cfm/ft<sup>2</sup> (0.000228 m<sup>3</sup>/s –m<sup>2</sup>) times the gross wall area exposed to ambient outdoor air. Coefficients A, B and D shall be zero. Coefficient C shall be 0.10016 hr/mile (0.224 s/m). The specified 0.0448 cfm/ft<sup>2</sup> is the infiltration rate at 10 mph wind speed. The infiltration schedule  $F_{schedule}$  is specified as 1.0

when HVAC is off and 0.25 otherwise. See Section 2.2.6 of this document for 2013 Title 24 ACM schedule.

### ***Infiltration Rate with Open Window***

The impacts of open windows are captured by increasing the design infiltration rate (see Table 2).

**Table 2: Simulated Design Infiltration Rates When Window is Open**

| <b>Infiltration Rate at Window Open</b> | <b>Label*</b> | <b>Design infiltration Rate (<math>I_{des}</math>)<br/>[m<sup>3</sup>/s-m<sup>2</sup>_extwall] (lcfm/ft<sup>2</sup>_extwall)</b> |
|-----------------------------------------|---------------|----------------------------------------------------------------------------------------------------------------------------------|
| Base                                    | Base          | 0.000228 (0.0448)                                                                                                                |
| Base + 0.005                            | Base + 2100%  | 0.005228 (1.0291)                                                                                                                |
| Base + 0.008                            | Base + 3500%  | 0.008228 (1.6196)                                                                                                                |
| Base + 0.010                            | Base + 4400%  | 0.010228 (2.0133)                                                                                                                |
| Base + 0.012                            | Base + 5300%  | 0.012228 (2.4070)                                                                                                                |
| Base + 0.015                            | Base + 6600%  | 0.015228 (2.9975)                                                                                                                |
| Base + 0.020                            | Base + 8800%  | 0.020228 (3.9818)                                                                                                                |

\*The percentage increase from baseline is rounded up for convenience

## **2.2.5 Results**

### ***Baseline Model***

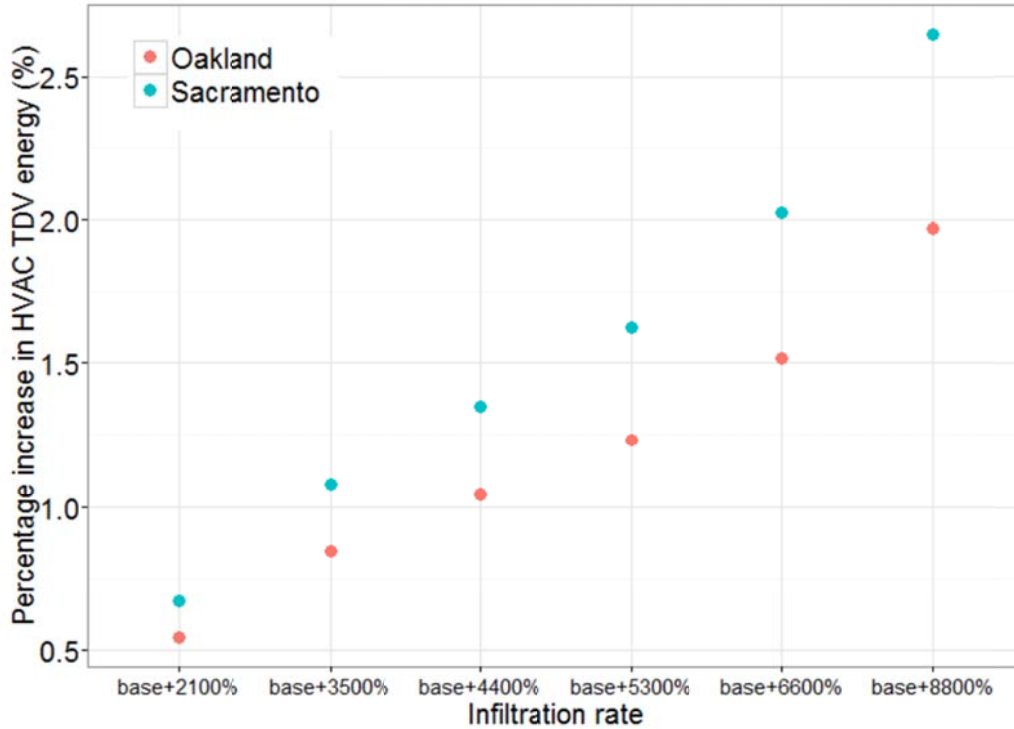
Table 3 summarizes the baseline model HVAC energy consumption. The site energy usages are converted to 15-year TDV energy consumption as required by Title 24.

**Table 3: Baseline Model HVAC TDV Energy Consumption**

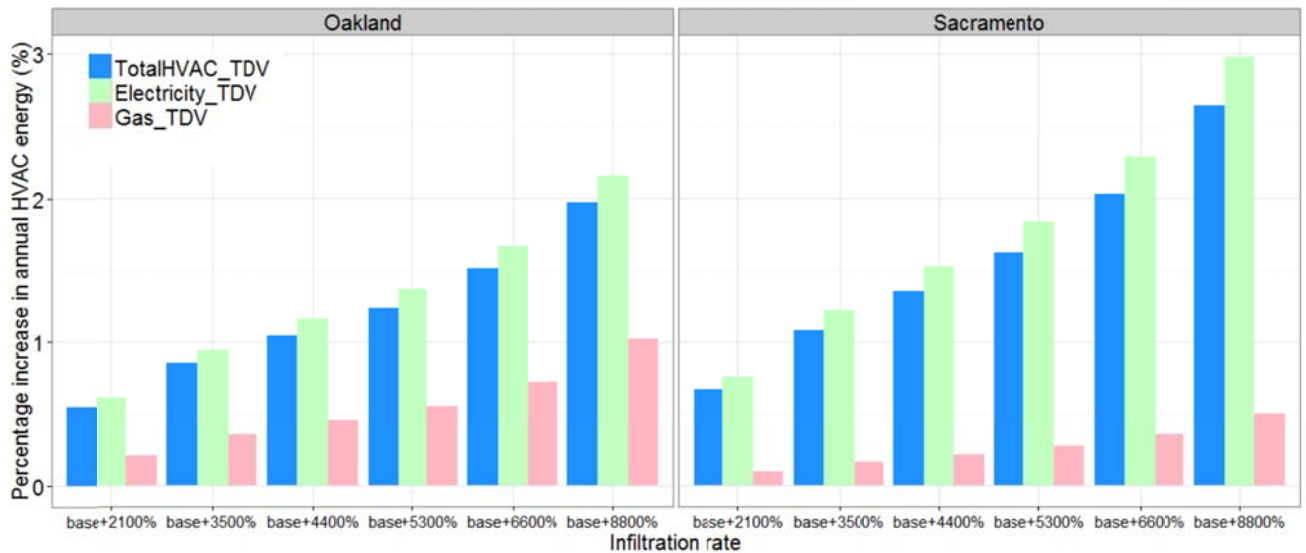
| <b>Location</b> | <b>HVAC Gas TDV (kBtu)</b> | <b>HVAC Electricity TDV (kBtu)</b> | <b>Total HVAC TDV (kBtu)</b> | <b>HVAC TDV Intensity (kBtu/ft<sup>2</sup>)</b> |
|-----------------|----------------------------|------------------------------------|------------------------------|-------------------------------------------------|
| Sacramento, CA  | 616,191                    | 3,914,688                          | 4,530,878                    | 84.5                                            |
| Oakland, CA     | 465,512                    | 2,465,710                          | 2,931,223                    | 54.7                                            |

### ***Penalty without Window Switch (Model 1)***

Figure 1 shows the percentage increase in total HVAC TDV energy consumption for buildings without window switch. Figure 2 shows the HVAC electricity and gas TDV consumption breakdown.



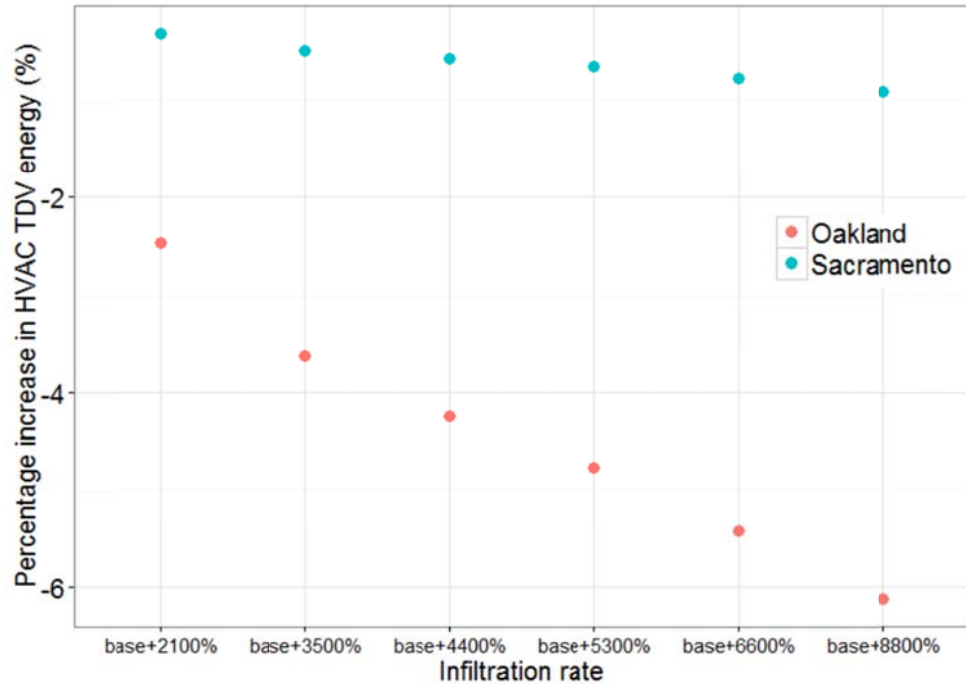
**Figure 1: Total Annual Energy Percentage Difference from the Baseline for Buildings without Window Switch**



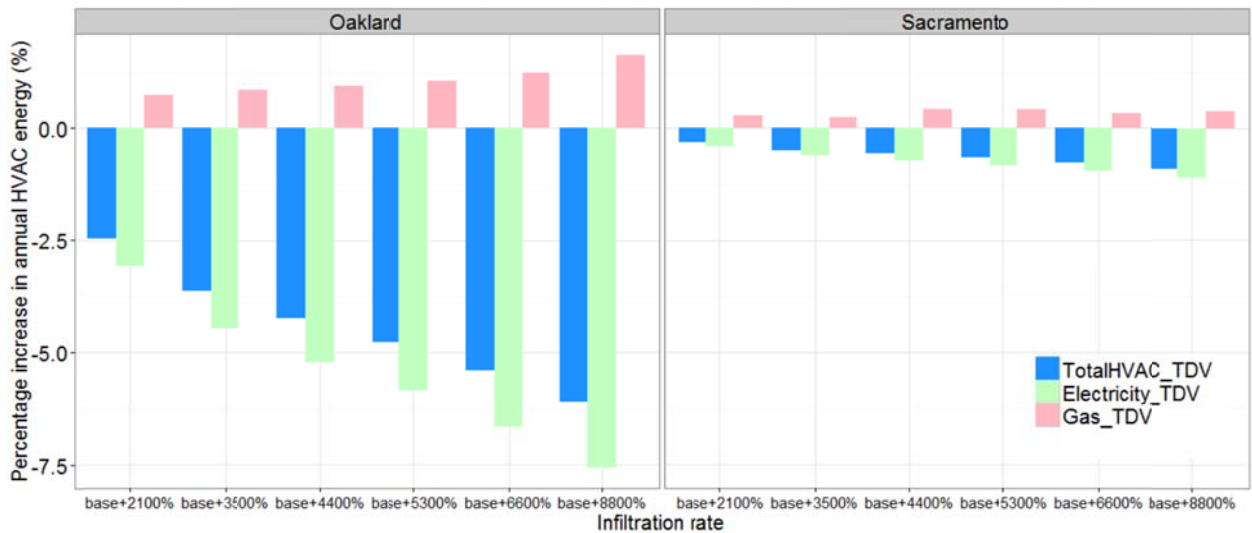
**Figure 2: Breakdown of Energy Percentage Difference from Baseline for Buildings without Window Switch**

### ***Benefit of Window Switch (Model 2)***

Figure 3 shows the percentage increase in total HVAC TDV energy consumption for buildings with window switch. **Figure 4** shows the HVAC electricity and gas TDV consumption breakdown. The benefit for Oakland is larger compared to Sacramento, because the buildings in Oakland can take advantage of free cooling for a longer period of time.



**Figure 3: Total HVAC TDV Energy Increase from the Baseline for Buildings with Window Switch (No Expanded Thermal Comfort Zone)**



**Figure 4: Breakdown of HVAC TDV Energy Increase from Baseline for Buildings with Window Switch**

## 2.2.6 2013 Title 24 ACM Schedule

| Description  |          | Daily Sch | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   |
|--------------|----------|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| HVAC Avail   | OnOff    | WD        | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    |
|              |          | Sat       | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    |
|              |          | Sun       | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    | 0    |
| HtgSetpt     | Temp     | WD        | 60   | 60   | 60   | 60   | 60   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   |
|              |          | Sat       | 60   | 60   | 60   | 60   | 60   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 70   | 60   | 60   | 60   | 60   | 60   |
|              |          | Sun       | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   | 60   |
| ClgSetpt     | Temp     | WD        | 85   | 85   | 85   | 85   | 85   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   |
|              |          | Sat       | 85   | 85   | 85   | 85   | 85   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 75   | 85   | 85   | 85   | 85   | 85   |
|              |          | Sun       | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   | 85   |
| Infiltration | Fraction | WD        | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
|              |          | Sat       | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1.00 | 1.00 | 1.00 | 1.00 |
|              |          | Sun       | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

### 3. THERMALLY DRIVEN COOLING

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The Statewide CASE Team recommends adding rulesets for thermally driven cooling. Adding these rulesets would enable a new compliance option that would allow applicants to take credit for the energy benefits of cooling spaces with a thermally driven cooling system. The Statewide CASE Team presented proposed language for the ACM Reference Manual in the Thermally Driven Cooling CASE Report, which is provided in Appendix A of this document and is available on CEC's website<sup>1</sup>.

The Statewide CASE Team recognizes that there is a placeholder for thermally driven cooling in Section 5.7.5.12 in the Draft ACM Reference Manual, and that CEC will be updating this section in the coming months. The CASE Report includes recommended content for this section. In the CASE Report, we also recommend the following addition to Section 5.10. Proposed additions to the 2013 ACM Reference Manual are underlined and proposed deletions are ~~struck~~.

#### 5.10 On-Site Power and Heat Generation

Building projects may incorporate other on-site electricity generation equipment, such as cogeneration plants or fuel cells that make electricity and produce heat. Projects may also include wind turbines. These systems may be modeled in various ways and the building descriptors described below should be considered an example of one set. In all cases, the baseline building will be modeled without on-site generation equipment. If there is no thermal link between the power generation equipment and building equipment (such as heat recovery from combined heat and power (CHP), on-site power generation can be modeled in a separate process; otherwise, it needs to be linked to the building simulation.

When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy, and all energy required to deliver the cooling to spaces within the building. If thermal storage is used, any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site.

RESERVED FOR FUTURE USE – onsite power generation systems are not currently modeled for Title 24 compliance or reach. Qualifying solar water heating systems are specified by a solar fraction, and referenced in Section 5.9.

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<sup>1</sup> [http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-06-12\\_workshop/final\\_case\\_reports/2016\\_T24\\_CASE\\_Report\\_Thermally\\_Driven\\_Cooling-Oct2014-V2.pdf](http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-06-12_workshop/final_case_reports/2016_T24_CASE_Report_Thermally_Driven_Cooling-Oct2014-V2.pdf)

## 4. EQUIPMENT EFFICIENCY

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The Statewide CASE Team recommends that the ACM Reference Manual include tables that present the minimum equipment efficiency values used in the Standard Design. Presenting these values in the ACM Reference Manual will allow users to easily verify that their default assumptions for the Standard Design are correct. It will also help software developers confirm the correct values when they are making updates to prepare for the 2016 Title 24 cycle. When developing the HVAC Equipment Efficiency Based on ASHRAE 90.1-2013 CASE Report, the Statewide CASE Team recommended updated equipment efficiency values based on the federal, ASHRAE 90.1 and Title 20 Standards. The Statewide CASE Team has submitted an Excel file titled *2016 Title 24 - CASE Team Comments on Draft NR ACM Manual - Min Equip Efficiency* to the docket that presents the minimum equipment efficiency values. This information can be used to develop tables for the ACM Reference Manual.

# **APPENDIX A: THERMALLY DRIVEN COOLING CASE REPORT**

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## CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

# Thermally Driven Cooling

Measure Number: 2016-NR-HVAC2-F

Nonresidential HVAC

## 2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team

October 2014

*Prepared by: Matthew Tyler, PE (PECI)*



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# TABLE OF CONTENTS

---

|            |                                                                                              |           |
|------------|----------------------------------------------------------------------------------------------|-----------|
| <b>1.</b>  | <b>Introduction.....</b>                                                                     | <b>1</b>  |
| <b>2.</b>  | <b>Measure Description.....</b>                                                              | <b>2</b>  |
| <b>2.1</b> | <b>Measure Overview.....</b>                                                                 | <b>2</b>  |
| 2.1.1      | Measure Description.....                                                                     | 2         |
| 2.1.2      | Measure History .....                                                                        | 3         |
| 2.1.3      | Existing Standards .....                                                                     | 4         |
| 2.1.4      | Alignment with Zero Net Energy Goals.....                                                    | 4         |
| 2.1.5      | Relationship to Other Title 24 Measures.....                                                 | 4         |
| <b>2.2</b> | <b>Summary of Changes to Code Documents.....</b>                                             | <b>5</b>  |
| 2.2.1      | Catalogue of Proposed Changes.....                                                           | 5         |
| 2.2.2      | Standards Change Summary.....                                                                | 6         |
| 2.2.3      | Standards Reference Appendices Change Summary .....                                          | 6         |
| 2.2.4      | Nonresidential Alternative Calculation Method (ACM) Reference Manual<br>Change Summary ..... | 6         |
| 2.2.5      | Compliance Forms Change Summary.....                                                         | 7         |
| 2.2.6      | Simulation Engine Adaptations.....                                                           | 7         |
| 2.2.7      | Other Areas Affected.....                                                                    | 7         |
| <b>2.3</b> | <b>Code Implementation.....</b>                                                              | <b>7</b>  |
| 2.3.1      | Verifying Code Compliance.....                                                               | 7         |
| 2.3.2      | Code Implementation .....                                                                    | 7         |
| 2.3.3      | Acceptance Testing .....                                                                     | 8         |
| <b>2.4</b> | <b>Issues Addressed During CASE Development Process .....</b>                                | <b>8</b>  |
| <b>3.</b>  | <b>Market Analysis .....</b>                                                                 | <b>9</b>  |
| <b>3.1</b> | <b>Market Structure.....</b>                                                                 | <b>9</b>  |
| <b>3.2</b> | <b>Market Availability and Current Practices.....</b>                                        | <b>9</b>  |
| <b>3.3</b> | <b>Useful Life, Persistence, and Maintenance .....</b>                                       | <b>11</b> |
| <b>3.4</b> | <b>Market Impacts and Economic Assessments.....</b>                                          | <b>11</b> |
| 3.4.1      | Impact on Builders .....                                                                     | 11        |
| 3.4.2      | Impact on Building Designers .....                                                           | 11        |
| 3.4.3      | Impact on Occupational Safety and Health.....                                                | 11        |
| 3.4.4      | Impact on Building Owners and Occupants.....                                                 | 12        |
| 3.4.5      | Impact on Retailers (including manufacturers and distributors) .....                         | 12        |

|            |                                                                                    |           |
|------------|------------------------------------------------------------------------------------|-----------|
| 3.4.6      | Impact on Energy Consultants.....                                                  | 12        |
| 3.4.7      | Impact on Building Inspectors.....                                                 | 12        |
| 3.4.8      | Impact on Statewide Employment.....                                                | 12        |
| <b>3.5</b> | <b>Economic Impacts .....</b>                                                      | <b>12</b> |
| 3.5.1      | Creation or Elimination of Jobs.....                                               | 13        |
| 3.5.2      | Creation or Elimination of Businesses within California.....                       | 13        |
| 3.5.3      | Competitive Advantages or Disadvantages for Businesses within California .....     | 14        |
| 3.5.4      | Increase or Decrease of Investments in the State of California.....                | 14        |
| 3.5.5      | Incentives for Innovation in Products, Materials, or Processes.....                | 14        |
| 3.5.6      | Effects on the State General Fund, State Special Funds and Local Governments ..... | 15        |
| <b>4.</b>  | <b>Methodology .....</b>                                                           | <b>16</b> |
| 4.1        | Existing Conditions .....                                                          | 16        |
| 4.2        | Proposed Conditions .....                                                          | 16        |
| 4.3        | Prototype Buildings.....                                                           | 17        |
| 4.3.1      | Large Office Prototype .....                                                       | 18        |
| 4.3.2      | Small Office Prototype .....                                                       | 19        |
| 4.4        | Climate Dependent.....                                                             | 20        |
| 4.5        | Time Dependent Valuation.....                                                      | 20        |
| 4.6        | Energy Impacts Methodology .....                                                   | 20        |
| 4.6.1      | Per Unit Energy Impacts Methodology .....                                          | 21        |
| 4.6.2      | Statewide Energy Impacts Methodology.....                                          | 23        |
| 4.7        | Cost-effectiveness Methodology .....                                               | 27        |
| 4.7.1      | Cost Savings Methodology.....                                                      | 27        |
| 4.8        | Environmental Impacts Methodology .....                                            | 27        |
| 4.8.1      | Greenhouse Gas Emissions Impacts Methodology .....                                 | 27        |
| 4.8.2      | Water Use and Water Quality Impacts Methodology .....                              | 28        |
| 4.8.3      | Other Impacts Methodology .....                                                    | 28        |
| <b>5.</b>  | <b>Analysis and Results .....</b>                                                  | <b>29</b> |
| 5.1        | Energy Impacts Results .....                                                       | 29        |
| 5.1.1      | Per Unit Energy Impacts Results.....                                               | 29        |
| 5.1.2      | Statewide Energy Impacts Results .....                                             | 30        |
| 5.2        | Cost-effectiveness Results .....                                                   | 31        |
| 5.2.1      | Cost Savings Results .....                                                         | 31        |
| 5.3        | Environmental Impacts Results.....                                                 | 32        |

|           |                                                            |           |
|-----------|------------------------------------------------------------|-----------|
| 5.3.1     | Greenhouse Gas Emissions Results.....                      | 32        |
| 5.3.2     | Water Use and Water Quality Impacts.....                   | 33        |
| 5.3.3     | Other Impacts Results.....                                 | 33        |
| <b>6.</b> | <b>Proposed Language.....</b>                              | <b>34</b> |
| 6.1       | Standards .....                                            | 34        |
| 6.2       | Reference Appendices.....                                  | 34        |
| 6.3       | ACM Reference Manual.....                                  | 34        |
| 6.4       | Compliance Manuals.....                                    | 35        |
| 6.5       | Compliance Forms .....                                     | 35        |
| <b>7.</b> | <b>Proposed Changes to CBECC-COM .....</b>                 | <b>36</b> |
| 7.1       | Absorption and Adsorption Chillers .....                   | 36        |
| 7.2       | Desiccant Cooling .....                                    | 39        |
| <b>8.</b> | <b>Proposed Changes to EnergyPlus.....</b>                 | <b>40</b> |
| 8.1       | Absorption and Adsorption Chillers .....                   | 40        |
| 8.2       | Desiccant Cooling .....                                    | 50        |
| <b>9.</b> | <b>References and Other Research .....</b>                 | <b>52</b> |
|           | <b>Appendix A: Environmental Impacts Methodology .....</b> | <b>54</b> |

## List of Tables

---

|                                                                                                                                           |      |
|-------------------------------------------------------------------------------------------------------------------------------------------|------|
| Table 1: Scope of Code Change Proposal.....                                                                                               | vii  |
| Table 2: Estimated First Year Energy Savings .....                                                                                        | xi   |
| Table 3: TDV 15-Year Energy Cost Savings – Per Unit .....                                                                                 | xii  |
| Table 4: Estimated First Year Statewide Greenhouse Gas Emissions Impacts .....                                                            | xiii |
| Table 5: Impacts on Water Use and Water Quality (2017) .....                                                                              | xiii |
| Table 6: Scope of Code Change Proposal.....                                                                                               | 5    |
| Table 7: Sections of ACM Impacted by Proposed Code Change .....                                                                           | 5    |
| Table 8: Industries Receiving Energy Efficiency Related Investment, by North American<br>Industry Classification System (NAICS) Code..... | 14   |
| Table 9: Prototype Buildings used for Energy, Demand, and Environmental Impacts Analysis .                                                | 18   |
| Table 10: Key Assumptions for Per Unit Energy Impacts Analysis .....                                                                      | 23   |
| Table 11: Description of Space Types used in the Nonresidential New Construction Forecast ..                                              | 24   |
| Table 12: Translation from FCZ to BCZ .....                                                                                               | 25   |
| Table 13: Estimated New Nonresidential Construction in 2017 by Climate Zone and Building<br>Type (Million Square Feet) .....              | 26   |
| Table 14: Energy Impacts per Unit <sup>1</sup> .....                                                                                      | 30   |
| Table 15: Statewide Energy Impacts .....                                                                                                  | 31   |
| Table 16: TDV Energy Cost Savings Over 15 Year Period of Analysis - Per Unit .....                                                        | 32   |
| Table 17: Statewide First Year Greenhouse Gas Emissions Impacts .....                                                                     | 33   |
| Table 18: Impacts of Water Use and Water Quality .....                                                                                    | 33   |
| Table 19: Fuel Sources Included in Energy Budget for the Proposed Design Building.....                                                    | 38   |
| Table 20: Performance Data for Typical Single-Stage Absorption Chillers .....                                                             | 42   |
| Table 21: Performance Data for Typical Two-Stage Absorption Chillers .....                                                                | 43   |
| Table 22: Performance Data for Typical Adsorption Chillers.....                                                                           | 43   |
| Table 23: Coefficients for Typical Adsorption Chiller Capacity Correction Function of Generator<br>Temperature .....                      | 47   |

## List of Figures

---

|                                                                                                                    |    |
|--------------------------------------------------------------------------------------------------------------------|----|
| Figure 1: Psychrometric Chart for Desiccant Cooling Process .....                                                  | 3  |
| Figure 2: District Cooling Projects Installed in Japan .....                                                       | 10 |
| Figure 3: Absorption Chillers Installed in Egypt.....                                                              | 10 |
| Figure 4: Typical Thermal Energy Demand from Solar Thermal System and Boiler, Mid-July in<br>Climate Zone 12 ..... | 17 |
| Figure 5. Large Office Prototype Model.....                                                                        | 19 |
| Figure 6. Small Office Prototype Model.....                                                                        | 20 |
| Figure 7: Climate Zone Mapping for Energy Simulations .....                                                        | 21 |
| Figure 8. California Climate Zone Map.....                                                                         | 22 |
| Figure 9: CBECC Chiller Type Selection.....                                                                        | 36 |
| Figure 10: CBECC Chiller Input Fuel Selection .....                                                                | 37 |
| Figure 11: EnergyPlus Chiller:Absorption:Indirect Input Screen .....                                               | 40 |
| Figure 12: Chiller COP by Percent Loading.....                                                                     | 44 |
| Figure 13: Chiller COP by Percent Loading Normalized to Full Load .....                                            | 45 |
| Figure 14: Chiller COP by Percent Loading Normalized to Full Load with ExhaustFired.idf<br>Example Curve.....      | 46 |
| Figure 15: Typical Adsorption Chiller Capacity as a Function of Evaporator Temperature.....                        | 48 |
| Figure 16: Typical Adsorption Chiller Capacity as a Function of Condenser Temperature .....                        | 49 |
| Figure 17: Typical Adsorption Chiller Capacity as a Function of Generator Temperature .....                        | 49 |

## **Document Information**

Category: Codes and Standards

Keywords: Statewide CASE, Statewide Codes and Standards Team, Statewide CASE Team, Codes and Standards Enhancements, Title 24, 2016, efficiency, thermal cooling, absorption, adsorption, desiccant.

# EXECUTIVE SUMMARY

---

## Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison and Southern California Gas Company – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical information for proposed regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to propose a code change proposal for measure name. The report contains pertinent information that justifies the code change including:

- Description of the code change proposal, the measure history, and existing standards (Section 2);
- Market analysis, including a description of the market structure for specific technologies, market availability, and how the proposed standard will impact building owners and occupants, builders, and equipment manufacturers, distributors, and sellers (Section 3);
- Methodology and assumption used in the analyses energy and electricity demand impacts, cost-effectiveness, and environmental impacts (Section 4);
- Results of energy and electricity demand impacts analysis and environmental impacts analysis (Section 5); and
- Proposed code change language (Section 6).

## Scope of Code Change Proposal

Thermally driven cooling will affect the following code documents listed Table 1.

**Table 1: Scope of Code Change Proposal**

| Standards Requirements<br>(see note below) | Compliance Option | Appendix | Modeling Algorithms | Simulation Engine | Forms |
|--------------------------------------------|-------------------|----------|---------------------|-------------------|-------|
| N/A                                        | Yes               | N/A      | Yes                 | Yes               | N/A   |

Note: An (M) indicates mandatory requirements, (Ps) Prescriptive, (Pm) Performance.

List of other areas affected including changes to trade-offs: None.

## Measure Description

This code change proposal would add a new compliance option for applicants that wish to comply with Title 24 through the performance approach (whole building simulation energy trade-off). Specifically, the proposed code change recommends revisions to the ruleset for the compliance software. This will allow applicants to take credit for the energy benefits of cooling spaces with a thermally driven cooling system to demonstrate compliance with Title 24. This proposed code change affects new construction or major retrofits in nonresidential buildings or high-rise residential buildings that use thermally driven cooling in which the cooling effect is driven by heat rather than mechanical compressors. The heat source could be a boiler, solar thermal, waste heat, or a combination. The waste heat could be process heat, cogeneration, or other sources.

The proposed code change would enable applicants to model the impacts of a thermally driven cooling system that uses either an absorption chiller, adsorption chiller, or desiccant system. Absorption chillers are the most common form of thermally driven cooling systems and have been available for over 50 years. A number of manufacturers currently offer a variety of absorption chillers. Adsorption chillers are also available but they are less common. Another form of cooling that makes use of waste heat is desiccant cooling. Desiccants are used to remove water vapor out of an air stream and waste heat is used to regenerate the desiccant so it is ready to absorb more water vapor.

When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy and all energy required to deliver the cooling to spaces within the building. If thermal storage is used any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site. The proposed code change is neither a prescriptive requirement nor a mandatory requirement and does not affect the base case, or standard budget, used to verify compliance with the performance approach.

Section 2 of this report provides detailed information about the code change proposal including: **Section 2.2 Summary of Changes to Code Documents (page 5)** provides a section-by-section description of the proposed changes to the standards, appendices, ACM, and/or other documents that will be modified as needed by the proposed code change. See the following tables for an inventory of sections of each document that will be modified:

- Table 6: Scope of Code Change Proposal (page 5)
- Table 7: Sections of ACM Impacted by Proposed Code Change (page 5)

Detailed proposed changes to the text of the building efficiency standards, the reference appendices, and are given in **Section 6 Proposed Language** of this report. This section proposes modifications to language with additions identified with underlined text and deletions identified with ~~struck-out~~ text.

## Market Analysis and Regulatory Impact Assessment

The products affected by this proposal include absorption and adsorption chillers and desiccant cooling systems. Absorption chillers are the most common form of thermally driven cooling system and have been available for over 50 years. The most well-known absorption chiller manufacturers, Carrier, Trane, York, Broad, McQuay and Yazaki, offer a variety of absorption chillers. Adsorption chillers are less common in the United States, although they are gaining popularity in Europe. Adsorption chillers have the advantage of using a lower temperature hot water loop, as low as 122 degrees Fahrenheit (°F), which could be useful in many cases especially involving waste heat. Adsorption chiller manufacturers include ECO-MAX, Kawasaki, SorTech, and Weatherite.

Desiccant cooling systems include both solid and liquid desiccant designs. The solid version requires more maintenance and very few systems are available. The liquid version has better efficiency but again very few systems are commercially available. Some of the desiccant cooling manufacturers include Munters, Kathabar and Advantix.

The market structure is similar to that of electric chillers and other typical heating, ventilation and air conditioning (HVAC) equipment, with manufacturers selling to customers through a distribution network and a trained technical workforce available to support installation, repair and maintenance.

The Statewide CASE Team did not perform a cost effectiveness analysis for this proposal because it is an optional compliance credit and not a prescriptive requirement or a mandatory requirement.

The expected impacts of the proposed code change on various stakeholders are summarized below:

- **Impact on builders:** The proposal is not expected to have a significant impact on builders other than additional compliance options available. However, considerable specialized experience will be required to install and start-up the system.
- **Impact on building designers:** The proposal is not expected to have a significant impact on building designers other than additional compliance options available. This particular revision to Title 24 will not require a departure from standard or common design practices for building designers, unless they choose to install a thermally driven cooling system. However, considerable specialized experience will be required to design and model the system if a designer chooses to take advantage of the new thermally driven cooling compliance option
- **Impact on occupational safety and health:** The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by California Division of Occupational Safety and Health. All existing health and safety rules will remain in place. Complying with the proposed code changes is not anticipated to have any impact on the safety or health occupants or those involved with the construction, commissioning, and ongoing maintenance of the building.

- **Impact on building owners and occupants:** The proposal is not expected to have a significant impact on building owners or occupants. However, considerable specialized experience will be required to operate and maintain the system.
- **Impact on equipment retailers (including manufacturers and distributors):** This group will see increased sales of thermally driven cooling systems.
- **Impact on energy consultants:** The proposal is not expected to have a significant impact on energy consultants. However, considerable specialized experience will be required to model the system.
- **Impact on building inspectors:** As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.
- **Statewide employment impacts:** As a whole, the proposed changes to Title 24 are expected to result in positive job growth as noted below in Section 3.5. This measure will create jobs by expanding the small industry associated with thermally driven cooling systems.
- **Impacts on the creation or elimination of businesses in California:** This measure will create new and expand existing California businesses by expanding the small industry associated with thermally driven cooling systems. It is not anticipated that this measure will have a measureable impact on businesses that manufacturer, distribute, or install traditional HVAC systems.
- **Impacts on the potential advantages or disadvantages to California businesses:** This measure will provide additional compliance options, thus California businesses have an advantage due to a greater number of options.
- **Impacts on the potential increase or decrease of investments in California:** As described in Section 3.5 of this report, the California Air Resources Board (CARB) economic analysis of greenhouse gas reduction strategies for the State of California indicates that higher levels of energy efficiency and 33 percent Renewable Portfolio Standard (RPS) will increase investment in California by about 3 percent in 2020 compared to 20% RPS and lower levels of energy efficiency. After reviewing the CARB analysis, the Statewide CASE Team concluded that the majority of the increased investment of the more aggressive strategy is attributed to the benefits of efficiency (CARB 2010b Figures 7a and 10a). The specific code change proposal presented in this report is not expected to have an appreciable impact on investments in California.
- **Impacts on incentives for innovations in products, materials or processes:** Manufacturers of thermally driven cooling systems will have an incentive to develop new products and improve existing products. Utility efficiency programs could offer new incentive programs to encourage increased adoption of thermally driven cooling systems.
- **Impacts on the State General Fund, Special Funds and local government:** The proposed measure is not expected to have an appreciable impact on the State General Fund, Special Funds, or local government funds.
- **Cost of enforcement to State government and local governments:** All revisions to Title 24 will result in changes to Title 24 compliance determinations. State and local code

officials will be required to learn how buildings can comply with the new provisions included in the 2016 Standards, however the Statewide CASE Team anticipates that the cost of training is part of the regular training activities that occur every time the code is updated.

The proposed code change adds a compliance option to the performance approach. The energy impacts will be modeled through the compliance software. The measure does not add additional acceptance tests or field verification requirements that enforcing agencies would be responsible for conducting. For this reason, it is not expected that the proposed revision will have a significant impact on code enforcement. While additional training is not necessary for code compliance, the Statewide CASE Team believes that an education and training campaign will result in more designers taking advantage of the thermally driven cooling compliance option.

- **Impacts on migrant workers; persons by age group, race, or religion:** This proposal and all measures adopted by the CEC into Title 24, Part 6 do not advantage or discriminate in regards to race, religion or age group.
- **Impact on Homeowners (including potential first time homeowners):** The proposal does not impact residential buildings, thus there is no expected impact on homeowners.
- **Impact on Renters:** The proposal is not expected to have a significant impact on renters.
- **Impact on Commuters:** This proposal and all measures adopted by the CEC into Title 24, part 6 are not expected to have an impact on commuters.

## Statewide Energy Impacts

Table 2 shows the estimated energy impacts over the first twelve months of implementation of the thermally driven cooling measure. These estimates are based on a series of building energy simulations as described in Section 4 of this report.

**Table 2: Estimated First Year Energy Savings**

|                          | First Year Statewide Savings |                             |                               | First Year TDV Savings                 |                                       |
|--------------------------|------------------------------|-----------------------------|-------------------------------|----------------------------------------|---------------------------------------|
|                          | Electricity Savings (GWh)    | Power Demand Reduction (MW) | Natural Gas Impact (MMtherms) | TDV Electricity Savings (Million kBTU) | TDV Natural Gas Impact (Million kBTU) |
| Thermally driven cooling | 1.2                          | 0.6                         | -2.2 (increase)               | 42                                     | -18 (increase)                        |

Section 4.6.1 discusses the methodology and Section 5.1.1 shows the results for the per unit energy impact analysis.

## Cost-effectiveness

The Statewide CASE Team did not perform a cost effectiveness analysis for this proposal because it is an optional compliance credit and not a prescriptive requirement or a mandatory requirement.

The Statewide CASE Team performed a TDV energy costs savings analysis and the results are presented in Table 3. The TDV energy costs savings are the present valued energy cost savings over the 15-year period of analysis. For a detailed description of the Cost-effectiveness Methodology see Section 4.7 of this report.

**Table 3: TDV 15-Year Energy Cost Savings – Per Unit**

| <b>Climate Zone</b> | <b>TDV Energy Cost Savings<br/>(2017 PV\$/ton)</b> |
|---------------------|----------------------------------------------------|
| Climate Zone 1      | \$311                                              |
| Climate Zone 2      | \$311                                              |
| Climate Zone 3      | \$311                                              |
| Climate Zone 4      | \$311                                              |
| Climate Zone 5      | \$420                                              |
| Climate Zone 6      | \$420                                              |
| Climate Zone 7      | \$420                                              |
| Climate Zone 8      | \$440                                              |
| Climate Zone 9      | \$440                                              |
| Climate Zone 10     | \$440                                              |
| Climate Zone 11     | \$380                                              |
| Climate Zone 12     | \$380                                              |
| Climate Zone 13     | \$380                                              |
| Climate Zone 14     | \$475                                              |
| Climate Zone 15     | \$475                                              |
| Climate Zone 16     | \$380                                              |

Section 4.7 of this report discusses the methodology and Section 5.2 shows the results of the Cost-Effectiveness Analysis.

## **Greenhouse Gas and Water Related Impacts**

For more a detailed and extensive analysis of the possible environmental impacts from the implementation of the proposed measure, please refer to Section 5.3 of this report.

## **Greenhouse Gas Impacts**

Table 4 presents the estimated impact to greenhouse gas (GHG) emissions of the proposed code change for the first year the standards are in effect. Assumptions used in developing the GHG impacts are provided in Section 4.8.1 of this report.

**Table 4: Estimated First Year Statewide Greenhouse Gas Emissions Impacts**

|                          | Increased GHG Emissions<br>(MTCO <sub>2</sub> e/yr) |
|--------------------------|-----------------------------------------------------|
| Thermally driven cooling | 11,200                                              |

Section 4.8.1 of this report discusses the methodology and Section 5.3.1 shows the results of the greenhouse gas emission impacts analysis.

## Water Use and Water Quality Impacts

Impacts on water use and water quality are presented in Table 5. The water impacts presented below do not include impacts that occur at power plants. The methodology used to derive water use and water quality impacts is presented in Section 4.8.2.

**Table 5: Impacts on Water Use and Water Quality (2017)**

|                                   | On-Site<br>Water<br>Impact <sup>1</sup><br>(gallons/yr) | Embedded<br>Energy<br>Impact <sup>2</sup><br>(kWh/yr) | Impact on Water Quality<br>Material Increase (I), Decrease (D), or No Change (NC)<br>compared to existing conditions |                                  |                                           |        |
|-----------------------------------|---------------------------------------------------------|-------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|----------------------------------|-------------------------------------------|--------|
|                                   |                                                         |                                                       | Mineralization<br>(calcium,<br>boron, and<br>salts)                                                                  | Algae or<br>Bacterial<br>Buildup | Corrosives as a<br>Result of PH<br>Change | Others |
| Impact (I, D, or NC)              | I                                                       | I                                                     | NC                                                                                                                   | NC                               | NC                                        | NC     |
| Per Unit Impacts <sup>3</sup>     | 2,800                                                   | 28                                                    | -                                                                                                                    | -                                | -                                         | -      |
| Statewide Impacts<br>(first year) | 15,600,000                                              | 156,000                                               | -                                                                                                                    | -                                | -                                         | -      |

<sup>1.</sup> Does not include water savings at power plant

<sup>2.</sup> Assumes embedded energy factor of 10,045 kWh per million gallons of water.

<sup>3.</sup> The unit is tons of cooling capacity. For description of prototype buildings refer to Methodology section below.

Section 4.8.2 of this report discusses the methodology and Section 5.3.2 shows the results of the water use and water quality analysis.

## Acceptance Testing

The existing Title 24 acceptance tests that apply to conventional electric chillers also apply to absorption and adsorption chillers. Depending on the design details for a particular project, this could include some or all of the following tests:

- Hydronic valve leakage
- Hydronic system variable flow controls
- Chiller isolation controls.

# 1. INTRODUCTION

---

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison and Southern California Gas Company – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to propose a code change for thermally driven cooling. The report contains pertinent information that justifies the code change.

Section 2 of this CASE Report provides a description of the measure, how the measure came about, and how the measure helps achieve the state's zero net energy (ZNE) goals. This section presents how the Statewide CASE Team envisions the proposed code change would be enforced and the expected compliance rates. This section also summarized key issues that the Statewide CASE Team addressed during the CASE development process, including issues discussed during a public stakeholder meeting that the Statewide CASE Team hosted in May 2014.

Section 3 presents the market analysis, including a review of the current market structure, a discussion of product availability, and the useful life and persistence of the proposed measure. This section offers an overview of how the proposed standard will impact various stakeholders including builders, building designers, building occupants, equipment retailers (including manufacturers and distributors), energy consultants, and building inspectors. Finally, this section presents estimates of how the proposed change will impact statewide employment.

Section 4 describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. Key assumptions used in the analyses are also found in Section 4.

Results from the energy, demand, costs, and environmental impacts analysis are presented in Section 5. The Statewide CASE Team calculated energy, demand, and environmental impacts using two metrics: (1) per unit, and (2) statewide impacts during the first year buildings complying with the 2016 Title 24 Standards are in operation. Time Dependent Valuation (TDV) energy impacts, which accounts for the higher value of peak savings, are presented for the first year both per unit and statewide. The incremental costs, relative to existing conditions are presented as are present value of year TDV energy cost savings and the overall cost impacts over the 30-year period of analysis.

The report concludes with specific recommendations for language for the Standards, Appendices, Alternate Calculation Manual (ACM) Reference Manual and Compliance Forms.

## 2. MEASURE DESCRIPTION

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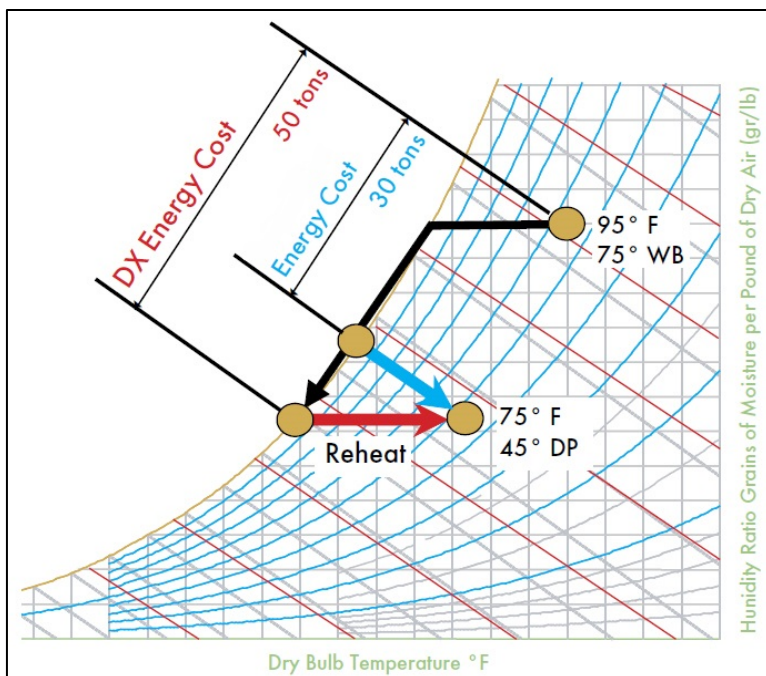
### 2.1 Measure Overview

#### 2.1.1 Measure Description

This code change proposal would add a new compliance option for applicants that wish to comply with Title 24 through the performance approach (whole building simulation energy trade-off). Specifically, the proposed code change recommends revisions to the ruleset for the compliance software. This will allow applicants to take credit for the energy benefits of cooling spaces with a thermally driven cooling system to demonstrate compliance with Title 24. This proposed code change affects new construction or major retrofits in nonresidential buildings or high-rise residential buildings that use thermally driven cooling in which the cooling effect is driven by heat rather than mechanical compressors. The heat source could be a boiler, solar thermal, waste heat, or a combination. The waste heat could be process heat, cogeneration, or other sources.

The proposed code change would enable applicants to model the impacts of a thermally driven cooling system that uses either an absorption chiller, adsorption chiller, or desiccant system. Absorption chillers are the most common form of thermally driven cooling systems and have been available for over 50 years. A number of manufacturers currently offer a variety of absorption chillers. Adsorption chillers are also available but they are less common. Another form of cooling that makes use of waste heat is desiccant cooling. Desiccants are used to remove water vapor out of an air stream and waste heat is used to regenerate the desiccant so it is ready to absorb more water vapor. The desiccant system operates mostly on heat energy rather than mechanical energy. Its electric demand is around 25% of a vapor-compression air conditioner. This system is especially effective at dehumidifying air and most of the cooling is latent heat transfer.

Figure 1 presents a psychrometric chart that illustrates the desiccant cooling process for a typical system. This unit includes a direct expansion (DX) pre-cooling coil, a desiccant wheel, and an integrated condensing package that reactivates the desiccant. At 6000 cfm airflow, for example, entering at 95°F db and 75°F wb, this unit uses 30 tons of compressor cooling. A conventional vapor compression DX unit uses 50 tons of compressor cooling to deliver the same conditions.



**Figure 1: Psychrometric Chart for Desiccant Cooling Process**

This change allows an applicant to model the energy impacts of cooling spaces with a thermally driven cooling system to demonstrate compliance with Title 24 through the performance (whole building simulation energy trade-off) approach. When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy and all energy required to deliver the cooling to spaces within the building. If thermal storage is used any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site.

The proposed code change is neither a prescriptive requirement nor a mandatory requirement and does not affect the base case budget used to verify compliance with the performance approach.

### 2.1.2 Measure History

The 2001 Title 24 Standards included nonresidential gas absorption cooling. Performance was calculated using default DOE-2 curves that describe the chiller efficiency versus leaving chilled water temperature and condenser temperature. The 2001 Title 24 Standards did not address gas engine chillers and heat pumps.

For the 2005 Title 24 Standards, the Statewide CASE Team developed a code change proposal that recommended:

- Modifying the ACM Reference Manual so the model for absorption cooling used a more conservative performance curve than the default DOE-2 curves. This new curve is based on manufacturer data.

- Adding minimum performance values to the Standards' tables for gas engine chillers and heat pumps. Changes to the default DOE-2 performance curves were not recommended for gas engine chillers or heat pumps.
- Modifying *Section 141 Performance Approach: Energy Budgets*. Modify as follows: All energy from depletable sources and recovered from space conditioning equipment used for space conditioning, lighting, and service water heating shall be included .

As of the 2013 Title 24 Standards, there is no provision to account for the use of waste heat or solar thermal when calculating energy budgets. In addition, adsorption chillers are not yet included in Title 24.

### 2.1.3 Existing Standards

The 2013 Title 24 Standards include minimum efficiency requirements for absorption chillers, minimum unloading ratios, and cooling efficiency adjustment curves.

ASHRAE 90.1-2013 includes minimum efficiency requirements for absorption chillers. It specifies that onsite renewable energy and site-recovered energy shall not be considered as purchased energy and shall not be included in the design energy cost for the proposed design. It thus allows a credit for the energy that would otherwise have been purchased. It also restricts the credit to a maximum of 5% of the calculated energy cost budget for the budget building design (standard design building). The renewable energy must be generated onsite by systems included on the building permit and used directly by the building. This prohibits taking credit for a renewable energy system that is rented to or from another facility.

### 2.1.4 Alignment with Zero Net Energy Goals

The Statewide CASE Team and the CEC are committed to achieving California's zero-net-energy (ZNE) goal. This measure will help achieve ZNE goals by greatly reducing the electricity use and peak electric demand of chillers. This proposed modeling will set the foundation for future code changes that will help ensure ZNE goals are achieved. In particular, this measure could lead directly to the following code changes in the 2019 and 2022 code change cycles:

- Prescriptive requirement for thermally driven cooling systems for certain building types; and
- Potential mandatory requirements for thermally driven cooling systems.

If thermally driven cooling is an important aspect of the CEC's strategy for achieving ZNE goals for multi-family buildings, the Statewide CASE Team recommends that adding this compliance option be coupled with an education and training campaign that aims to encourage building designers to take advantage of the new compliance option.

### 2.1.5 Relationship to Other Title 24 Measures

There are no overlaps with other Title 24 code change proposals for the 2016 cycle.

## 2.2 Summary of Changes to Code Documents

The sections below provide a summary of how each Title 24 document will be modified by the proposed change. See Section 6 of this report for detailed proposed revisions to code language.

### 2.2.1 Catalogue of Proposed Changes

#### *Scope*

Table 6 identifies the scope of the code change proposal. This measure will impact the following areas.

**Table 6: Scope of Code Change Proposal**

| <b>Mandatory</b> | <b>Prescriptive</b> | <b>Performance</b> | <b>Compliance Option</b> | <b>Trade-Off</b> | <b>Modeling Algorithms</b> | <b>Forms</b> |
|------------------|---------------------|--------------------|--------------------------|------------------|----------------------------|--------------|
| No               | No                  | Yes                | Yes                      | No               | Yes                        | No           |

#### *Standards*

No changes are needed to the Standards.

#### *Nonresidential Alternative Calculation Method (ACM) Reference Manual*

The proposed code change will modify the sections of the Nonresidential Alternative Calculation Method References identified in Table 7.

**Table 7: Sections of ACM Impacted by Proposed Code Change**

| <b>Nonresidential Alternative Calculation Method Reference</b> |                                                             |                                                                                    |
|----------------------------------------------------------------|-------------------------------------------------------------|------------------------------------------------------------------------------------|
| <b>Section Number</b>                                          | <b>Section Title</b>                                        | <b>Modify Existing (E)<br/>New Section (N)</b>                                     |
| 5.7.7.2                                                        | Desiccant Heat Source                                       | E: Add new heat sources for waste hot water, solar hot water, and condenser heat   |
| 5.8.2                                                          | Chiller Type                                                | E: Add adsorption chiller                                                          |
| 5.8.2                                                          | Chiller Fuel Source                                         | E: Add adsorption chiller                                                          |
| 5.8.2                                                          | Chiller Minimum Unloading Ratio                             | E: Add adsorption chiller                                                          |
| 5.8.2                                                          | Fuel and Steam Chiller Cooling Efficiency Adjustment Curves | E: Add adsorption chiller                                                          |
| 5.10                                                           | On-Site Power Generation                                    | E: Describes ruleset for on-site renewable energy or site recovered thermal energy |

#### *Simulation Engine Adaptations*

The proposed code changes cannot be entirely modeled using EnergyPlus, which is the current simulation engine. Changes to the simulation engine are thus necessary. EnergyPlus already includes a well-developed model for absorption chillers and desiccant systems but it's missing

the capability for adsorption chillers. Section 8: Proposed Changes to EnergyPlus describes the necessary changes in detail.

### **2.2.2 Standards Change Summary**

This proposal would modify the following sections of the Building Energy Efficiency Standards.

#### **Changes in Scope**

No changes are needed to the Standards.

#### **Changes in Mandatory Requirements**

No changes are needed in the mandatory requirements.

#### **Changes in Prescriptive Requirements**

No changes are needed in the prescriptive requirements.

#### **Changes in Performance Requirements**

No changes are needed in the performance requirements.

### **2.2.3 Standards Reference Appendices Change Summary**

No changes are needed to the Standards Reference Appendices.

### **2.2.4 Nonresidential Alternative Calculation Method (ACM) Reference Manual Change Summary**

This proposal would modify the following sections of the Alternative Calculation Method (ACM) Reference Manual as shown below. See **Section 6.3 ACM Reference Manual** of this report for the detailed proposed revisions to the text of the Alternative Calculation Method (ACM) Reference Manual.

#### **Section 5.7 HVAC Secondary Systems and Section 5.8 HVAC Primary Systems**

In summary, this proposal will add new heat sources for waste hot water, solar hot water, and condenser heat. It also adds adsorption chillers, which are currently missing.

**Section 5.7.7.2 Desiccant Heat Source:** Add new heat sources for waste hot water, solar hot water, and condenser heat to ACM Reference Manual.

**Section 5.8.2 Chiller Type:** Add adsorption chiller to ACM Reference Manual

**Section 5.8.2 Chiller Fuel Source:** Add adsorption chiller to ACM Reference Manual.

**Section 5.8.2 Chiller Minimum Unloading Ratio:** Add adsorption chiller to ACM Reference Manual.

**Section 5.8.2 Fuel and Steam Chiller Cooling Efficiency Adjustment Curves:** Add adsorption chiller to ACM Reference Manual.

**Section 5.10 On-Site Power Generation:** Describes ruleset for on-site renewable energy or site recovered thermal energy.

### **2.2.5 Compliance Forms Change Summary**

The proposed code change will not modify the Compliance Forms.

### **2.2.6 Simulation Engine Adaptations**

The proposed code changes cannot be entirely modeled using EnergyPlus, which is the current simulation engine. Changes to the simulation engine are thus necessary. EnergyPlus already includes well-developed models for desiccant systems and absorption chillers but it's missing the capability for adsorption chillers. Section 8: Proposed Changes to EnergyPlus describes the necessary changes in detail.

### **2.2.7 Other Areas Affected**

The California Building Energy Code Compliance (for Commercial/Nonresidential buildings) software (CBECC-Com) is a nonresidential compliance software approved by the CEC for Title 24 compliance. The proposed code changes cannot be modeled using CBECC-Com, thus a number of software changes are needed. Section 7: Proposed Changes to CBECC-COM describes these changes in detail.

## **2.3 Code Implementation**

### **2.3.1 Verifying Code Compliance**

Code enforcement entities will determine if a building complies with the proposed code change similar to the current process for electric chillers. With regard to the new heat sources for waste hot water, solar hot water, and condenser heat, the code enforcement entities will need to review the design and construction documents, especially the plumbing drawings, and compare them with the actual installation.

Field verifications and acceptance tests for the absorption and adsorption changes are identical to those for electric chillers. No additional compliance forms are needed. With regard to the new heat sources for waste hot water, solar hot water, and condenser heat, no field verifications and acceptance tests are needed.

### **2.3.2 Code Implementation**

This proposal will add compliance options for new heat sources including solar hot water, refrigeration condenser heat, heat from fuel cells, engine cooling jacket and exhaust, and turbine exhaust, across various heat transfer fluids including air, water, refrigerant, glycol, and steam. It also adds adsorption chillers, which are currently not included in the compliance software. These changes allow for more design options, which is a benefit to designers and builders. Absorption chillers and desiccant systems are already included in the compliance software and can be used to verify compliance with Title 24 through the performance approach. Adsorption chillers will be added but they are very similar to absorption chillers from a code implementation perspective. The affected industry is the HVAC industry, which is already very familiar with Title 24. Thermally driven cooling systems – particularly systems that use waste heat and heat generated from solar – are not already a common industry practice, which is why this is not a prescriptive or mandatory requirement.

Correct implementation of these changes should not present any undue burden or complexity to designers. It should be relatively easy for building inspectors to verify compliance during the inspection by comparing the design and construction documents, especially the plumbing drawings, with the actual installation. This is a similar process to electric chillers. The Statewide CASE Team does not anticipate that building officials or the building industry will have opposition to this measure.

### **2.3.3 Acceptance Testing**

The existing Title 24 acceptance tests that apply to conventional electric chillers also apply to absorption and adsorption chillers. Depending on the design details for a particular project, this could include some or all of the following tests:

- Hydronic valve leakage
- Hydronic system variable flow controls
- Chiller isolation controls

There are no existing Title 24 acceptance tests that apply to desiccant systems and none are proposed at this time.

## **2.4 Issues Addressed During CASE Development Process**

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the code change proposal presented in this report. In addition to personal outreach to key stakeholders, the Statewide CASE Team conducted a public stakeholder meeting to discuss the proposals. The team spoke with a number of researchers, product engineers and CEOs, project designers and engineers, and program managers. A few questions from stakeholders arose during development of the code change proposal as described here.

It was initially proposed that the energy budget of the proposed design will be reduced by the amount of on-site renewable energy generation or recovered energy that is used for space-conditioning and that the total reduction in the energy budget shall be no more than 15% of the calculated energy budget for the standard design building. It was pointed out that this approach would limit renewables, which was not our intent. The resolution was to include the following language in the ACM Reference Manual:

When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy and all energy required to deliver the cooling to spaces within the building. If thermal storage is used any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site.

Another question arose regarding the temperature of the heat sources used for thermally driven cooling: should these temperatures be limited to certain ranges? The Statewide CASE Team decided to not establish limits on the fluid temperatures. This is because EnergyPlus directly uses the input temperatures, flow rates, and type of fluid (air, water, glycol, etc.) to calculate

the available heat capacity on a sub-hourly basis. If this heat capacity is insufficient to entirely meet the needs of the thermally driven cooling system, then the backup heat source will be used and accounted for by EnergyPlus.

### **3. MARKET ANALYSIS**

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The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market players. Estimates of market size and measure applicability were identified through research and outreach with key stakeholders including utility program staff, CEC, and a wide range of industry players who were invited to participate in a public stakeholder meetings that the Statewide CASE Team held in May 2014.

#### **3.1 Market Structure**

The products affected by this proposal include absorption and adsorption chillers and desiccant cooling systems. Absorption chillers are the most common form of thermally driven cooling system and have been available for over 50 years. Carrier, Trane, York, Broad, McQuay, Yazaki, Thermax and others offer a variety of absorption chillers. Adsorption chillers are less common in the United States, although they are gaining popularity in Europe. Adsorption chillers have the advantage of using a lower temperature hot water loop, as low as 122 degrees Fahrenheit (°F), which could be useful in many cases especially involving waste heat. Adsorption chiller manufacturers include ECO-MAX, Kawasaki, SorTech, and Weatherite.

Desiccant cooling systems include both solid and liquid desiccant designs. The solid version requires more maintenance and very few systems are available. The liquid version has better efficiency, but very few systems are commercially available. Some of the manufacturers include Munters, Kathabar and Advantix.

The market structure is similar to that of electric chillers, with manufacturers selling to customers through a distribution network and a trained workforce available to support installation, repair and maintenance.

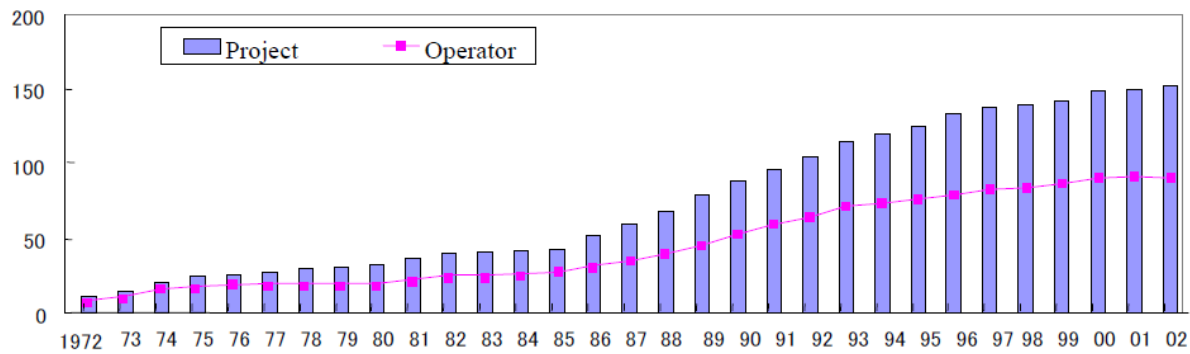
#### **3.2 Market Availability and Current Practices**

The current market for absorption and adsorption chillers and desiccant cooling systems is relatively small. As of September 1, 2014, there are approximately seven different manufacturers of absorption chillers, four different manufacturers of adsorption chillers, and at least four different manufacturers of desiccant cooling systems.

Good applications for thermally driven cooling systems are sites that have a source of recovered energy that is coincident with the need for air conditioning and locations where the peak electric demand charge is high. Thermally driven cooling can help reduce or flatten the electric peaks in a building's electric load profile.

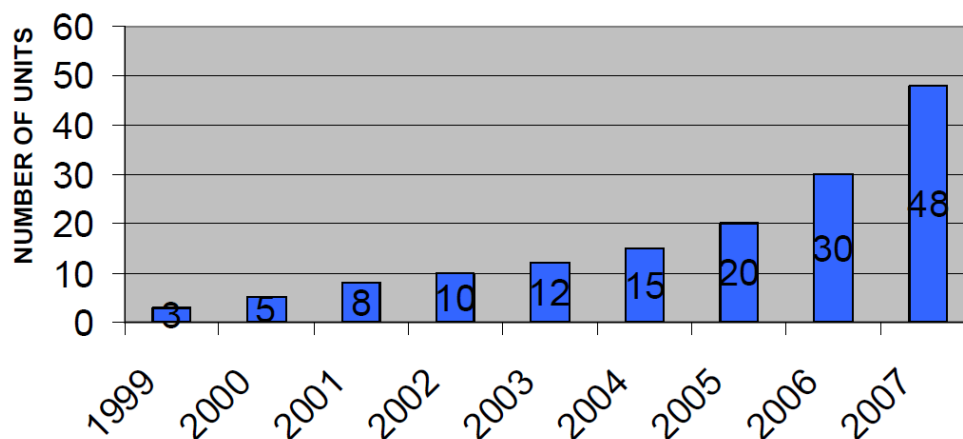
Current or historical sales data was difficult to obtain for these products. Figure 2 displays data from one of the major absorption chiller manufacturers. It shows the cumulative number of

district cooling projects installed in Japan, with 152 total projects across 90 operators (district plants) as of 2002. Of these 152 installations, 57% use absorption chillers, or 87 absorption chillers in total. The apparent sales rate for absorption chillers in this example is around two units per year on average in recent history (1992-2002), or three units per year on average over the past 30 years (1972-2002). Again, this example is for one manufacturer in Japan for district cooling.



**Figure 2: District Cooling Projects Installed in Japan**

Figure 3 displays data from the same major absorption chiller manufacturer. It shows the cumulative number of absorption chillers installed in Egypt, with 48 units installed as of 2007. The apparent sales rate for absorption chillers in this example is around five to eighteen units per year, depending on the reference years.



**Figure 3: Absorption Chillers Installed in Egypt**

New Jersey offers the only apparent incentive program in the country for thermally driven cooling systems using waste heat, called NJ SmartStart Buildings. This program is specifically targeted to direct-fired and indirect-fired absorption chillers and regenerative desiccant units. The incentive for absorption chillers ranges from \$185/ton for large units (>400 tons) to \$450/ton for smaller units (<100 tons). The incentive for desiccant units is \$1/CFM based on process airflow. The Statewide CASE Team spoke with the program manager and learned this program has been available since before 2005. They have very few projects that enroll in the program, typically only around five units each year.

The proposed Standards change is projected to slowly increase awareness and sales of these technologies. There is no reason why the market cannot ramp up production to meet this slowly increasing demand. The system designs are mature and no additional product development or refinements are needed in response to this proposed Standards change.

These code change proposals are estimated to increase the current market share of thermally driven cooling systems by less than 5% per year. A value of five chillers per year is used in the statewide impact calculations.

### **3.3 Useful Life, Persistence, and Maintenance**

The effective useful life of absorption and adsorption chillers is estimated at approximately 20 to 25 years per stakeholder input. Desiccant systems have an estimated useful life of 15 years. Maintenance procedures are not unlike those for electric chillers and include the typical items such as keeping the heat transfer surfaces free of scale and sludge and maintaining the pumps and other mechanical components. However, specially trained and experienced personnel are required to perform maintenance and repairs. The persistence of the energy savings is related to proper maintenance.

### **3.4 Market Impacts and Economic Assessments**

#### **3.4.1 Impact on Builders**

There is no anticipated impact on builders other than additional compliance options available. However, considerable specialized experience will be required to install and start-up the system.

#### **3.4.2 Impact on Building Designers**

There is no anticipated impact on designers other than additional compliance options available. Title 24 is updated on a three-year revision cycle, so acclimating to changes in Title 24 Standards is routine practice for building designers; adjusting design practices to comply with changing code practices is within the normal practices of building designers.

This particular revision to Title 24 will not require a departure from standard or common design practices for building designers, unless they choose to install a thermally driven cooling system. That is, building designers do need to take advantage of this additional compliance option. For designers that choose not to comply using thermally driven cooling, this measure does not result in any changes to standard design practices. However, considerable specialized experience will be required to design and model thermally driven cooling systems. If a designer chooses to use a thermally driven cooling system, the proposed change will allow designers to count the energy benefits of the systems toward compliance with Title 24.

#### **3.4.3 Impact on Occupational Safety and Health**

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Department of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have any impact on

the safety or health occupants or those involved with the construction, commissioning, and ongoing maintenance of the building.

#### **3.4.4 Impact on Building Owners and Occupants**

There is no anticipated impact on owners other than additional compliance options available. There is no impact on the occupants. However, considerable specialized experience will be required to operate and maintain the system.

#### **3.4.5 Impact on Retailers (including manufacturers and distributors)**

This group will see increased sales of thermally driven cooling systems.

#### **3.4.6 Impact on Energy Consultants**

There is no anticipated impact on energy consultants other than additional compliance options available. However, considerable specialized experience will be required to model the system.

#### **3.4.7 Impact on Building Inspectors**

As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes. Inspectors will not be required to complete any tasks that they are not already conducting to verify compliance with the 2013 Standards.

#### **3.4.8 Impact on Statewide Employment**

This measure will create jobs by expanding the small industry associated with thermally driven cooling systems.

### **3.5 Economic Impacts**

The proposed Title 24 code changes, including this measure, are expected to increase job creation, income, and investment in California. As a result of the proposed code changes, it is anticipated that less money will be sent out of state to fund energy imports, and local spending is expected to increase due to higher disposable incomes due to reduced energy costs.

These economic impacts of energy efficiency are documented in several resources including the California Air Resources Board's (CARB) Updated Economic Analysis of California's Climate Change Scoping Plan, which compares the economic impacts of several scenario cases (CARB, 2010b). CARB include one case (Case 1) with a 33% renewable portfolio standard (RPS) and higher levels of energy efficiency compared to an alternative case (Case 4) with a 20% RPS and lower levels of energy efficiency. Gross state production (GSP), personal income, and labor demand were between 0.6% and 1.1% higher in the case with the higher RPS and more energy efficiency (CARB 2010b, Table 26). While CARB's analysis does not report the benefits of energy efficiency and the RPS separately, we expect that the benefits of the package of measures are primarily due to energy efficiency. Energy efficiency measures are expected to reduce costs by \$2,133 million annually (CARB 2008, pC-117) whereas the RPS implementation is expected to cost \$1,782 million annually, not including the benefits of GHG and air pollution reduction (CARB 2008, pC-130).

Macroeconomic analysis of past energy efficiency programs and forward-looking analysis of energy efficiency policies and investments similarly show the benefits to California's economy of investments in energy efficiency (Roland-Holst 2008; UC Berkeley 2011).

### **3.5.1 Creation or Elimination of Jobs**

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation estimates that this scenario would result in a 1.1% increase in statewide labor demand in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Tables 26 and 27). CARB's economic analysis also estimates a 1.3% increase in small business employment levels in 2020 (CARB 2010b, Table 32).

### **3.5.2 Creation or Elimination of Businesses within California**

This measure will create new and expand existing California businesses by expanding the small industry associated with thermally driven cooling systems. It is not anticipated that this measure will have a measureable impact on businesses that manufacturer, distribute, or install traditional HVAC systems.

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation (as described above) estimates that this scenario would result in 0.6% additional GSP in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Table ES-2). We expect that higher GSP will drive additional business creation in California. In particular, local small businesses that spend a much larger proportion of revenue on energy than other businesses (CARB 2010b, Figures 13 and 14) should disproportionately benefit from lower energy costs due to energy efficiency standards. Increased labor demand, as noted earlier, is another indication of business creation.

Table 8 below shows California industries that are expected to receive the economic benefit of the proposed Title 24 code changes. It is anticipated that these industries will expand due to an increase in funding as a result of energy efficiency improvements. The list of industries is based on the industries that the University of California, Berkeley identified as being impacted by energy efficiency programs (UC Berkeley 2011 Table 3.8).<sup>1</sup> This list provided below is not specific to one individual code change proposal, rather it is an approximation of the industries that may receive benefit from the 2016 Title 24 code changes. A table listing total expected job creation by industry that is expected in 2015 and 2020 from all investments in California energy efficiency and renewable energy is presented in the Appendix B of this CASE Report.

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<sup>1</sup> Table 3.8 of the UC Berkeley report includes industries that will receive benefits of a wide variety of efficiency interventions, including Title 24 standards and efficiency programs. The authors of the UC Berkeley report did not know in 2011 which Title 24 measures would be considered for the 2016 adoption cycle, so the UC Berkeley report was likely conservative in their approximations of industries impacted by Title 24. The Statewide CASE Team believes that industries impacted by utilities efficiency programs is a more realistic and reasonable proxy for industries potentially affected by upcoming Title 24 standards. Therefore, the table provided in this CASE Report includes the industries that are listed as benefiting from Title 24 and utility energy efficiency programs.

**Table 8: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code**

| Industry                                                                                   | NAICS Code |
|--------------------------------------------------------------------------------------------|------------|
| Nonresidential Building Construction                                                       | 2362       |
| Electrical Contractors                                                                     | 23821      |
| Plumbing, Heating, and Air-Conditioning Contractors                                        | 23822      |
| Boiler and Pipe Insulation Installation                                                    | 23829      |
| Insulation Contractors                                                                     | 23831      |
| Manufacturing                                                                              | 32412      |
| Industrial Machinery Manufacturing                                                         | 3332       |
| Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equipment Manufacturing | 3334       |
| Computer and Peripheral Equipment Manufacturing                                            | 3341       |
| Engineering Services                                                                       | 541330     |
| Building Inspection Services                                                               | 541350     |
| Environmental Consulting Services                                                          | 541620     |
| Other Scientific and Technical Consulting Services                                         | 541690     |
| Advertising and Related Services                                                           | 5418       |
| Corporate, Subsidiary, and Regional Managing Offices                                       | 551114     |
| Commercial & Industrial Machinery & Equip. (exc. Auto. & Electronic) Repair & Maintenance  | 811310     |

### 3.5.3 Competitive Advantages or Disadvantages for Businesses within California

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation (as described above) estimates that this scenario would result in 0.6% additional GSP in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Table ES-2). We expect that higher GSP will drive additional business creation in California. In particular, local small businesses that spend a much larger proportion of revenue on energy than other businesses (CARB 2010b, Figures 13 and 14) should disproportionately benefit from lower energy costs due to energy efficiency standards. Increased labor demand, as noted earlier, is another indication of business creation.

### 3.5.4 Increase or Decrease of Investments in the State of California

California businesses would benefit from an overall reduction in energy costs. This could help California businesses gain competitive advantage over businesses operating in other states or countries and an increase in investment in California, as noted below.

### 3.5.5 Incentives for Innovation in Products, Materials, or Processes

Manufacturers of thermally driven cooling systems will have an incentive to develop new products and improve existing products. Utility efficiency programs could offer new incentive programs to encourage increased adoption of thermally driven cooling systems.

### **3.5.6 Effects on the State General Fund, State Special Funds and Local Governments**

There is no significant additional burden expected on state agencies, other than the documentation required for the compliance manuals for this measure, and subsequent training and support efforts.

#### **3.5.6.1 Cost of Enforcement**

The proposed code change adds a compliance option to the performance approach. The energy impacts will be modeled through the compliance software. The measure does not add additional acceptance tests or field verification requirements that enforcing agencies would be responsible for conducting. For this reason, it is not expected that the proposed revision will have a significant impact on code enforcement. While additional training is not necessary for code compliance, the Statewide CASE Team believes that an education and training campaign will result in more designers taking advantage of the thermally driven cooling compliance option.

#### **Cost to the State**

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24 Standards, including updating education and compliance materials and responding to questions about the revised Standards, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.

#### **Cost to Local Governments**

All revisions to Title 24 will result in changes to Title 24 compliance determinations. Local governments will need to train permitting staff on the revised Title 24 Standards. While this retraining is an expense to local governments, it is not a new cost associated with the 2016 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining. As noted earlier, although retraining is a cost of the revised Standards, Title 24 Standards are expected to increase economic growth and income with positive impacts on local revenue. The cost to local governments should be minimal because the compliance verification and enforcement requirements are not changing.

#### **3.5.6.2 Impacts on Specific Groups of Persons**

The proposed changes to Title 24 are not expected to have a differential impact on any of the following groups relative to the state population as a whole:

- Migrant Workers
- Persons by age
- Persons by race
- Persons by religion
- Commuters

## 4. METHODOLOGY

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This section describes the methodology the Statewide CASE Team used to estimate energy, demand, and environmental impacts for the proposed measures. The Statewide CASE Team calculated the impacts of the proposed code change by comparing existing conditions to the conditions if the proposed code change is adopted. This section of the CASE Report goes into more detail on the assumptions about the existing and proposed conditions, prototype buildings, and the methodology used to estimate energy, demand, and environmental impacts.

### 4.1 Existing Conditions

These measures affect new thermally driven cooling systems utilizing waste heat and heat from renewable energy sources that serve commercial buildings including high-rise residential buildings. The analysis for the absorption and adsorption chillers relies on a large office building simulation. The existing conditions are based on the 2013 ACM Reference Manual that specifies the HVAC system in the standard design. It specifies that buildings larger than 150,000 square feet (SF) and taller than one story must use a built-up variable air volume (VAV) system in the standard design. This is the only building type that uses a built-up system in the standard design. Thus, the existing conditions assume a building larger than 150,000 SF, taller than one story, and with a built-up variable volume system with chilled water and hot water coils, water-cooled electric chiller, tower and central boiler.

The 2013 Standards allow applicants to model absorption chillers to verify compliance with Title 24, but does not allow applicant to model adsorption chillers. However, the current version of CBECC-Com does not allow for selection of either absorption or adsorption chillers. In any case, electric chillers are much more commonly installed than absorption and adsorption chillers, which are mature technologies but rarely installed. The base case is thus an electric chiller as that is the common design specification. The 2013 ACM Reference Manual also specifies an electric chiller for the standard design.

The analysis for the desiccant cooling system relies on a small 1-story office building simulation. The existing conditions are based on the 2013 ACM Reference Manual that specifies the HVAC system in the standard design. It specifies that 1-story buildings smaller than 10,000 SF use a packaged single zone (PSZ) unit in the standard design. Thus, the existing conditions assume a 1-story building smaller than 10,000 SF with PSZ units with constant volume DX and gas heating. Each of the five thermal zones in the simulation is modeled with its own PSZ system, per the 2013 ACM Reference Manual standard design.

The 2013 standards allow for desiccant cooling. However, the current version of CBECC-Com does not allow input of any desiccant system. In any case, desiccant cooling systems are a mature technology but not commonly installed. The base case is thus a PSZ unit without desiccant cooling.

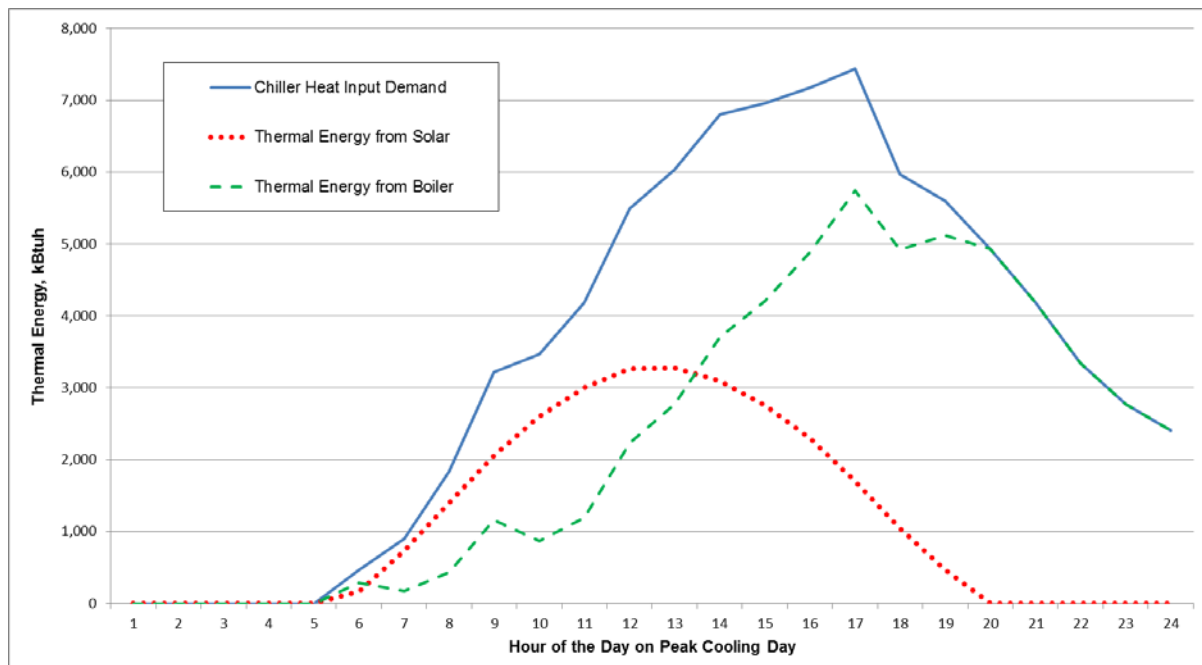
### 4.2 Proposed Conditions

The proposed conditions are defined as the design conditions that will comply with the proposed code change. They are summarized here for the three measures:

- Absorption chiller using solar heat for the generator heat source
- Adsorption chiller using solar heat for the generator heat source
- Desiccant cooling system using condenser heat for the regeneration heat load

Alternately, hot water, hot air, or steam, derived from waste heat could be used for the chiller or cooling system heat source.

The solar thermal system for the absorption and adsorption chiller models is sized to generate approximately 25% of the chiller heat demand on the peak day. The remaining 75% of the chiller heat demand on the peak day is satisfied by central gas boilers. The solar fraction on non-peak days is higher than 25%. Figure 4 illustrates a typical peak day, in this case for climate zone 12 in mid-July. The sum of the areas under the curves Thermal Energy from Solar and Thermal Energy from Boiler is equivalent to the area under the curve Chiller Heat Input Demand.



**Figure 4: Typical Thermal Energy Demand from Solar Thermal System and Boiler, Mid-July in Climate Zone 12**

### 4.3 Prototype Buildings

To assess the energy, demand, and environmental impacts for nonresidential prototype buildings, the Statewide CASE Team used a new construction small office and large office for the prototype buildings.

The prototype building simulation files originated from the CBECC-Com software installation package, which includes a number of example input files. These models include various building types and HVAC systems. The files with “-CECStd” in the name are intended to represent minimally compliant buildings with respect to the 2013 Title 24 Standards. That is, these files were developed to pass compliance with as small a compliance margin as possible,

ideally zero. The models used in this analysis are: 020012-OffSml-CECStd (desiccant cooling model) and 040012-OffLrg-CECStd (absorption and adsorption chiller model).

CBECC-Com does not yet allow for modeling absorption and adsorption chillers or desiccant cooling systems. A workaround was thus used to model the measure cases. The -CECStd files were first run in CBECC-Com. One of the CBECC-Com output files is an EnergyPlus input file. CBECC-Com automatically created this file by mapping the CBECC input file to an EnergyPlus input file. The Statewide CASE Team modified this EnergyPlus input file as needed to include an absorption chiller, adsorption chiller, or a desiccant system for the measure cases. These revised files were then run in EnergyPlus to yield the measure case simulation results.

Table 9 summarizes some of the details of these prototype buildings. Note that the base case system is electric for all prototype buildings. The thermally driven cooling systems modeled for the measure case are not all-electric systems, and the proposed compliance option will use different fuels and/or heat sources than are assumed in the prescriptive baseline.

**Table 9: Prototype Buildings used for Energy, Demand, and Environmental Impacts Analysis**

| Measure             | Occupancy type | Floor area (SF) | Number of floors | Base case                          | Measure case                      | Heat source     |
|---------------------|----------------|-----------------|------------------|------------------------------------|-----------------------------------|-----------------|
| Absorption chillers | Large office   | 498,589         | 12 + basement    | Built up VAV with electric chiller | Indirect fired absorption chiller | Solar hot water |
| Adsorption chillers | Large office   | 498,589         | 12 + basement    | Built up VAV with electric chiller | Indirect fired adsorption chiller | Solar hot water |
| Desiccant cooling   | Small office   | 5,502           | 1                | PSZ DX units                       | PSZ DX + desiccant cooling        | Condenser heat  |

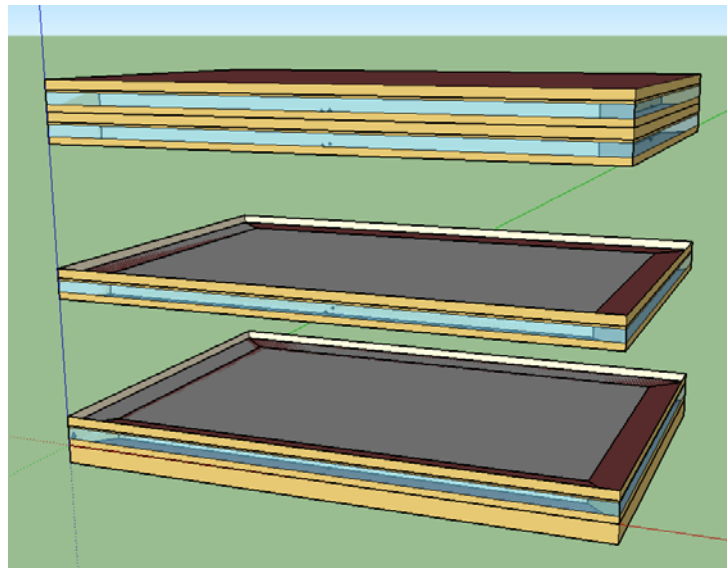
### 4.3.1 Large Office Prototype

The large office prototype is a typical large office building with 12 floors and a basement. The conditioned floor area is 498,589 SF. The HVAC system is a central plant with a variable air volume system, chilled water plant, central gas boiler, variable speed cooling towers, and hot water reheat at the terminal units. The HVAC systems for the measure cases are identical to the base case except for an absorption and adsorption chiller instead of electric chiller.

The internal load values are consistent with typical large office buildings in California:

- Lighting power density: 0.75 W/SF
- Equipment power density: 1.0 W/SF
- Occupancy density: 200 SF/person

As shown in Figure 5, the model includes the top floor, an upper floor with multiplier of 5, a mid-floor with multiplier of 5, the ground floor and the basement. Glazing is distributed around all four sides on all floors.



**Figure 5. Large Office Prototype Model**

#### **4.3.2 Small Office Prototype**

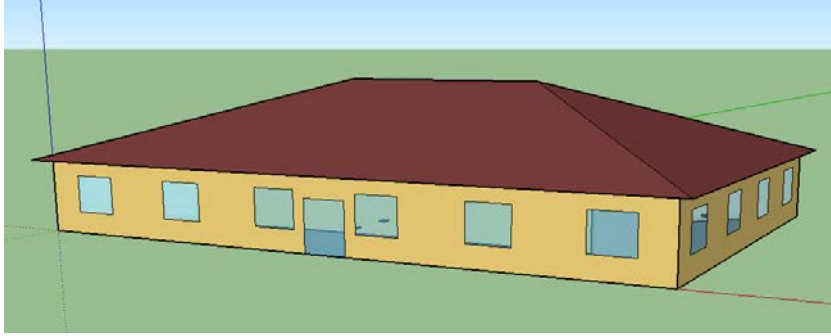
The small office prototype is a typical small office building with a single floor. The conditioned floor area is 5,502 SF. The HVAC system consists of five PSZ units with DX cooling coils and gas heat. The units are rated at 13.0 SEER, 10.8 EER, and 0.78 AFUE.

The HVAC systems for the measure case are identical to the base case but adds the EnergyPlus input object Dehumidifier:Desiccant:System. This system is located in the main air loop immediately downstream of the DX cooling coils. The dehumidifier operation is coordinated with the operation of the companion DX coil. The DX system's condenser waste heat is used to help regenerate the desiccant heat exchanger. This is described in more detail in the EnergyPlus Engineering Reference Manual.

The internal load values are consistent with typical small office buildings in California:

- Lighting power density: 0.75 W/SF
- Equipment power density: 1.0 W/SF
- Occupancy density: 200 SF/person

The model is illustrated in Figure 6.



**Figure 6. Small Office Prototype Model**

## 4.4 Climate Dependent

The impacts of the proposed measure are climate specific, thus the impacts were modeled in a variety of climate zones to illustrate the full range of impacts that are expected statewide.

## 4.5 Time Dependent Valuation

The TDV (Time Dependent Valuation) of savings is a normalized format for comparing electricity and natural gas savings that takes into account the cost of electricity and natural gas consumed during different times of the day and year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in 2017 present value dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of “TDV kBtUs” so that the savings are evaluated in terms of energy units and measures with different periods of analysis can be combined into a single value.

The CEC derived the 2016 TDV values that were used in the analyses for this report (CEC 2014). The TDV energy impacts are presented in Section 5.1 of this report, and the statewide TDV cost impacts are presented in Section 5.2.

## 4.6 Energy Impacts Methodology

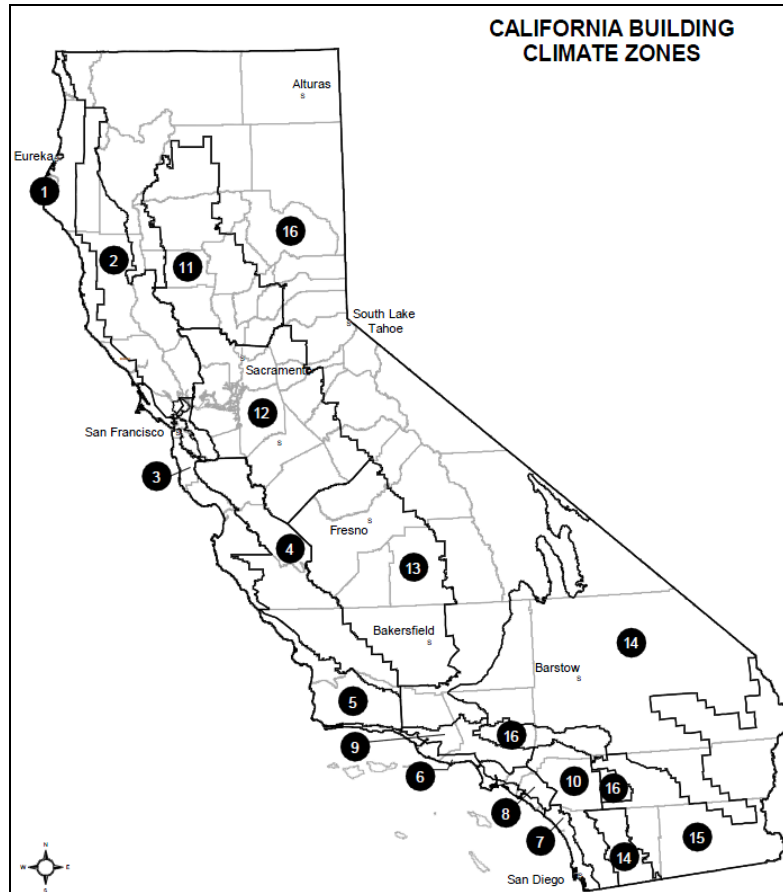
This measure adds a compliance option that designers can use if they opt to comply with the Standards using the performance approach, but the measure does not change the baseline energy budget. It is assumed that designers that elect to use this compliance option will combine a thermally driven cooling system with other design features that will allow the building to be minimally compliant with Title 24. Using this new compliance option will not necessarily result in buildings that perform better than code minimum. Despite there being no intrinsic savings associated with this measure, the Statewide CASE Team did calculate the per unit impacts and statewide energy impact of the proposed compliance option relative to the prescriptive baseline. The statewide savings account for energy impacts associated with all new construction, alterations, and additions during the first year buildings complying with the 2016 Title 24 Standards are in operation.

#### 4.6.1 Per Unit Energy Impacts Methodology

The Statewide CASE Team estimated the electricity and natural gas impacts associated with the proposed code change. The energy impacts were calculated per ton of cooling capacity. A series of building energy simulations and corresponding TDV analysis were conducted to estimate the potential energy impacts resulting from these code change proposals. A representative sample of California climate zones were modeled, including: 3, 6, 9, 12, 14, and 16. The other California climate zones were not included in these energy simulations as they are sufficiently represented by the selected zones for the purposes of this research. Figure 7 indicates which climate zones the selected zones represent and Figure 8 shows a map of the climate zones.

| <b>Simulated<br/>climate<br/>zone</b> | <b>Maps to<br/>climate<br/>zones:</b> |
|---------------------------------------|---------------------------------------|
| 3                                     | 1, 2, 3, 4                            |
| 6                                     | 5, 6, 7                               |
| 9                                     | 8, 9, 10                              |
| 12                                    | 11, 12, 13                            |
| 14                                    | 14, 15                                |
| 16                                    | 16                                    |

**Figure 7: Climate Zone Mapping for Energy Simulations**



**Figure 8. California Climate Zone Map**

### ***Analysis Tools***

The Statewide CASE Team used CBECC-Com 2013 v2b (Build 609), EnergyPlus v8.1, and spreadsheet analysis to quantify energy impacts and peak electricity demand reductions resulting from the proposed measure.

### ***Key Assumptions***

As mentioned, the CEC provided a number of key assumptions to be used in the energy impacts analysis (CEC 2011). Some of the assumptions included in the CEC's Lifecycle Cost Methodology Guidelines (LCC Methodology) include hours of operation, weather data, and prototype building design. The key assumptions used in the per unit energy impacts analysis that are not already included in the assumptions provided in the LCC Methodology, or vary from the assumptions the CEC provided, are presented in Table 10.

**Table 10: Key Assumptions for Per Unit Energy Impacts Analysis**

| Parameter               | Assumption     | Source                                                      |
|-------------------------|----------------|-------------------------------------------------------------|
| Large office floor area | 498,589 SF     | CBECC-Com CEC-Std prototype model                           |
| Small office floor area | 5,502 SF       | CBECC-Com CEC-Std prototype model                           |
| Lighting power density  | 0.75 W/SF      | PNNL ASHRAE 90.1 Prototype Building Modeling Specifications |
| Equipment power density | 1.0 W/SF       | PNNL ASHRAE 90.1 Prototype Building Modeling Specifications |
| Occupancy density       | 200 SF/person  | PNNL ASHRAE 90.1 Prototype Building Modeling Specifications |
| Zone Supply Air Temp    | 55°F (cooling) | CBECC-Com CEC-Std prototype model                           |
| Zone Supply Air Temp    | 95°F (heating) | CBECC-Com CEC-Std prototype model                           |

#### **4.6.2 Statewide Energy Impacts Methodology**

##### ***First Year Statewide Impacts***

The Statewide CASE Team estimated statewide impacts for the first year buildings that comply with the 2016 Title 24 Standards by multiplying per unit savings estimates by statewide construction forecasts.

The proposed code change applies to only a fraction of new construction, additions and alterations. This is because these changes are optional and not mandatory or prescriptive. The Statewide CASE Team assumed that the proposed code change would apply to only five new chillers in the first year.

The CEC Demand Analysis Office provided the Statewide CASE Team with the residential and nonresidential new construction forecast for 2017, broken out by building type and forecast climate zones (FCZ). The Statewide CASE Team translated this data to building climate zones (BCZ) using the same weighting of FCZ to BCZ as the previous code update cycle (2013), as presented in Table 12.

The projected nonresidential new construction forecast is presented in Table 13. Table 11 provides a more complete definition of the various space types used in the forecast.

**Table 11: Description of Space Types used in the Nonresidential New Construction Forecast**

|           |                                                        |
|-----------|--------------------------------------------------------|
| OFF-SMALL | Offices less than 30,000 ft <sup>2</sup>               |
| OFF-LRG   | Offices larger than 30,000 ft <sup>2</sup>             |
| REST      | Any facility that serves food                          |
| RETAIL    | Retail stores and shopping centers                     |
| FOOD      | Any service facility that sells food and or liquor     |
| NWHSE     | Nonrefrigerated warehouses                             |
| RWHSE     | Refrigerated Warehouses                                |
| SCHOOL    | Schools K-12, not including colleges                   |
| COLLEGE   | Colleges, universities, community colleges             |
| HOSP      | Hospitals and other health-related facilities          |
| HOTEL     | Hotels and motels                                      |
| MISC      | All other space types that do not fit another category |

**Table 12: Translation from FCZ to BCZ**

Source: CEC Demand Analysis Office

|                              |    | Building Standards Climate Zones (BCZ) |       |       |       |      |       |       |       |        |       |       |        |       |       |       |       | Grand Total |
|------------------------------|----|----------------------------------------|-------|-------|-------|------|-------|-------|-------|--------|-------|-------|--------|-------|-------|-------|-------|-------------|
|                              |    | 1                                      | 2     | 3     | 4     | 5    | 6     | 7     | 8     | 9      | 10    | 11    | 12     | 13    | 14    | 15    | 16    |             |
| Forecast Climate Zones (FCZ) | 1  | 22.5%                                  | 20.6% | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 9.8%  | 33.1%  | 0.2%  | 0.0%  | 0.0%  | 13.8% | 100%        |
|                              | 2  | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 22.0% | 75.7%  | 0.0%  | 0.0%  | 0.0%  | 2.3%  | 100%        |
|                              | 3  | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 21.0% | 22.8%  | 54.5% | 0.0%  | 0.0%  | 1.8%  | 100%        |
|                              | 4  | 0.2%                                   | 13.7% | 8.4%  | 46.0% | 8.9% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 22.8%  | 0.0%  | 0.0%  | 0.0%  | 0.0%  | 100%        |
|                              | 5  | 0.0%                                   | 4.2%  | 89.1% | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 6.6%   | 0.0%  | 0.0%  | 0.0%  | 0.0%  | 100%        |
|                              | 6  | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 100.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%  | 100%        |
|                              | 7  | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%   | 75.8% | 7.1%  | 0.0%  | 17.1% | 100%        |
|                              | 8  | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 40.4% | 0.0%  | 51.1% | 8.1%   | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%  | 0.5%  | 100%        |
|                              | 9  | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 7.0%  | 0.0%  | 24.5% | 57.9%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 6.7%  | 0.0%  | 4.0%  | 100%        |
|                              | 10 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 74.9% | 0.0%  | 0.0%   | 0.0%  | 12.3% | 7.9%  | 4.9%  | 100%        |
|                              | 11 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 33.0% | 0.0%  | 24.8% | 42.2%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%  | 0.0%  | 100%        |
|                              | 12 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.9%  | 0.0%  | 20.2% | 75.2%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%  | 3.7%  | 100%        |
|                              | 13 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 69.6% | 0.0%  | 0.0%   | 28.8% | 0.0%  | 0.0%   | 0.0%  | 1.6%  | 0.1%  | 0.0%  | 100%        |
|                              | 14 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 100.0% | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%  | 0.0%  | 100%        |
|                              | 15 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.1%  | 99.9% | 0.0%  | 100%        |
|                              | 16 | 0.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 100.0% | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%  | 0.0%  | 100%        |
|                              | 17 | 3.0%                                   | 0.0%  | 0.0%  | 0.0%  | 0.0% | 0.0%  | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%   | 0.0%  | 0.0%  | 0.0%  | 97.1% | 100%        |

**Table 13: Estimated New Nonresidential Construction in 2017 by Climate Zone and Building Type (Million Square Feet)**

Source: CEC Demand Analysis Office

| Climate Zone | New Construction in 2017 (Million Square Feet) |       |        |       |        |       |        |         |       |        |        |         | TOTAL   |
|--------------|------------------------------------------------|-------|--------|-------|--------|-------|--------|---------|-------|--------|--------|---------|---------|
|              | OFF-SMALL                                      | REST  | RETAIL | FOOD  | NWHSE  | RWHSE | SCHOOL | COLLEGE | HOSP  | HOTEL  | MISC   | OFF-LRG |         |
| 1            | 0.058                                          | 0.016 | 0.041  | 0.014 | 0.040  | 0.002 | 0.046  | 0.018   | 0.028 | 0.031  | 0.094  | 0.069   | 0.457   |
| 2            | 0.227                                          | 0.088 | 0.630  | 0.163 | 0.327  | 0.031 | 0.244  | 0.163   | 0.200 | 0.350  | 0.742  | 1.140   | 4.306   |
| 3            | 0.728                                          | 0.408 | 2.913  | 0.677 | 2.518  | 0.183 | 1.000  | 0.625   | 0.729 | 1.400  | 3.894  | 4.952   | 20.026  |
| 4            | 0.484                                          | 0.190 | 1.586  | 0.413 | 0.595  | 0.071 | 0.541  | 0.408   | 0.490 | 0.890  | 1.641  | 2.935   | 10.245  |
| 5            | 0.094                                          | 0.037 | 0.308  | 0.080 | 0.116  | 0.014 | 0.105  | 0.079   | 0.095 | 0.173  | 0.319  | 0.570   | 1.990   |
| 6            | 0.811                                          | 0.825 | 3.072  | 0.756 | 2.649  | 0.122 | 0.659  | 0.649   | 0.508 | 0.571  | 4.144  | 2.264   | 17.030  |
| 7            | 0.959                                          | 0.300 | 1.635  | 0.502 | 1.004  | 0.013 | 0.772  | 0.448   | 0.325 | 1.059  | 3.077  | 1.253   | 11.347  |
| 8            | 1.078                                          | 1.106 | 4.241  | 1.034 | 3.588  | 0.162 | 0.856  | 0.931   | 0.773 | 0.872  | 5.860  | 3.186   | 23.686  |
| 9            | 0.971                                          | 0.916 | 3.975  | 0.937 | 3.287  | 0.119 | 0.600  | 1.095   | 1.127 | 1.329  | 5.376  | 5.675   | 25.408  |
| 10           | 1.372                                          | 0.707 | 2.995  | 0.839 | 2.630  | 0.074 | 0.883  | 0.580   | 0.528 | 1.056  | 8.010  | 1.496   | 21.170  |
| 11           | 0.333                                          | 0.088 | 0.770  | 0.268 | 0.875  | 0.089 | 0.504  | 0.156   | 0.239 | 0.197  | 0.737  | 0.629   | 4.885   |
| 12           | 1.710                                          | 0.502 | 3.656  | 1.014 | 3.157  | 0.202 | 1.687  | 0.678   | 1.048 | 1.480  | 3.637  | 4.721   | 23.493  |
| 13           | 0.668                                          | 0.205 | 1.606  | 0.544 | 1.706  | 0.286 | 1.401  | 0.390   | 0.520 | 0.359  | 1.884  | 0.817   | 10.387  |
| 14           | 0.224                                          | 0.138 | 0.609  | 0.162 | 0.527  | 0.025 | 0.156  | 0.128   | 0.115 | 0.185  | 1.472  | 0.431   | 4.171   |
| 15           | 0.349                                          | 0.096 | 0.675  | 0.238 | 0.761  | 0.022 | 0.192  | 0.098   | 0.133 | 0.204  | 1.123  | 0.289   | 4.180   |
| 16           | 0.199                                          | 0.106 | 0.506  | 0.142 | 0.449  | 0.042 | 0.205  | 0.122   | 0.125 | 0.144  | 0.931  | 0.394   | 3.367   |
| TOTAL        | 10.264                                         | 5.729 | 29.218 | 7.784 | 24.228 | 1.457 | 9.852  | 6.570   | 6.983 | 10.301 | 42.941 | 30.821  | 186.148 |

## 4.7 Cost-effectiveness Methodology

This measure does not propose mandatory or prescriptive requirements. A lifecycle cost analysis is not necessary because the measure is not proposed to be part of the baseline level of stringency. The energy cost savings were calculated to better understand the energy trade-off benefits for these measures.

### 4.7.1 Cost Savings Methodology

#### *Energy Cost Savings Methodology*

The present value (PV) of the energy impacts were calculated using the method described in the LCC Methodology. In short, the hourly energy impacts estimates for the first year of building operation were multiplied by the 2016 TDV cost values to arrive at the PV of the cost savings over the period of analysis. This analysis used the 15-year nonresidential TDV cost values. This measure is climate sensitive, so the energy cost savings were calculated in each climate zone using TDV values for each unique climate zone. The nonresidential 15-year conversion factor is \$0.089/TDVkBtu expressed in 2017 dollars, which is used to convert between kBtu and PV\$.

#### *Other Cost Savings Methodology*

This measure does not have any non-energy cost savings.

## 4.8 Environmental Impacts Methodology

### 4.8.1 Greenhouse Gas Emissions Impacts Methodology

#### *Greenhouse Gas Emissions Impacts Methodology*

The Statewide CASE Team calculated GHG emissions assuming an emission factor of 353 metric tons of carbon dioxide equivalents (MTCO<sub>2</sub>e) per GWh of electricity. As described in more detail in Appendix A, the electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard (RPS) goal of 33 percent renewable electricity generation by 2020. GHG emissions from natural gas were calculated using an emission factor of 5,303 MTCO<sub>2</sub>e/million therms (U.S. EPA 2011).

This measure does not recommend changes to the baseline energy budget. It is anticipated that designers that elect to use this new compliance option will combine a thermally driven cooling system with other measures that will allow the building to achieve the required energy budget. We do not anticipate that designers that elect to use this measure will necessarily design buildings that perform more efficiently than is required by the Standards. As such, there are no inherent savings associated with this compliance option. The Statewide CASE Team did evaluate the impacts of complying using this compliance option relative to the prescriptive baseline. As mentioned previously, the prescriptive baseline assumes all-electric systems but thermally driven cooling systems are oftentimes not all-electric. As such the analysis presented

in this report assumes some fuel switching. Further, as described in more detail in Section 4.8.3, the Statewide CASE Team does anticipate an incremental increase of onsite emissions from the combustion of fossil fuel and, potentially, renewable fuel such as landfill gas. The GHG emissions impacts presented in this report account for the increase in natural gas use.

#### **4.8.2 Water Use and Water Quality Impacts Methodology**

The embedded energy value used in the analysis is 10,045 kWh/million gallons of water (MG). This value was derived from a California Energy Commission PIER study (CEC 2006), which states the embedded energy values presented in the report “are sufficient for informing policy and prioritization of research and development investments.” See Appendix A: Environmental Impacts Methodology for a more detailed description of the methodology used to calculate embedded energy savings.

Per ton of cooling, water cooled absorption chillers require larger heat rejection equipment (cooling towers) and therefore will use more water on-site as compared to a water cooled electric chiller. If evaporative cooling is used (with desiccants) more water will also be used. However, less water is needed at the power plants due to the electricity savings and demand reduction. The water impacts presented in Section 5.3.2 present the increased water use from larger heat rejection equipment, but it does not account for the reduction in water use at the power plant.

#### **4.8.3 Other Impacts Methodology**

The Statewide CASE Team does anticipate an incremental increase of onsite emissions from the combustion of fossil fuel and, potentially, renewable fuel such as landfill gas. Not all projects will have increased combustion. This combustion will be a result of systems that are generating onsite electricity (turbine and engine generators), supplemental/back-up boilers (used when waste heat and/or renewable heat is not available but cooling is required), and other combustion equipment that is used for supplemental/back-up heating. In some cases, the cooling system may be direct-fired (e.g. direct-fired absorption chiller and utilizes waste heat to preheat combustion air) that would also increase onsite combustion. The onsite emissions increase is frequently offset by the decrease in power plant emissions. The Statewide CASE Team assumed that the proposed code change would apply to only five new chillers in the first year. Perhaps one or two of these units will be direct-fired. The other units will indirectly result in increased combustion from the back-up heating sources. Based on this small number of units there is not a significant environmental impact in the state air districts resulting from approval of this proposal.

## 5. ANALYSIS AND RESULTS

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Results from the energy, demand, and environmental impacts analyses are presented in this section. This measure does not propose mandatory or prescriptive requirements. A lifecycle cost analysis is not necessary because the measure is not proposed to be part of the baseline level of stringency. The energy cost savings were calculated to better understand the energy trade-off benefits for these measures.

### 5.1 Energy Impacts Results

#### 5.1.1 Per Unit Energy Impacts Results

Per unit energy and demand impacts of the proposed measure are presented in Table 14. Per unit savings for the first year are expected to be 216 kilowatt-hours per year per ton of cooling (kWh/yr/ton) and -406 therms/yr/ton (increased consumption). Demand savings are expected to be 0.12 kilowatts per ton of cooling (kW/ton).

It is estimated that the first year TDV electricity and natural gas savings will be 7,800 kBTU/ton and -3,300 kBTU/ton (increased consumption), respectively. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods. Thermally driven cooling can help reduce or flatten the electric peaks in a building's load profile for peak electricity savings.

**Table 14: Energy Impacts per Unit<sup>1</sup>**

| Climate Zone    | Per Unit First Year Savings <sup>2</sup>         |                            |                                       | Per Unit First Year TDV Savings <sup>3</sup>       |                                                   |
|-----------------|--------------------------------------------------|----------------------------|---------------------------------------|----------------------------------------------------|---------------------------------------------------|
|                 | Electricity Savings <sup>4</sup><br>(kWh/yr/ton) | Demand Savings<br>(kW/ton) | Natural Gas Impact<br>(Therms/yr/ton) | TDV Electricity Savings <sup>5</sup><br>(kBTU/ton) | TDV Natural Gas Impact <sup>5</sup><br>(kBTU/ton) |
| Climate Zone 1  | 137                                              | 0.09                       | -212                                  | 5,917                                              | -2,426                                            |
| Climate Zone 2  | 137                                              | 0.09                       | -212                                  | 5,917                                              | -2,426                                            |
| Climate Zone 3  | 137                                              | 0.09                       | -212                                  | 5,917                                              | -2,426                                            |
| Climate Zone 4  | 137                                              | 0.09                       | -212                                  | 5,917                                              | -2,426                                            |
| Climate Zone 5  | 251                                              | 0.10                       | -444                                  | 8,140                                              | -3,419                                            |
| Climate Zone 6  | 251                                              | 0.10                       | -444                                  | 8,140                                              | -3,419                                            |
| Climate Zone 7  | 251                                              | 0.10                       | -444                                  | 8,140                                              | -3,419                                            |
| Climate Zone 8  | 258                                              | 0.13                       | -366                                  | 8,990                                              | -4,046                                            |
| Climate Zone 9  | 258                                              | 0.13                       | -366                                  | 8,990                                              | -4,046                                            |
| Climate Zone 10 | 258                                              | 0.13                       | -366                                  | 8,990                                              | -4,046                                            |
| Climate Zone 11 | 207                                              | 0.12                       | -383                                  | 7,367                                              | -3,094                                            |
| Climate Zone 12 | 207                                              | 0.12                       | -383                                  | 7,367                                              | -3,094                                            |
| Climate Zone 13 | 207                                              | 0.12                       | -383                                  | 7,367                                              | -3,094                                            |
| Climate Zone 14 | 278                                              | 0.14                       | -651                                  | 9,194                                              | -3,861                                            |
| Climate Zone 15 | 278                                              | 0.14                       | -651                                  | 9,194                                              | -3,861                                            |
| Climate Zone 16 | 163                                              | 0.13                       | -378                                  | 7,119                                              | -2,848                                            |

1. The unit is ton of cooling capacity.

2. Savings from one ton of cooling capacity for the first year the building is in operation.

3. TDV energy impacts for one ton of cooling capacity for the first year the building is in operation.

4. Site electricity savings. Does not include TDV of electricity savings.

5. Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas. The negative values for natural gas indicate increased consumption rather than savings.

## 5.1.2 Statewide Energy Impacts Results

### *First Year Statewide Energy Impacts*

The statewide energy impacts of the proposed measure are presented in Table 15. During the first year buildings complying with the 2016 Title 24 Standards are in operation, the proposed measure is expected to reduce annual statewide electricity use by 1.2 GWh with an associated demand reduction of 0.6 MW. Natural gas use is expected to increase by 2.2 MMtherms.

**Table 15: Statewide Energy Impacts**

|                          | First Year Statewide Savings <sup>1</sup> |                                |                                   | First Year TDV Savings <sup>2</sup>                    |                                                        |
|--------------------------|-------------------------------------------|--------------------------------|-----------------------------------|--------------------------------------------------------|--------------------------------------------------------|
|                          | Electricity Savings <sup>3</sup><br>(GWh) | Power Demand Reduction<br>(MW) | Natural Gas Savings<br>(MMtherms) | TDV Electricity Savings <sup>4</sup><br>(Million kBTU) | TDV Natural Gas Savings <sup>4</sup><br>(Million kBTU) |
| Thermally driven cooling | 1.2                                       | 0.6                            | -2.2<br>(increase)                | 42                                                     | -18 (increase)                                         |

1. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
2. First year TDV savings from all buildings built statewide during the first year the 2016 Standards are in effect.
3. Site electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology.

## 5.2 Cost-effectiveness Results

This measure does not propose mandatory or prescriptive requirements. A lifecycle cost analysis is not necessary because the measure is not proposed to be part of the baseline level of stringency. The energy cost savings were calculated to better understand the energy trade-off benefits for these measures.

### 5.2.1 Cost Savings Results

#### *Energy Cost Savings Results*

The per unit TDV energy cost savings over the 15 year period of analysis are presented in Table 16. Refer to Section 4.7.1 Cost Savings Methodology for the calculation details. The proposed measure results in cost savings in every climate zone.

**Table 16: TDV Energy Cost Savings Over 15 Year Period of Analysis - Per Unit**

| <b>Climate Zone</b> | <b>TDV Electricity<br/>Cost Savings<br/>(2017 PV\$/ton)</b> | <b>TDV Natural Gas<br/>Cost Savings<br/>(2017PV\$/ton)</b> | <b>Total TDV Energy<br/>Cost Savings<br/>(2017 PV\$/ton)</b> |
|---------------------|-------------------------------------------------------------|------------------------------------------------------------|--------------------------------------------------------------|
| Climate Zone 1      | \$527                                                       | (\$216)                                                    | \$311                                                        |
| Climate Zone 2      | \$527                                                       | (\$216)                                                    | \$311                                                        |
| Climate Zone 3      | \$527                                                       | (\$216)                                                    | \$311                                                        |
| Climate Zone 4      | \$527                                                       | (\$216)                                                    | \$311                                                        |
| Climate Zone 5      | \$724                                                       | (\$304)                                                    | \$420                                                        |
| Climate Zone 6      | \$724                                                       | (\$304)                                                    | \$420                                                        |
| Climate Zone 7      | \$724                                                       | (\$304)                                                    | \$420                                                        |
| Climate Zone 8      | \$800                                                       | (\$360)                                                    | \$440                                                        |
| Climate Zone 9      | \$800                                                       | (\$360)                                                    | \$440                                                        |
| Climate Zone 10     | \$800                                                       | (\$360)                                                    | \$440                                                        |
| Climate Zone 11     | \$656                                                       | (\$275)                                                    | \$380                                                        |
| Climate Zone 12     | \$656                                                       | (\$275)                                                    | \$380                                                        |
| Climate Zone 13     | \$656                                                       | (\$275)                                                    | \$380                                                        |
| Climate Zone 14     | \$818                                                       | (\$344)                                                    | \$475                                                        |
| Climate Zone 15     | \$818                                                       | (\$344)                                                    | \$475                                                        |
| Climate Zone 16     | \$634                                                       | (\$253)                                                    | \$380                                                        |

The Statewide CASE Team estimates that TDV energy cost savings for 15 years of all thermally driven cooling measures installed during the first year the 2016 Standards are in effect will be \$1.97 million.

#### ***Other Cost Savings Results***

This measure does not have any non-energy cost savings.

## **5.3 Environmental Impacts Results**

### **5.3.1 Greenhouse Gas Emissions Results**

Table 17 presents the estimated first year GHG emissions impacts of the proposed code change. During the first year the 2016 Standards are in effect the proposed measure will result in an increase in GHG emissions of 11,200 MTCO<sub>2e</sub>. As discussed in Section 4.8.1, this increase is attributed, in part, to the switch from all-electric cooling. The monetary value of GHG emissions is included in TDV cost factors (TDV \$) for each hour of the year and thus included in the Cost-effectiveness Analysis presented in this report.

**Table 17: Statewide First Year Greenhouse Gas Emissions Impacts**

|                          | <b>Increased GHG Emissions<sup>1</sup><br/>(MTCO<sub>2</sub>e/yr)</b> |
|--------------------------|-----------------------------------------------------------------------|
| Thermally driven cooling | 11,200                                                                |

<sup>1.</sup> First year savings from buildings built in 2017; assumes 353 MTCO<sub>2</sub>e/GWh and 5,303 MTCO<sub>2</sub>e/MMTherms.

### 5.3.2 Water Use and Water Quality Impacts

Per ton of cooling, water cooled absorption chillers require larger heat rejection equipment (cooling towers) and therefore will use more water on-site as compared to a water cooled electric chiller. If evaporative cooling is used (with desiccants) more water will also be used. However, less water is needed at the power plants due to the electricity savings and demand reduction. Impacts on the onsite water use and water quality are presented in Table 18. The values presented in the table below do not account for water savings at the power plant.

**Table 18: Impacts of Water Use and Water Quality**

|                                   | <b>On-Site Water Savings<sup>1</sup><br/>(gallons/yr)</b> | <b>Embedded Energy Savings<sup>2</sup><br/>(kWh/yr)</b> | <b>Impact on Water Quality</b><br>Material Increase (I), Decrease (D), or No Change (NC)<br>compared to existing conditions |                                           |                                                    |               |
|-----------------------------------|-----------------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------------------------------------------|---------------|
|                                   |                                                           |                                                         | <b>Mineralization<br/>(calcium,<br/>boron, and<br/>salts)</b>                                                               | <b>Algae or<br/>Bacterial<br/>Buildup</b> | <b>Corrosives as<br/>a Result of<br/>PH Change</b> | <b>Others</b> |
| Impact (I, D, or NC)              | I                                                         | I                                                       | NC                                                                                                                          | NC                                        | NC                                                 | NC            |
| Per Unit Impacts <sup>3</sup>     | 2,800                                                     | 28                                                      | -                                                                                                                           | -                                         | -                                                  | -             |
| Statewide Impacts<br>(first year) | 15,600,000                                                | 156,000                                                 | -                                                                                                                           | -                                         | -                                                  | -             |

<sup>2.</sup> Does not include water savings at power plant

<sup>3.</sup> Assumes embedded energy factor of 10,045 kWh per million gallons of water.

<sup>4.</sup> The unit is tons of cooling capacity. For description of prototype buildings refer to Methodology section below.

### 5.3.3 Other Impacts Results

The Statewide CASE Team does anticipate that a subset of the thermally driven cooling systems will use on-site fuel combustion to provide a source of heat when other heat sources are not available. The Statewide CASE Team did not conduct a quantitative analysis of the impacts of on-site combustion. However, we anticipate that only one or two systems that use on-site combustion will be installed during the first year the Standards are in effect. Based on this small number of systems that will use on-site combustion, the Statewide CASE Team anticipates that this measure will not result in significant environmental impact in the state air districts resulting from approval of this proposal.

## 6. PROPOSED LANGUAGE

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The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2013 documents are marked with underlining (new language) and ~~striketroughs~~ (deletions).

### 6.1 Standards

No revisions are needed.

### 6.2 Reference Appendices

No revisions are needed.

### 6.3 ACM Reference Manual

#### 5.7.7.2 Desiccant

##### *Desiccant Heat Source: Definition*

- Gas – Hydronic – the regeneration heat load is met with a gas-fired heater
- Hot water – the heat load is met with hot water from the plant
- Waste hot water – the regeneration heat load is met with waste hot water
- Solar hot water – the regeneration heat load is met with hot water from solar thermal
- Condenser heat – the regeneration heat load is met with hot air from a condenser

#### 5.8.2 Chillers

Definition: The type of chiller, either a vapor-compression chiller, ~~or an absorption chiller,~~ or an adsorption chiller.

##### *Chiller Fuel Source*

- Electricity (for all vapor-compression chillers)
- Gas (Absorption units only, designated as direct-fired units)
- Hot Water (Absorption and adsorption units only, designated as indirect-fired units)
- Steam (Absorption units only, designated as indirect-fired units)

Chiller Rated Efficiency: add adsorption chiller

##### *Fuel and Steam Chiller Cooling Efficiency Adjustment Curves*

Default Curves for Steam-Driven Single and Double Effect Absorption Chillers

Default Curves for Direct-Fired Double Effect Absorption Chillers

Default Curves for Hot Water-Driven Absorption and Adsorption Chillers. The default curves are the same format as those for the Steam-Driven Single and Double Effect Absorption Chillers.

### **5.10 On-Site Power and Heat Generation**

Building projects may incorporate other on-site electricity generation equipment, such as cogeneration plants or fuel cells that make electricity and produce heat. Projects may also include wind turbines. These systems may be modeled in various ways and the building descriptors described below should be considered an example of one set. In all cases, the baseline building will be modeled without on-site generation equipment. If there is no thermal link between the power generation equipment and building equipment (such as heat recovery from CHP), on-site power generation can be modeled in a separate process; otherwise, it needs to be linked to the building simulation.

When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy and all energy required to deliver the cooling to spaces within the building. If thermal storage is used any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site.

RESERVED FOR FUTURE USE – onsite power generation systems are not currently modeled for Title 24 compliance or reach. Qualifying solar water heating systems are specified by a solar fraction, and referenced in Section 5.9.

## **6.4 Compliance Manuals**

No revisions to the compliance manual are needed.

## **6.5 Compliance Forms**

No revisions to the compliance forms are needed.

## 7. PROPOSED CHANGES TO CBECC-COM

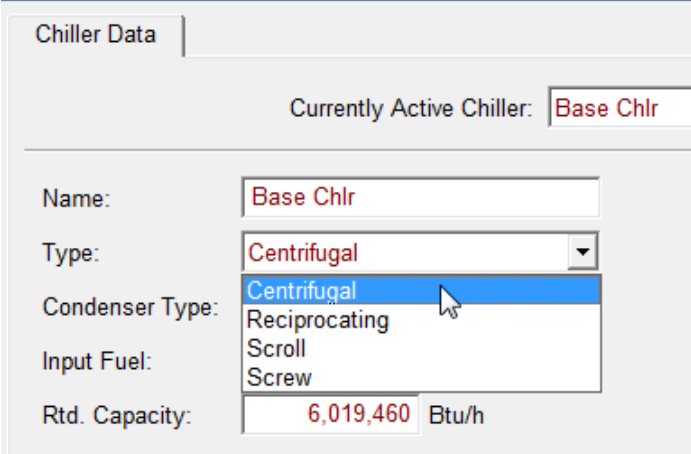
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CBECC-Com is a nonresidential compliance software approved by the CEC for Title 24 compliance. As of early September 2014, CBECC-Com 2013 v2b (Build 609) is the current approved version. Another version is publicly available, CBECC-Com 2013 v3-beta (Build 645), but has not yet been approved by the CEC for Title 24 compliance. A number of changes to CBECC-Com v2b and v3beta are needed for the software to correctly handle thermally driven cooling systems. These changes are described here. In addition, the CBECC-Com User Manual will need updated based on these revisions.

### 7.1 Absorption and Adsorption Chillers

The CBECC-Com Chiller Data input screen does not yet allow for absorption or adsorption chillers. The Type field includes centrifugal, reciprocating, scroll, and screw chiller types. This needs to be expanded to include the following selection options. Note that adsorption chillers are only available in single-stage and not two-stage.

- Single-stage absorption, air-cooled
- Single-stage absorption, water-cooled
- Two-stage absorption, indirect-fired
- Two-stage absorption, direct-fired
- Single-stage adsorption



The screenshot shows the 'Chiller Data' input screen. At the top, it says 'Currently Active Chiller: Base Chlr'. Below this, there are several fields: 'Name' (Base Chlr), 'Type' (a dropdown menu with 'Centrifugal' selected and a list of options: Centrifugal, Reciprocating, Scroll, Screw), 'Condenser Type' (empty), 'Input Fuel' (empty), and 'Rtd. Capacity' (6,019,460 Btu/h).

**Figure 9: CBECC Chiller Type Selection**

The chiller Input Fuel field as currently available in CBECC is shown below.

Chiller Data

Currently Active Chiller: **Base Chlr**

Name: **Base Chlr**

Type: **Centrifugal**

Condenser Type: **Fluid**

Input Fuel: **Electric**

Rtd. Capacity: **0.0134 Btu/h**

**Figure 10: CBECC Chiller Input Fuel Selection**

The chiller Input Fuel field should be modified to allow for the following fuel options for absorption chillers:

- Direct-fired from natural gas
- Exhaust-fired from onsite recovered heat source (waste heat)
- Hot water from a natural gas boiler
- Hot water from solar thermal
- Hot water from district heating plant
- Hot water from onsite recovered heat source (waste heat)
- Hot water from electric chiller condenser heat
- Steam from natural gas boiler
- Steam from district heating plant
- Steam from onsite recovered heat source (waste heat)
- Other onsite recovered heat source (waste heat)

The chiller Input Fuel field should be modified to allow for the following fuel options for adsorption chillers. Note that steam, direct-fired, or exhaust-fired are not input fuel options for adsorption chillers due to the batch cooling/heating nature of the process.

- Hot water from a natural gas boiler
- Hot water from solar thermal
- Hot water from district heating plant
- Hot water from onsite recovered heat source (waste heat)
- Hot water from electric chiller condenser heat
- Other onsite recovered heat source (waste heat)

The chiller Input Fuel field shall allow the user to select multiple fuel sources of a common fuel type. That is, choose multiple sources of hot water or choose multiple sources of steam, with one designated as the primary source and the other as a backup source. For example, a user could select the primary fuel source as hot water from solar thermal and the backup as hot water from a natural gas boiler. In this case, the user shall input a fuel schedule by fuel type and hour of the day and day of the week. The schedule type should be On-Off or Fractional. When solar thermal is selected as the primary fuel source, the simulation engine should determine when the solar thermal hot water supply is sufficient to meet the demand and thus when to rely on the backup fuel source.

On-site renewable energy sources or recovered energy shall not be considered to be purchased energy and shall not be included in the energy budget for the proposed design building. Where on-site renewable or recovered sources are used, the energy budget for the standard design building shall be based on the energy source used as the backup energy source or electricity if no backup energy source has been specified. The following table shows which fuel options shall be included in the energy budget for the proposed design building.

**Table 19: Fuel Sources Included in Energy Budget for the Proposed Design Building**

| <b>Fuel Source</b>                                           | <b>Include in Energy Budget for Proposed Design?</b> |
|--------------------------------------------------------------|------------------------------------------------------|
| Direct-fired from natural gas                                | Yes                                                  |
| Exhaust-fired from onsite recovered heat source (waste heat) | No                                                   |
| Hot water from a natural gas boiler                          | Yes                                                  |
| Hot water from solar thermal                                 | No                                                   |
| Hot water from district heating plant                        | Yes                                                  |
| Hot water from onsite recovered heat source (waste heat)     | No                                                   |
| Hot water from electric chiller condenser heat               | No                                                   |
| Steam from natural gas boiler                                | Yes                                                  |
| Steam from district heating plant                            | Yes                                                  |
| Steam from onsite recovered heat source (waste heat)         | No                                                   |
| Other onsite recovered heat source (waste heat)              | No                                                   |

In all cases, the software shall allow hot water and steam loops to connect with the absorption chillers and hot water loops with the adsorption chillers. For example, a solar hot water loop will need to connect with the HVAC plant loop when the user specifies such a configuration.

The Chiller Data input screen needs to allow for the numerous parameters and performance curves used as inputs to EnergyPlus. Changes to the software should be coordinated with changes to EnergyPlus as described in the section Proposed Changes to EnergyPlus. For

example, the default values and range of allowed values for the various parameters should be coordinated in particular. These parameters and performance curves are extensive and are described in more detail in the section Proposed Changes to EnergyPlus.

Finally, the software shall follow these procedures:

When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy and all energy required to deliver the cooling to spaces within the building. If thermal storage is used any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site.

## 7.2 Desiccant Cooling

CBECC-Com does not yet allow for desiccant cooling as a modeling option. The software needs to allow for the numerous parameters and performance curves used as inputs to EnergyPlus. Changes to the software should be coordinated with changes to EnergyPlus as described in the section Proposed Changes to EnergyPlus. For example, the default values and range of allowed values for the various parameters should be coordinated in particular. These parameters and performance curves are described in more detail in the section Proposed Changes to EnergyPlus. In addition, the CBECC-Com User Manual will need updated based on these revisions.

The software shall follow these procedures:

When on-site renewable energy or site recovered thermal energy is used to provide space cooling, the energy consumption of the proposed cooling system includes all energy consumption required to extract the heat and to convert this into cooling energy and all energy required to deliver the cooling to spaces within the building. If thermal storage is used any heat losses and equipment energy usage is also accounted for. The solar energy or thermal energy recovered from a process is treated as free and thus is not included in the energy budget. There is no credit for cooling energy created that is not used for space conditioning on site.

## 8. PROPOSED CHANGES TO ENERGYPLUS

CBECC-Com relies on EnergyPlus version 8.1 as its simulation engine, which comes bundled with the CBECC-Com installation package. A number of changes to EnergyPlus are needed for the software to correctly handle thermally driven cooling systems. These changes are described here.

### 8.1 Absorption and Adsorption Chillers

The EnergyPlus object Chiller:Absorption:Indirect is an absorption chiller model that relies on performance curves and various parameters to describe the chiller operation and performance. The following table shows the complete list of parameters available as inputs for this object. A similar EnergyPlus object must be developed for adsorption chillers as EnergyPlus does not specifically support adsorption chillers. As a workaround, a user could use Chiller:Absorption:Indirect with adsorption chiller performance data. The list of input parameters for adsorption chillers will be identical to that for absorption chillers.

| Field                                                                            | Units |
|----------------------------------------------------------------------------------|-------|
| Name                                                                             |       |
| Nominal Capacity                                                                 | W     |
| Nominal Pumping Power                                                            | W     |
| Chilled Water Inlet Node Name                                                    |       |
| Chilled Water Outlet Node Name                                                   |       |
| Condenser Inlet Node Name                                                        |       |
| Condenser Outlet Node Name                                                       |       |
| Minimum Part Load Ratio                                                          |       |
| Maximum Part Load Ratio                                                          |       |
| Optimum Part Load Ratio                                                          |       |
| Design Condenser Inlet Temperature                                               | C     |
| Condenser Inlet Temperature Lower Limit                                          | C     |
| Chilled Water Outlet Temperature Lower Limit                                     | C     |
| Design Chilled Water Flow Rate                                                   | m3/s  |
| Design Condenser Water Flow Rate                                                 | m3/s  |
| Chiller Flow Mode                                                                |       |
| Generator Heat Input Function of Part Load Ratio Curve Name                      |       |
| Pump Electric Input Function of Part Load Ratio Curve Name                       |       |
| Generator Inlet Node Name                                                        |       |
| Generator Outlet Node Name                                                       |       |
| Capacity Correction Function of Condenser Temperature Curve Name                 |       |
| Capacity Correction Function of Chilled Water Temperature Curve Name             |       |
| Capacity Correction Function of Generator Temperature Curve Name                 |       |
| Generator Heat Input Correction Function of Condenser Temperature Curve Name     |       |
| Generator Heat Input Correction Function of Chilled Water Temperature Curve Name |       |
| Generator Heat Source Type                                                       |       |
| Design Generator Fluid Flow Rate                                                 | m3/s  |
| Temperature Lower Limit Generator Inlet                                          | C     |
| Degree of Subcooling in Steam Generator                                          | C     |
| Degree of Subcooling in Steam Condensate Loop                                    | C     |
| Sizing Factor                                                                    |       |

**Figure 11: EnergyPlus Chiller:Absorption:Indirect Input Screen**

The first half of the Chiller:Absorption:Indirect object input screen includes a few inputs to describe how the chiller connects with the rest of the simulation model (e.g. chilled water inlet and outlet node names). The first half of this screen also includes input fields related to basic characteristics for the modeled chiller (e.g. nominal capacity and minimum part load ratio), which should be readily available from product catalogs and communication with sales engineers. The second half of the Chiller:Absorption:Indirect object input screen includes inputs for the chiller performance curves (e.g. how the capacity varies with chilled water temperature). These curves should be readily available from product catalogs, communication with sales engineers, or monitored data from prior projects.

The input fields for the first half of the input screen are described here:

The *Nominal Capacity* is a user defined input for the cooling capacity in units of Watts.

The *Nominal Pumping Power* is a user defined input that contains the nominal pumping power of the absorber in Watts. From stakeholder input, the pumping power for adsorption chillers varies linearly with cooling capacity as described by the following equation. If the user does not input a value to this field, then the equation should be used to estimate the value.

$$\text{Nominal Pumping Power} = 0.0012 * \text{Nominal Capacity} + 125$$

The field *Minimum Part Load Ratio* contains the chiller's minimum part-load ratio. The expected range is between 0 and 1, while the typical value is between 0.05 and 0.12 per stakeholder input. The default value should be 0.12. The minimum part load is not the load where the machine shuts off, but where the amount of power remains constant to produce smaller loads than this fraction.

The field *Maximum Part Load Ratio* contains the chiller's maximum part-load ratio. This value may exceed 1, but the normal range is between 0 and 1.15. The typical value is between 1.0 and 1.15, while 1.0 should be set as the default value.

The field *Optimum Part Load Ratio* contains the chiller's optimum part-load ratio. This is the part-load ratio at which the chiller performs at its maximum COP. The normal range is between 1.0 and 1.1. The typical value is 1.0, which should be set as the default value.

The field *Design Condenser Inlet Temperature* contains the chiller's condenser inlet design temperature in Celsius. The default value for this field is 30° C (also confirmed with stakeholder input) and is only used when the Design Chilled Water Flow Rate is auto-sized.

The field *Condenser Inlet Temperature Lower Limit* contains the chiller's lower limit for the condenser entering water temperature in Celsius. The default value for this field is 15°C. Per stakeholder input, this value can be as low as 4°C. If this limit is exceeded, a warning message will report the incident. No correction to chiller capacity is made for low condenser entering water temperatures.

The field *Chilled Water Outlet Temperature Lower Limit* contains the chiller's lower limit for the evaporator leaving water temperature in Celsius. The default value for this field is 5°C. Per stakeholder input, this value can be as low as 3°C. If this limit is exceeded, a warning message

will report the incident. No correction to chiller capacity is made for low evaporator leaving water temperatures.

The field *Design Chilled Water Flow Rate* specifies the design evaporator volumetric flow rate in cubic meters per second. The value specified must be greater than 0 or this field is auto-sizable. For variable volume chiller this is the maximum flow and for constant flow chiller this is the design flow rate. For adjustable flowrates, the flow is typically between 50% and 120% of design flow.

The field *Design Condenser Water Flow Rate* specifies the chiller's design condenser water flow rate in cubic meters per second. The value specified must be greater than 0 or this field is auto-sizable.

The following tables summarize the basic performance data of typical absorption and adsorption chillers based on stakeholder input.

**Table 20: Performance Data for Typical Single-Stage Absorption Chillers**

|                                    | Typical Small Chiller | Typical Medium Chiller | Typical Large Chiller | Units |
|------------------------------------|-----------------------|------------------------|-----------------------|-------|
| Nominal Cooling Capacity           | 205                   | 2,046                  | 10,230                | kW    |
| Rated COP                          | 0.76                  | 0.76                   | 0.76                  |       |
| Power Demand                       | 2.5                   | 8.6                    | 27.3                  | kW    |
| Minimum Part Load Ratio            | 0.05                  | 0.05                   | 0.05                  |       |
| Maximum Part Load Ratio            | 1.15                  | 1.15                   | 1.15                  |       |
| Design Condenser Water Flow Rate   | 61.7                  | 616                    | 3082                  | m3/h  |
| Design Condenser Inlet Temperature | 30                    | 30                     | 30                    | C     |
| Min Condenser Water Temp           | 10                    | 10                     | 10                    | C     |
| Design CHW Flow Rate               | 25.1                  | 251                    | 1253                  | m3/h  |
| Adjustable CHW Flow Rate           | 50% - 120%            | 50% - 120%             | 50% - 120%            | %     |
| Design Leaving CHW Temp            | 7                     | 7                      | 7                     | C     |
| Min Leaving CHW Temp               | 5                     | 5                      | 5                     | C     |
| Design Hot Water Flow Rate         | 23.2                  | 232                    | 1158                  | m3/h  |
| Design Hot Water Inlet Temperature | 98                    | 98                     | 98                    | C     |

Source: Broad and SOLID

**Table 21: Performance Data for Typical Two-Stage Absorption Chillers**

|                                    | Typical Small Chiller | Typical Medium Chiller | Typical Large Chiller | Units |
|------------------------------------|-----------------------|------------------------|-----------------------|-------|
| Nominal Cooling Capacity           | 233                   | 2,326                  | 11,630                | kW    |
| Rated COP                          | 1.41                  | 1.41                   | 1.41                  |       |
| Power Demand                       | 1.7                   | 10.2                   | 34.9                  | kW    |
| Minimum Part Load Ratio            | 0.05                  | 0.05                   | 0.05                  |       |
| Maximum Part Load Ratio            | 1.15                  | 1.15                   | 1.15                  |       |
| Design Condenser Water Flow Rate   | 48.8                  | 488                    | 2442                  | m3/h  |
| Design Condenser Inlet Temperature | 30                    | 30                     | 30                    | C     |
| Min Condenser Water Temp           | 10                    | 10                     | 10                    | C     |
| Design CHW Flow Rate               | 28.5                  | 285                    | 1429                  | m3/h  |
| Adjustable CHW Flow Rate           | 50% - 120%            | 50% - 120%             | 50% - 120%            | %     |
| Design Leaving CHW Temp            | 7                     | 7                      | 7                     | C     |
| Min Leaving CHW Temp               | 5                     | 5                      | 5                     | C     |
| Design Hot Water Flow Rate         | 10.3                  | 103                    | 514                   | m3/h  |
| Design Hot Water Inlet Temperature | 180                   | 180                    | 180                   | C     |

Source: Broad and SOLID

**Table 22: Performance Data for Typical Adsorption Chillers**

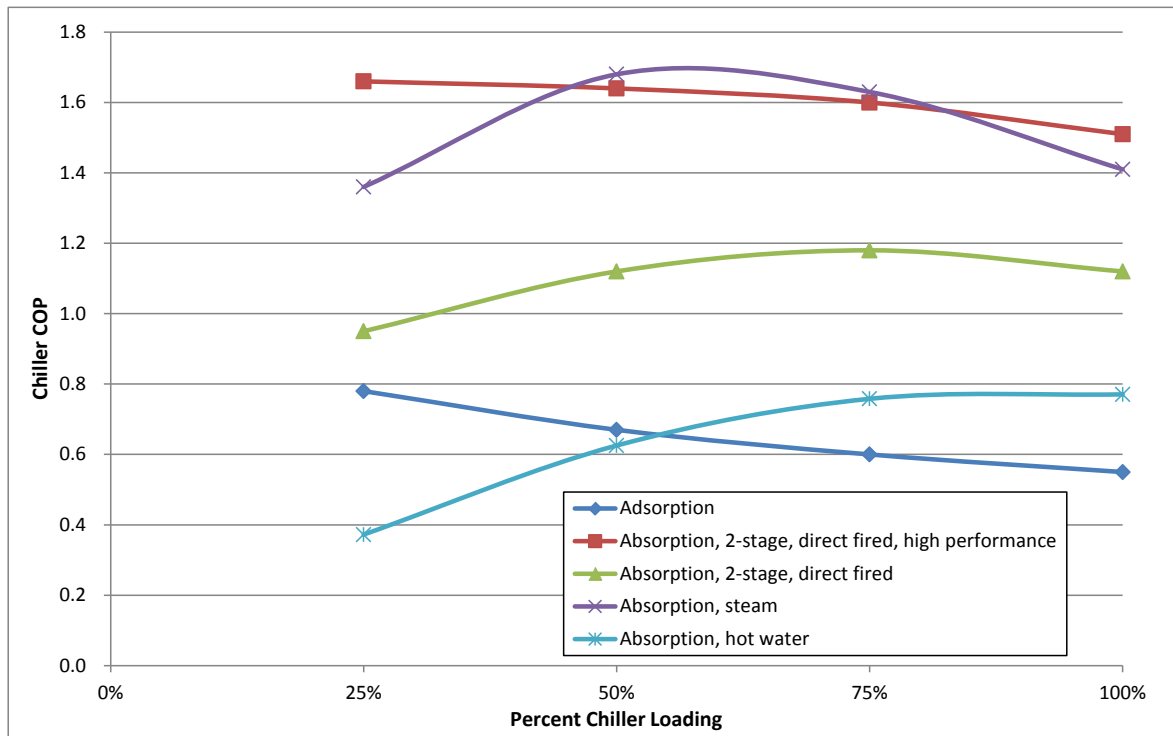
|                                    | Typical Small Chiller | Typical Medium Chiller | Typical Large Chiller | Units |
|------------------------------------|-----------------------|------------------------|-----------------------|-------|
| Nominal Cooling Capacity           | 106                   | 528                    | 1,161                 | kW    |
| Nominal Pumping Power              | 0.25                  | 0.25                   | 1.5                   | kW    |
| Minimum Part Load Ratio            | 0.12                  | 0.12                   | 0.12                  |       |
| Maximum Part Load Ratio            | 1                     | 1                      | 1                     |       |
| Optimum Part Load Ratio            | 1                     | 1                      | 1                     |       |
| Design Condenser Water Flow Rate   | 48                    | 238                    | 524                   | m3/h  |
| Design Condenser Inlet Temperature | 29                    | 29                     | 29                    | C     |
| Min Condenser Water Temp           | 4.4                   | 4.4                    | 4.4                   | C     |
| Max Condenser Water Temp           | 35                    | 35                     | 35                    | C     |
| Design CHW Flow Rate               | 16                    | 82                     | 180                   | m3/h  |
| Design Leaving CHW Temp            | 7.2                   | 7.2                    | 7.2                   | C     |
| Min Leaving CHW Temp               | 3.3                   | 3.3                    | 3.3                   | C     |
| Max Leaving CHW Temp               | 21                    | 21                     | 21                    | C     |
| Design Hot Water Flow Rate         | 27                    | 136                    | 300                   | m3/h  |
| Design Hot Water Inlet Temperature | 91                    | 91                     | 91                    | C     |
| Min Hot Water Inlet Temperature    | 54                    | 54                     | 54                    | C     |
| Max Hot Water Inlet Temperature    | 93                    | 93                     | 93                    | C     |

Source: ECO-MAX and Power Partners

The input fields for the second half of the input screen, namely the various performance curves, are described here:

The field *Generator Heat Input Function of Part Load Ratio Curve* specifies the name of the curve used to determine the heat input to the chiller. The curve is a quadratic or cubic curve that characterizes the heat input as a function of chiller part-load ratio. The curve output is

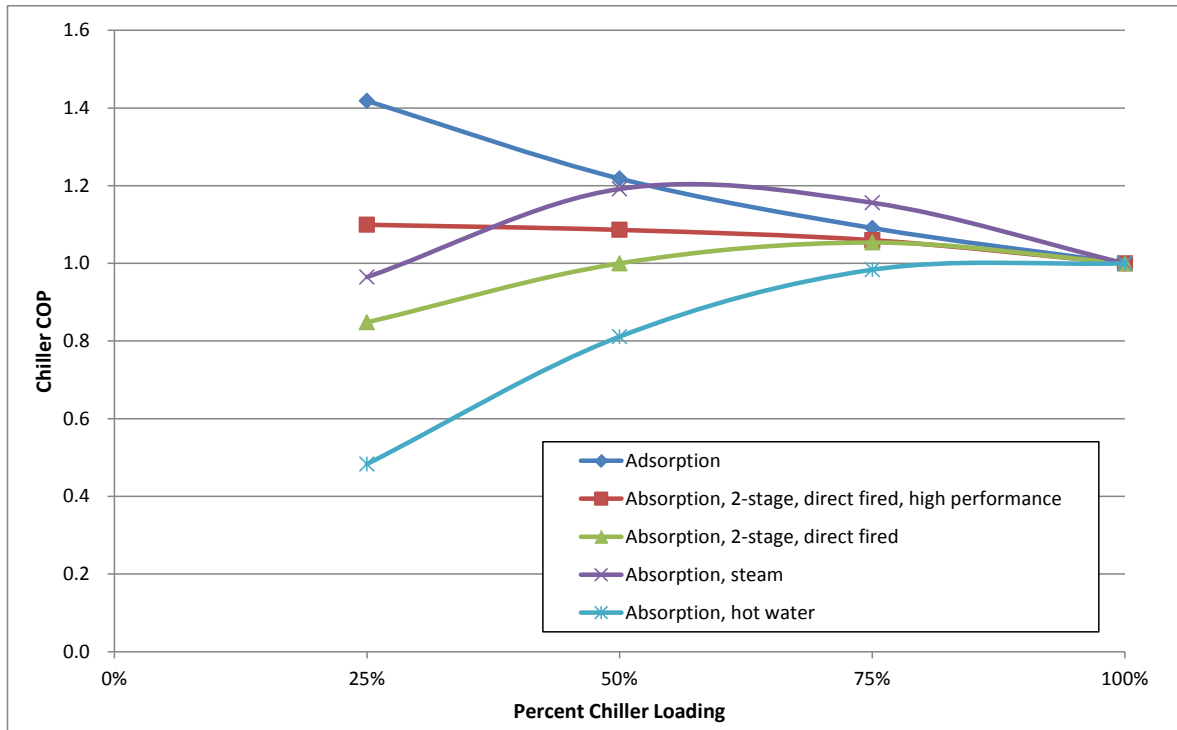
multiplied by the chiller's nominal capacity and operating part-load ratio or minimum part-load ratio, whichever is greater, to determine the amount of heat input required for the given operating conditions. This field is related to chiller COP as a function of part-load ratio. The following series of figures show how the COP varies by part-load ratio for a variety of typical absorption and adsorption chillers. This is based on performance data provided by various stakeholders. The curve shapes primarily depend on the type of chiller, number of stages, and fuel source.



**Figure 12: Chiller COP by Percent Loading**

Source: ECO-MAX, Power Partners, Broad, SOLID

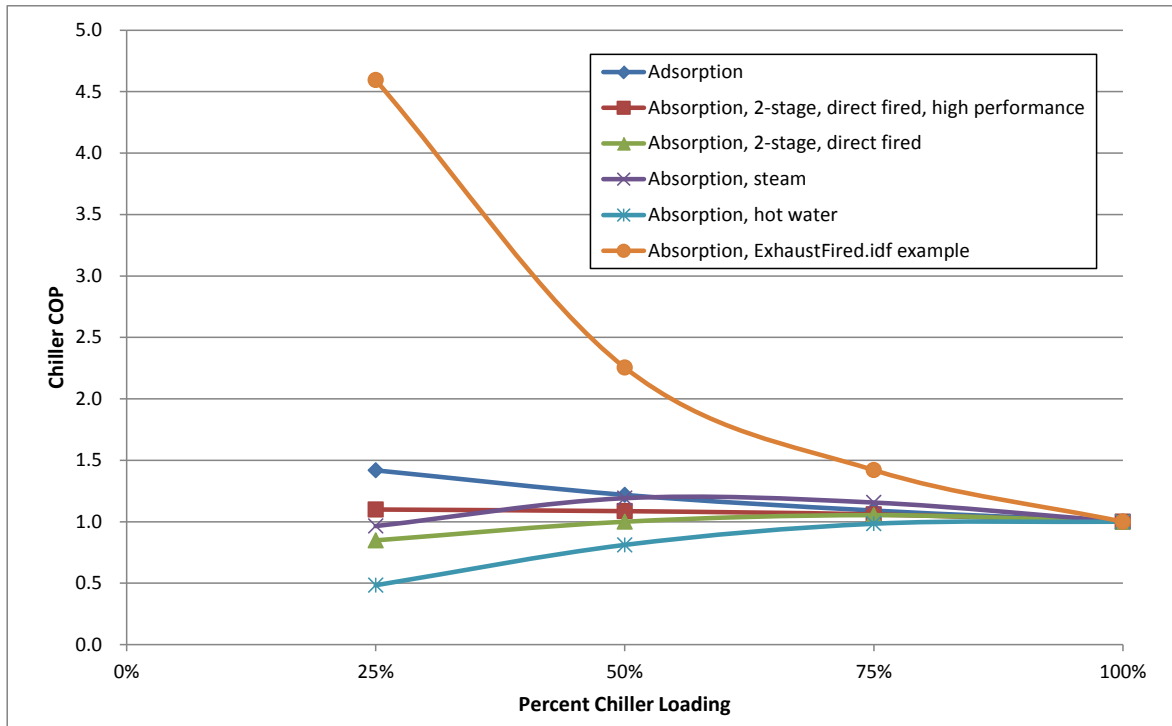
Similarly, the next figure shows how the COP varies by part-load ratio but normalized so the COP is 1.0 at full load.



**Figure 13: Chiller COP by Percent Loading Normalized to Full Load**

Source: ECO-MAX, Power Partners, Broad, SOLID

Finally, the next figure shows how the COP varies by part-load ratio but including the performance curve data for one additional chiller. This new chiller curve is provided as an example file in EnergyPlus called ExhaustFired.idf. This particular curve significantly deviates from the other five chiller performance curves. We recommend the EnergyPlus developers review this ExhaustFired.idf performance curve for potential errors and revise the ExhaustFired.idf example file if needed.



**Figure 14: Chiller COP by Percent Loading Normalized to Full Load with ExhaustFired.idf Example Curve**

Source: ECO-MAX, Power Partners, Broad, SOLID

The field *Pump Electric Input Function of Part Load Ratio Curve* specifies the name of the curve used to determine the pump electrical input to the chiller. The curve is a quadratic or cubic curve that characterizes the pump electrical power as a function of chiller part-load ratio. The curve output is multiplied by the chiller's nominal pumping power and operating part-load ratio or minimum part-load ratio, whichever is greater, to determine the amount of pumping power required for the given operating conditions.

The field *Capacity Correction Function of Condenser Temperature Curve* specifies the name of a quadratic or cubic curve that correlates the chiller's evaporator capacity as a function of condenser entering water temperature. This curve is used to correct nominal capacity at off-design condensing temperatures.

The field *Capacity Correction Function of Chilled Water Temperature Curve* specifies the name of a quadratic or cubic curve that correlates the chiller's evaporator capacity as a function of evaporator leaving water temperature. This curve is used to correct nominal capacity at off-design evaporator temperatures.

The field *Capacity Correction Function of Generator Temperature Curve* specifies the name of a quadratic or cubic curve that correlates the chiller's evaporator capacity as a function of generator entering water temperature. This curve is used to correct nominal capacity at off-design evaporator temperatures and is only used when the Generator Fluid Type is specified as Hot Water.

The following equations describe the capacity correction as a function of condenser, chilled water, and generator temperatures, as mentioned in the previous three paragraphs.

$$CAPFT_{evaporator} = a + b(T_{evaporator}) + c(T_{evaporator})^2 + d(T_{evaporator})^3$$

$$CAPFT_{condenser} = e + f(T_{condenser}) + g(T_{condenser})^2 + h(T_{condenser})^3$$

$$CAPFT_{generator} = i + j(T_{generator}) + k(T_{generator})^2 + l(T_{generator})^3 \text{ (Hot Water only)}$$

Where:

$CAPFT_{evaporator}$  = Capacity correction (function of evaporator temperature) factor

$CAPFT_{condenser}$  = Capacity correction (function of condenser temperature) factor

$CAPFT_{generator}$  = Capacity correction (function of generator temperature) factor

$T_{evaporator}$  = evaporator outlet water temperature [°C]

$T_{condenser}$  = condenser inlet water temperature [°C]

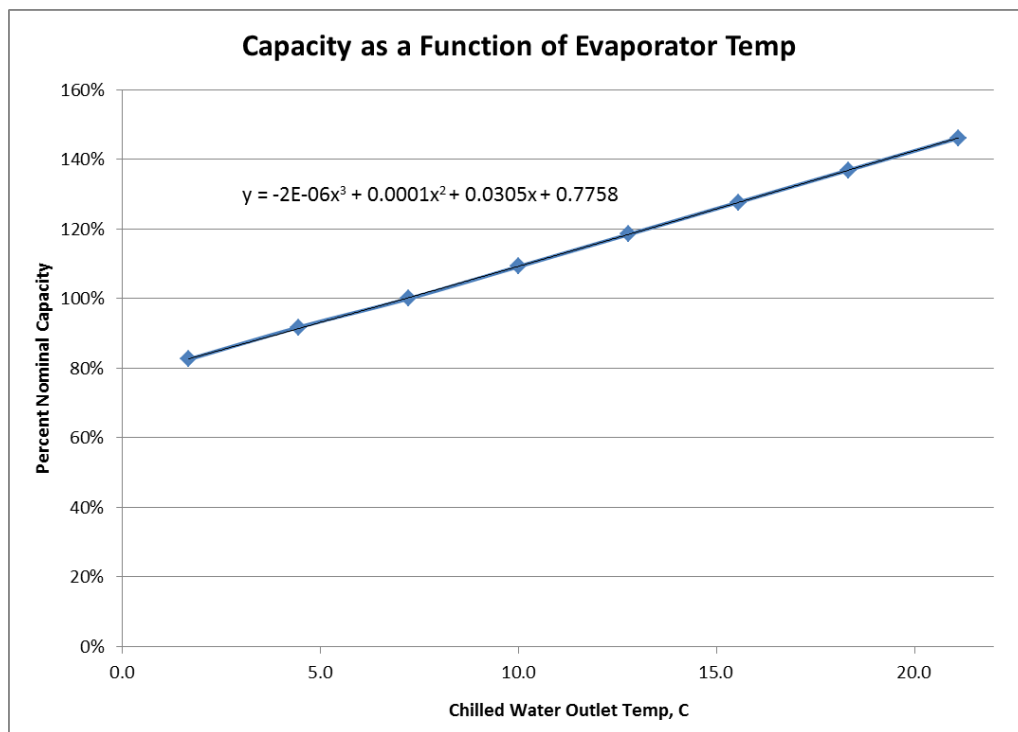
$T_{generator}$  = generator inlet water temperature [°C]

These equation coefficients are a user defined input that will vary with each chiller. The following table shows some example data for an adsorption chiller as provided by stakeholder input. These values could be used as default values in EnergyPlus.

**Table 23: Coefficients for Typical Adsorption Chiller Capacity Correction Function of Generator Temperature**

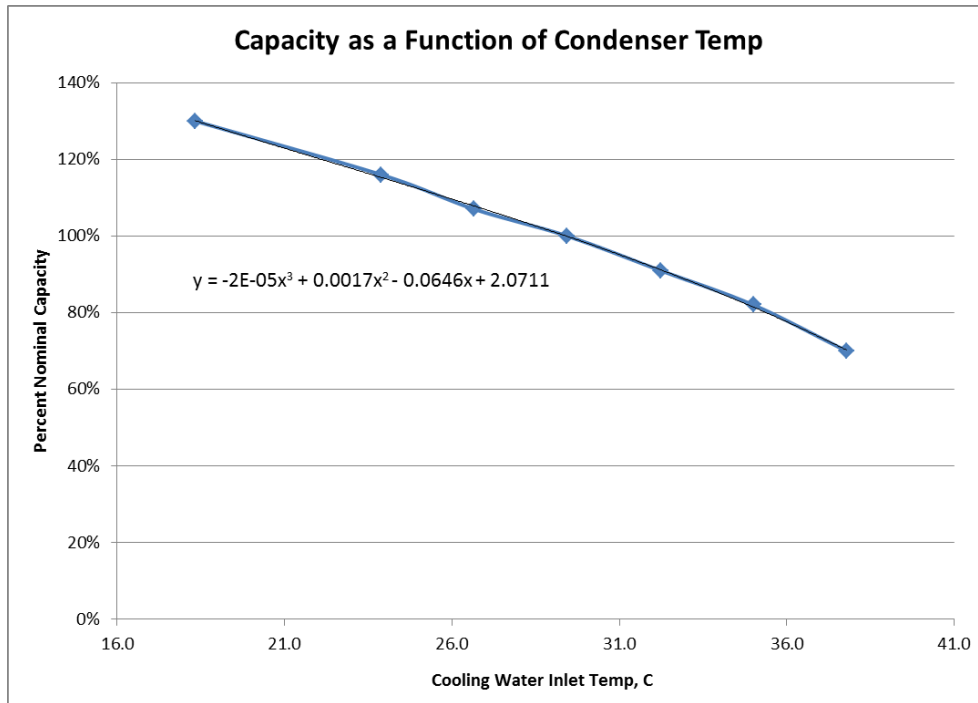
| Equation coefficients | Default values for adsorption chiller |
|-----------------------|---------------------------------------|
| a                     | 0.7758                                |
| b                     | 0.0305                                |
| c                     | 0.0001                                |
| d                     | 0                                     |
| e                     | 2.0711                                |
| f                     | -0.0646                               |
| g                     | 0.0017                                |
| h                     | 0                                     |
| i                     | -1.0966                               |
| j                     | -0.01                                 |
| k                     | 0.0009                                |
| l                     | 0                                     |

The associated performance curves are included in the following three figures. These curves could be used as default performance curves in EnergyPlus. They are based on performance data provided by stakeholders.



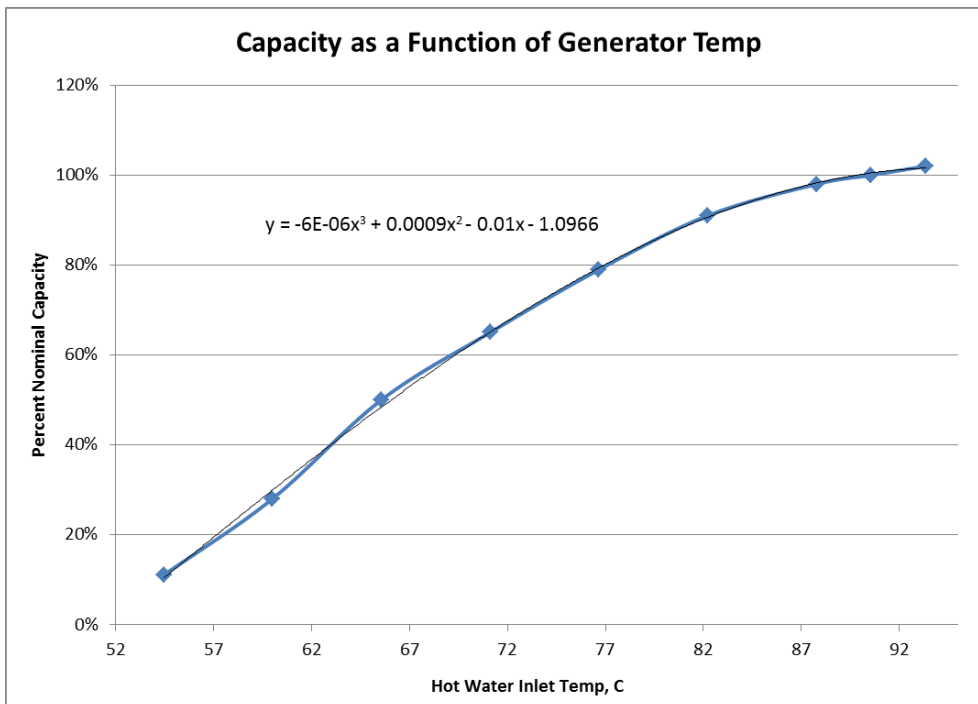
**Figure 15: Typical Adsorption Chiller Capacity as a Function of Evaporator Temperature**

Source: ECO-MAX and Power Partners



**Figure 16: Typical Adsorption Chiller Capacity as a Function of Condenser Temperature**

Source: ECO-MAX and Power Partners



**Figure 17: Typical Adsorption Chiller Capacity as a Function of Generator Temperature**

Source: ECO-MAX and Power Partners

The field *Generator Heat Input Correction Function of Condenser Temperature Curve* specifies the name of a quadratic or cubic curve that correlates the chiller's heat input as a function of condenser entering water temperature. This curve is used to correct generator heat input at off-design condensing temperatures.

The field *Generator Heat Input Correction Function of Chilled Water Temperature Curve* specifies the name of a quadratic or cubic curve that correlates the chiller's heat input as a function of evaporator leaving water temperature. This curve is used to correct generator heat input at off-design evaporator temperatures.

## 8.2 Desiccant Cooling

EnergyPlus already allows for desiccant cooling as a modeling option. It provides two options as described here. No apparent changes are needed to the software to support thermally driven cooling.

The EnergyPlus object `Dehumidifier:Desiccant:NoFans` models a solid desiccant dehumidifier (excluding associated fans). It is described here as reported in the EnergyPlus Input-Output Reference Manual:

The process air stream is the air which is dehumidified. The regen air stream is the air which is heated to regenerate the desiccant. This object determines the process air outlet conditions, the load on the regeneration heating coil, the electric power consumption for the wheel rotor motor, and the regeneration air fan mass flow rate. All other heat exchangers are modeled as separate objects connected to the inlet and outlet nodes of the dehumidifier. The solid desiccant dehumidifier is typically used in an `AirLoopHVAC:OutdoorAirSystem` object, but can also be specified in any `AirLoopHVAC`. The regeneration heating coil can be Gas, Electric, Steam, or Hot Water coil. When hot water coil is selected as regeneration heating coil user-defined curves designed for lower temperature operation must be specified in the input field `Performance Model Type` along with the `Nominal Regeneration Temperature` input field. The default performance model type is valid for higher nominal regeneration temperature (e.g. 121C).

The EnergyPlus object `Dehumidifier:Desiccant:System` also models a solid desiccant dehumidifier. It is described here as reported in the EnergyPlus Input-Output Reference Manual:

The `Dehumidifier:Desiccant:System` object models the dehumidification of an air stream, normally called the process air stream. A second heated air stream, called the regeneration air stream, is used to remove the collected moisture from the desiccant heat exchanger and this moisture-laden air is then usually exhausted from the building. This `Dehumidifier:Desiccant:System` object is similar to the `Dehumidifier:Desiccant:NoFans` object but has some additional modeling capabilities.

The `Dehumidifier:Desiccant:System` object in EnergyPlus is a compound object that can be placed anywhere in an air loop (`AirLoopHVAC`). Common locations for this object are in an `AirLoopHVAC:OutdoorAirSystem` or in the main air loop (`AirLoopHVAC`)

downstream of a cooling coil (postcooling desiccant dehumidifier). This compound object coordinates the operation of several ‘children’ objects: a desiccant heat exchanger, a regeneration air fan, and an optional regeneration air heater. Gas, Electric, Steam, or Hot Water heating coils can be used for regenerator air heaters. If this dehumidifier is placed in the main air loop immediately downstream of a direct expansion (DX) cooling coil, then the dehumidifier’s operation can be coordinated with the operation of the companion DX coil and it is also possible to specify that the DX system’s condenser waste heat can be used to help regenerate the desiccant heat exchanger. For the case of condenser waste heat regeneration, an optional exhaust fan can also be modeled by this desiccant dehumidifier compound object to help maintain a set point temperature for air entering the regeneration side of the desiccant heat exchanger.

## 9. REFERENCES AND OTHER RESEARCH

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# APPENDIX A: ENVIRONMENTAL IMPACTS

## METHODOLOGY

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### Greenhouse Gas Emissions Impacts Methodology

#### *Greenhouse Gas Emissions Impacts Methodology*

The GHG emissions impacts were calculated assuming an emission factor of 353 metric tons of carbon dioxide equivalents (MTCO<sub>2</sub>e) per GWh of electricity. The Statewide CASE Team calculated air quality impacts associated with the electricity impacts from the proposed measure using emission factors that indicate emissions per GWh of electricity generated.<sup>2</sup> When evaluating the impact of increasing the Renewable Portfolio Standard (RPS) from 20 percent renewables by 2020 to 33 percent renewables by 2020, California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The Statewide CASE Team used data from CARB's analysis to inform the air quality analysis presented in this report.

The GHG emissions factor is a projection for 2020 assuming the state will meet the 33 percent RPS goal. CARB calculated the emissions for two scenarios: (1) a high load scenario in which load continues at the same rate; and (2) a low load rate that assumes the state will successfully implement energy efficiency strategies outlined in the AB32 scoping plan thereby reducing overall electricity load in the state.

To be conservative, the Statewide CASE Team calculated the emissions factors of the incremental electricity between the low and high load scenarios. These emission factors are intended to provide a benchmark of emission reductions attributable to energy efficiency measures that could help achieve the low load scenario. The incremental emissions were calculated by dividing the difference between California emissions in the high and low generation forecasts by the difference between total electricity generated in those two scenarios. While emission rates may change over time, 2020 was considered a representative year for this measure.

The GHG emissions from natural gas impacts were calculated using an emission factor of 5,303 MTCO<sub>2</sub>e/million therms (U.S. EPA 2011).

### Water Use and Water Quality Impacts Methodology

Per ton of cooling, water cooled absorption chillers require larger heat rejection equipment (cooling towers) and therefore will use more water on-site as compared to a water cooled electric chiller. If evaporative cooling is used (with desiccants) more water will also be used.

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<sup>2</sup> California power plants are subject to a GHG cap and trade program and linked offset programs until 2020 and potentially beyond.

However, less water is needed at the power plants due to the electricity savings and demand reduction. The change in water use is calculated by the EnergyPlus simulations.

### ***Embedded Energy in Water***

The embedded energy value used in the analysis is 10,045 kWh/million gallons of water (MG). This value was derived from a California Energy Commission PIER study (CEC 2006), which states the embedded energy values shown in the table below “are sufficient for informing policy and prioritization of research and development investments.”

**Table A- 1: Recommended Embedded Energy Estimates**

Source: CEC 2006. Table 7.

|                             | Indoor Uses                   |                               | Outdoor Uses                  |                               |
|-----------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                             | Northern California<br>kWh/MG | Southern California<br>kWh/MG | Northern California<br>kWh/MG | Southern California<br>kWh/MG |
| Water Supply and Conveyance | 2,117                         | 9,727                         | 2,117                         | 9,727                         |
| Water Treatment             | 111                           | 111                           | 111                           | 111                           |
| Water Distribution          | 1,272                         | 1,272                         | 1,272                         | 1,272                         |
| Wastewater Treatment        | 1,911                         | 1,911                         | 0                             | 0                             |
| Regional Total              | 5,411                         | 13,022                        | 3,500                         | 11,111                        |

The total regional values shown in Table A- 1 were weighted based on the population in Northern and Southern California in 2011 (U.S. Census Bureau). All water used in toilets and urinals is used indoors, so only the indoor embedded energy values apply.

The California Public Utilities Commission (CPUC) has conducted additional research on embedded energy since the CEC’s 2006 report was released. However, the values presented in the CEC’s 2006 report are still the most up-to-date values recommended for use to inform policies the Statewide CASE Team has used the CEC’s 2006 embedded energy values for this analysis.

The CPUC has made notable progress in improving understanding of the relationship between water and energy in California. CPUC’s Decision 07-12-050, issued December 20, 2007, authorized the largest electricity utilities to partner with water utilities and administer pilot programs that aimed to save water and energy (CPUC 2011c). The Decision also authorized three studies to validate claims that saving water can save energy and explore whether embedded energy savings associated with water use efficiency are measurable and verifiable. The pilot programs succeed at demonstrating that water conservation measures also result in energy savings.

The CPUC studies were effective at obtaining a more granular understanding of how energy use varies based on a number of factors including supply, (i.e. surface, ground, brackish, or ocean desalination), geography, and treatment technology. The authors found “that the value of

energy embedded in water is higher than initially estimated in the CEC's 2005 and 2006 studies." Although the data collected for the studies is the most comprehensive set of data on energy used to meet water demand, the data is still just a small sampling of all the potential data points in California. Since the authors did not find strong patterns within the sample data and there was no strong evidence that the sample data was representative for a particular region, process, or technology type, the authors did not have a strong basis to estimate the embedded energy values for specific geographic regions. Further, the CPUC studies did not recommend changes to the embedded energy values presented in the CEC's 2006 report.

While the CASE Report analysis uses the embedded energy values associated with water supply and conveyance, there is no evidence that reducing water use at the building level will impact water supply and conveyance activities. Thus water efficiency standards may result in reductions to energy used to supply and convey water.