



Codes and Standards Enhancement (CASE) Initiative 2019 California Building Energy Efficiency Standards

Hybrid Condensers for Refrigerated Warehouses and Commercial Refrigeration – Draft Report

Measure Number: 2019-NR-MECH6-D

Process Refrigeration

April 2017



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DRAFT

EXECUTIVE SUMMARY

This is a draft report. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this version of the report. When possible, provide supporting data and justifications in addition to comments. Readers' suggested revisions will be considered when refining proposals and analyses. The final CASE Report will be submitted to the California Energy Commission in the third quarter of 2017. For this report, the Statewide CASE Team is requesting input on the following:

1. *The impact on product manufacturers; and*
2. *The impact on the code compliance documentation process.*

Email comments and suggestions to info@title24stakeholders.com. Comments will not be released for public review or will be anonymized if shared with stakeholders.

Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) 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 SoCalGas® – and two Publicly Owned Utilities (POUs) – Los Angeles Department of Water and Power (LADWP) and Sacramento Municipal Utility District (SMUD) – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposals presented herein is a part of the effort to develop technical and cost-effectiveness information for proposed requirements on building energy efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process:

<http://www.energy.ca.gov/title24/2019standards/>.

Measure Description

The proposed measure will add adiabatic condensers to the California Building Energy Efficiency Standards. For the purposes of this code change proposal the Statewide CASE Team defines adiabatic condensers as follows:

A refrigeration system component that condenses refrigerant vapor by rejecting heat to air mechanically circulated over its heat transfer surface, causing a temperature rise in the air, with the additional capability to utilize evaporative precooling of the entering air, for operation only during high ambient temperatures, and accomplished as part of a single factory-made and rated unit.

The mandatory requirements in Section 120.6 cover air cooled and evaporative condensers. Hybrid condensers are not currently mentioned in the code, even as an exception and therefore there is confusion in the industry.

The new mandatory code requirements will be added to Section 120.6 (a) and (b) and applies to refrigerated warehouses and commercial refrigeration, respectively.

The Statewide CASE Team discussed including adiabatic condensers for the 2013 Title 24, Part 6 code update cycle but product information was limited at that time and the Statewide CASE Team did not feel there was adequate time to address the energy savings and cost issues within the adoption schedule.

Since the development of the 2013 Title 24, Part 6 CASE Report analysis (approximately six years) market interest as greatly increased due to:

- Large water savings compared with evaporative condensers.
- Large kW savings and potential kWh savings compared to air-cooled condensers.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which the sections of the Standards, references appendices, and compliance documents that will be modified as a result of the proposed change.

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Will Compliance Software Be Modified	Modified Compliance Document(s)
Hybrid Condensers for Refrigerated Warehouses	Mandatory	120.6(a)	NA7.10.3	N/A	New NRCA PRC form for Adiabatic Condenser
Hybrid Condensers for Commercial Refrigeration	Mandatory	120.6(b)	NA7.10.3	N/A	New NRCA PRC form for Adiabatic Condenser

Market Analysis and Regulatory Impact Assessment

This proposal is cost-effective over the 15-year period of analysis. Overall, this proposal increases the wealth of the State of California. California consumers and businesses save more money on energy than they do for financing the efficiency measure.

The proposed changes to Title 24, Part 6 have a negligible impact on the complexity of the standards or the cost of enforcement. When developing this code change proposal, the Statewide CASE Team interviewed building officials, Title 24 energy analysts and others involved in the code compliance process to simplify and streamline the compliance and enforcement of this proposal.

The commercial refrigeration (supermarkets) market currently has a balance of air-cooled and evaporative condensers throughout California with market entry of adiabatic condensers beginning approximately five years ago. Refrigerated warehouses historically use of only evaporative condensers for ammonia systems.

Currently, the market supplies adiabatic condensers that come from the primary manufacturer with variable speed fan capacity control and fixed or two-speed Saturated Condensing Temperature (SCT) setpoint control. Slight design changes might be required in order to comply with some of the proposed conditions for variable SCT setpoint.

Cost-Effectiveness

The proposed code change was found to be cost-effective for all climate zones where it is proposed to be required. The benefit-to-cost (B/C) ratio compares the lifecycle benefits (cost savings) to the

lifecycle costs. Measures that have a (B/C) ratio of 1.0 or greater are cost-effective. The larger the B/C ratio, the faster the measure pays for itself from energy savings. The B/C ratio for these measures vary by climate zone and prototype as shown in Table 2.

Table 2: Range of Benefit-to-Cost Ratios for Proposed Measure

Measure	B/C ratio range
Variable SCT Setpoint (Option B)	0 – 328.33
Dry Mode Hybrid Condenser Sizing	0 - Infinite
Hybrid Condenser Specific Efficiency = 45 Btuh/W	1 (simulated in base case)

See Section 4.3 for a detailed description of the cost-effectiveness analysis.

Statewide Energy Impacts

Table 3 shows the estimated energy savings over the first twelve months of implementation of the proposed code change. See Section 5.5 for more details.

Table 3: Estimated Statewide First-Year¹ Energy and Water Savings

First-Year Electricity Savings (GWh/yr)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Water Savings (million gallons/yr)	First-Year Natural Gas Savings (million therms/yr)
1.746	0.18	-	-

1. First-year savings from all buildings completed statewide in 2020.

Compliance and Enforcement

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process will have on various market actors. The compliance process is described in Section 2.5. The impacts the proposed measure will have on various market actors is described in Section 3.3 and Appendix B.

Although a needs analysis has been conducted with the affected market actors while developing the code change proposal, the code requirements may change between the time the final CASE Report is submitted and the time the 2019 Standards are adopted. The recommended compliance process and compliance documentation may also evolve with the code language. To effectively implement the adopted code requirements, a plan should be developed that identifies potential barriers to compliance when rolling-out the code change and approaches that should be deployed to minimize the barriers.

1. INTRODUCTION

This is a draft report. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this version of the report. When possible, provide supporting data and justifications in addition to comments. Readers' suggested revisions will be considered when refining proposals and analyses. The final CASE Report will be submitted to the California Energy Commission in the third quarter of 2017. For this report, the Statewide CASE Team is requesting input on the following:

1. *The impact on product manufacturers; and*
2. *The impact on the code compliance documentation process.*

Email comments and suggestions to info@title24stakeholders.com. Comments will not be released for public review or will be anonymized if shared with stakeholders.

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) 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 SoCalGas and two Publicly Owned Utilities (POUs) — Los Angeles Department of Water and Power (LADWP) and Sacramento Municipal Utility District (SMUD) 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 requirements on building energy efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process:
<http://www.energy.ca.gov/title24/2019standards/>.

The overall goal of this CASE Report is to propose a code change proposal for Hybrid Condensers for Refrigerated Warehouses and Commercial Refrigeration. The report contains pertinent information that supports the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including building officials, manufacturers, builders, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during a public stakeholder workshops that the Statewide CASE Team held on December 12, 2016 and March 21, 2017.

Section 2 of this CASE Report provides a description of the measure and its background. This section also presents a detailed description of how this change is accomplished in the various sections and documents that make up the Title 24, Part 6.

Section 3 presents the market analysis, including a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards such as fire, seismic, and other safety standards and whether technical, compliance, or enforceability challenges exist.

Section 4 presents the per-unit energy, demand, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate energy, demand, and energy cost savings.

Section 5 presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of additional materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs. That is, equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.

Section 6 presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2019 Standards take effect. This includes the amount of energy that will be saved by California building owners and tenants, statewide Greenhouse Gas (GHG) reductions associated with reduced energy consumption, and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic. Statewide water consumption impacts are also considered.

Section 7 concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Standards, Appendices, Alternate Calculation Manual (ACM) Reference Manual, Compliance Manual, and Compliance Documents.

2. MEASURE DESCRIPTION

2.1 Measure Overview

The proposed measure will add adiabatic condensers to the California Building Energy Efficiency Standards. For the purposes of this code change proposal the Statewide CASE Team defines adiabatic condensers as follows:

A condenser that has the ability to use two heat transfer processes in series as accomplished by a single factory-made unit. The first heat transfer process is the evaporative pre-cooling of the entering air by lowering the entering air drybulb temperature. The second heat transfer process is forced-air circulation cooling over the heat transfer surface of the condenser. Also known as hybrid condenser.

The mandatory requirements in Section 120.6 cover air cooled and evaporative condensers. Adiabatic condensers are not currently mentioned in the code, even as an exception and therefore there is confusion in the industry.

The new mandatory code requirements will be added to Section 120.6 (a) and (b) and applies to refrigerated warehouses and commercial refrigeration, respectively.

2.2 Measure History

The Statewide CASE Team discussed including adiabatic condensers for the 2013 Title 24, Part 6 code update cycle but product information was limited at that time and the Statewide CASE Team did not feel there was adequate time to address the energy savings and cost issues within the adoption schedule.

Since the development of the 2013 Title 24, Part 6 CASE analysis (approximately six years) market interest as greatly increased due to:

- Large water savings compared with evaporative condensers.
- Large kW savings and potential kWh savings compared to air-cooled condensers.

The Statewide CASE Team is proposing this measure for several reasons including reducing code enforcement conflicts and confusion and establishing a baseline against which high efficiency choices can be evaluated and incentives can be provided by energy efficiency programs.

There are now at least three vendors compared to only one vendor in 2010-2011.

2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each Title 24, Part 6 document will be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.1 Standards Change Summary

This proposal will modify the following sections of the Building Energy Efficiency Standards as follows:

- Include mandatory variable speed fan control
- Include variable set point control at least for dry mode operation
- Include floating head pressure control requirements
- Establish minimum specific efficiency for dry mode
- Establish maximum temperature difference (TD) (size) for dry mode operation
- Define saturated condensing temperature (SCT) for glide refrigerants

See Section 7.1 of this report for the detailed proposed revisions to the code language.

Section 120.6 MANDATORY REQUIREMENTS FOR COVERED PROCESSES

(a) Mandatory Requirements for Refrigerated Warehouses

Subsection 120.6(a)4

(b) Mandatory Requirements for Commercial Refrigeration

Subsections 120.6(b)1 and 2

2.3.2 Reference Appendices Change Summary

This proposal will modify the following sections of the Standards Appendices as shown below. See Section 7.2 of this report for the detailed proposed revisions to the text of the reference appendices.

JOINT APPENDICIES

JA1 – Glossary

NONRESIDENTIAL APPENDICIES

The proposed requirements will add a new section to this appendix to address adiabatic condensers.

NA7.10.3.3 Adiabatic Condenser Fan Motor Variable Speed Controls

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

The proposed code change will not modify the ACM Reference Manuals.

2.3.4 Compliance Manual Change Summary

The proposed code change will modify the following section of the Title 24, Part 6 Nonresidential including changes to Chapters 10 and 13 of the nonresidential manual.

- Section 10.5 Commercial Refrigeration
- Section 10.6 Refrigerated Warehouse

- Section 13 Test Procedures for Process
 - 13.x.x NA7.10.3.3 Adiabatic Condenser Fan Motor Variable Speed Controls
 - 13.x.x Test Procedure: NA7.10.3.3 Adiabatic Condenser Fan Motor Variable
 - Speed Controls

2.3.5 Compliance Documents Change Summary

The proposed code change will modify the compliance documents listed below. Examples of the revised forms are presented in Section 7.5.

- NRCC-PRC-05-E for Commercial Refrigeration
- NRCC-PRC-06-E for Refrigerated Warehouses
- NRCC-PRC-08-E for Refrigerated Warehouse
- NRCA-PRC-XX for Adiabatic Condenser

2.4 Regulatory Context

2.4.1 Existing Title 24, Part Standards

Refrigerated warehouse and commercial refrigeration condensers are included in the mandatory requirements for covered processes Section 120.6 in Title 24, Part 6.

2.4.2 Relationship to Other Title 24 Requirements

There are no other requirements in Title 24 that are impacted by this change.

2.4.3 Relationship to State or Federal Laws

There are no federal regulatory requirements concerning efficiency of adiabatic condensers.

The federal walk-in efficiency requirements, applying to refrigerated spaces up to 3,000 square feet, would cover systems that utilize adiabatic condensers, although the walk-in standards only address overall efficiency and do not differentiate based on the means of condensing.

2.4.4 1.1.2 Relationship to Industry Standards

Hybrid condensers are not included or addressed in any model codes or industry standards.

2.5 Compliance and Enforcement

The Statewide CASE Team collected input on what compliance and enforcement issues may be associated with this measure during the stakeholder outreach process. This section summarizes how the proposed code change will modify the code compliance process. Appendix B presents a detailed description of how the proposed code changes could impact various market actors. When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced.

This code change proposal addresses mandatory measures only. The key changes to the compliance process are summarized below:

- **Design Phase:** This code change proposal will not require changes in design practices that are onerous for building designers and energy consultants. Unlike air-cooled and evaporative cooled condensers, both of which have a long historical experience with sizing, there is uncertainty over what will be most efficient when sizing adiabatic condensers. By including them in Title 24, Part 6, it will assist designers with sizing practices that realize the obvious benefits of lower peak demand without failing to meet or exceed a minimum efficiency standard

in light of no other design guidance. It will also make it easier for designers to appreciate that adiabatic condensers are an available option compared to air-cooled and evaporative cooled condensers. As with air-cooled and evaporative cooled condensers, there is no proposed requirement to use adiabatic condensers. The proposed code language only provides guidelines for designers who choose adiabatic condensers as a third option to meet a baseline efficiency.

- **Permit Application Phase:** This code change proposal will not substantially change the existing permit application phase process.
- **Construction Phase:** This code change proposal will not impact the existing construction phase process.
- **Inspection Phase:** Building inspectors will need to identify adiabatic condensers and verify all relevant code requirements. The general approach to reviewing refrigeration requirements will not change.

If this code change proposal is adopted, the Statewide CASE Team recommends that information presented in this section, Section 3 and Appendix B be used to develop a plan that identifies a process to develop compliance documentation and how to minimize barriers to compliance.

3. MARKET ANALYSIS

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 actors. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry players who were invited to participate in Utility-Sponsored Stakeholder Meetings held on December 12, 2016 and March 21, 2017.

3.1 Market Structure

The Statewide CASE Team investigated available products, and first cost considerations and the increased need for water savings issues.

3.2 Technical Feasibility, Market Availability and Current Practices

The commercial refrigeration (supermarkets) market currently has a balance of air-cooled and evaporative condensers throughout California with market entry of adiabatic condensers beginning approximately five years ago. Refrigerated warehouses historically use of only evaporative condensers for ammonia systems.

Currently, the market supplies adiabatic condensers that come from the primary manufacturer with variable speed fan capacity control and fixed or two-speed SCT setpoint control. Slight design changes might be required in order to comply with the proposed conditions for variable SCT setpoint Option C. Option C requires an ambient temperature sensor to be installed between the adiabatic pad material and the condenser coil/microchannel structure that is currently not included with the available offerings in the market.

Ambient temperature sensors necessary to achieve this are a readily available technology and could be supplied to meet the proposed changes by the effective date of the standards. Additionally, supermarket installations show that adiabatic condensers are already integrated into the larger supervisory control

system for a typical store. Therefore, the incremental cost to adding variable SCT setpoint control from the supervisory system would be minimal.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

It is expected that builders will not be impacted significantly by any one proposed code change or the collective effect of all of the proposed changes to Title 24, Part 6. This particular code change proposal will have a minimal impact on builders. Much of the coordination will need to occur among mechanical engineers and refrigeration contractors.

3.3.2 Impact on Building Designers and Energy Consultants

This particular revision to Title 24, Part 6 will not require changes in design practices that are onerous for building designers and energy consultants. Unlike air-cooled and evaporative cooled condensers, both of which have a long historical experience with sizing, there is uncertainty over what will be most efficient when sizing adiabatic condensers. By including them in Title 24, Part 6, it will assist designers with sizing practices that realize the obvious benefits of lower peak demand without failing to meet or exceed a minimum efficiency standard in light of no other design guidance. It will also make it easier for designers to appreciate that adiabatic condensers are an available option compared to air-cooled and evaporative cooled condensers. As with air-cooled and evaporative cooled condensers, there is no proposed requirement to use adiabatic condensers. The proposed code language only provides guidelines for designers who choose adiabatic condensers as a third option to meet a baseline efficiency.

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Building code and model national building codes published by the International Code Council, the International Association of Plumbing and Mechanical Officials and ASHRAE 90.) are typically updated on a three-year revision cycles. As discussed in Section 3.3.1, all market actors should (and do) plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. As a whole, the measures the Statewide CASE Team are proposing for the 2019 code cycle aim to provide designers and energy consultants with opportunities to comply with code requirements in multiple ways, thereby providing flexibility in requirements can be met.

3.3.3 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 adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

3.3.4 Impact on Building Owners and Occupants

Building owners and occupants will benefit from lower energy bills. As discussed in Section 3.4.1, when building occupants save on energy bills, they tend to spend it elsewhere in the economy, thereby creating jobs and economic growth for the California economy. This particular code change proposal will have a minimal impact on building owners and occupants.

3.3.5 Impact on Building Component Retailers (including manufacturers and distributors)

This particular code change proposal will have a minimal impact on companies who manufacture, distribute, or sell products. Those companies who manufacture and sell adiabatic condensers will see an increase in business, which may result in a decrease in the market elsewhere (for evaporative or air-cooled products).

3.3.6 Impact on Building Inspectors

Building inspectors will need to identify adiabatic condensers and verify all relevant code requirements. The general approach to reviewing refrigeration requirements will not change.

3.3.7 Impact on Statewide Employment

Section 3.4.1 discusses statewide job creation from the energy efficiency sector in general, including updates to Title 24, Part 6. The Statewide CASE Team expects no impact on statewide employment from this particular measure for new construction, as manufacturing and building practices will remain essentially the same.

For retrofit applications, increased understanding and adoption in new construction is expected to accelerate consideration of adiabatic condensers for customers concerned with balancing energy and water consumption. This could possibly lead to a large retrofit market sector that focuses on the replacement of both air and evaporative cooled condensers with adiabatic condensers. While no equipment manufacturer of adiabatic condensers is located in California, the direct and related construction work would be large considering the number of large supermarkets and refrigerated warehouses in California.

3.4 Economic Impacts

The estimated impacts that the proposed code change will have on California's economy are discussed below.

3.4.1 Creation or Elimination of Jobs

In 2015, California's building energy efficiency industry employed more than 321,000 workers who worked at least part time or a fraction of their time on activities related to building efficiency. Employment in the building energy efficiency industry grew six percent between 2014 and 2015 while the overall statewide employment grew three percent (BW Research Partnership 2016). Lawrence Berkeley National Laboratory's 2010 *Characterizing the Energy Efficiency Services Sector* report provides a detail on the types of jobs in the energy efficiency sector that are likely to be supported by revisions to building codes.

Building codes that reduce energy consumption provide jobs through *direct employment*, *indirect employment*, and *induced employment*.¹ Title 24, Part 6 creates jobs in all three categories with a significant amount created from induced employment, which accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees (e.g., non-industry jobs created such as teachers, grocery store clerks, and postal workers). A large portion of the induced jobs from energy efficiency are the jobs created by the energy cost savings due to the energy efficiency measures. Wei et al. (2010) estimates that energy efficiency creates 0.17 to

¹ The definitions of direct, indirect, and induced jobs vary widely by study. Wei et al (2010) describes the definitions and usage of these categories as follows: "*Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. *Indirect employment* refers to the "supplier effect" of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job. *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g. non industry jobs created such as teachers, grocery store clerks, and postal workers."

0.59 net job-years² per GWh saved (Wei, Patadia and Kammen 2010). By comparison, they estimate that the coal and natural gas industries create 0.11 net job-years per GWh produced.

The Statewide CASE Team does not expect this code change to impact California job creation, either positively or negatively. Existing design and control installation businesses, the California businesses most likely to be impacted by this measure, should not see a change in staffing.

3.4.2 Creation or Elimination of Businesses within California

There are approximately 43,000 businesses that play a role in California's advanced energy economy (BW Research Partnership 2016). California's clean economy grew ten times more than the total state economy between 2002 and 2012 (20 percent compared to two percent). The energy efficiency industry, which is driven in part by recurrent updates to the building code, is the largest component of the core clean economy (Ettenson and Heavey 2015). Adopting cost-effective code changes for the 2019 Title 24, Part 6 code cycle will help maintain the energy efficiency industry.

Table 4 lists industries that will likely benefit from the proposed code change classified by their North American Industry Classification System (NAICS) Code.

Table 4: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code.

Industry	NAICS Code
Nonresidential Building Construction	2362
Electrical Contractors	23821
Manufacturing	32412
Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equip. Manf.	3334
Engineering Services	541330
Building Inspection Services	541350
Environmental Consulting Services	541620
Other Scientific and Technical Consulting Services	541690

3.4.3 Competitive Advantages or Disadvantages for Businesses within California

In 2014, California's electricity statewide costs were 1.7 percent of the state's gross domestic product (GPD) while electricity costs in the rest of the United States were 2.4 percent of GDP (Thornberg, Chong and Fowler 2016). As a result of spending a smaller portion of overall GDP on electricity relative to other states, Californians and California businesses save billions of dollars in energy costs per year relative to businesses located elsewhere. Money saved on energy costs can otherwise be invested, which provides California businesses with an advantage that will only be strengthened by the adoption of the proposed codes changes that impact nonresidential buildings.

The Statewide CASE Team does not expect this code change to impact California businesses, either positively or negatively. Existing design and control installation businesses, the California businesses most likely to be impacted by this measure, will not see a change in costs or profits.

3.4.4 Increase or Decrease of Investments in the State of California

The proposed changes to the building code are not expected to impact investments in California on a macroeconomic scale, nor are they expected to affect investments by individual firms. The allocation of resources for the production of goods in California is not expected to change as a result of this code change proposal.

3.4.5 Effects on the State General Fund, State Special Funds and Local Governments

² One job-year (or "full-time equivalent" FTE job) is full time employment for one person for a duration of one year.

The proposed code changes are not expected to have a significant impact on the California's General Fund, any state special funds, or local government funds. Revenue to these funds comes from taxes levied. The most relevant taxes to consider for this proposed code change are: personal income taxes, corporation taxes, sales and use taxes, and property taxes. The proposed changes for the 2019 Title 24, Part 6 Standards are not expected to result in noteworthy changes to personal or corporate income, so the revenue from personal income taxes or corporate taxes is not expected to change. As discussed, reductions in energy expenditures are expected to increase discretionary income. State and local sales tax revenues may increase if building owners spend their additional discretionary income on taxable items. Although logic indicates there may be changes to sales tax revenue, the impacts that are directly related to revisions to Title 24, Part 6 have not been quantified. Finally, revenue generated from property taxes is directly linked to the value of the property, which is usually linked to the purchase price of the property. The proposed changes will not increase construction costs or change the property value. Therefore, this proposed code change is not expected to impact revenue generated from property taxes.

3.4.5.1 Cost of Enforcement

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, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, 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.

This proposed code change is not expected to impact state buildings.

The Statewide CASE Team does not expect this code change will impact enforcement costs since it is a small incremental review step to the existing building energy code enforcement process.

Cost to Local Governments

All revisions to Title 24, Part 6 will result in changes to compliance determinations. Local governments will need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2019 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, including tools, training and resources provided by the IOU codes and standards program (such as Energy Code Ace). As noted in Section 2.5 and Appendix B, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

The Statewide CASE Team does not expect this code change will impact costs to local governments.

3.4.5.2 Impacts on Specific Persons

The proposed changes to Title 24, Part 6 are not expected to have a differential impact on any groups relative to the state population as a whole, including migrant workers, commuters or persons by age, race or religion.

4. ENERGY SAVINGS

4.1 Key Assumptions for Energy Savings Analysis

The Statewide CASE team based key assumptions on previous Title 24 models and installations, discussions with California chains and contractors, and operating data from select operating adiabatic condenser installations in California, including:

- Site visits and snapshots of key operating parameters and load balance
- Data collection via remote access through existing network or energy management control system

The outside air temperature setpoint used to switch the adiabatic condenser from dry mode to wet mode was a key assumption in developing the adiabatic condenser base case. Recommendations for appropriate setpoints varied by stakeholder (primary manufacturers, refrigeration system design engineers) and by climate considerations.

The Statewide CASE team decided that the mean coincident wet bulb (MCWB) temperature should be used as the switching set point for each climate zone so that variations in climate would be factored into the analysis. On-site observations further support this assumption. A supermarket located in Climate Zone 13 had a switching setpoint observed at 75°F compared to its MCWB temperature of 73°F. Assuming a lower value for the switching setpoint would likely result in an increase in energy savings, but would also result in an increase in water consumption. The MCWB value provides a basis for the setpoint that considers both water usage and energy usage.

Other key assumptions are summarized in Table 5 below.

Table 5: Key Assumptions

Parameter	Assumption	Source/Basis
Adiabatic Mode Condenser Capacity	Approximately 2.5 times larger than the associated dry mode capacity	Manufacturer data
Condenser Fan Motor Type	Electronically Commutated (EC) Motors	Standard market offering

4.2 Energy Savings Methodology

To assess the energy, demand, and energy cost impacts, the Statewide CASE Team compared current design practices to design practices that will comply with the proposed requirements. There are no existing Title 24, Part 6 requirements that cover adiabatic condensers for refrigerated warehouses and commercial refrigeration. The Statewide CASE Team used current design practices in addition to existing Title 24, Part 6 code language applicable to air-cooled and evaporative cooled condensers to develop the adiabatic condenser base case. The current minimum compliance standards for air-cooled and evaporative cooled condensers compared to the adiabatic condenser base case is summarized in Table 6 below.

Table 6: Minimum Code Requirements for Air-Cooled and Evaporative-Cooled Compared to Hybrid Condenser Base Case

Requirement	Air-Cooled	Evaporative Cooled	Hybrid (Base Case)
Fan Control	Continuous Variable Speed in Unison	Continuous Variable Speed in Unison	Continuous Variable Speed in Unison
Minimum SCT	70°F	70°F	70°F
Condensing Temperature Reset	Drybulb	Wetbulb	Fixed SCT
Minimum Efficiency	75 Btuh/W (ammonia, RWH) 65 Btuh/W (halocarbon, RWH) 65 Btuh/W (Commercial Refrigeration)	350 Btuh/W (THR>8,000 MBH, RWH) 160 Btuh/W (THR<8,000 MBH, RWH) 160 Btuh/W (THR<8,000 MBH, Commercial Refrigeration)	35 Btuh/W(ammonia) 45 Btuh/W (halocarbon)¹
Rating Condition	105°F Saturated Condensing Temperature (SCT), 95°F Outdoor Drybulb Temperature	100°F Saturated Condensing Temperature (SCT), 70°F Outdoor Wetbulb Temperature	Same as air-cooled for dry mode

1. Denotes dry mode specific efficiency. Specific efficiency for the hybrid condenser base case was calculated for each prototype model such that the total annual TDV was approximately equal to that of the reference case (air-cooled condenser meeting minimum Title 24, Part 6 requirements) without raising the specific efficiency higher than the specific efficiency currently available in the market.

The proposed conditions are defined as the design conditions that will comply with the proposed code change. Table 7 below summarizes each proposed condition and the assumptions that were changed relative to the base case in order to determine the energy, demand, and energy cost impacts.

Table 7: Proposed Conditions Compared to the Hybrid Condenser Base Case

Variable	Base Case	Variable SCT Setpoint	Dry Mode Sizing	Dry Mode Minimum Specific Efficiency
Condensing Temperature Reset	Fixed SCT	Option A: Dry bulb (both wet and dry mode) Option B: Dry bulb (dry mode); Fixed 70°F SCT (wet mode) Option C: Condenser Inlet Air (both wet and dry mode) ¹	Option B	Option B
Rating Temperature Difference (TD) ²	10 TD (dry mode) 30 TD (wet mode)	Same as Base Case	Rated TD varies from 12°F LT/18°F MT to 24°F LT /36°F MT (Dry mode)	Same as Base Case
Minimum Efficiency	See Table 6 above.	Same as Base Case	Same as Base Case	Varies from 25 Btuh/W to 65 Btuh/W for all prototypes

1. Assumes temperature sensor is placed between condenser coil/microchannel and the adiabatic pad material, which allows for condensing temperature reset in both dry and wet modes.
2. Temperature difference is the difference between the SCT and the ambient air temperature (drybulb for air-cooled condensers; wetbulb for evaporative condensers). For glide refrigerants, mid-point temperature (average of dew-point and bubble-point) is used.

The Energy Commission provided guidance on the type of prototype buildings that must be modeled. Three prototypes were selected to assess the cost-effectiveness of the proposed Title 24, Part 6 code

changes addressed in this report: large supermarket prototype (LSM) for the commercial refrigeration code section, and small and large refrigerated warehouse prototypes (SRWH/LRWH) for the refrigerated warehouse code section.

The LSM, SRWH, and LRWH prototypes were based on the “Central Large Supermarket”, “Small Refrigerated Warehouse with Refrigerated Shipping Dock”, and “Large Refrigerated Warehouse with Refrigerated Shipping Dock” prototypes respectively. These prototypes were previously developed for 2013 Title 24, Part 6 CASE Study work and were updated to conform with the minimum requirements of 2016 Title 24, Part 6. System types, design loads, and operating schedules were assumed to represent industry-standard practice and typical operation for these building types based on over ten years of Savings By Design data.

Savings By Design is a design assistance and incentive program offered by utilities in California, including an initiative specifically focused on supermarkets and refrigerated warehouses since 2001. Under this program, several hundred supermarkets and refrigerated warehouses have been evaluated using whole-building simulation focused on refrigeration measures, as well as receiving incentives following post-installation field inspections. Information obtained from this program provided a detailed understanding of current industry practice.

Table 8 presents the details of the prototype buildings used in the analysis.

Table 8: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype ID	Occupancy Type (Residential, Retail, Office, etc.)	Area (ft ²)	Number of Stories	Refrigerant	Compressor Type
Large Supermarket (LSM)	Supermarket	60,700	1	R-407A	Reciprocating
Small Refrigerated Warehouse (SRWH)	Refrigerated Warehouse	26,000	1	R-407A	Reciprocating
Large Refrigerated Warehouse (LRWH)	Refrigerated Warehouse	92,000	1	R-717 (Ammonia)	Screw

The energy usage for each prototype was evaluated using DOE-2.2R energy simulation software. The DOE-2.2R version used (2.2R) is a sophisticated component-based energy simulation program that can accurately model the building envelope, lighting systems, HVAC systems, and refrigeration systems – including the complex interaction between refrigerated supermarket display cases and the surrounding indoor environment. The 2.2R version is specifically design to include refrigeration systems, using refrigerant properties, mass flow and component models to accurately describe refrigeration system operation and controls system effects. The energy savings modeling builds on the existing models used for 2013 Title 24, Part 6 CASE Report analysis work.

The energy savings from the proposed conditions varies by climate zone. As a result, the energy impacts and cost-effectiveness were evaluated using the following climate zones:

- Climate Zone 01 - Arcata
- Climate Zone 03 – Oakland
- Climate Zone 05 – Santa Maria
- Climate Zone 07 – San Diego (Lindbergh Field)
- Climate Zone 08 - Fullerton
- Climate Zone 10 – Riverside
- Climate Zone 12 – Sacramento (Sacramento Executive Airport)
- Climate Zone 13 – Fresno
- Climate Zone 14 – Palmdale

- Climate Zone 15 – Palm Springs

These climate zones were selected to cover a sufficient diversity of California climates to represent the sensitivity of supermarket refrigeration measures to climatic differences. Energy savings, energy cost savings, and peak demand reductions were calculated using the Energy Commission’s TDV (Time Dependent Valuation) methodology.

4.3 Per-unit Energy Impacts Results

4.3.1 LSM Prototype

4.3.1.1 Variable SCT Setpoint

Energy savings and peak demand reductions per square foot for new construction are presented in Table 9 through

Table 11 for the three variable SCT setpoint options described in Table 7 in Section 4.2. Each variable SCT option was simulated with operating TD equal to 90 percent of the design TD to account for pressure drop from compressor discharge to the condenser for a given climate zone. While three control options were studied for comparison purposes, proposed code language is based on control option B to ensure that the code does not inhibit innovation for control in precool mode.

All three variable SCT setpoint options achieved TDV Energy savings compared to a fixed SCT setpoint in the base case. Energy savings for option B ranges from approximately 1,000 kWh/yr to 88,400 kWh/yr depending on climate zone. Option B TDV Energy savings ranged from 0.57 kBtu/yr/ft² to 37.76 kBtu/yr/ft² depending on climate zone.

Table 9: Variable SCT Setpoint Option A: First-Year Energy Impacts per LSM Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	6,108	24.7	3.09
3	45,930	21.7	26.85
5	41,805	12.8	23.31
7	109,229	23.0	53.40
8	78,396	8.7	34.61
10	36,420	6.1	16.85
12	30,636	6.9	14.99
13	29,630	6.8	14.76
14	15,897	0.0	8.51
15 ³	-	-	-

³ CZ15 not compatible with Option A strategy due to high SCT values. Would be resolved with implementing a maximum SCT value in DOE2.2R simulation software.

Table 10: Variable SCT Setpoint Option B: First-Year Energy Impacts per LSM Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	993	0.0	0.57
3	24,347	1.5	10.81
5	21,522	0.0	10.72
7	88,389	0.4	37.76
8	58,110	0.1	22.97
10	29,560	0.0	11.61
12	23,272	(0.1)	9.15
13	21,739	(0.1)	8.63
14	6,668	0.0	2.61
15	10,585	0.1	4.23

Table 11: Variable SCT Setpoint Option C: First-Year Energy Impacts per LSM Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	5,736	24.3	2.89
3	45,162	5.5	27.08
5	41,644	7.6	23.26
7	108,968	9.7	54.29
8	88,151	12.4	41.05
10	50,904	6.1	23.70
12	40,950	6.9	19.98
13	43,489	6.7	20.95
14	26,961	0.0	12.98
15	29,193	0.1	13.34

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Table 18 through Table 20 in Section 5.2.1.1. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.1.2 Dry Mode Hybrid Condenser Sizing

Energy savings and TDV savings for various condenser sizing options ranging from 12°F for low temperature (LT) freezer applications and 18°F for medium temperature (MT) cooler applications to 24°F LT/36°F MT dry mode design TD at a fixed specific efficiency. The warm Climate Zones (7, 8, 10, 12, 13, 14, and 15) were shown to have the highest annual energy savings for 16/24°F dry mode design TD, with up to 21,900 kWh/yr depending on the climate zone. The cool Climate Zones (1, 3, and 5) were shown to have the lowest annual energy consumption at a dry mode design TD of 12/18°F, which corresponded to the base case design TD. The base case consumed approximately 21,500 kWh/yr less energy as compared to smaller sized condensers depending on climate zone. Climate Zone 3 is an exception, which showed 16/24°F as the most efficient dry-mode design TD.

TDV Energy savings measured on a kBtu/yr/ft² basis was shown to vary between -18.941 and 9.97 depending on climate zone for warm climates. The TDV energy savings varied between -9.19

kBtu/yr/ft² and 1.68 kBtu/yr/ft² depending on the climate zone for cool climates. The TDV Energy savings is shown in Figure 1 and Figure 2 below.

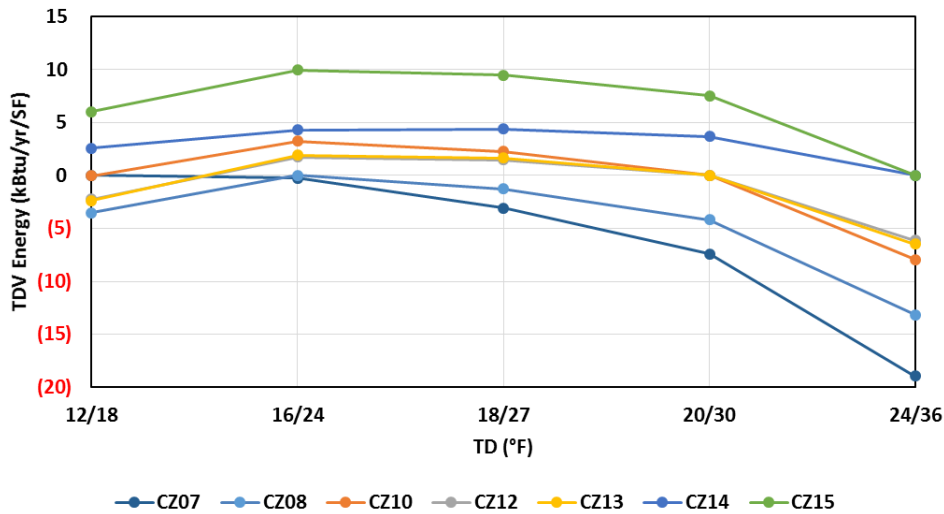


Figure 1: Warm climate TDV energy savings vs. dry mode condenser sizing

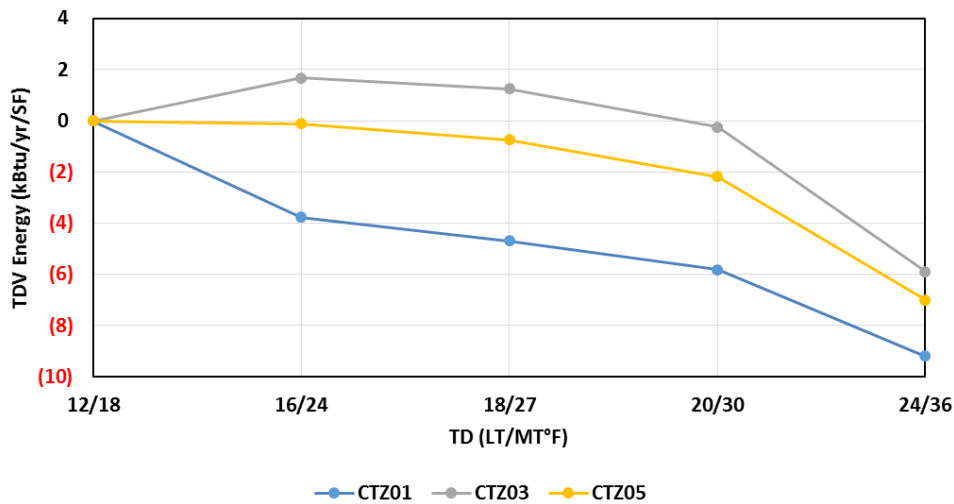


Figure 2: Cool climate TDV energy savings vs. dry mode condenser sizing

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Section 5.2.1.2. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.1.3 Hybrid Condenser Specific Efficiency

Energy savings and peak demand reductions per unit for new construction are presented for various specific efficiency values at a fixed dry mode TD of 10°F. A specific efficiency of 65 Btuh/W was selected as the maximum possible specific efficiency based on current market offerings. This maximum specific efficiency in warm climate zones showed a range of annual kWh savings from approximately 11,500 kWh/yr to 21,000 kWh/yr depending on the climate compared to a base case specific efficiency

of 45 Btuh/W. Cool climate zone annual kWh savings ranged from approximately 3,800 kWh/yr to 10,370 kWh/yr depending on the climate compared to a base case specific efficiency of 45 Btuh/W.

TDV Energy savings measured on a kBtu/yr/ft² basis was shown to vary between -27.27 and 10.5 depending on climate zone for warm climates. The TDV Energy savings varied between -18.8 kBtu/yr/ft² and 7.24 kBtu/yr/ft² depending on the climate zone for cool climates. The TDV Energy savings is shown in and Figure 3 and Figure 4 below.

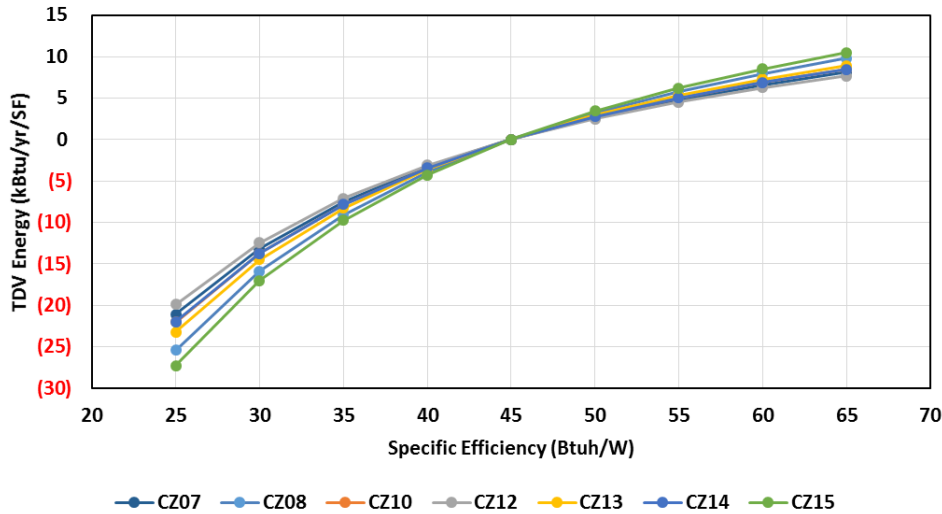


Figure 3: Warm climate TDV energy savings vs. specific efficiency

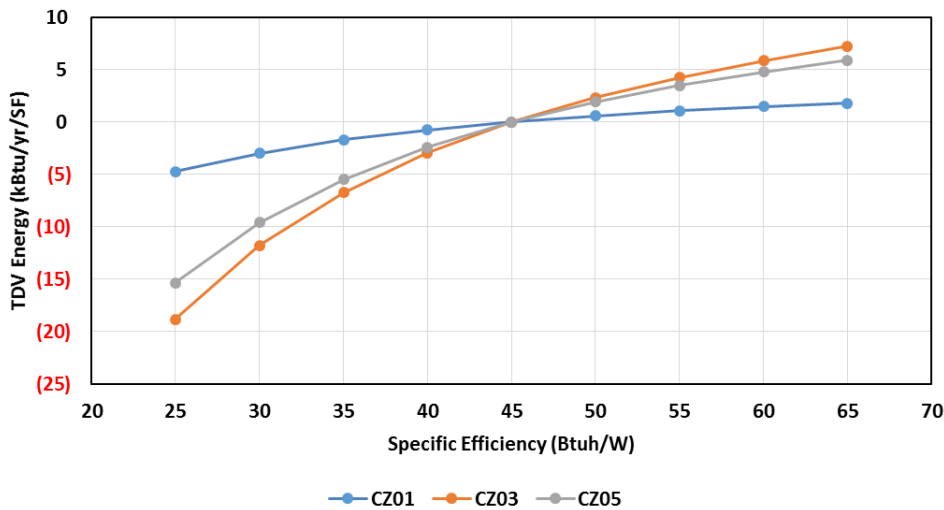


Figure 4: Cool climate TDV energy savings vs. specific efficiency

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Section 5.2.1.3. These are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.2 SRWH Prototype

4.3.2.1 Variable SCT Setpoint

Energy savings and peak demand reductions per square foot for new construction are presented in Table 12 through Table 13 for the three variable SCT setpoint options described in Table 7 in Section 4.2. Each variable SCT option was simulated with operating TD equal to 90 percent of the design TD to account for pressure drop from compressor discharge to the condenser for a given climate zone. The operating TD was not optimized per climate zone basis. While three control options were studied for comparison, proposed code language is based on control option B to ensure that the code does not inhibit innovation for control in precool mode.

Variable SCT setpoint resulted in TDV energy savings compared to a fixed SCT setpoint in the base case for most of the climate zones. Energy savings for option B ranges from approximately -3,600 kWh/yr to 60,400 kWh/yr depending on climate zone. Option B TDV Energy savings ranged from -3.43 kBtu/yr/ft² to 62.37 kBtu/yr/ft² depending on climate zone.

Table 12: Variable SCT Setpoint Option A: First-Year Energy Impacts per SRWH Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	(357)	20.5	(0.55)
3	26,028	16.6	38.46
5	21,631	15.1	28.23
7	78,811	14.6	94.90
8	50,675	8.8	55.48
10	25,934	5.7	29.72
12	12,712	4.4	17.44
13	16,266	5.9	20.69
14	(4,173)	4.0	0.73
15	(7,076)	2.9	(5.66)

Table 13: Variable SCT Setpoint Option B: First-Year Energy Impacts per SRWH Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	(882)	0.0	(0.95)
3	13,637	0.0	14.75
5	13,301	0.0	16.05
7	60,427	0.0	62.37
8	34,140	0.0	31.67
10	19,446	0.0	17.88
12	7,749	0.0	7.05
13	10,786	0.0	9.94
14	(3,641)	0.0	(3.43)
15	3,189	0.0	2.90

Table 14: Variable SCT Setpoint Option C: First-Year Energy Impacts per SRWH Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	451	23.4	0.44
3	28,902	4.7	45.19
5	25,792	1.3	34.13
7	80,917	3.0	101.04
8	62,598	6.7	73.69
10	43,777	8.1	51.57
12	23,786	4.9	29.33
13	31,313	3.5	35.87
14	4,618	(2.9)	6.17
15	13,403	(6.9)	11.17

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Table 20 through Table 22 in Section 5.2.2.1. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.2.2 Dry Mode Hybrid Condenser Sizing

Energy savings and TDV savings for various condenser sizing options ranging from 12/18°F to 24/36°F dry mode design TD at a fixed specific efficiency. The warm Climate Zones (7, 8, 10, 12, 13, 14, and 15) were shown to have the highest annual energy savings for 16/24°F dry mode design TD, saving up to 27,500 kWh/yr depending on the climate zone. The cool Climate Zones (1, 3, and 5) were shown to have the lowest annual energy consumption at a dry mode design TD of 12/18°F, which was also the base case design TD. The base case consumed approximately 46,000 kWh/yr less as compared to smaller sized condensers depending on climate zone.

TDV Energy savings measured on a kBtu/yr/ft² basis was shown to vary between -43.69 and 16.02 depending on climate zone for warm climates. The TDV Energy savings varied between -50.5 kBtu/yr/ft² and 0 kBtu/yr/ft² depending on the climate zone for cool climates. The TDV Energy savings are shown in Figure 5 and Figure 6 below.

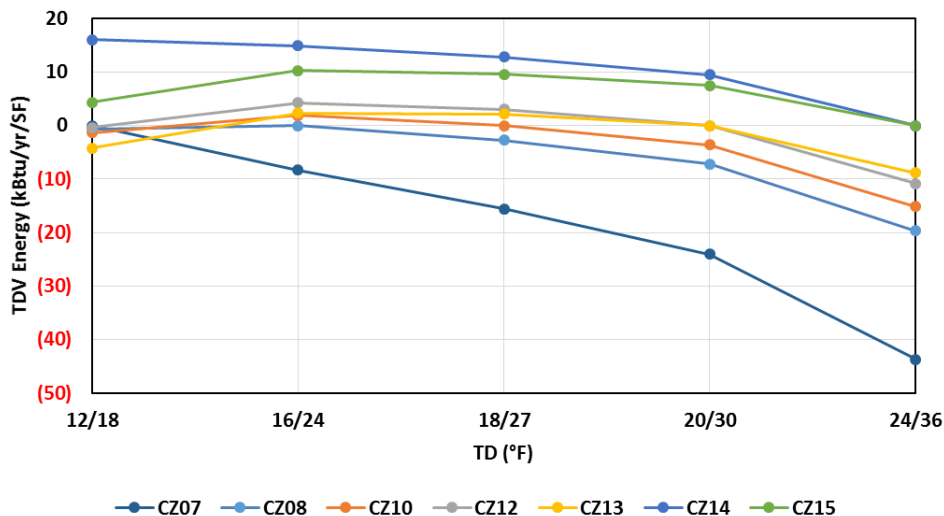


Figure 5: Warm climate TDV energy savings vs. dry mode condenser sizing

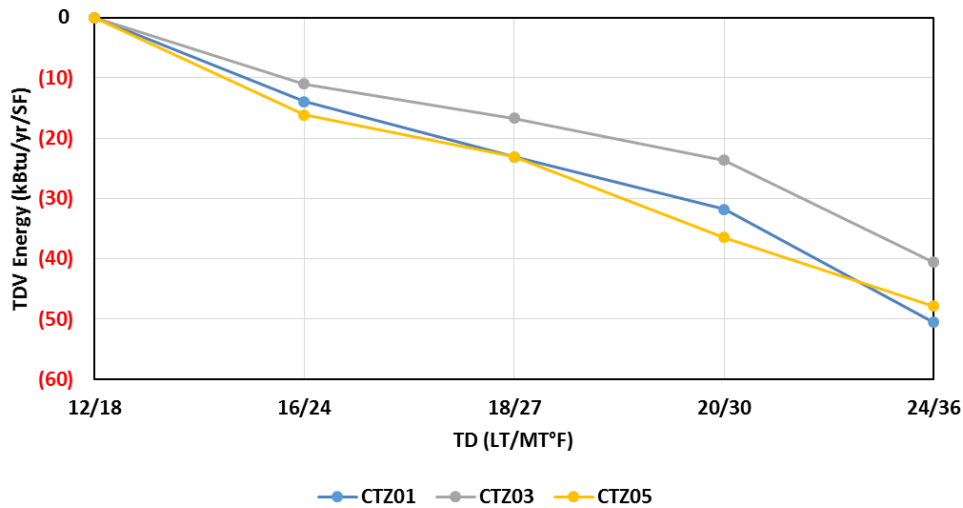


Figure 6: Cool climate TDV energy savings vs. dry mode condenser sizing

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Section 5.2.2.2. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.2.3 Hybrid Condenser Specific Efficiency

Energy savings and peak demand reductions per unit for new construction are presented for various specific efficiency values at a fixed dry mode TD of 10°F. A specific efficiency of 65 Btuh/W was selected as the maximum possible specific efficiency based on current market offerings. This maximum specific efficiency in warm climate zones showed a range of annual kWh savings from approximately 10,000 kWh/yr to 20,000 kWh/yr depending on the climate compared to a base case specific efficiency of 45 Btuh/W. Cool climate zone annual kWh savings ranged from approximately 2,500 kWh/yr to 8,500 kWh/yr depending on the climate compared to a base case specific efficiency of 45 Btuh/W.

TDV Energy savings measured on a kBtu/yr/ft² basis was shown to vary between -62.72 and 24.12 depending on climate zone for warm climates. The TDV Energy savings varied between -37.62 kBtu/yr/ft² and 14.46 kBtu/yr/ft² depending on the climate zone for cool climates. The TDV Energy savings is shown in Figure 7 and Figure 8 below.

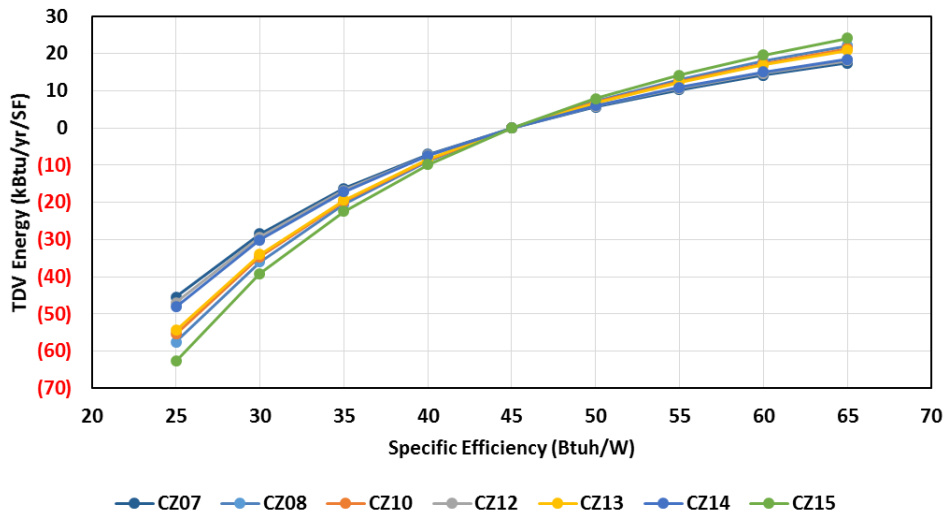


Figure 7: Warm climate TDV energy savings vs. specific efficiency

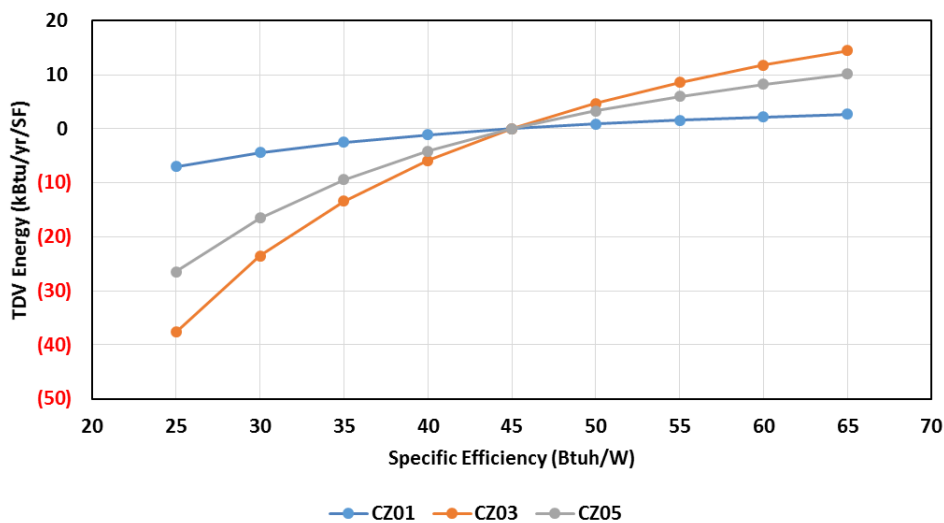


Figure 8: Cool climate TDV energy savings vs. specific efficiency

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Section 5.2.2.3. These are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.3 LRWH Prototype

4.3.3.1 Variable SCT Setpoint

Energy savings and peak demand reductions per square foot for new construction are presented in Table 15 through Table 17 for the three variable SCT setpoint options described in Table 7 in Section 4.2. Each variable SCT option was simulated with operating TD equal to 90 percent of the design TD to account for pressure drop from compressor discharge to the condenser for a given climate zone. The operating TD was not optimized per climate zone basis. While three control options were studied for comparison, proposed code language is based on control option B to ensure that the code does not inhibit innovation for control in precool mode.

Variable SCT setpoint resulted in TDV energy savings compared to a fixed SCT setpoint in the base case for some of the climate zones. Energy savings for option B ranges from approximately -86,600 kWh/yr to 122,000 kWh/yr depending on climate zone. Option B TDV energy savings ranged from -24.56 kBtu/yr/ft² to 34.77 kBtu/yr/ft² depending on climate zone.

Table 15: Variable SCT Setpoint Option A: First-Year Energy Impacts per LRWH Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	(64,953)	29.8	(17.18)
3	(18,116)	23.5	1.08
5	(16,823)	20.5	(0.08)
7	146,717	28.0	47.57
8	117,176	19.5	38.42
10	71,722	23.5	25.18
12	(4,897)	13.5	4.52
13	80,737	26.4	29.29
14	(20,025)	(0.7)	0.60
15	91,740	(35.4)	25.51

Table 16: Variable SCT Setpoint Option B: First-Year Energy Impacts per LRWH Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	(86,627)	0.0	(24.56)
3	(45,560)	0.0	(11.91)
5	(42,832)	0.0	(10.47)
7	122,045	0.0	34.77
8	72,920	0.0	19.16
10	43,780	0.0	11.39
12	(26,983)	0.0	(7.16)
13	40,472	0.0	10.54
14	(21,410)	0.0	(5.64)
15	80,581	0.0	21.08

Table 17: Variable SCT Setpoint Option C: First-Year Energy Impacts per LRWH Prototype (New Construction)

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	TDV Energy Savings (TDV kBtu/yr/ft ²)
1	(74,055)	15.5	(20.22)
3	(23,396)	10.4	(1.52)
5	(19,197)	14.4	(0.99)
7	157,295	27.3	52.71
8	150,588	16.7	50.35
10	126,001	26.1	42.98
12	7,023	(15.0)	2.78
13	133,841	21.1	44.50
14	13,003	(70.8)	6.25
15	241,425	(36.3)	72.96

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Table 23 through

Table 25 in Section 5.2.3.1. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.3.2 Dry Mode Hybrid Condenser Sizing

Energy savings and TDV savings for various condenser sizing options ranging from 12/18°F to 24/36°F dry mode design TD at a fixed specific efficiency. The warm Climate Zones (7, 8, 9, 10, 12, 13, 14, and 15) were shown to have the highest annual energy savings for 16/24°F dry mode design TD, up to 100,000 kWh/yr depending on the climate zone. The cool Climate Zones (11, 3, and 5) were shown to have the highest annual energy savings at a dry mode design TD of 12/18°F, with base case saving up to 175,000 kWh/yr depending on climate zone.

TDV Energy savings measured on a kBtu/yr/ft² basis was shown to vary between -20.14 and 22.87 depending on climate zone for warm climates. The TDV Energy savings varied between 0 kBtu/yr/ft² and 53.67 kBtu/yr/ft² depending on the climate zone for cool climates. The TDV Energy savings is shown in Figure 9 and Figure 10 below.

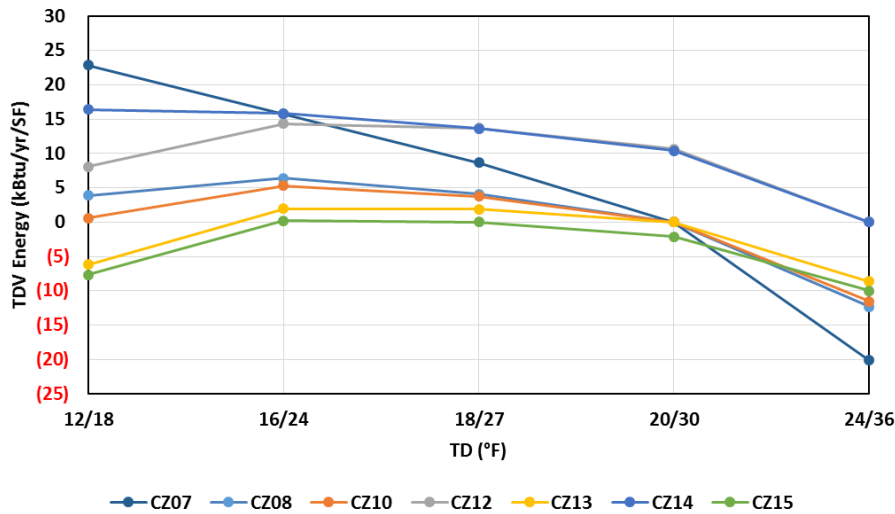


Figure 9: Warm climate TDV energy savings vs. dry mode condenser sizing

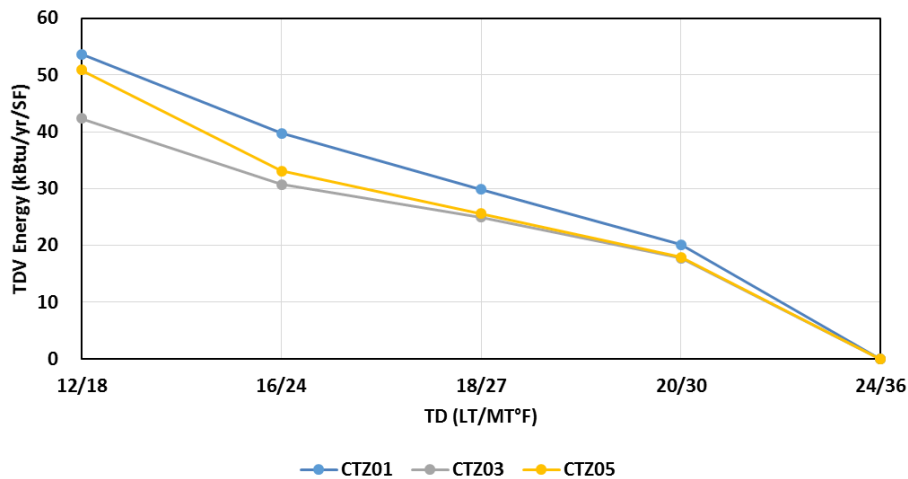


Figure 10: Cool climate TDV energy savings vs. dry mode condenser sizing

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Section 5.2.3.2. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.3.3 Hybrid Condenser Specific Efficiency

Energy savings and peak demand reductions per unit for new construction are presented for various specific efficiency values at a fixed dry mode TD of 10°F. A specific efficiency of 65 Btuh/W was selected as the maximum possible specific efficiency based on current market offerings. This maximum specific efficiency in warm climate zones showed a range of annual kWh savings from approximately 40,000 kWh/yr to 150,000 kWh/yr depending on the climate compared to a base case specific efficiency of 35 Btuh/W. Cool climate zone annual kWh savings ranged from approximately 20,500 kWh/yr to 37,000 kWh/yr depending on the climate compared to a base case specific efficiency of 35 Btuh/W.

TDV Energy savings measured on a kBtu/yr/ft² basis was shown to vary between -44.8 and 51.7 depending on climate zone for warm climates. The TDV Energy savings varied between -13.9 kBtu/yr/ft² and 16 kBtu/yr/ft² depending on the climate zone for cool climates. The TDV Energy savings is shown in Figure 11 and Figure 12 below.

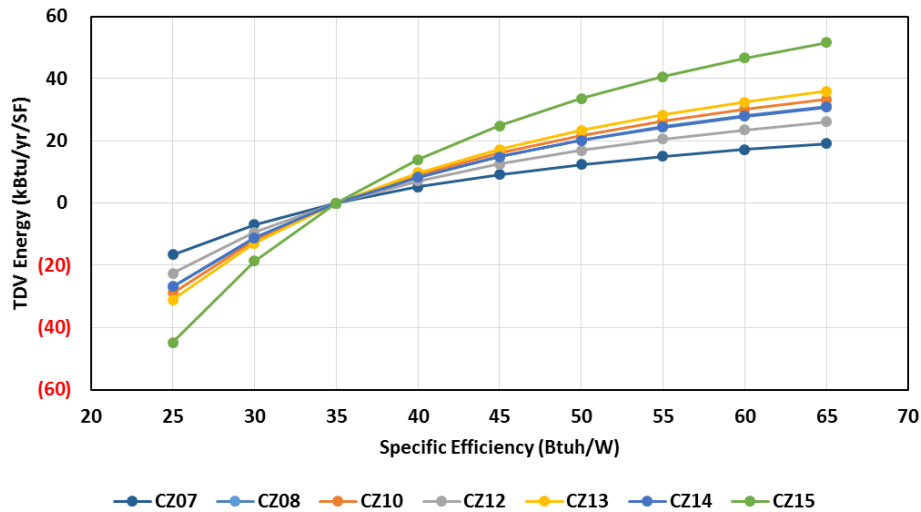


Figure 11: Warm climate TDV energy savings vs. specific efficiency

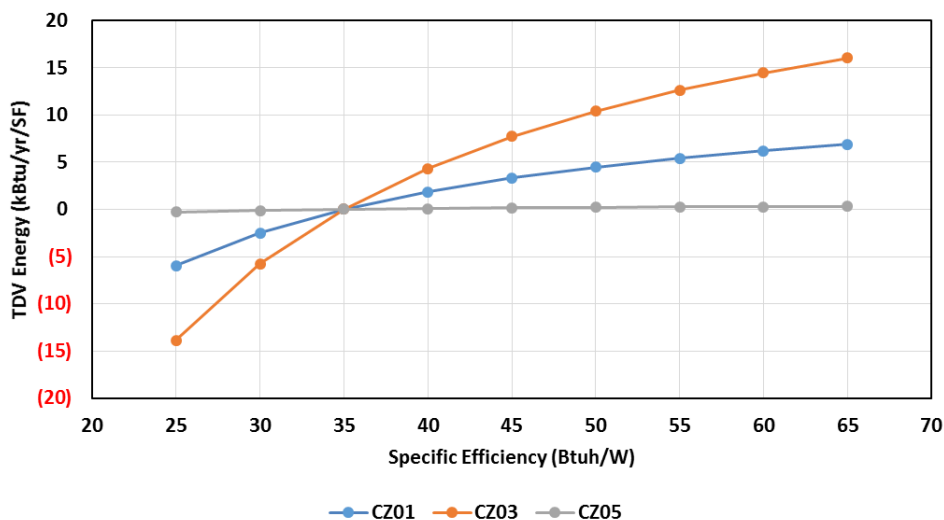


Figure 12: Cool climate TDV energy savings vs. specific efficiency

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Section 5.2.3.3. These are presented as the discounted present value of the energy cost savings over the analysis period.

5. LIFECYCLE COST AND COST-EFFECTIVENESS

5.1 Energy Cost Savings Methodology

TDV energy is a normalized format for comparing electricity and natural gas cost savings that takes into account the cost of electricity and natural gas consumed during each hour of the 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 2020 present valued dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of “TDV kBtu.” Peak demand reductions are presented in peak power reductions (kW). The Energy Commission derived the 2020 TDV values that were used in the analyses for this report (Energy + Environmental Economics 2016).

As discussed in Section 4, the energy usage for each prototype was evaluated using DOE-2.2R energy simulation software. The most up to date TDV files (2019 version) were integrated into DOE-2.2R in order to automatically calculate the total TDV for each simulation run. TDV files were verified outside of the DOE-2.2R model before being used in the analysis.

5.2 Energy Cost Savings Results

5.2.1 LSM Prototype

5.2.1.1 Variable SCT Setpoint

Per-unit energy cost savings over the 15-year period of analysis are presented in Table 18 through Table 20 for each of the variable SCT setpoint options. It is estimated that the first-year TDV energy cost savings for option B can be as high as \$3.36 per square foot over the 15-year life time of the proposed conditions.

Table 18: Variable SCT Option A: TDV Energy Cost Savings Over 15-Year Period of Analysis Per LSM Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	\$0.27
3	\$2.39
5	\$2.07
7	\$4.75
8	\$3.08
10	\$1.50
12	\$1.33
13	\$1.31
14	\$0.76
15	-

Table 19: Variable SCT Option B: TDV Energy Cost Savings Over 15-Year Period of Analysis Per LSM Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	\$0.05
3	\$0.96
5	\$0.95
7	\$3.36
8	\$2.04
10	\$1.03
12	\$0.81
13	\$0.77
14	\$0.23
15	\$0.38

Table 20: Variable SCT Option C: TDV Energy Cost Savings Over 15-Year Period of Analysis Per LSM Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	\$0.26
3	\$2.41
5	\$2.07
7	\$4.83
8	\$3.65
10	\$2.11
12	\$1.78
13	\$1.86
14	\$1.16
15	\$1.19

5.2.1.2 Dry Mode Hybrid Condenser Sizing

Per-unit energy cost savings over the 15-year period of analysis are presented below in Figure 13 and Figure 14. It is estimated that the first-year TDV energy cost savings range from -\$1.69 per square foot to \$0.89 per square foot for warm climate zones with maximum savings at 16/24°F design TD. For cool climate zones, the TDV energy cost savings range from -\$0.82 per square foot to \$0.15 per square foot with maximum savings at 12/18°F design TD.

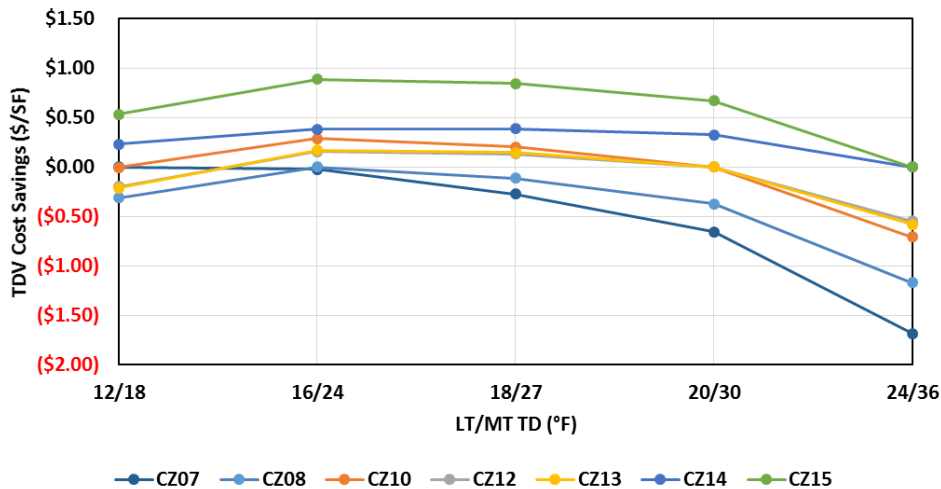


Figure 13: Warm climate TDV energy cost savings vs. dry mode TD

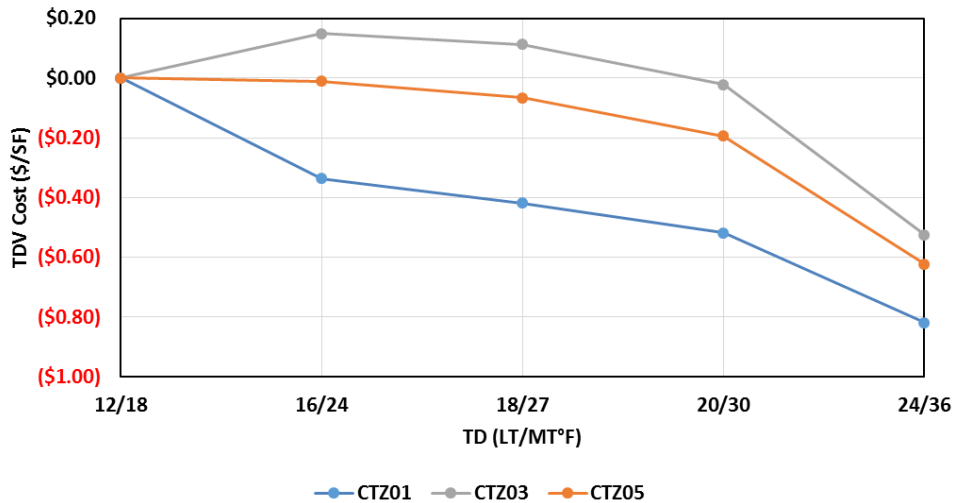


Figure 14: Cool climate TDV energy cost savings vs. dry mode TD

5.2.1.3 Hybrid Condenser Specific Efficiency

Per-unit energy cost savings over the 15-year period of analysis are presented in below in Figure 15 and Figure 16. It is estimated that the year average TDV energy cost savings for warm climate zones is approximately \$0.79 per square foot at a specific efficiency of 65 Btuh/W. The estimated average first-year TDV energy cost savings for cool climate zones is approximately \$0.44 per square foot at a specific efficiency of 65 Btuh/W.

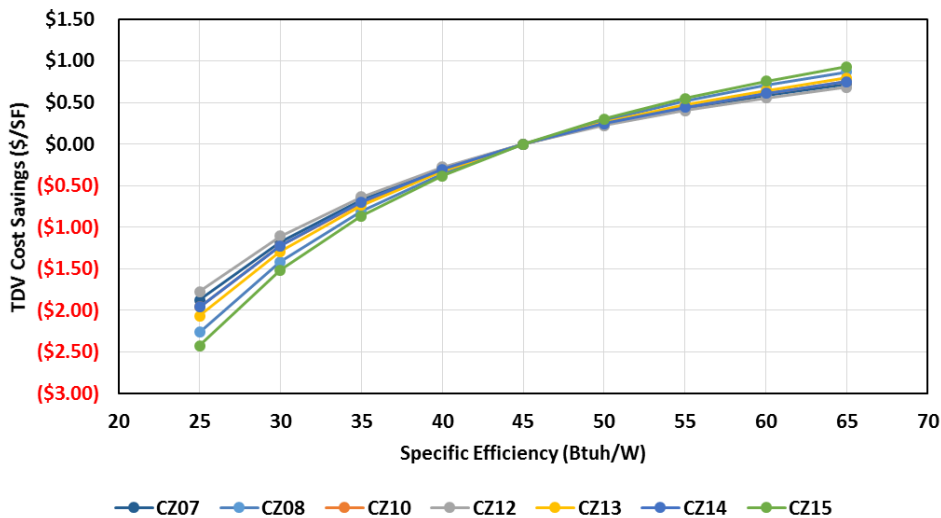


Figure 15: Warm climate TDV energy savings vs. specific efficiency

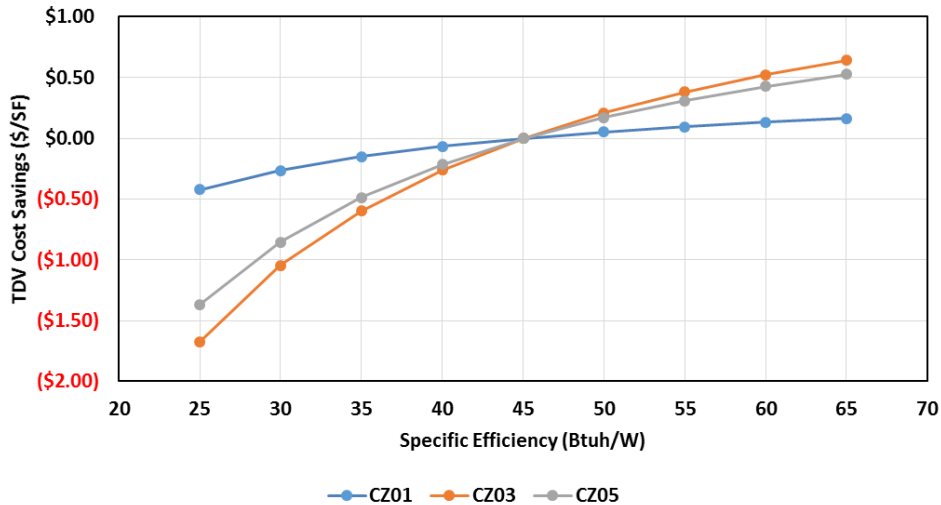


Figure 16: Cool climate TDV energy savings vs. specific efficiency

5.2.2 SRWH Prototype

5.2.2.1 Variable SCT Setpoint

Per-unit energy cost savings over the 15-year period of analysis are presented in Table 21 through Table 23 for each of the variable SCT setpoint options. It is estimated that the first-year TDV energy cost savings for option B can be as high as \$5.55 per square foot over the 15-year life time of the proposed conditions.

Table 21: Variable SCT Option A: TDV Energy Cost Savings Over 15-Year Period of Analysis Per SRWH Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	(\$0.05)
3	\$3.42
5	\$2.51
7	\$8.45
8	\$4.94
10	\$2.65
12	\$1.55
13	\$1.84
14	\$0.06
15	(\$0.50)

Table 22: Variable SCT Option B: TDV Energy Cost Savings Over 15-Year Period of Analysis Per SRWH Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020PV \$/ft ²)
1	(\$0.08)
3	\$1.31
5	\$1.43
7	\$5.55
8	\$2.82
10	\$1.59
12	\$0.63
13	\$0.88
14	(\$0.31)
15	\$0.26

Table 23: Variable SCT Option C: TDV Energy Cost Savings Over 15-Year Period of Analysis Per SRWH Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020PV \$/ft ²)
1	\$0.04
3	\$4.02
5	\$3.04
7	\$8.99
8	\$6.56
10	\$4.59
12	\$2.61
13	\$3.19
14	\$0.55
15	\$0.99

5.2.2.2 Dry Mode Hybrid Condenser Sizing

Per-unit energy cost savings over the 15-year period of analysis are presented below in Figure 17 and Figure 18. It is estimated that the first-year TDV energy cost savings range from -\$3.89 per square foot to \$1.43 per square foot for warm climate zones with maximum savings at 16/24°F design TD. For cool climate zones, the TDV energy cost savings range from -\$4.5 per square foot to \$0 per square foot.

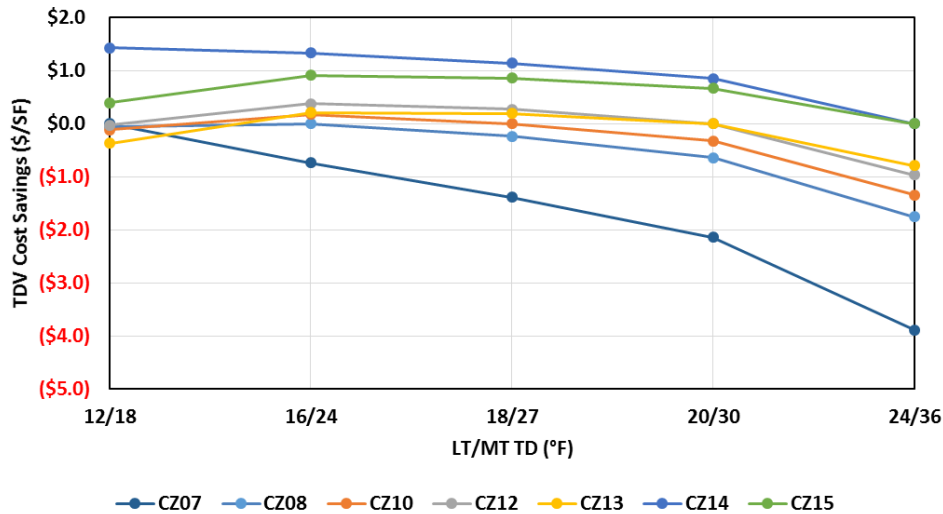


Figure 17: Warm climate TDV energy cost savings vs. dry mode TD

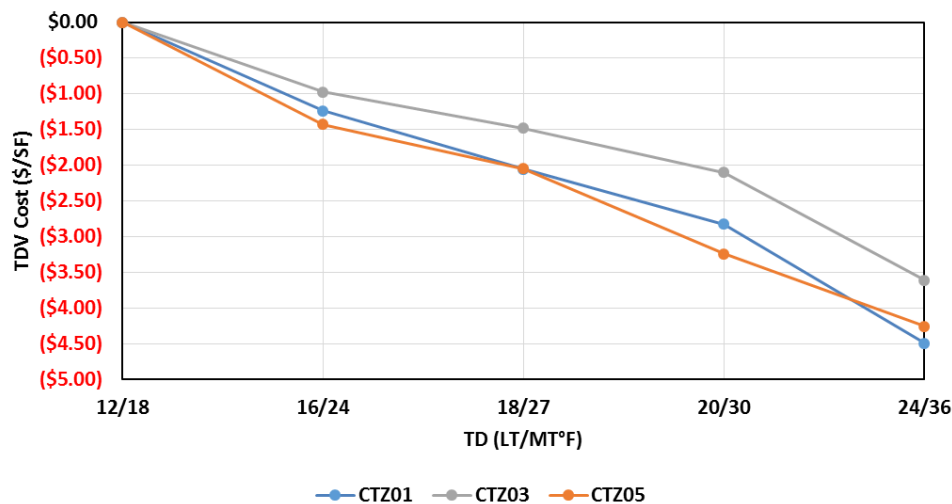


Figure 18: Cool climate TDV energy cost savings vs. dry mode TD

5.2.2.3 Hybrid Condenser Specific Efficiency

Per-unit energy cost savings over the 15-year period of analysis are presented in below in Figure 19 and Figure 20. It is estimated that the year average TDV energy cost savings for warm climate zones is approximately \$1.81 per square foot at a specific efficiency of 65 Btuh/W. The estimated first-year average TDV energy cost savings for cool climate zones is approximately \$0.81 per square foot at a specific efficiency of 65 Btuh/W.

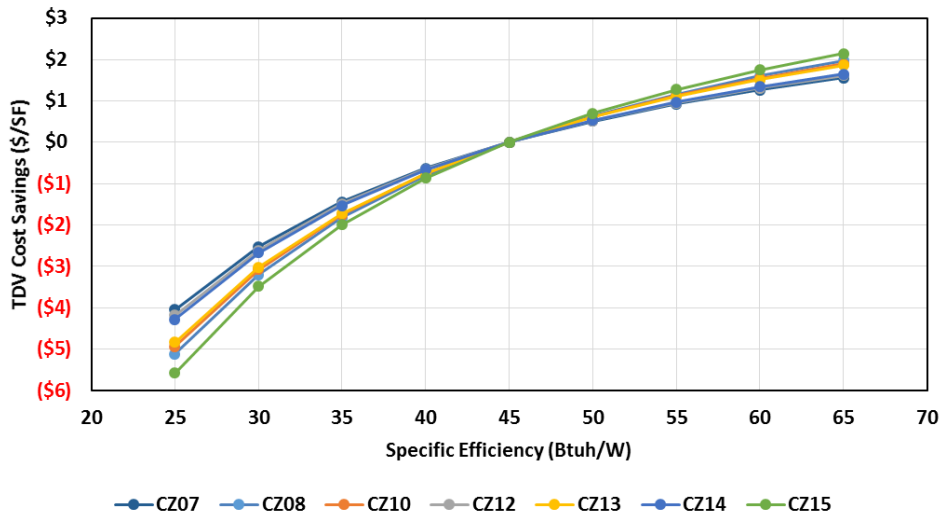


Figure 19: Warm climate TDV energy cost savings vs. specific efficiency

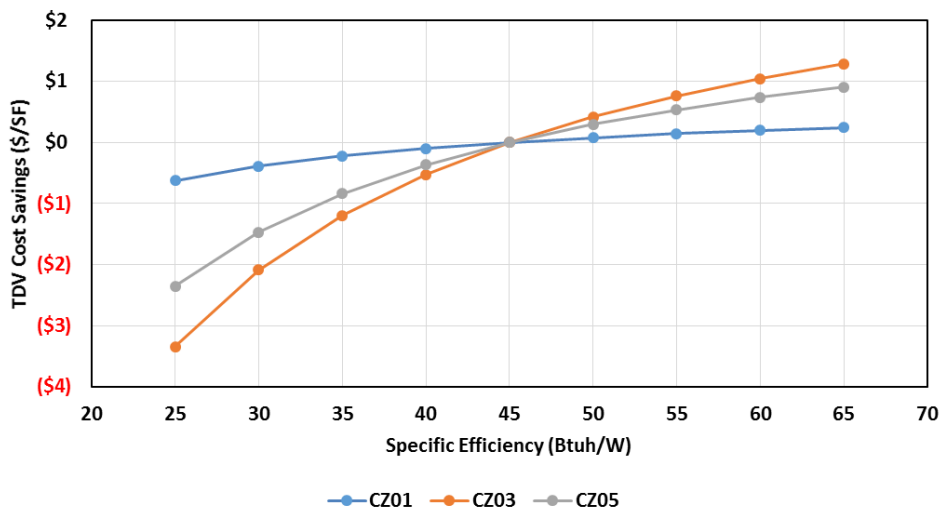


Figure 20: Cool climate TDV energy cost savings vs. specific efficiency

5.2.3 LRWH Prototype

5.2.3.1 Variable SCT Setpoint

Per-unit energy cost savings over the 15-year period of analysis are presented in Table 24 through Table 26 for each of the variable SCT setpoint options. It is estimated that the first-year TDV energy cost savings for option B can be as high as \$3.09 per square foot over the 15-year life time of the proposed conditions.

Table 24: Variable SCT Option A: TDV Energy Cost Savings Over 15-Year Period of Analysis Per LRWH Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	(\$1.53)
3	\$0.10
5	(\$0.01)
7	\$4.23
8	\$3.42
10	\$2.24
12	\$0.40
13	\$2.61
14	\$0.05
15	\$2.27

Table 25: Variable SCT Option B: TDV Energy Cost Savings Over 15-Year Period of Analysis Per LRWH Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	(\$2.19)
3	(\$1.06)
5	(\$0.93)
7	\$3.09
8	\$1.70
10	\$1.01
12	(\$0.64)
13	\$0.94
14	(\$0.50)
15	\$1.88

Table 26: Variable SCT Option C: TDV Energy Cost Savings Over 15-Year Period of Analysis Per LRWH Prototype (New Construction)

Climate Zone	15-Year TDV Electricity Cost Savings (2020 PV \$/ft ²)
1	(\$1.80)
3	(\$0.14)
5	(\$0.09)
7	\$4.69
8	\$4.48
10	\$3.83
12	\$0.25
13	\$3.96
14	\$0.56
15	\$6.49

5.2.3.2 Dry Mode Hybrid Condenser Sizing

Per-unit energy cost savings over the 15-year period of analysis are presented below in Figure 21 and Figure 22. It is estimated that the first-year TDV energy cost savings range from -\$1.79 per square foot to \$2.04 per square foot for warm climate zones with maximum savings between 12/18°F and 16/24°F. For cool climate zones, the TDV energy cost savings range from -\$1.79 per square foot to \$4.78 per square foot with maximum savings at 12/18°F.

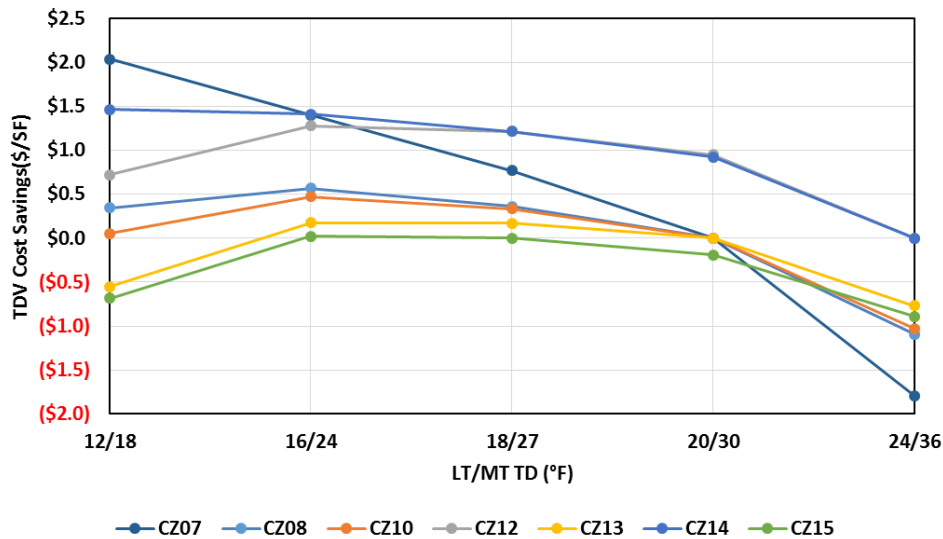


Figure 21: Warm climate TDV energy cost savings vs. dry mode TD

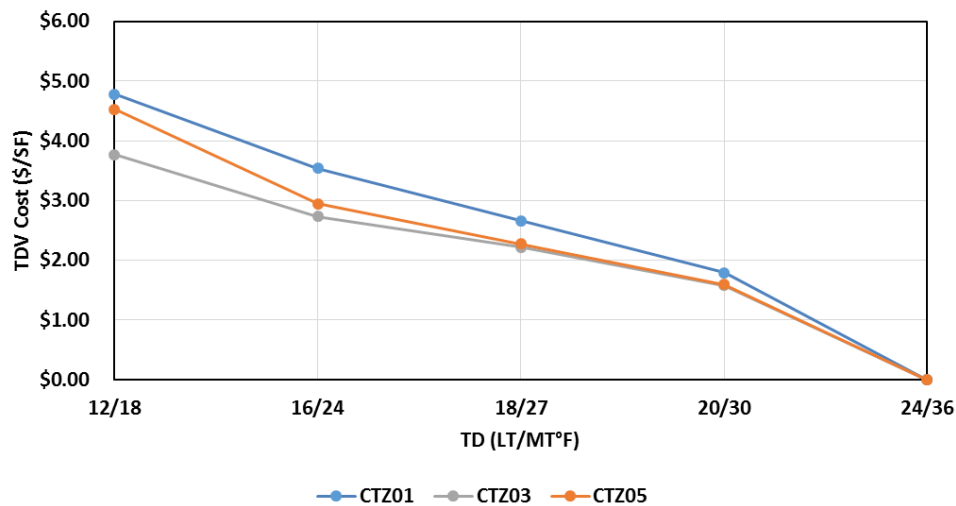


Figure 22: Cool climate TDV energy cost savings vs. dry mode TD

5.2.3.3 Hybrid Condenser Specific Efficiency

Per-unit energy cost savings over the 15-year period of analysis are presented in below in Figure 23 and Figure 24. It is estimated that the year average TDV energy cost savings for warm climate zones is approximately \$2.9 per square foot at a specific efficiency of 65 Btuh/W. The estimated average first-year average TDV energy cost savings for cool climate zones is approximately \$1.1 per square foot at a specific efficiency of 65 Btuh/W.

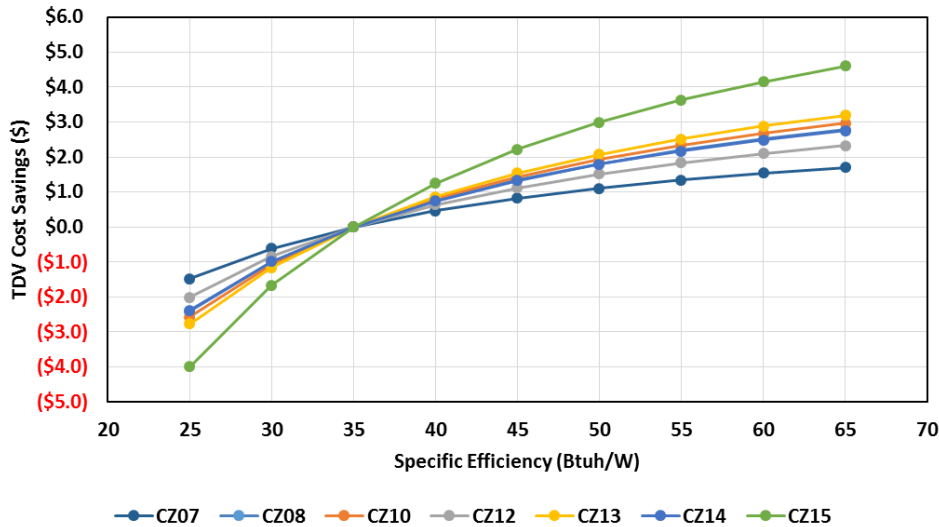


Figure 23: Warm climate TDV energy cost savings vs. specific efficiency

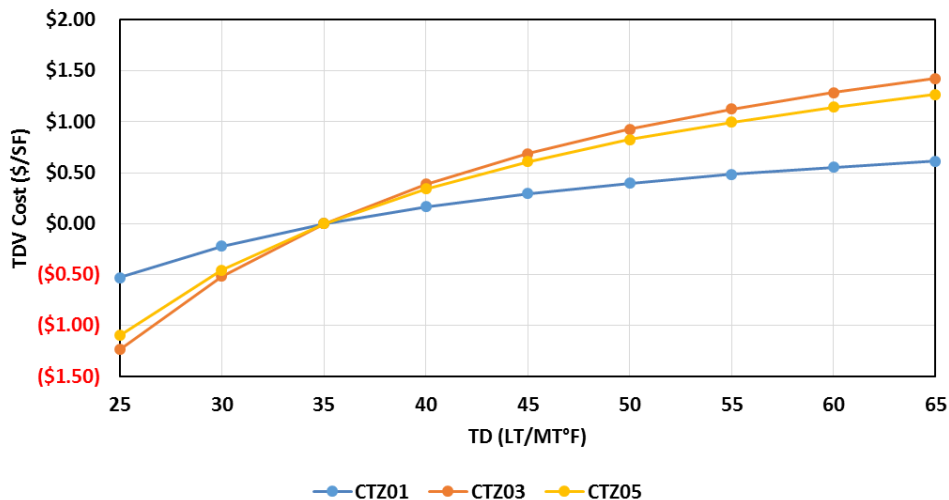


Figure 24: Cool climate TDV energy cost savings vs. specific efficiency

5.3 Incremental First Cost

The Statewide CASE Team estimated the Current Incremental Construction Costs and Post-Adoption Incremental Construction Costs. The Current Incremental Construction Cost represents the incremental cost of the measure if a building meeting the proposed standard were built today. The Post-Adoption Incremental Construction Cost represents the anticipated cost assuming full market penetration of the measure as a result of the new standards, resulting in possible reduction in unit costs as manufacturing

practices improve over time and with increased production volume of qualifying products the year the Standard becomes effective.

Per the Energy Commission's guidance, design costs are not included in the incremental first cost.

5.3.1 Variable SCT Setpoint

Currently, adiabatic condensers do not come with the ability to vary the SCT setpoint based on ambient conditions using the local controller from the manufacturer. However, typical installations observed on-site and discussions with refrigeration system design engineers show that commercial installations have the condenser integrated into the supervisory control system. Option A and B have a lower cost compared to Option C as they involve costs only for start-up, programming and fine tuning. The cost for Option A and B are summarized in Table 27 below.

Table 27: Variable SCT Setpoint Option A and B Incremental First Cost per Condenser for All Prototypes

Cost Component	Cost
Incremental Labor (programming and fine tuning)	\$720
Tax (8.5%)	\$61
Contingency (5%)	\$36
Total (2016 \$)	\$817
Total (2020PV \$)	\$867

Option C requires an incremental temperature sensor to be installed between the adiabatic pad and the condenser heat transfer surface. The cost of the sensor, associated electrical equipment, and additional labor needed to install and fine tune the new sensor is summarized in Table 28 through Table 30 below.

Table 28: Variable SCT Setpoint Option C Incremental First Cost per Condenser (LSM Prototype)

Cost Component	Cost
Ambient Drybulb Temperature Sensor	\$59
Associated Electrical Equipment (wiring)	\$615
Incremental Labor (install and fine tuning)	\$840
Tax (8.5%)	\$129
Contingency (5%)	\$76
Total (2016 \$)	\$1,719
Total (2020PV \$)	\$1,824,824

Table 29: Variable SCT Setpoint Option C Incremental First Cost per Condenser (SRWH Prototype)

Cost Component	Cost
Ambient Drybulb Temperature Sensor	\$59
Associated Electrical Equipment (wiring)	\$923
Incremental Labor (install and fine tuning)	\$840
Tax (8.5%)	\$155
Contingency (5%)	\$91
Total (2016 \$)	\$2,068
Total (2020PV \$)	\$2,194

Table 30: Variable SCT Setpoint Option C Incremental First Cost per Condenser (LRWH Prototype)

Cost Component	Cost
Ambient Drybulb Temperature Sensor	\$59
Associated Electrical Equipment (wiring)	\$1,231
Incremental Labor (install and fine tuning)	\$840
Tax (8.5%)	\$181
Contingency (5%)	\$106
Total (2016 \$)	\$2,417
Total (2020PV \$)	\$2,565

5.3.2 Dry Mode Sizing

Using cost data available from manufacturers, the Statewide CASE Team calculated average cost per MBH per °F for dry mode capacities only. This cost was used to estimate incremental increase or decrease in first cost when using condensers of different sizes. The first costs for each condenser size for each prototype are summarized in Table 31 through Table 33 below.

Table 31: Incremental Cost for Dry-Mode Sizing (LSM Prototype)

Rated TD (LT,MT)	THR (MBH)	MBH/°F	\$/MBH/°F	First Cost (2020\$)
12,18	1920	114.08	\$127.90	\$145,918.55
16,24	1920	85.56	\$127.90	\$109,438.92
18,27	1920	76.04	\$127.90	\$97,259.77
20,30	1920	68.45	\$127.90	\$87,551.13
24,36	1920	57.02	\$127.90	\$72,937.61

Table 32: Incremental Cost for Dry-Mode Sizing (SRWH Prototype)

Rated TD (LT,MT)	THR (MBH)	MBH/°F	\$/MBH/°F	First Cost (2020\$)
12,18	1981	114.08	\$127.90	\$150,554.51
16,24	1981	85.56	\$127.90	\$112,915.88
18,27	1981	76.04	\$127.90	\$100,349.80
20,30	1981	68.45	\$127.90	\$90,332.71
24,36	1981	57.02	\$127.90	\$75,254.90

Table 33: Incremental Cost for Dry-Mode Sizing (LRWH Prototype)

Rated TD (LT,MT)	THR (MBH)	MBH/°F	\$/MBH/°F	First Cost (2020\$)
12,18	6238	114.08	\$124.39	\$461,047.67
16,24	6238	85.56	\$124.39	\$345,785.75
18,27	6238	76.04	\$124.39	\$307,304.25
20,30	6238	68.45	\$124.39	\$276,628.60
24,36	6238	57.02	\$124.39	\$230,455.37

5.3.3 Specific Efficiency

To calculate incremental cost for this measure, the CASE Team grouped condenser models into narrow bins of 10 MBH rated capacity starting from 200 MBH to 800 MBH using dry-mode heat rejection information only. The CASE Team analyzed each bin to determine the incremental cost per increase in the condenser specific efficiency while controlling the overall size of the condenser (\$/Btuh/W). The overall average was used for cost analysis, which was found to be \$500/Btuh/W. Specific efficiency values below the base case were evaluated to see if the associated decrease in first cost of less efficient units would outweigh the energy cost increase during the 15-year study period.

Table 34: Incremental Cost for Specific Efficiency Change (LSMLSM and SRWH Prototypes)

Specific Efficiency (Btuh/W)	Incremental Cost (2020\$)
25	(\$10,000.00)
30	(\$7,500.00)
35	(\$5,000.00)
40	(\$2,500.00)
45 (Base case)	-
50	\$2,500.00
55	\$5,000.00
60	\$7,500.00

Table 35: Incremental Cost for Specific Efficiency Change (LRWH Prototype)

Specific Efficiency (Btuh/W)	Incremental cost (2020\$)
25	(\$5,000.00)
30	(\$2,500.00)
35 (Base case)	-
40	\$2,500.00
45	\$5,000.00
50	\$7,500.00
55	\$10,000.00
60	\$12,500.00

5.4 Lifetime Incremental Maintenance Costs

Incremental maintenance cost is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the period of analysis. The present value of equipment and maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2019 TDV. The present value of maintenance costs that occurs in the n^{th} year is calculated as follows (where d is the discount rate of 3 percent):

$$\text{Present Value of Maintenance Cost} = \text{Maintenance Cost} \times \left[\frac{1}{1 + d} \right]^n$$

There are no incremental maintenance costs associated with the proposed conditions.

5.5 Lifecycle Cost-Effectiveness

This measure proposes a mandatory requirement. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 15-year period of analysis.

The Energy Commission establishes the procedures for calculating lifecycle cost-effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology described in this report is consistent with their guidelines, including which costs were included in the analysis. In this case, incremental first cost and incremental maintenance costs over the 15-year period of analysis were included. The TDV energy cost savings from electricity savings were also included in the evaluation.

Design costs were not included nor was the incremental cost of code compliance verification.

According to the Energy Commission's definitions, a measure is cost-effective if the Benefit-to-Cost (B/C) Ratio is greater than 1.0. The B/C Ratio is calculated by dividing the total present lifecycle cost benefits by the present value of the total incremental costs.

Results of the per-unit lifecycle cost-effectiveness analyses are presented in the following sections.

5.5.1 *LSM Prototype*

5.5.1.1 Variable SCT Setpoint

The TDV cost savings were higher for option C as compared to option A and option B and are presented below in Table 36 to Table 38. Options A and B have lower incremental costs as compared to option C. While three control options were studied for comparison, proposed code language is based on control option B to ensure that the code does not inhibit innovation for control in adiabatic mode.

The benefit-to-cost ratio for option B ranges from 33.5 to 235.2 depending on the climate zone.

Table 36: Variable SCT Setpoint Option A: Lifecycle Cost-Effectiveness Summary Per LSM Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings ⁴ (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs ⁵ (2020PV \$)	Benefit-to- Cost Ratio
1	\$16,687.50	\$867	19.2
3	\$145,061.10	\$867	167.3
5	\$125,908.30	\$867	145.2
7	\$288,493.50	\$867	332.7
8	\$186,971.20	\$867	215.6
10	\$91,029.20	\$867	105.0
12	\$80,990.00	\$867	93.4
13	\$79,752.90	\$867	92.0
14	\$45,977.40	\$867	53.0
15	-	\$867	-

Table 37: Variable SCT Setpoint Option B: Lifecycle Cost-Effectiveness Summary Per LSM Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	\$3,052.70	\$867	3.5
3	\$58,384.00	\$867	67.3
5	\$57,921.20	\$867	66.8
7	\$204,005.80	\$867	235.2
8	\$124,092.70	\$867	143.1
10	\$62,727.20	\$867	72.3
12	\$49,421.70	\$867	57.0
13	\$46,609.30	\$867	53.7
14	\$14,124.30	\$867	16.3
15	\$22,855.20	\$867	26.4

⁴ **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (CEC 2016, Chapter 5 p.51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

⁵ **Costs: Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative it is treated as a positive benefit. If there are no Total Incremental Present Valued Costs, the Benefit/Cost Ratio is Infinite.

Table 38: Variable SCT Setpoint Option C: Lifecycle Cost-Effectiveness Summary Per LSM Prototype (New Construction)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	\$15,628.40	\$1,824	8.6
3	\$146,307.10	\$1,824	80.2
5	\$125,641.30	\$1,824	68.9
7	\$293,281.70	\$1,824	160.8
8	\$221,779.10	\$1,824	121.6
10	\$128,053.20	\$1,824	70.2
12	\$107,930.30	\$1,824	59.2
13	\$113,181.30	\$1,824	62.1
14	\$70,123.10	\$1,824	38.4
15	\$72,063.30	\$1,824	39.5

5.5.1.2 Dry Mode Hybrid Condenser Sizing

Condensers with lower specific efficiency are cheaper and thus, have a negative incremental cost. For condensers that were sized larger than the base case sizing, the savings in energy consumption is the benefit, and incremental first cost for the condenser is the cost. For condensers smaller than base case, the savings in condenser first cost becomes the benefit, and higher energy consumption becomes the cost. If a particular case has negative incremental costs, then it has an infinite benefit to cost ratio as the cost term tends to be zero. Results, as shown in Table 39, indicate that a condenser sized with TD of 18/27°F or 20/30°F is most cost-effective for warm climate zones, and that a condenser sized with TD of 16/24°F or 18/27°F is most cost-effective for cool climate zones.

Table 39: Dry Mode Hybrid Condenser Sizing: Lifecycle Cost-Effectiveness – LSM prototype

Climate Zone	Climate Zone Type	Dry-mode sizing TD (LT/MT °F)				
		12/18	16/24	18/27	20/30	24/36
1	Cool	1.00	1.79	1.92	1.86	1.47
3	Cool	1.00	Infinite	Infinite	45.23	2.29
5	Cool	1.00	55.39	11.99	4.93	1.93
7	Warm	1.00	25.62	2.95	1.46	0.71
8	Warm	0.00	1.00	1.77	0.97	0.51
10	Warm	0.00	0.80	1.27	1.00	0.34
12	Warm	0.00	0.43	0.83	1.00	0.44
13	Warm	0.00	0.47	0.91	1.00	0.42
14	Warm	0.19	0.64	0.97	1.36	1.00
15	Warm	0.45	1.48	2.11	2.78	1.00

5.5.1.3 Hybrid Condenser Specific Efficiency

Condensers with lower specific efficiency are cheaper and thus, have a negative incremental cost. For condensers with higher specific efficiency as compared to base case, the savings in energy consumption is the benefit, and incremental first cost for the condenser is the cost. For condensers with lower specific efficiency as compared to base case, the savings in condenser cost becomes the benefit, and higher energy consumption becomes the cost. If a particular case has negative incremental costs and energy

savings, then it has infinite benefit to cost ratio as the cost term tends to be zero. Results indicate specific efficiency of 50 Btu/W is the most cost-effective for LSM prototype (Halocarbons).

While the most cost-effective specific efficiency was shown to be 50 Btu/W as presented in Figure 25 and Figure 26, the proposed code changes recommend a minimum specific efficiency value of 45 Btu/W, which remains highly cost-effective and does not put undue restrictions on current market offerings.

For Climate Zone 1, the average ambient temperature is much lower than other climate zones, which causes very low average fan speeds. Due to this, there is no significant effect of change in specific efficiency for Climate Zone 1.

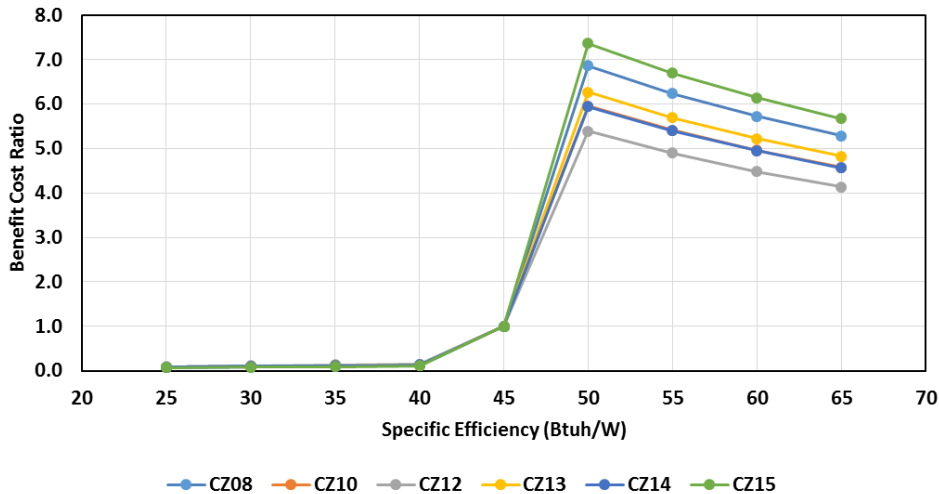


Figure 25: Specific efficiency: lifecycle cost-effectiveness – warm climate (LSM prototype)

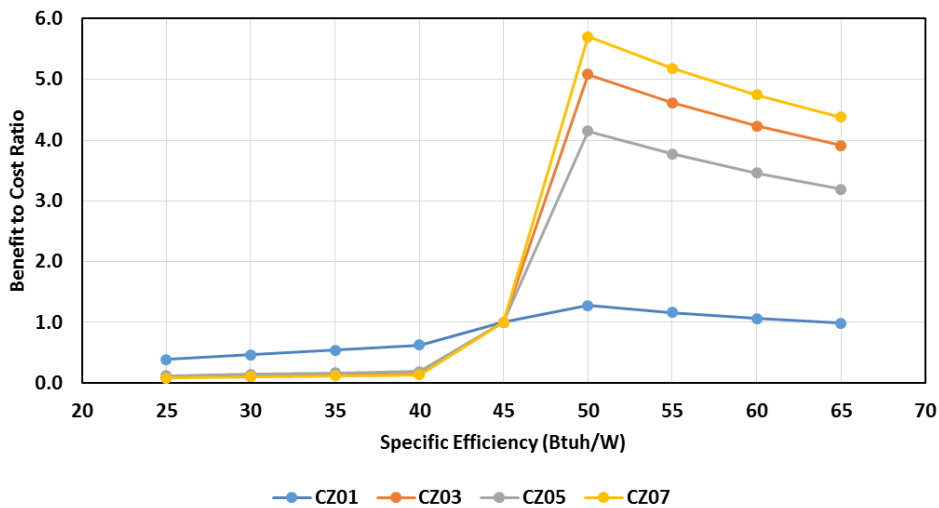


Figure 26: Specific efficiency: lifecycle cost-effectiveness – cool climate (LSM prototype)

5.5.2 SRWH Prototype

5.5.2.1 Variable SCT Setpoint

The TDV cost savings were higher for option C as compared to option A and option B and are presented below in Table 40 to Table 42. Options A and B have lower incremental costs as compared to option C. While three control options were studied for comparison, proposed code language is based on control option B to ensure that the code does not inhibit innovation for control in adiabatic mode.

The benefit-to-cost ratio for option B ranges from 0 to 166.44 depending on the climate zone.

Table 40: Variable SCT Setpoint Option A: Lifecycle Cost-Effectiveness Summary Per SRWH Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	(\$1,272.70)	\$867	0.00
3	\$89,000.00	\$867	102.66
5	\$65,326.00	\$867	75.33
7	\$219,607.50	\$867	253.22
8	\$128,391.40	\$867	148.00
10	\$68,770.30	\$867	79.33
12	\$40,361.50	\$867	46.55
13	\$47,882.00	\$867	55.22
14	\$1,682.10	\$867	1.99
15	(\$13,100.80)	\$867	0.0

Table 41: Variable SCT Setpoint Option B: Lifecycle Cost-Effectiveness Summary Per SRWH Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	(\$2,207.20)	\$867	0.00
3	\$34,131.50	\$867	39.44
5	\$37,148.60	\$867	42.88
7	\$144,322.40	\$867	166.44
8	\$73,282.60	\$867	84.55
10	\$41,385.00	\$867	47.77
12	\$16,322.60	\$867	18.88
13	\$22,997.60	\$867	26.55
14	(\$7,938.80)	\$867	0.00
15	\$6,701.70	\$867	7.77

Table 42: Variable SCT Setpoint Option C: Lifecycle Cost-Effectiveness Summary Per SRWH Prototype (New Construction)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	\$1,023.50	\$2,194	0.55
3	\$104,575.00	\$2,194	47.77
5	\$78,987.50	\$2,194	36.00
7	\$233,803.00	\$2,194	106.55
8	\$170,524.00	\$2,194	77.77
10	\$119,340.10	\$2,194	54.44
12	\$67,880.30	\$2,194	30.99
13	\$82,992.50	\$2,194	37.88
14	\$14,266.70	\$2,194	6.55
15	\$25,845.60	\$2,194	11.88

5.5.2.2 Dry Mode Hybrid Condenser Sizing

Smaller sized condensers are cheaper and thus, have a negative incremental cost. For condensers larger than the base case, the savings in energy consumption becomes the benefit, and incremental cost for the condenser becomes the cost. For condensers smaller than base case, the savings in condenser cost becomes the benefit, and higher energy consumption becomes the cost. If a particular case has negative incremental costs and energy savings, then theoretically it has infinite benefit to cost ratio as the cost term tends to be zero. Results, as shown in Table 43, indicate that a condenser sized with TD of 20/30°F is most cost-effective for warm climate zones, whereas a condenser sized with TD of 16/24°F is most cost-effective in cool climates.

Table 43: Dry Mode Hybrid Condenser Sizing: Lifecycle Cost-Effectiveness (SRWH prototype)

Climate Zone	Climate Zone Type	Dry-mode sizing TD (LT/MT °F)				
		12/18	16/24	18/27	20/30	24/36
1	Cool	1.00	1.17	0.94	0.82	0.64
3	Cool	1.00	1.48	1.30	1.10	0.80
5	Cool	1.00	1.01	0.94	0.71	0.68
7	Warm	1.00	1.95	1.39	1.08	0.74
8	Warm	0.00	1.00	2.00	1.36	0.83
10	Warm	0.00	0.35	1.00	1.19	0.72
12	Warm	0.00	0.43	0.70	1.00	0.60
13	Warm	0.00	0.24	0.49	1.00	0.73
14	Warm	0.49	0.92	1.18	1.46	1.00
15	Warm	0.13	0.63	0.88	1.14	1.00

5.5.2.3 Hybrid Condenser Specific Efficiency

Condensers with lower specific efficiency are cheaper and thus, have a negative incremental cost. For condensers with higher specific efficiency as compared to base case, the savings in energy consumption becomes the benefit, and incremental cost for the condenser becomes the cost. For condensers with lower specific efficiency as compared to base case, the savings in condenser cost becomes the benefit, and higher energy consumption becomes the cost. If a particular case has negative incremental costs and

energy savings, then theoretically it has infinite benefit to cost ratio as the cost term tends to be zero. Results indicate specific efficiency of 50 Btuh/W is the most cost-effective for SRWH prototype (Halocarbons).

While the most cost-effective specific efficiency was shown to be 50 Btuh/W as presented in Figure 27 and Figure 28, the proposed code changes recommend a minimum specific efficiency value of 45 Btuh/W which remains highly cost-effective and does not put undue restrictions on current market offerings.

For Climate Zone 1, the average ambient temperature is much lower than other climate zones and which causes very low average fan speeds. Due to this, there is no significant effect of change in specific efficiency for Climate Zone 1.

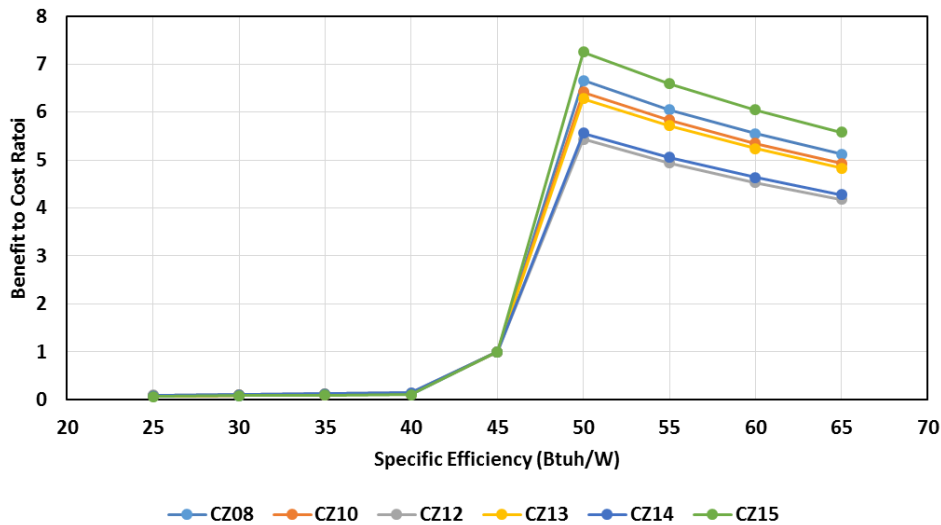


Figure 27: Specific efficiency: lifecycle cost-effectiveness – warm climate (SRWH prototype)

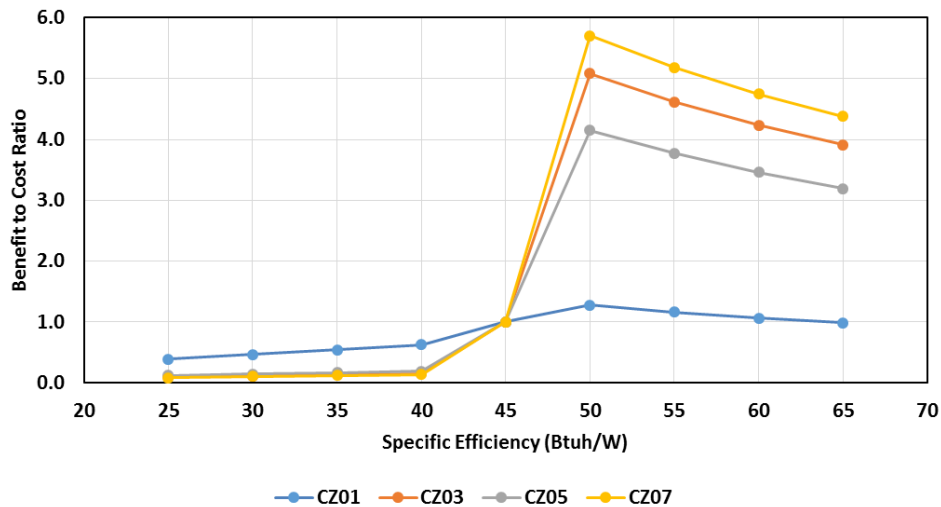


Figure 28: Specific efficiency: lifecycle cost-effectiveness – cool climate (SRWH prototype)

5.5.3 LRWH Prototype

5.5.3.1 Variable SCT Setpoint

The TDV cost savings were higher for option C as compared to option A and option B and are presented below in Table 44 to Table 46. Options A and B have lower incremental costs as compared to option C. While three control options were studied for comparison, proposed code language is based on control option B to ensure that the code does not inhibit innovation for control in adiabatic mode.

The benefit-to-cost ratio for option B ranges from 0 to 328.33 depending on the climate zone.

Table 44: Variable SCT Setpoint Option A: Lifecycle Cost-Effectiveness Summary Per LRWH Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	(\$140,646.70)	\$867	0.00
3	\$8,828.80	\$867	10.22
5	(\$614.10)	\$867	0.00
7	\$389,490.70	\$867	449.1
8	\$314,606.10	\$867	362.88
10	\$206,186.30	\$867	237.88
12	\$36,979.50	\$867	42.66
13	\$239,855.00	\$867	276.66
14	\$4,903.90	\$867	5.77
15	\$208,900.80	\$867	240.99

Table 45: Variable SCT Setpoint Option B: Lifecycle Cost-Effectiveness Summary Per LRWH Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	(\$201,077.70)	\$867	0.00
3	(\$97,490.60)	\$867	0.00
5	(\$85,689.20)	\$867	0.00
7	\$284,693.20	\$867	328.33
8	\$156,853.60	\$867	180.99
10	\$93,263.10	\$867	107.55
12	(\$58,624.30)	\$867	0.00
13	\$86,276.60	\$867	99.55
14	(\$46,146.50)	\$867	0.00
15	\$172,588.80	\$867	199.00

Table 46: Variable SCT Setpoint Option C: Lifecycle Cost-Effectiveness Summary Per LRWH Prototype (New Construction)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV \$)	Costs Total Incremental Present Valued (PV) Costs (2020PV \$)	Benefit-to- Cost Ratio
1	(\$165,522.20)	\$1,824	0.00
3	(\$12,468.90)	\$1,824	0.00
5	(\$8,125.70)	\$1,824	0.00
7	\$431,614.40	\$1,824	168.33
8	\$412,274.70	\$1,824	160.77
10	\$351,950.50	\$1,824	137.22
12	\$22,801.80	\$1,824	8.99
13	\$364,401.60	\$1,824	142.11
14	\$51,183.90	\$1,824	20.00
15	\$597,412.50	\$1,824	232.99

5.5.3.2 Dry Mode Hybrid Condenser Sizing

Smaller sized condensers are cheaper and thus, have a negative incremental cost. For condensers larger than the base case, the savings in energy consumption becomes the benefit, and incremental cost for the condenser becomes the cost. For condensers smaller than base case, the savings in condenser cost becomes the benefit, and higher energy consumption becomes the cost. If a particular case has negative incremental costs and energy savings, then theoretically it has infinite benefit to cost ratio as the cost term tends to be zero. Results, as shown in Table 47, indicate that a condenser sized with TD of 20/30°F (LT/MT) is most cost-effective in most climate zones.

Table 47: Dry Mode Hybrid Condenser Sizing: Lifecycle Cost-Effectiveness (SRWH prototype)

Climate Zone	Dry-mode sizing TD (LT/MT °F)				
	12/18	16/24	18/27	20/30	24/36
1	1.91	2.82	3.18	3.57	1.00
3	1.50	2.18	2.66	3.15	1.00
5	1.81	2.35	2.73	3.18	1.00
7	1.02	1.86	2.31	1.00	0.28
8	0.17	0.75	1.09	1.00	0.46
10	0.03	0.63	1.00	1.00	0.49
12	0.29	1.02	1.46	1.89	1.00
13	0.00	0.23	0.51	1.00	0.65
14	0.58	1.12	1.45	1.84	1.00
15	0.00	0.05	1.00	1.75	0.94

5.5.3.3 Hybrid Condenser Specific Efficiency

Condensers with lower specific efficiency are cheaper and thus, have a negative incremental cost. For condensers with higher specific efficiency as compared to base case, the savings in energy consumption becomes the benefit, and incremental cost for the condenser becomes the cost. For condensers with lower specific efficiency as compared to base case, the savings in condenser cost becomes the benefit, and higher energy consumption becomes the cost. If a particular case has negative incremental costs and energy savings, then theoretically it has infinite benefit to cost ratio as the cost term tends to be zero.

Results indicate specific efficiency of 40 Btu/W is the most cost-effective for LRWH prototype (Ammonia).

While the most cost-effective specific efficiency was shown to be 40 Btu/W as presented in Figure 29 and Figure 30, the proposed code changes do not recommend any minimum specific efficiency values for ammonia refrigeration systems due to the limited amount of data available in the market place on ammonia system condenser performance.

For Climate Zone 1, the average ambient temperature is much lower than other climate zones and which causes very low average fan speeds. Due to this, there is no significant effect of change in specific efficiency for Climate Zone 1.

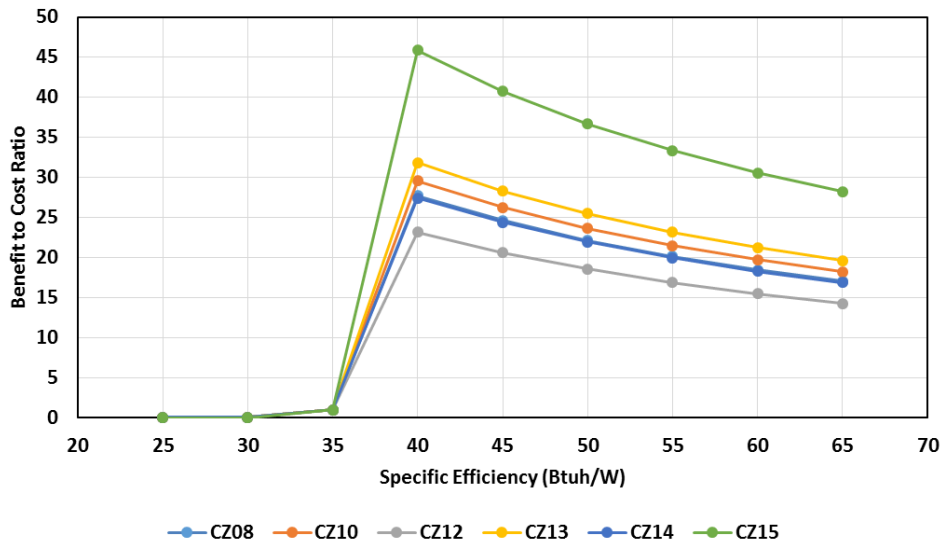


Figure 29: Specific efficiency: lifecycle cost-effectiveness – warm climate (LRWH prototype)

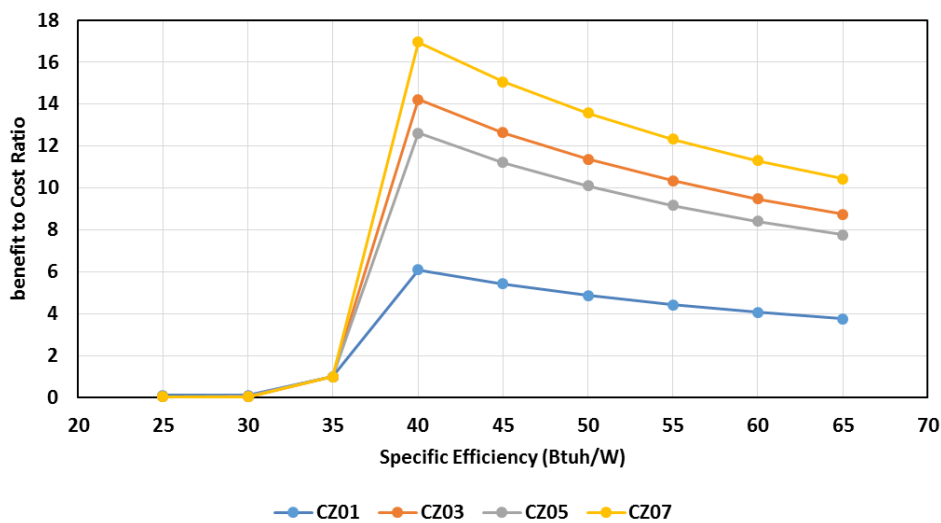


Figure 30: Specific efficiency: lifecycle cost-effectiveness – cool climate (LRWH prototype)

6. FIRST-YEAR STATEWIDE IMPACTS

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings by multiplying the per-unit savings, which are presented in Section 4.3, by the statewide new construction forecast for 2020 or expected alterations in 2020, which is presented in more detail in Appendix A. The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2020. The lifecycle energy cost savings represents the energy cost savings over the entire 15-year analysis period. Results are presented in Table 48 for new construction.

Given data regarding the new construction forecast and expected alterations in 2020, the Statewide CASE Team estimates that the proposed code change will reduce annual statewide electricity use by 700 MWh with an associated demand reduction of 74kW. The energy savings for buildings constructed in 2020 are associated with a present valued energy cost savings of approximately PV \$1.6 million in (discounted) energy costs over the 15- year period of analysis.

Table 48: Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide Construction in 2020 (nonresidential: million ft ²)	First-year Electricity Savings (MWh)	First-year Peak Electrical Demand Reduction (kW)	Lifecycle ² Present Valued Energy Cost Savings (PV\$)
1	0.0047	(1)	1	(1,919)
2	0.0332	(8)	4	(15,089)
3	0.1348	25	23	107,078
4	0.0795	15	14	64,602
5	0.0154	3	1	12,026
6	0.1127	28	11	93,327
7	0.0776	107	9	259,317
8	0.1611	146	2	314,090
9	0.163	147	2	317,044
10	0.1384	80	2	170,076
11	0.043	24	1	51,801
12	0.1689	57	(1)	126,431
13	0.098	39	(0)	78,965
14	0.0271	6	1	14,978
15	0.0297	14	2	31,793
16	0.0356	18	3	38,794
TOTAL	1.3225	700	74	1,663,314

1. First-year savings from all buildings completed statewide in 2020.

6.2 Statewide Water Use Impacts

Because the scope of the proposed code changes does not have an effect on pre-cool mode operation of adiabatic condensers, there are no statewide water use impacts associated with these measures.

However, because the inclusion of adiabatic condensers in the code will increase awareness of the technology, stakeholders in California might realize water savings benefits by selecting adiabatic condensers over evaporative condensers when designing their facilities.

6.3 Statewide Material Impacts

There are no statewide material impacts.

6.4 Other Non-Energy Impacts

There are no other impacts.

7. PROPOSED REVISIONS TO CODE LANGUAGE

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

7.1 Standards

SECTION 101 – DEFINITIONS

CONDENSER is a refrigeration component that condenses refrigerant vapor by rejecting heat to air mechanically circulated over its heat transfer surface.

ADIABATIC CONDENSER is a condenser that has the ability to use two heat transfer processes in series as accomplished by a single factory-made unit. The first heat transfer process is the pre-cooling of the entering air by lowering the entering air drybulb temperature. The second heat transfer process is forced-air circulation cooling over the heat transfer surface of the condenser. Also known as a hybrid condenser.

DRY MODE is an operating condition of an adiabatic condenser wherein the only means of heat transfer is accomplished through forced-air circulation over the heat transfer surface of the condenser without any pre-cooling of the entering air.

PRE-COOL MODE is an operating condition of an adiabatic condenser wherein the entering air is pre-cooled.

ADIABATIC PAD is a material located before the heat transfer surface of an adiabatic condenser, which pre-cools the ambient air by becoming fully wetted during pre-cool mode operation.

TRANSCRITICAL CO₂ REFRIGERATION SYSTEM is a type of refrigeration system that uses CO₂ as the refrigerant where the ultimate heat rejection to ambient air can take place above the critical point.

TRANSCRITICAL MODE is a system operating condition for a refrigeration system wherein the refrigerant pressure and temperature leaving the compressor is such that the refrigerant is at or above the critical point. Typically used in reference to CO₂ refrigeration systems.

SUBCRITICAL MODE is a system operating condition for a refrigeration system wherein the refrigerant pressure and temperature leaving the compressor is such that the refrigerant is below the critical point. Typically used in reference to CO₂ refrigeration systems.

CASCADE REFRIGERATION SYSTEM is a type of refrigeration system that uses a low-stage refrigerant where the heat rejected from condensing the low-stage refrigerant is absorbed by a separate high-stage refrigerant, and the ultimate heat rejection to ambient air is accomplished through the separate high-stage refrigerant.

CRITICAL POINT is a thermodynamic state point for pure substances defined by its pressure and temperature wherein the distinction between the liquid phase and gas phase no longer exists.

GAS COOLER is a refrigeration component that reduces the temperature of a refrigerant vapor by rejecting heat to air mechanically circulated over its heat transfer surface.

SECTION 120.6 – MANDATORY REQUIREMENTS FOR COVERED PROCESSES

(a) Mandatory Requirements for Refrigerated Warehouses

4. Condensers. New fan-powered condensers on new refrigeration systems shall conform to the following:

- A. Design saturated condensing temperatures for evaporative-cooled condensers and water-cooled condensers served by fluid coolers or cooling towers shall be less than or equal to:
 - i. The design wetbulb temperature plus 20°F in locations where the design wetbulb temperature is less than or equal to 76°F; or
 - ii. The design wetbulb temperature plus 19°F in locations where the design wetbulb temperature is between 76°F and 78°F; or
 - iii. The design wetbulb temperature plus 18°F in locations where the design wetbulb temperature is greater than or equal to 78°F.

EXCEPTION 1 to Section 120.6(a) 4A: Compressors and condensers on a refrigeration system for which more than 20 percent of the total design refrigeration cooling load is for quick chilling or freezing, or process refrigeration cooling for other than a refrigerated space.

EXCEPTION 2 to Section 120.6(a) 4A: Transcritical CO₂ refrigeration systems.

- B. Design saturated condensing temperatures for air-cooled condensers shall be less than or equal to the design drybulb temperature plus 10°F for systems serving freezers and shall be less than or equal to the design drybulb temperature plus 15°F for systems serving coolers.

EXCEPTION 1 to Section 120.6(a) 4B: Condensing units with a total compressor horsepower less than 100 HP.

EXCEPTION 2 to Section 120.6(a) 4B: Compressors and condensers on a refrigeration system for which more than 20 percent of the total design refrigeration cooling load is for quick chilling or freezing, or process refrigeration cooling for other than a refrigerated space.

EXCEPTION 3 to Section 120.6(a) 4B: Transcritical CO₂ refrigeration systems.

- C. The saturated condensing temperature necessary for adiabatic condensers to reject the design total heat of rejection of a refrigeration system assuming dry mode performance shall be less than or equal to the design drybulb temperature plus 20°F for systems serving freezers and shall be less than or equal to the design drybulb temperature plus 30°F for systems serving coolers.

EXCEPTION 1 to Section 120.6(a) 4C: Compressors and condensers on a refrigeration system for which more than 20 percent of the total design refrigeration cooling load is for quick chilling or freezing, or process refrigeration cooling for other than a refrigerated space.

EXCEPTION 2 to Section 120.6(a) 4C: Transcritical CO₂ refrigeration systems.

- D. All condenser fans for evaporative-cooled condensers or fans on cooling towers or fluid coolers shall be continuously variable speed, and the condensing temperature control system shall control the speed of all fans serving a common condenser high side in unison. The minimum condensing temperature setpoint shall be less than or equal to 70°F.

EXCEPTION to Section 120.6(a) 4D: Transcritical CO₂ refrigeration systems while operating in transcritical mode.

- E. All condenser fans for air-cooled condensers shall be continuously variable speed and the condensing temperature or pressure control system shall control the speed of all condenser fans serving a common condenser high side in unison. The minimum condensing temperature setpoint shall be less than or equal to 70°F.

EXCEPTION to Section 120.6(a) 4E: Transcritical CO₂ refrigeration systems while operating in transcritical mode.

- F. All condenser fans for adiabatic condensers shall be continuously variable speed and the condensing temperature or pressure control system shall control the speed of all condenser fans serving a common condenser high side in unison. The minimum condensing temperature setpoint shall be less than or equal to 70°F.

EXCEPTION to Section 120.6(a) 4F: Transcritical CO₂ refrigeration systems while operating in transcritical mode.

- G. Condensing temperature reset. The condensing temperature set point of systems served by air-cooled condensers shall be reset in response to ambient drybulb temperature. The condensing temperature set point of systems served by evaporative-cooled condensers or water-cooled condensers (via cooling towers or fluid coolers) shall be reset in response to ambient wetbulb temperatures. The condensing temperature set point for systems served by adiabatic condensers shall be reset in response to ambient drybulb temperature while operating in dry mode.

EXCEPTION 1 to Section 120.6(a) 4G: Condensing temperature control strategies approved by the Executive Director that have been demonstrated to provide at least equal energy savings.

EXCEPTION 2 to Section 120.6(a) 4G: Transcritical CO₂ refrigeration systems while operating in transcritical mode.

EXCEPTION 3 to Section 120.6(a) 4G: Systems served by adiabatic condensers in Climate Zones 1, 3, 5, 12, and 14.

- H. Fan-powered condensers shall meet the condenser efficiency requirements listed in TABLE 120.6-B. Condenser efficiency is defined as the Total Heat of Rejection (THR) capacity divided by all electrical input power including fan power at 100 percent fan speed, and power of spray/water pumps for evaporative condensers or adiabatic condensers.

EXCEPTION 1 to Section 120.6(b) 4H: Transcritical CO₂ refrigeration systems.

EXCEPTION 2 to Section 120.6(b) 4H: Adiabatic condensers with ammonia as refrigerant.

- I. Air-cooled condensers shall have a fin density no greater than 10 fins per inch.

EXCEPTION to Section 120.6(a) 4G: Micro-channel condensers

TABLE 120.6-B FAN-POWERED CONDENSERS-MINIMUM EFFICIENCY REQUIREMENTS

CONDENSER TYPE	REFRIGERANT TYPE	MINIMUM SPECIFIC EFFICIENCY*	RATING CONDITION
Outdoor Evaporative-Cooled with THR Capacity > 8,000 MBH	All	350 Btuh/W	100°F Saturated Condensing Temperature (SCT), 70°F Outdoor Wetbulb Temperature
Outdoor Evaporative-Cooled with THR	All	160 Btuh/W	

Capacity < 8,000 MBH and Indoor Evaporative-Cooled			
Outdoor Air-Cooled	Ammonia	75 Btuh/W	105°F Saturated Condensing Temperature (SCT), 95°F Outdoor Drybulb Temperature
	Halocarbon	65 Btuh/W	
<u>Adiabatic Dry Mode</u>	<u>Halocarbon</u>	<u>45 Btuh/W</u>	<u>105°F Saturated Condensing Temperature (SCT), 95°F Outdoor Drybulb Temperature</u>
Indoor Air-Cooled	All	Exempt	

(a) Mandatory Requirements for Commercial Refrigeration

Retail food stores with 8,000 square feet or more of conditioned area, and that utilize either: refrigerated display cases, or walk-in coolers or freezers connected to remote compressor units or condensing units, shall meet the requirements of Subsections 1 through 4.

1. Condensers serving refrigeration systems. Fan-powered condensers shall conform to the following requirements:

- A. All condenser fans for air-cooled condensers, evaporative-cooled condensers, adiabatic condensers, gas coolers, air or water-cooled fluid coolers or cooling towers shall be continuously variable speed, with the speed of all fans serving a common condenser high side controlled in unison.
- B. The refrigeration system condenser controls for systems with air-cooled condensers shall use variable setpoint control logic to reset the condensing temperature setpoint in response to ambient drybulb temperature.
- C. The refrigeration system condenser controls for systems with evaporative-cooled condensers shall use variable-setpoint control logic to reset the condensing temperature setpoint in response to ambient wetbulb temperature.
- D. The refrigeration system condenser controls for systems with adiabatic condensers shall use variable setpoint control logic to reset the condensing temperature setpoint in response to ambient drybulb temperature while operating in dry mode.

EXCEPTION 1 to Section 120.6(b) 1B, and C, and D: Condensing temperature control strategies approved by the executive director that have been demonstrated to provide equal energy savings.

EXCEPTION 2 to Section 120.6(b) 1B, and C, and D: Transcritical CO₂ refrigeration while operating in transcritical mode.

- E. The saturated condensing temperature necessary for adiabatic condensers to reject the design total heat of rejection of a refrigeration system assuming dry mode performance shall be less than or equal to the design drybulb temperature plus 20°F for systems serving freezers and shall be less than or equal to the design drybulb temperature plus 30°F for systems serving coolers.

EXCEPTION to Section 120.6(a) 1E: Transcritical CO₂ refrigeration systems.

- F. The minimum condensing temperature setpoint shall be less than or equal to 70°F.
- G. Fan-powered condensers shall meet the specific efficiency requirements listed in Table 120.6-C.

EXCEPTION to Section 120.6(b) 1G: Transcritical CO₂ refrigeration systems.

TABLE 120.6-C FAN-POWERED CONDENSERS-SPECIFIC EFFICIENCY REQUIREMENTS

CONDENSER TYPE	MINIMUM SPECIFIC EFFICIENCY*	RATING CONDITION
Evaporative-Cooled	160 Btuh/W	100°F Saturated Condensing Temperature (SCT), 70°F Entering Wetbulb Temperature
Air-Cooled	65 Btuh/W	105°F Saturated Condensing Temperature (SCT), 95°F Entering Drybulb Temperature
<u>Adiabatic Dry Mode</u>	<u>45 Btuh/W (Halocarbon)</u>	<u>105°F Saturated Condensing Temperature (SCT), 95°F Entering Drybulb Temperature</u>
*See Section 100.1 for definition of condenser specific efficiency		

7.2 Reference Appendices

Terms will need to be added to JA – Glossary.

The proposed requirements will add a new section to NA7.10.3 to address hybrid condensers.

7.3 ACM Reference Manual

There are no proposed changes to the ACM Reference Manual.

7.4 Compliance Manuals

Subsections 10.5 Commercial Refrigeration and 10.6 Refrigerated Warehouse of Chapter 10 and Chapter 13 of the Nonresidential Compliance Manual will need to be revised.

7.5 Compliance Documents

A new form NRCA-PRC will need to be created to address adiabatic compressor requirements.

8. BIBLIOGRAPHY

- Association, National Energy Assistance Directors. 2011. "2011 National Energy Assistance Survey Final Report." Accessed February 2, 2017.
<http://www.appriseinc.org/reports/Final%20NEADA%202011%20Report.pdf>.
- BW Research Partnership. 2016. *Advanced Energy Jobs in California: Results of the 2016 California Advanced Energy*. Advanced Energy Economy Institute.
- CA DWR (California Department of Water Resources). 2016. "California Counties by Hydrologic Regions." Accessed April 3, 2016.
<http://www.water.ca.gov/landwateruse/images/maps/California-County.pdf>.
- California Energy Commission. 2015. "2016 Building Energy Efficiency Standards: Frequently Asked Questions." Accessed February 2, 2017.

- http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/2016_Building_Energy_Efficiency_Standards_FAQ.pdf.
- California Public Utilities Commission. 2015a. "Water/Energy Cost-Effectiveness Analysis: Errata to the Revised Final Report." Prepared by Navigant Consulting, Inc. .
<http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5350>.
- . 2015b. "Water/Energy Cost-Effectiveness Analysis: Revised Final Report." Prepared by Navigant Consulting, Inc. <http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5360>.
- Energy + Environmental Economics. 2016. "Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2019 Time Dependent Valuation (TDV) Data Sources and Inputs." Prepared for the California Energy Commission. July.
http://docketpublic.energy.ca.gov/PublicDocuments/16-BSTD-06/TN212524_20160801T120224_2019_TDV_Methodology_Report_7222016.pdf.
- Ettenson, Lara , and Christa Heavey. 2015. *California's Golden Energy Efficiency Opportunity: Ramping Up Success to Save Billions and Meet Climate Goals*. Natural Resources Defense Council & Environmental Entrepreneurs (E2).
- Goldman, Charles, Merrian C. Fuller, Elizabeth Stuart, Jane S Peters, Marjorie McRay, Nathaniel Albers, Susan Lutzenhiser, and Mersiha Spahic. 2010. *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth*. Lawrence Berkeley National Laboratory.
- Thornberg, Christopher, Hoyu Chong, and Adam Fowler. 2016. *California Green Innovation Index - 8th Edition*. Next 10.
- U.S. Census Bureau, Population Division. 2014. "Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2014."
<http://factfinder2.census.gov/bkmk/table/1.0/en/PEP/2014/PEPANNRES/0400000US06.05000>.
- U.S. EPA (United States Environmental Protection Agency). 2011. "Emission Factors for Greenhouse Gas Inventories." Accessed December 2, 2013.
<http://www.epa.gov/climateleadership/documents/emission-factors.pdf>.
- Wei, Max, Shana Patadia, and Daniel M. Kammen. 2010. "Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?" *Energy Policy* 38: 919-931.
- Zabin, Carol, and Karen Chapple. 2011. *California Workforce Education & Training Needs Assessment: For Energy Efficiency, Distributed Generation, and Demand Reponse*. University of California, Berkeley Donald Vial Center on Employment in the Green Economy. Accessed February 3, 2017. http://laborcenter.berkeley.edu/pdf/2011/WET_Appendices_ALL.pdf.

Appendix A: STATEWIDE SAVINGS

METHODOLOGY

The projected nonresidential new construction forecast that will be impacted by the proposed code change in 2020 is presented in Table 49.

The Energy Commission Demand Analysis Office provided the Statewide CASE Team with the nonresidential new construction forecast for 2020, broken out by building type and forecast climate zones (FCZ). The raw data from the Energy Commission is not provided in this report, but can be available upon request.

The Statewide CASE Team completed the following steps to refine the data and develop estimates of statewide floorspace that will be impacted by the proposed code changes:

1. Translated data from FCZ data into building climate zones (BCZ). This was completed using the FCZ to BCZ conversion factors provided by the Energy Commission (see Table 50).
2. Redistributed square footage allocated to the “Miscellaneous” building type. The Energy Commission’s forecast allocated 18.5 percent of the total square footage from nonresidential new construction in 2020 and the nonresidential existing building stock in 2020 to the miscellaneous building type, which is a category for all space types that do not fit well into another building category. It is likely that the Title 24, Part 6 requirements apply to the miscellaneous building types, and savings will be realized from this floorspace. The new construction forecast does not provide sufficient information to distribute the miscellaneous square footage into the most likely building type, so the Statewide CASE Team redistributed the miscellaneous square footage into the remaining building types in such a way that the percentage of building floorspace in each climate zone, net of the miscellaneous square footage, will remain constant. See Table 52 for an example calculation.
3. Made assumptions about the percentage of nonresidential new construction in 2020 that will be impacted by proposed code change by building type and climate zone. The Statewide CASE Team’s assumptions are presented in Table 53 and Table 54 and discussed further below.
4. Made assumptions about the percentage of the total nonresidential building stock in 2020 that will be impacted by the proposed code change (additions and alterations) by building type and climate zone. The Statewide CASE Team’s assumptions are presented in Table 53 and Table 54 and discussed further below.
5. Calculated nonresidential floorspace that will be impacted by the proposed code change in 2020 by building type and climate zone for both new construction and alterations. Results are presented in Table 49.

Table 49: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2020, by Climate Zone and Building Type (Million ft²)

Climate Zone	New Construction in 2020 (Million Square Feet)											
	OFF-SMALL	REST	RETAIL	FOOD	NWHSE	RWHSE	SCHOOL	COLLEGE	HOSP	HOTEL	OFF-LRG	TOTAL
1	0	0	0	0.0044	0	0.0003	0	0	0	0	0	0.0047
2	0	0	0	0.0284	0	0.0048	0	0	0	0	0	0.0332
3	0	0	0	0.1117	0	0.0231	0	0	0	0	0	0.1348
4	0	0	0	0.0676	0	0.0119	0	0	0	0	0	0.0795
5	0	0	0	0.0131	0	0.0023	0	0	0	0	0	0.0154
6	0	0	0	0.1009	0	0.0118	0	0	0	0	0	0.1127
7	0	0	0	0.0765	0	0.0011	0	0	0	0	0	0.0776
8	0	0	0	0.1447	0	0.0164	0	0	0	0	0	0.1611
9	0	0	0	0.1492	0	0.0138	0	0	0	0	0	0.163
10	0	0	0	0.1309	0	0.0075	0	0	0	0	0	0.1384
11	0	0	0	0.0335	0	0.0095	0	0	0	0	0	0.043
12	0	0	0	0.1410	0	0.0279	0	0	0	0	0	0.1689
13	0	0	0	0.0734	0	0.0246	0	0	0	0	0	0.098
14	0	0	0	0.0248	0	0.0023	0	0	0	0	0	0.0271
15	0	0	0	0.0276	0	0.0021	0	0	0	0	0	0.0297
16	0	0	0	0.0314	0	0.0042	0	0	0	0	0	0.0356
TOTAL	0	0	0	1.1590	0	0.16350	0	0	0	0	0	1.3225

Table 50: Translation from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BCZ)

		Building Climate Zone (BCZ)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Forecast Climate Zone (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%	20.9%	22.8%	54.5%	0.0%	0.0%	1.8%	100%
	4	0.1%	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%	40.1%	0.0%	50.8%	8.7%	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%	6.4%	0.0%	26.9%	54.8%	0.0%	0.0%	0.0%	0.0%	6.1%	0.0%	5.8%	100%
	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	74.9%	0.0%	0.0%	0.0%	0.0%	12.3%	7.9%	4.9%	100%
	11	0.0%	0.0%	0.0%	0.0%	0.0%	27.0%	0.0%	30.6%	42.4%	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%	0.1%	0.0%	4.2%	95.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	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	2.9%	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%
	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%

Table 51: Description of Building Types and Sub-Types (Prototypes) in Statewide Construction Forecast

Energy Commission Building Type ID	Energy Commission Description	Prototype Description			
		Prototype ID	Floor Area (ft ²)	Stories	Notes
OFF-SMALL	Offices less than 30,000 ft ²	Small Office	5,502	1	Five zone office model with unconditioned attic and pitched roof.
REST	Any facility that serves food	Small Restaurant	2,501	1	Similar to a fast food joint with a small kitchen and dining areas.
RETAIL	Retail stores and shopping centers	Stand-Alone Retail	24,563	1	Stand Alone store similar to Walgreens or Banana Republic.
		Large Retail	240,000	1	Big box retail building, similar to a Target or Best Buy store.
		Strip Mall	9,375	1	Four-unit strip mall retail building. West end unit is twice as large as other three.
		Mixed-Use Retail	9,375	1	Four-unit retail representing the ground floor units in a mixed use building. Same as the strip mall with adiabatic ceilings.
FOOD	Any service facility that sells food and or liquor	N/A	N/A	N/A	N/A
NWHSE	Non-refrigerated warehouses	Warehouse	49,495	1	High ceiling warehouse space with small office area.
RWHSE	Refrigerated Warehouses	N/A	N/A	N/A	N/A
SCHOOL	Schools K-12, not including colleges	Small School	24,413	1	Similar to an elementary school with classrooms, support spaces and small dining area.
		Large School	210,886	2	Similar to high school with classrooms, commercial kitchen, auditorium, gymnasium and support spaces.
COLLEGE	Colleges, universities, community colleges	Small Office	5,502	1	Five zone office model with unconditioned attic and pitched roof.
		Medium Office	53,628	3	Five zones per floor office building with plenums on each floor.
		Medium Office/Lab		3	Five zones per floor building with a combination of office and lab spaces.
		Public Assembly		2	TBD
		Large School	210,886	2	Similar to high school with classrooms, commercial kitchen, auditorium, gymnasium and support spaces.
		High Rise Apartment	93,632	10	75 residential units along with common spaces and a penthouse. Multipliers are used to represent typical floors.
HOSP	Hospitals and other health-related facilities	N/A	N/A	N/A	N/A
HOTEL	Hotels and motels	Hotel	42,554	4	Hotel building with common spaces and 77 guest rooms.
MISC	All other space types that do not fit another category	N/A	N/A	N/A	N/A
OFF-LRG	Offices larger than 30,000 ft ²	Medium Office	53,628	3	Five zones per floor office building with plenums on each floor.
		Large Office	498,589	12	Five zones per floor office building with plenums on each floor. Middle floors represented using multipliers.

Table 52: Example of Redistribution of Miscellaneous Category - 2020 New Construction in Climate Zone 1

Building Type	2020 Forecast (Million ft ²)	Distribution Excluding Miscellaneous Category	Redistribution of Miscellaneous Category (Million ft ²)	Revised 2020 Forecast (Million ft ²)
	[A]	[B]	[C] = B × 0.11	[D] = A + C
Small Office	0.049	12%	0.013	0.062
Restaurant	0.016	4%	0.004	0.021
Retail	0.085	20%	0.022	0.108
Food	0.029	7%	0.008	0.036
Non-refrigerated Warehouse	0.037	9%	0.010	0.046
Refrigerated Warehouse	0.002	1%	0.001	0.003
School	0.066	16%	0.017	0.083
College	0.028	7%	0.007	0.035
Hospital	0.031	7%	0.008	0.039
Hotel/motel	0.025	6%	0.007	0.032
Miscellaneous	0.111	---	-	---
Large Office	0.055	13%	0.014	0.069
Total	0.534	100%	0.111	0.534

Table 53: Percent of Floorspace Impacted by Proposed Measure, by Building Type

Building Type <i>Building Sub-Type</i>	Composition of Building Type by Sub-types ¹	Percent of Square Footage Impacted ²	
		New Construction	Existing Building Stock (Alterations) ³
Small Office		0%	0%
Restaurant		0%	0%
Retail		0%	0%
<i>Stand-Alone Retail</i>	10%	0%	0%
<i>Large Retail</i>	75%	0%	0%
<i>Strip Mall</i>	5%	0%	0%
<i>Mixed-Use Retail</i>	10%	0%	0%
Food		12.18%	0%
Non-refrigerated Warehouse		0%	0%
Refrigerated Warehouse		10%	0%
Schools		0%	0%
<i>Small school</i>	60%	0%	0%
<i>Large school</i>	40%	0%	0%
College		0%	0%
<i>Small Office</i>	5%	0%	0%
<i>Medium Office</i>	15%	0%	0%
<i>Medium Office/Lab</i>	20%	0%	0%
<i>Public Assembly</i>	5%	0%	0%
<i>Large School</i>	30%	0%	0%
<i>High Rise Apartment</i>	25%	0%	0%
Hospital		0%	0%
Hotel/motel		0%	0%
Large offices		0%	0%
<i>Medium Office</i>	50%	0%	0%
<i>Large Office</i>	50%	0%	0%

1. Presents the assumed composition of the main building type category by the building sub-types. All 2019 CASE Reports assumed the same percentages of building sub-types.
2. When the building type is comprised of multiple sub-types, the overall percentage for the main building category was calculated by weighing the contribution of each sub-type.
3. Percent of existing floorspace that will be altered during the first-year the 2019 Standards are in effect.

Table 54: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone

Climate Zone	Percent of Square Footage Impacted	
	New Construction	Existing Building Stock (Alterations) ¹
1	100%	0%
2	100%	0%
3	100%	0%
4	100%	0%
5	100%	0%
6	100%	0%
7	100%	0%
8	100%	0%
9	100%	0%
10	100%	0%
11	100%	0%
12	100%	0%
13	100%	0%
14	100%	0%
15	100%	0%
16	100%	0%

1. Percent of existing floorspace that will be altered during the first-year the 2019 Standards are in effect.

Appendix B: DISCUSSION OF IMPACTS OF COMPLIANCE PROCESS ON MARKET ACTORS

This section discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. The Statewide CASE Team asked stakeholders for feedback on how the measure will impact various market actors during public stakeholder meetings that were held on the Statewide CASE Team held on December 12, 2016 and March 21, 2017 (Statewide CASE Team 2016). In addition to the stakeholder meetings, the CASE Team had extensive interaction with individual market actors including refrigeration system design engineers and facility managers during site visits. The key results from feedback received during stakeholder meetings and other target outreach efforts are detailed below in Table 55.

This proposal will improve the compliance process for refrigeration systems by clarifying requirements as they apply to adiabatic (hybrid) condensers. The lack of any information on adiabatic systems has been confusing to designers, installers, inspectors and equipment manufacturers.

This appendix identifies the market actors who will play a role in complying with the proposed change, the tasks for which they will be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated.

Specific comments include:

- Supermarket refrigeration contractor - for a site we surveyed to understand how difficult/easy it is to incorporate variable setpoint for adiabatic. He explained they already have seen this implemented in multiple installations and would provide little additional effort if at all.
- Engineering firm - to understanding the current practice for condenser sizing. Typical dry mode sizing is 16-20°F from engineering documents provided, which is not in conflict with the maximum TD recommendation. Data from other commercial refrigeration projects, as well as at least one condenser manufacturer, had consistent sizing in the mid 20°F range.
- The Statewide CASE Team conducted additional outreach to understand implications of the CO2 proposed code language. Manufacturers are developing technologies, such as parallel compression, gas ejectors, liquid ejector, and external subcooling that is making transcritical CO2 operation more efficient. The proposed changes are deliberately trying to stay out of market actors' way so they can continue this innovation and research.
- When studying minimum specific efficiency, the Statewide CASE Team reached out to the two main manufacturers to get rating data on all available models. The Statewide CASE Team selected the minimum efficiency level in order to not disrupt the current market, while at the same time identifying outliers that would lead to poor energy efficiency. The recommend changes would eliminate approximately 30 percent of the available models.

Table 55: Roles of Market Actors in The Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Refrigeration Systems Designers/Specifiers	- Refrigeration system design drawings, specifications - Specify code compliant equipment and document code requirements	- Quickly and easily determine requirements based on scope and system selection - A successful design is one that cost-effectively meets the refrigeration needs of project, and meets code requirements - Clearly communicate system requirements to installation contractors - Minimize coordination during construction	Code change will clarify adiabatic condenser systems, so should minimize confusion of code requirements	- This proposed code change may encourage more adiabatic systems, thereby making them more common. As they become more common in the market all market actors will become more familiar with the equipment and the code requirements - Provide clear guidance on system requirements - Create new compliance document to address adiabatic condensers
Refrigeration Systems Installers	- The installer coordinates with designer to properly install equipment according to specifications - Work is installing a properly working refrigeration system	The task objective in to install equipment that meets the specifications provided, installation meets building owner needs	Code change will clarify adiabatic condenser systems, so should minimize confusion of code requirements	This proposed code change may encourage more adiabatic systems, thereby making them more common. As they become more common in the market all market actors will become more familiar with the equipment and the code requirements

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Building Enforcement Agency / Inspector	- Review the permit submittal for code compliance - Review installation - Coordinate with the designer during the permitting process	- Review full permit application submission, and review installation in as timely a manner as possible - Want to get things right the first time to avoid re-inspection	Code change will clarify adiabatic condenser systems, so should minimize confusion of code requirements	- Building department plan reviewers and inspectors will need to be trained to identify adiabatic condensers and verify code requirements. - Enforcement community already reviews and inspects air cooled and evaporative condensers, so this should not present a bug obstacle - A new form NRCA-PRC will need to be created to address adiabatic compressor requirements
Energy Efficiency Program Implementers	Not directly involved in compliance, but need the compliance process to work to ensure program projects are meeting baseline program requirements	- Advise the design team on program requirements - Work includes coordinating with the designer, and ensuring submittal is correct	Code requirements provide a clear baseline for energy efficiency programs	Program implementers should receive training on adiabatic condensers and applicable code requirements

Appendix C: ON-SITE OBSERVATIONS AND STAKEHOLDER DISCUSSIONS

This section describes the on-site surveys that were made to adiabatic condenser installations, as well describing design discussions with stakeholders. Three site surveys were made to installations of adiabatic condensers located in California in order to observe their operation in practice. The goals of these surveys were to:

1. Understand how the adiabatic condensers were integrated into the supervisory control system.
2. Record the outdoor air temperature setpoint that switches the adiabatic condensers from dry mode operation to adiabatic mode operation.
3. Observe the operating TD of the adiabatic condensers.
4. Communicate with site personnel on maintenance issues or requirements.

Site Survey #1: Large Supermarket Chain (Dublin, CA)

On February 22, 2017, a large supermarket chain located in Dublin, CA was surveyed. The refrigeration system consisted of a high stage ammonia system and cascaded CO₂ system. The high stage ammonia system discharged high pressure vapor refrigerant to two BAC Trillium TSDC-085-9.6 microchannel condensers that shared a common discharge line. The switching setpoint for one of the condensers (hereafter referred to as HC-1) was set at 60°F and was operating in adiabatic mode at low fan speeds of approximately 25 percent. The other condenser's (hereafter referred to as HC-2) switching setpoint was not able to be observed and was operating in dry mode at higher fan speeds of 90%. The drybulb temperature was recorded at 58°F. It was unclear why HC-1 was operating in adiabatic mode despite being below the switching setpoint. The condensers were integrated into the supervisory controls, but it was not observed that there was variable setpoint operation.

	HC-1	HC-2
Suction Group Designation	Rack 1	Rack 1
Drybulb (measured)	58F	58F
Wetbulb (measured)	52F	52F
Drybulb (on local condenser controller)	57.7F	N/A
Switching Setpoint	60F	N/A
Operation Mode	Adiabatic	Dry
Fan Speed	25%	90% (estimated)
Incoming Air Temperature	53.9F	58F
SCT	68F	68F
Operating TD	14.1F	10F
Integrated Into Supervisory Control	Yes	Yes
Observed Variable SCT Setpoint	No	No

Site Survey #2: Large Supermarket Chain (Fremont, CA)

On February 22, 2017, a large supermarket chain located in Fremont, CA was surveyed. The refrigeration system consisted of four scroll compressor racks (Rack A-D) with Rack A and B discharging to a single common condenser. The refrigerant of the system was R-407A. There were three

BAC TSDC-058-6.2 microchannel condensers. The switching setpoint for all three condensers was set at 74°F and all were operating in dry mode with high fan speeds. The operating dry mode TD ranged from 21°F for the Rack A/B condenser to 3°F for the Rack C condenser.

	HC-AB	HC-C	HC-D
Suction Group Designation	Rack A/B	Rack C	Rack D
Drybulb (on local condenser controller)	55	55	57
Switching Setpoint	74F	74F	74F
Operation Mode	Dry	Dry	Dry
Fan Speed	100%	100%	100%
SCT	81	60	61
Operating TD	21F	3F	5F
Integrated Into Supervisory Control	Yes	Yes	Yes
Observed Variable SCT Setpoint	No	No	No

Site Survey #3: Large Supermarket Chain (Fresno, CA)

On February 23, 2017, a large supermarket chain located in Fresno, CA was surveyed. The refrigeration system consisted of two reciprocating compressor racks (Racks 1 and 2) with Rack 1 and 2 discharging to two separate condensers. The refrigerant of the system was R-404A. There were two BAC TSDC-116-12.4 microchannel condensers. The switching setpoint for all three condensers was set at 75°F and all were operating in dry mode with low to moderate fans speeds. The operating dry mode TD ranged from 21°F for the Rack 1 condenser to 14°F for the Rack 2 condenser.

	HC-1	HC-2
Suction Group Designation	Rack 1	Rack 2
Drybulb (on local condenser controller)	51F	51F
Switching Setpoint	75F	75F
Operation Mode	Dry	Dry
Fan Speed	10%	60%
SCT	71F	65F
Operating TD	20F	14F
Integrated Into Supervisory Control	Yes	Yes
Observed Variable SCT Setpoint	No	No

Other Discussions

Refrigeration system design engineers were contacted in order to better understand design conditions and owner requirements for real installations in CA. A list of key discussion points is noted below:

- Hybrid condensers are typically integrated into the supervisory control so that operators can manually adjust the switching setpoint and maintain a variable SCT setpoint control strategy. Fan power however is typically controlled through the local controller.

- Typical installations include EC motors with variable frequency drives.
- Commercial refrigeration customers are typically more interested in the energy-savings aspect of adiabatic condensers as compared to air-cooled condensers. There has been little discussion from stakeholders about water considerations.
- Selecting the switching setpoint not only has an impact on energy and water consumption but also can affect the effective useful life of the adiabatic pad. A pad that is wetted more frequently is estimated to have a shorter effective useful life.
- Typically adiabatic condensers have been sized for a design TD of 15-18°F.
- There is a tendency to design to a lower SCT in order to reduce the size of the condenser.
- Commercial refrigeration customers are selecting adiabatic condensers due to smaller footprint and reduced noise as compared to air-cooled condensers, especially in higher ambient temperature areas.