DOCKETED

Docket Number:	17-BSTD-02
Project Title:	2019 Title 24, Part 6, Building Energy Efficiency Standards Rulemaking
TN #:	222182
Document Title:	CASE Report Adiabatic Condensers
Description:	Codes and Standards Enhancement (CASE) Initiative Report for the 2019 California Building Energy Efficiency Standards.
Filer:	Adrian Ownby
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	1/18/2018 2:13:08 PM
Docketed Date:	1/18/2018

Codes and Standards Enhancement (CASE) Initiative

2019 California Building Energy Efficiency Standards

Adiabatic Condensers for Refrigerated Warehouses and Commercial Refrigeration – Final Report

Measure Number**:** 2019-NR-MECH6-F

Process Refrigeration

August 2017

This report was prepared by the California Statewide Codes and Standards Enhancement (CASE) Program that is funded, in part, by California utility customers under the auspices of the California Public Utilities Commission.

Document Information

Category:	Codes and Standards
Keywords:	Statewide Codes and Standards Enhancement (CASE) Initiative, Statewide Utility Codes and Standards Team, Codes and Standards Enhancements, 2019 Title 24 Part 6, efficiency, commercial refrigeration, supermarket refrigeration, refrigerated warehouse, adiabatic condenser.
Authors:	Doug Scott, Trevor Bellon (VaCom); Catherine Chappell (TRC)
Project Management:	California Utilities Statewide Codes and Standards Team: Pacific Gas and Electric Company, Southern California Edison, SoCalGas®, San Diego Gas & Electric Company, Los Angeles Department of Water and Power, and Sacramento Municipal Utility District

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

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 and Sacramento Municipal Utility District – 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. 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.

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 with 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)
Adiabatic Condensers for Refrigerated Warehouses	Mandatory	120.6(a)	NA7.10.3	N/A	New NRCA PRC form for Adiabatic Condenser Updates to NRCC-PRC-06&08 to include Adiabatic Condenser
Adiabatic Condensers for Commercial Refrigeration	Mandatory	120.6(b)	NA7.10.3	N/A	New NRCA PRC form for Adiabatic Condenser Updates to NRCC-PRC-05 to include 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
Dry Mode Adiabatic Condenser Sizing	0 - Infinite
Adiabatic 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-Year[a] Energy and Water Savings

Construction Type	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)
New Construction	0.68	0.06	0	0
Additions and Alterations	N/A	N/A	N/A	N/A
TOTAL	**0.68**	**0.06**	**0**	**0**

a. 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

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 and Sacramento Municipal Utility District – 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 Adiabatic Condensers for Refrigerated Warehouses and Commercial Refrigeration. The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with several 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, 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, Reference Appendices, Alternative 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.*

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.

As the proposed measures were being developed, the Statewide CASE Team identified areas of further potential study that were excluded from this CASE Report due to limited field experience with adiabatic condensers, evolving knowledge and methods to optimize overall annual performance, and the desire to address water-vs.-energy tradeoffs carefully and deliberately. These topics are opportunities for the 2022 (or later) code cycle update:

- Minimum requirement for saturation effectiveness of the evaporative pre-cool media, including potential tradeoffs using fan speed control
- Requirements for ambient parameters used for switching from dry mode to pre-cool mode to minimize water usage vs. small marginal energy savings is small

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.

- 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 Relationship to Industry Standards

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

2.5 Compliance and Enforcement

The Statewide CASE Team collected input during the stakeholder outreach process on what compliance and enforcement issues may be associated with these measures. 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. The acceptance test procedure for the proposed controls is expected to be similar to current procedures for air cooled condensers.

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

The Statewide CASE Team does not expect the proposed code changes for the 2019 code cycle to have an adverse impact on builders. 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 90.1) 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 Division of Occupational Safety and Health. 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. The Statewide CASE Team does not expect the proposed code change for the 2019 code cycle to impact building owners or occupants adversely.

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 report titled *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth* (2010) provides details 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 attributed to 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, Patadia, and Kammen (2010) estimates that energy efficiency creates 0.17 to 0.59 net job-years[2] per GWh saved (Wei, Patadia and Kammen 2010). By

---

[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."

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

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 in 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 in 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 be otherwise invested, which provides California businesses with an advantage that will only be strengthened by the adoption of the proposed code 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

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.

3.4.6 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 Adiabatic Condenser Base Case

Requirement	Air-Cooled	Evaporative Cooled	Adiabatic (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)[a]
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

a. Denotes dry mode specific efficiency. Specific efficiency for the adiabatic 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 through Table 9 below summarize each proposed condition and changes relative to the base case to determine the energy, demand, and energy cost impacts.

Table 7: Variable SCT Proposed Conditions Compared to the Adiabatic Condenser Base Case

Variable	Base Case	Proposed Variable SCT Setpoint
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)[a]
Rating Temperature Difference (TD)[b]	10 TD (dry mode) 30 TD (wet mode)	Same as Base Case
Minimum Efficiency	See Table 6 above.	Same as Base Case

a. 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.

b. 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.

Table 8: Dry Mode Sizing Proposed Conditions Compared to the Adiabatic Condenser Base Case

Variable	Base Case	Proposed Dry Mode Sizing
Condensing Temperature Reset	Fixed SCT	Option B
Rating Temperature Difference (TD)	10 TD (dry mode) 30 TD (wet mode)	Rated TD varies from 12°F LT/18°F MT to 24°F LT /36°F MT (Dry mode)
Minimum Efficiency	See Table 6 above.	Same as Base Case

Table 9: Dry Mode Specific Efficiency Proposed Conditions Compared to the Adiabatic Condenser Base Case

Variable	Base Case	Proposed Dry Mode Minimum Specific Efficiency
Condensing Temperature Reset	Fixed SCT	Option B
Rating Temperature Difference (TD)	10 TD (dry mode) 30 TD (wet mode)	Same as Base Case
Minimum Efficiency	See Table 6 above.	Varies from 25 Btuh/W to 65 Btuh/W for all prototypes

Three different options for variable SCT setpoint control were used to assess the energy impact of different control strategies. Option A utilized SCT setpoint reset based on dry bulb temperature when the adiabatic condenser was operating in both pre-cool and dry mode. Option B utilized SCT setpoint reset based on dry bulb temperature only when the adiabatic condenser was operating in dry mode, with a fixed SCT setpoint when operating in pre-cool mode. Option C utilized condenser SCT setpoint reset based on the temperature of the air between the pre-cool pad and the condenser coil/microchannel in both pre-cool and dry mode. Dry Mode sizing and specific efficiency measures were considered incremental measures to the variable SCT setpoint control measure. Therefore, once option B was selected as the recommended control strategy in the proposed code language, the Statewide CASE Team used the option B SCT setpoint control for Dry Mode sizing and specific efficiency measure analysis.

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 10 presents the details of the prototype buildings used in the analysis.

Table 10: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype ID	Occupancy Type	Area (ft^2)	Approx. Design Load (TR)	Refrigerant	Compressor Type
Large Supermarket (LSM)	Supermarket	60,700	100	R-407A	Reciprocating
Small Refrigerated Warehouse (SRWH)	Refrigerated Warehouse	26,000	100	R-407A	Reciprocating
Large Refrigerated Warehouse (LRWH)	Refrigerated Warehouse	92,000	300	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 for each of the 16 California climate zones. 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 Large Supermarket Prototype

4.3.1.1 Variable SCT Setpoint

Energy savings and peak demand reductions per square foot for new construction are presented in Table 11 through Table 13 for the three variable SCT setpoint options described in Table 7 in Section 4.2.

Variable setpoint control is a means of controlling condenser fan speed to minimize total annual energy, considering the trade-off between compressor power and condenser fan power (i.e., lower head pressure reduces compressor power but increases fan power), and considering hourly ambient temperature changes and load changes through the year. In addition, the non-linear relationship of condenser fan power and capacity, as well as the diminishing effect of increased condenser capacity on condensing temperature, influence the optimum condenser fan speed in any hour. The variable SCT control strategy involves adding a TD value to the ambient temperature to produce a SCT setpoint value, hence varying the SCT setpoint as ambient changes. Lacking variable setpoint control, condenser fans would operate at 100 percent fan speed and power until the system reached the minimum SCT limit. With typical condenser fan selections and typical part load conditions, and in most moderate climates, this results in excessive fan power consumption.

Each variable SCT option was simulated with a TD value equal to 90 percent of the design TD as an approximation to allow for part-load and condenser derating factors, both at average hourly conditions. It is important to note that condensing temperature in the simulation study is the actual condensing temperature at the condenser. Common practice is to instead control the condenser using saturation temperature at the compressor discharge pressure, with piping pressure drop increasing the apparent TD by 1-2 degrees. Accordingly, the study essentially uses the design TD, if one is accustomed to considering or observing the TD based on discharge pressure.

The Statewide CASE Team intentionally did not optimize the TD control value in the hourly simulation for each climate zone, since this degree of optimization is not common, either through simulation or other means.

While the Statewide CASE Team studied three control options for comparison, the proposed code language is based on control option B, to avoid inhibiting future innovation of control methods and optimization 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 70 kWh/yr to 88,400 kWh/yr depending on climate zone. Option B TDV Energy savings ranged from 0.03 kBtu/yr/ft^2 to 37.76 kBtu/yr/ft^2 depending on climate zone.

Table 11: 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
2	36,830	9.6	19.08
3	45,930	21.7	26.85
4	63,626	14.9	33.01
5	41,805	12.8	23.31
6	99,829	21.8	48.07
7	109,229	23.0	53.40
8	78,396	8.7	34.61
9	69,242	9.7	32.63
10	36,420	6.1	16.85
11	29,851	1.5	3.09
12	30,636	6.9	14.99
13	29,630	6.8	14.76
14	15,897	0.0	8.51
15[a]	-	-	-
16	2,795	13.7	1.88

a. Climate Zone 15 is 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 12: 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
2	22,231	0.0	9.01
3	24,347	1.5	10.81
4	29,655	0.5	11.76
5	21,522	0.0	10.72
6	64,206	0.0	26.38
7	88,389	0.4	37.76
8	58,110	0.1	22.97
9	46,673	0.0	18.38
10	29,560	0.0	11.61
11	18,000	0.0	0.57
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
16	72	0.0	0.03

Table 13: 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
2	45,790	7.0	24.89
3	45,162	5.5	27.08
4	68,298	6.2	37.71
5	41,644	7.6	23.26
6	102,519	13.9	50.87
7	108,968	9.7	54.29
8	88,151	12.4	41.05
9	79,169	9.7	37.13
10	50,904	6.1	23.70
11	43,904	1.5	2.89
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
16	9,825	23.9	5.98

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Table 23 through Table 25 in Section 5.2.1.1. They are presented as the discounted present value of the energy cost savings over the analysis period.

4.3.1.2 Dry Mode Adiabatic Condenser Sizing

Energy savings and TDV savings were calculated 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 (2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15) have the highest annual TDV Energy savings for 16/24°F dry mode design TD, as shown in Figure 1. The cool Climate Zones (1, 3, 5 and 16) have the highest annual TDV Energy savings for 12/18°F and 16/24°F, as shown in Figure 2.

TDV Energy savings measured on a kBtu/yr/ft^2 basis vary between -18.941 and 9.97 depending on climate zone for warm climates. The TDV energy savings varied between -10.56 kBtu/yr/ft^2 and 1.68 kBtu/yr/ft^2 depending on the climate zone for cool climates.

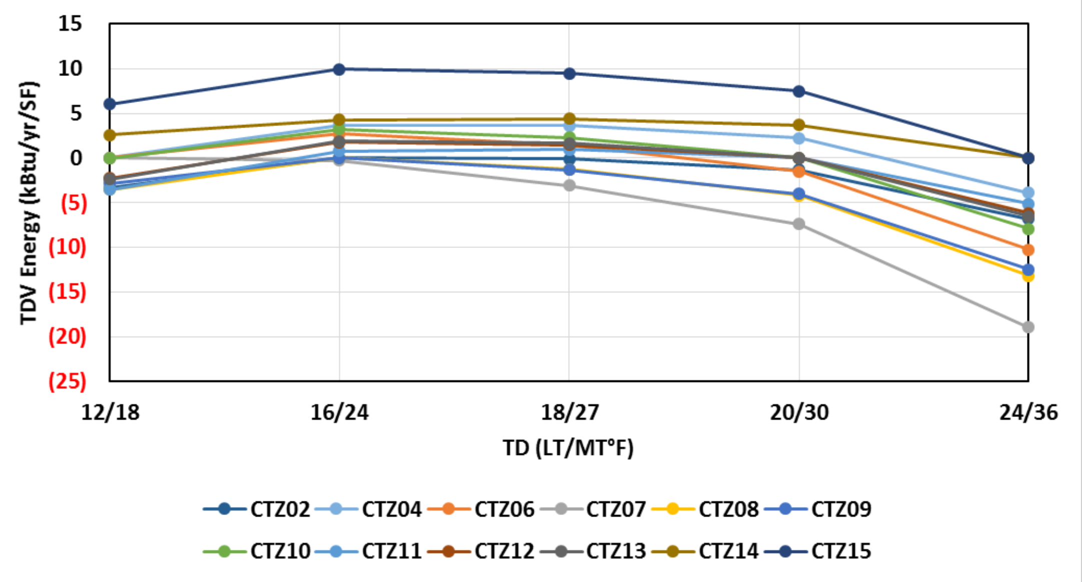

Figure 1: Warm climate TDV energy savings vs. dry mode condenser sizing.

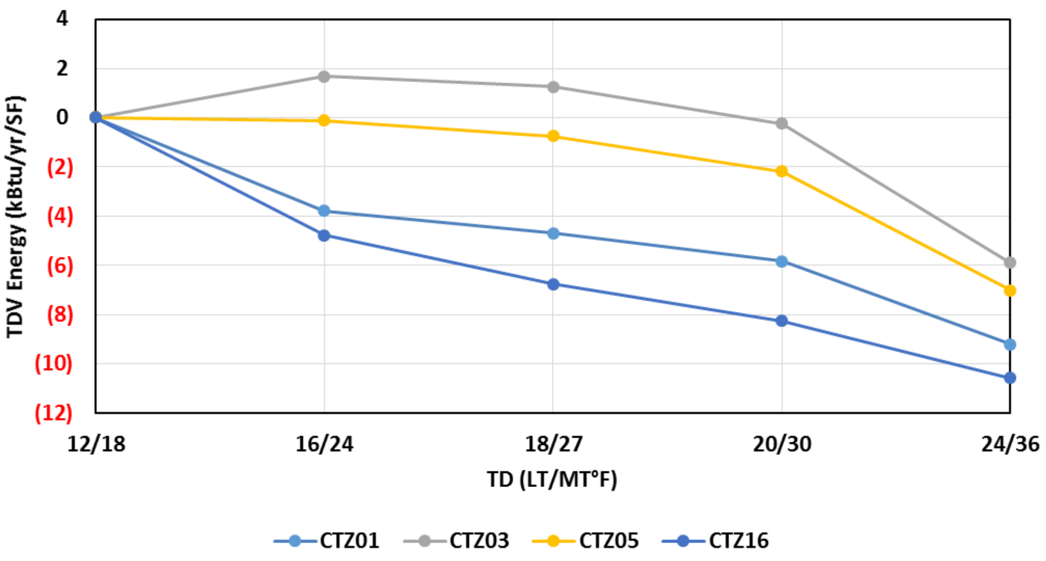

Figure 2: Cool climate TDV energy savings vs. dry mode condenser sizing.

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 Adiabatic 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 specific efficiency based on market research conducted in the first quarter of 2017[3]. This maximum specific efficiency showed a range of annual kWh savings from approximately 3,800 kWh/yr to 21,000 kWh/yr depending on the climate compared to a base case specific efficiency of 45 Btuh/W. The kWh savings are shown in Table 14 below.

---

[3] The Statewide CASE Team's market research consisted of discussions with adiabatic condenser manufacturers to obtain specific efficiency values. Reference to manufacturers is not provided due to the competitive nature of the information.

Table 14: Electricity Savings from Maximum 65 Btuh/W Specific Efficiency Compared to 45 Btuh/W Base Case

Climate Zone	Electricity Savings (kWh/yr)
1	3,785
2	11,760
3	10,370
4	17,453
5	9,970
6	17,572
7	11,583
8	16,351
9	17,748
10	14,620
11	16,524
12	12,489
13	15,487
14	15,654
15	20,816
16	6,302

TDV Energy savings measured on a kBtu/yr/ft^2 basis varied between -29.65 and 11.41 depending on climate zone for warm climates as shown in Figure 3. The TDV Energy savings varied between -18.8 kBtu/yr/ft^2 and 7.24 kBtu/yr/ft^2 depending on the climate zone for cool climate, is shown in Figure 4.

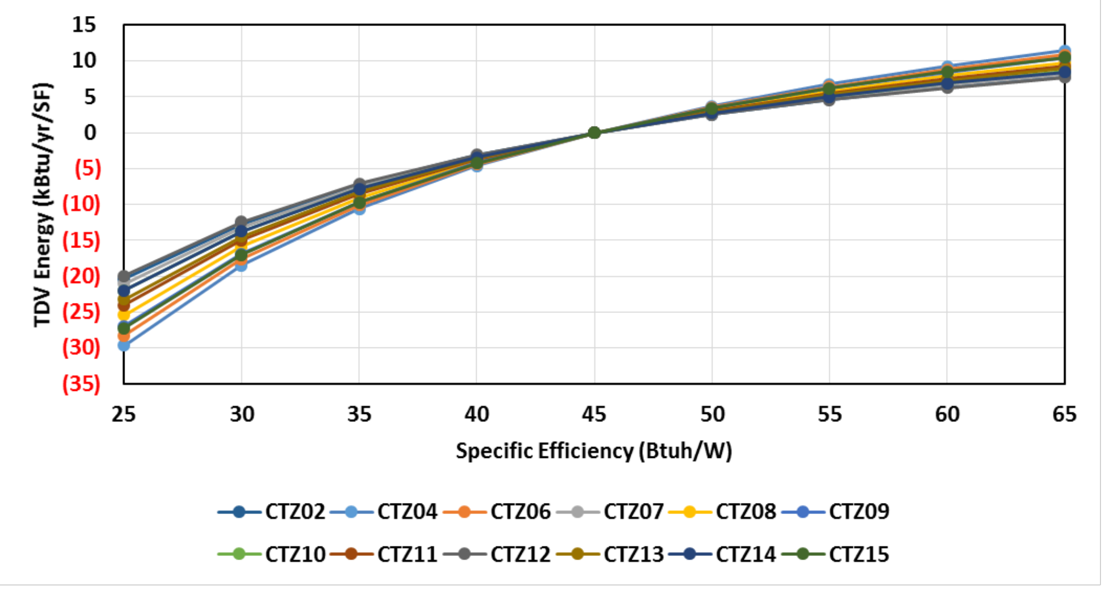

Figure 3: Warm climate TDV energy savings vs. specific efficiency.

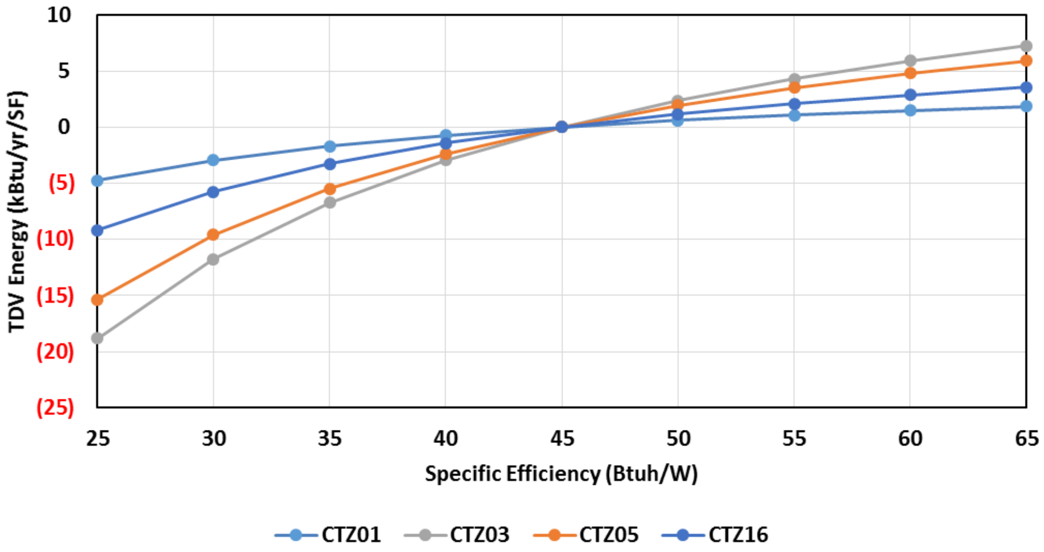

Figure 4: Cool climate TDV energy savings vs. specific efficiency.

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 Small Refrigerated Warehouse Prototype

4.3.2.1 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.

Variable setpoint control is a means of controlling condenser fan speed to minimize total annual energy, considering the trade-off between compressor power and condenser fan power (i.e., lower head pressure reduces compressor power but increases fan power), and considering hourly ambient temperature changes and load changes through the year. In addition, the non-linear relationship of condenser fan power and capacity, as well as the diminishing effect of increased condenser capacity on condensing temperature, influence the optimum condenser fan speed in any hour. The variable SCT control strategy involves adding a TD value to the ambient temperature to produce a SCT setpoint value, hence varying the SCT setpoint as ambient changes. Lacking variable setpoint control, condenser fans would operate at 100 percent fan speed and power until the system reached the minimum SCT limit. With typical condenser fan selections and typical part load conditions, and in most moderate climates, this results in excessive fan power consumption.

Each variable SCT option was simulated with a TD value equal to 90 percent of the design TD as an approximation to allow for part-load and condenser derating factors, both at average hourly conditions. It is important to note that condensing temperature in the simulation study is the actual condensing temperature at the condenser. Common practice is to instead control the condenser using saturation temperature at the compressor discharge pressure, with piping pressure drop increasing the apparent TD by 1-2 degrees. Accordingly, the study essentially uses the design TD, if one is accustomed to considering or observing the TD based on discharge pressure.

The Statewide CASE Team intentionally did not optimize the TD control value in the hourly simulation for each climate zone, since this degree of optimization is not common, either through simulation or other means. Thus, some climate zones were shown to have an increase in energy use, typically cool climates where the system would normally be at minimum SCT and reduced fan speed when using fixed setpoint control.

While the Statewide CASE Team studied three control options for comparison, the proposed code language is based on control option B, to avoid inhibiting future innovation of control methods and optimization 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/ft^2 to 62.37 kBtu/yr/ft^2 depending on climate zone.

Table 15: 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)
2	15,358	(22.6)	9.72
3	26,028	16.6	38.46
4	37,797	(5.0)	40.48
5	21,631	15.1	28.23
6	70,888	(13.5)	77.64
7	78,811	14.6	94.90
8	50,675	8.8	55.48
9	20,702	(34.9)	3.56
10	25,934	5.7	29.72
11	(22,858)	(53.4)	(0.55)
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)
16	(17,220)	2.4	(21.27)

Table 16: 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)
2	12,494	0.0	12.01
3	13,637	0.0	14.75
4	20,205	0.0	18.73
5	13,301	0.0	16.05
6	43,221	0.0	42.33
7	60,427	0.0	62.37
8	34,140	0.0	31.67
9	21,727	0.0	20.06
10	19,446	0.0	17.88
11	6,918	0.0	(0.95)
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
16	(340)	0.0	(0.32)

Table 17: 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
2	32,639	11.6	46.13
3	28,902	4.7	45.19
4	52,385	7.4	75.37
5	25,792	1.3	34.13
6	78,697	3.7	95.49
7	80,917	3.0	101.04
8	62,598	6.7	73.69
9	44,877	5.5	51.13
10	43,777	8.1	51.57
11	27,387	1.9	0.44
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
16	3,267	22.8	4.64

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Table 26 through Table 28 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 Adiabatic Condenser Sizing

Energy savings and TDV savings for various condenser sizing options range from 12/18°F to 24/36°F dry mode design TD at a fixed specific efficiency. The warm Climate Zones (2, 4 and 6 to 15) have the highest annual TDV Energy savings for 16/24°F dry mode design TD on average, as shown in Figure 5. The cool Climate Zones (1, 3, 5 and 16) have the lowest annual energy consumption at a dry mode design TD of 12/18°F, which was also the base case design TD, as shown in Figure 6.

TDV Energy savings measured on a kBtu/yr/ft^2 basis was shown to vary between -43.69 and 16.02 kBtu/yr/ft^2 depending on climate zone for warm climates. The TDV Energy savings varied between -50.5 kBtu/yr/ft^2 and 0 kBtu/yr/ft^2 depending on the climate zone for cool climates.

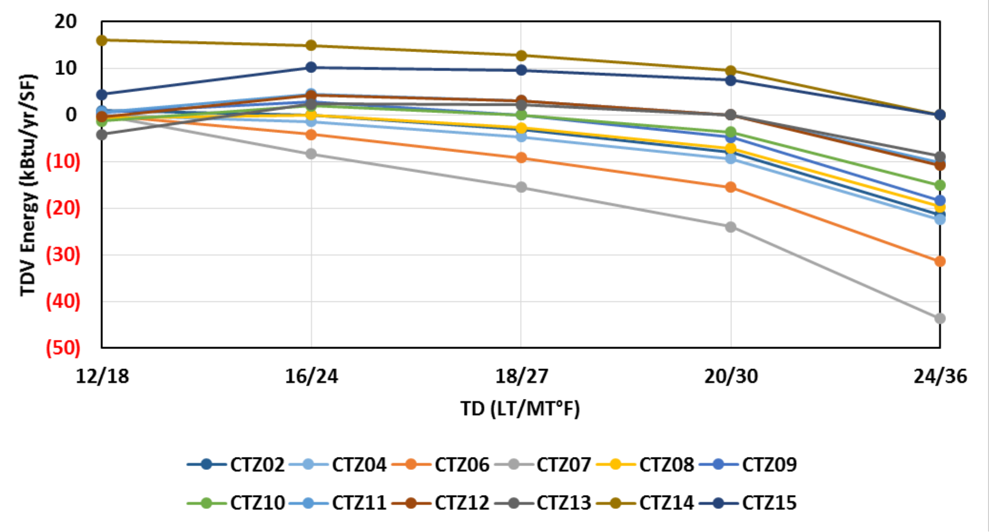

Figure 5: Warm climate TDV energy savings vs. dry mode condenser sizing.

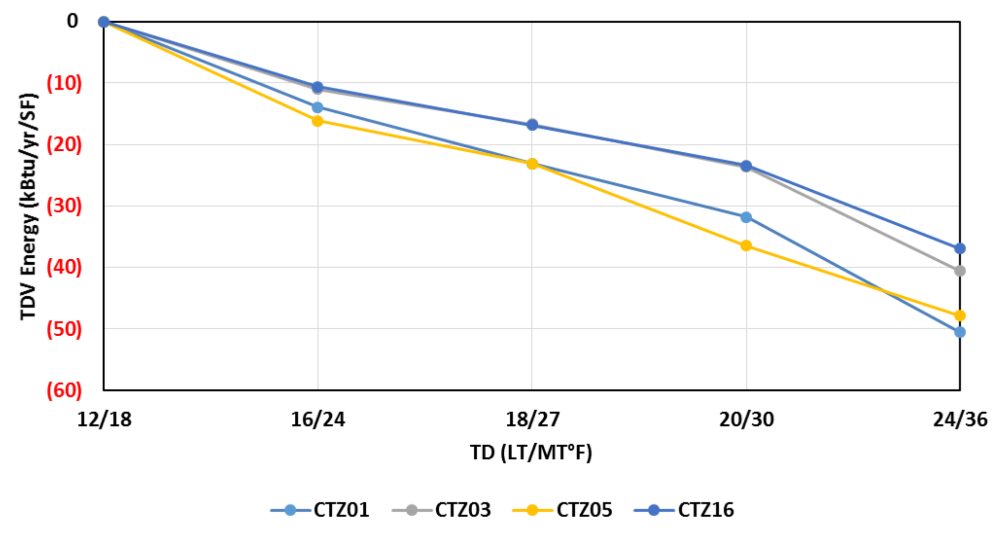

Figure 6: Cool climate TDV energy savings vs. dry mode condenser sizing.

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 Adiabatic 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 market research conducted in the first quarter of 2017. This maximum specific efficiency showed a range of annual kWh savings from approximately 2,500 kWh/yr to 20,000 kWh/yr depending on the climate compared to a base case specific efficiency of 45 Btuh/W. The kWh savings are shown in Table 18.

Table 18: Electricity Savings from Maximum 65 Btuh/W Specific Efficiency Compared to 45 Btuh/W Base Case

Climate Zone	Electricity Savings (kWh/yr)
1	2,447
2	11,453
3	8,375
4	15,528
5	7,395
6	16,356
7	10,241
8	15,371
9	15,419
10	15,246
11	16,006
12	12,430
13	15,306
14	14,068
15	20,200
16	3,829

TDV Energy savings measured on a kBtu/yr/ft^2 basis varies between -62.7 and 25.26 depending on climate zone for warm climates is shown in Figure 7. The TDV Energy savings varies between -37.62 kBtu/yr/ft^2 and 14.46 kBtu/yr/ft^2 depending on the climate zone for cool climates, as shown in Figure 8.

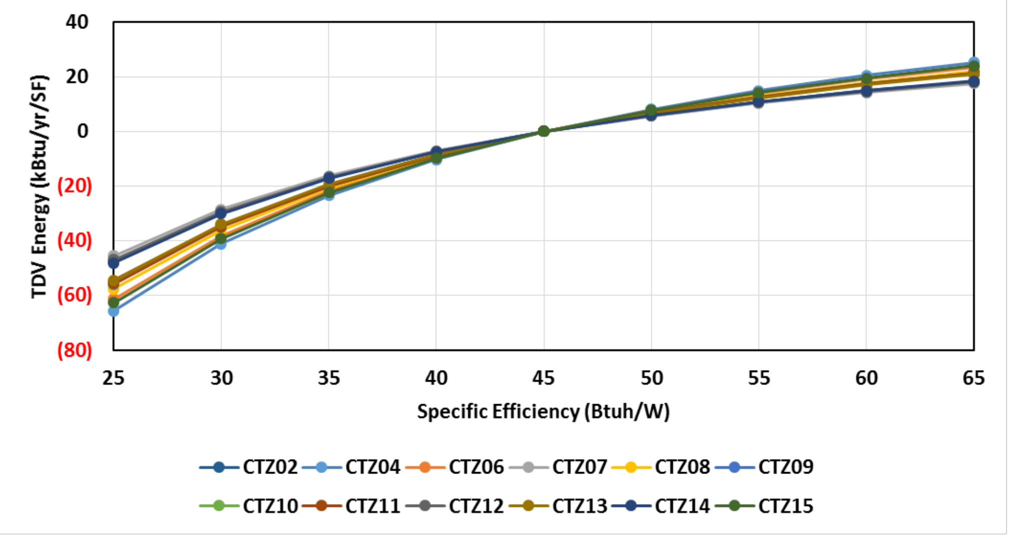

Figure 7: Warm climate TDV energy savings vs. specific efficiency.

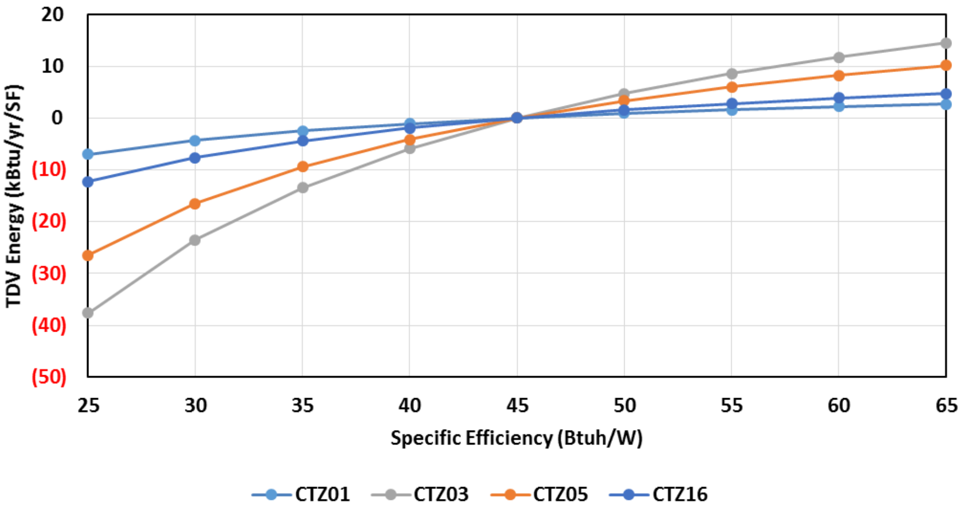

Figure 8: Cool climate TDV energy savings vs. specific efficiency.

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 Large Refrigerated Warehouse Prototype

4.3.3.1 Variable SCT Setpoint

Energy savings and peak demand reductions per square foot for new construction are presented in Table 19 through Table 21 for the three variable SCT setpoint options described in Table 7 in Section 4.2.

Variable setpoint control is a means of controlling condenser fan speed to minimize total annual energy, considering the trade-off between compressor power and condenser fan power (i.e., lower head pressure reduces compressor power but increases fan power), and considering hourly ambient temperature changes and load changes through the year. In addition, the non-linear relationship of condenser fan power and capacity, as well as the diminishing effect of increased condenser capacity on condensing temperature, influence the optimum condenser fan speed in any hour. The variable SCT control strategy involves adding a TD value to the ambient temperature to produce a SCT setpoint value, hence varying the SCT setpoint as ambient changes. Lacking variable setpoint control, condenser fans would operate at 100% fan speed and power until the system reached the minimum SCT limit. With typical condenser fan selections and typical part load conditions, and in most moderate climates, this results in excessive fan power consumption.

Each variable SCT option was simulated with a TD value equal to 90 percent of the design TD as an approximation to allow for part-load and condenser derating factors, both at average hourly conditions. It is important to note that condensing temperature in the simulation study is the actual condensing temperature at the condenser. Common practice is to instead control the condenser using saturation temperature at the compressor discharge pressure, with piping pressure drop increasing the apparent TD by 1-2 degrees. Accordingly, the study essentially uses the design TD, if one is accustomed to considering or observing the TD based on discharge pressure.

The Statewide CASE Team intentionally did not optimize the TD control value in the hourly simulation for each climate zone, since this degree of optimization is not common, either through simulation or other means. Thus, some climate zones were shown to have an increase in energy use, typically cool climates where the system would normally be at minimum SCT and reduced fan speed when using fixed setpoint control.

While the Statewide CASE Team studied three control options for comparison, the proposed code language is based on control option B, to avoid inhibiting future innovation of control methods and optimization 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/ft^2 to 34.77 kBtu/yr/ft^2 depending on climate zone.

Table 19: 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)
2	(6,102)	(164.4)	(12.47)
3	(18,116)	23.5	1.08
4	13,664	(156.6)	(14.86)
5	(16,823)	20.5	(0.08)
6	95,370	(183.0)	23.68
7	146,717	28.0	47.57
8	117,176	19.5	38.42
9	33,892	(190.3)	(12.31)
10	71,722	23.5	25.18
11	(70,944)	(186.6)	(17.18)
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
16	(140,071)	(132.9)	(43.88)

Table 20: 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)
2	5,998	0.0	1.88
3	(45,560)	0.0	(11.91)
4	16,678	0.0	4.38
5	(42,832)	0.0	(10.47)
6	70,667	0.0	19.46
7	122,045	0.0	34.77
8	72,920	0.0	19.16
9	46,889	0.0	12.28
10	43,780	0.0	11.39
11	20,995	0.0	(24.56)
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
16	(36,832)	0.0	(9.87)

Table 21: 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)
2	62,205	24.3	27.59
3	(23,396)	10.4	(1.52)
4	86,177	27.6	33.19
5	(19,197)	14.4	(0.99)
6	134,387	28.8	46.64
7	157,295	27.3	52.71
8	150,588	16.7	50.35
9	125,195	(44.9)	40.29
10	126,001	26.1	42.98
11	109,163	(47.3)	(20.22)
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
16	(34,399)	15.1	(7.53)

The per-unit TDV energy cost savings over the 15-year period of analysis are presented in Table 29 through Table 31in 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 Adiabatic 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 (2, 4 and 6 to 15) have the highest annual TDV energy savings for 16/24°F dry mode design TD on average, as shown in Figure 9. The cool Climate Zones (1, 3, 5 and 16) have the highest annual TDV energy savings at a dry mode design TD of 12/18°F as shown in Figure 10.

TDV Energy savings measured on a kBtu/yr/ft^2 basis vary between -20.14 and 22.87 depending on climate zone for warm climates. The TDV Energy savings varied between 0 kBtu/yr/ft^2 and 53.67 kBtu/yr/ft^2 depending on the climate zone for cool climates. The TDV Energy savings is shown in Figure 9 and Figure 10 below.

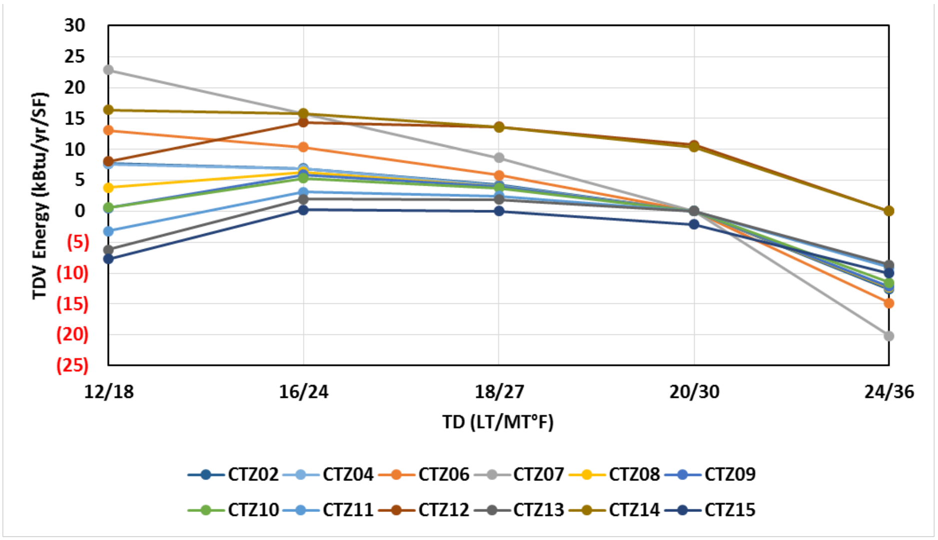

Figure 9: Warm climate TDV energy savings vs. dry mode condenser sizing.

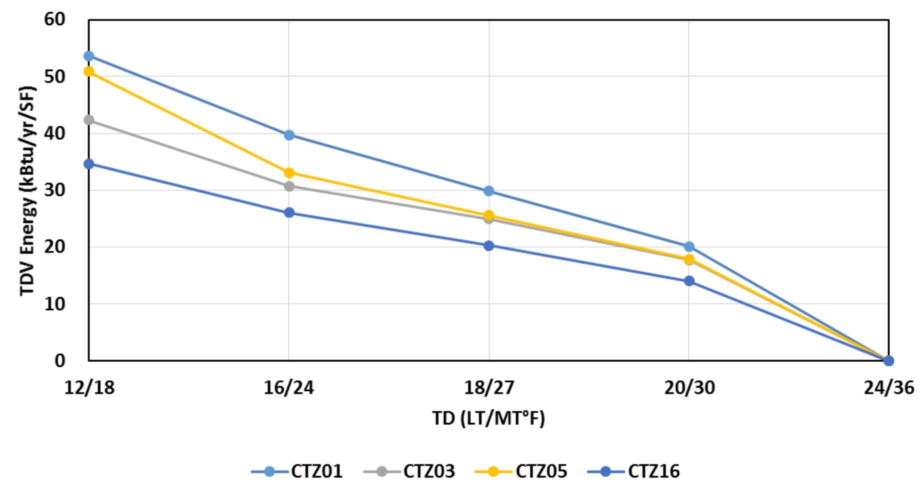

Figure 10: Cool climate TDV energy savings vs. dry mode condenser sizing.

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 Adiabatic 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 market research conducted in the first quarter of 2017. This maximum specific efficiency showed a range of annual kWh savings from approximately 20,000 kWh/yr to 150,000 kWh/yr depending on the climate compared to a base case specific efficiency of 35 Btuh/W. The kWh savings are shown in Table 22 below.

Table 22: Electricity Savings from Maximum 65 Btuh/W Specific Efficiency Compared to 35 Btuh/W Base Case

Climate Zone	Electricity Savings (kWh/yr)
1	20,826
2	57,395
3	35,209
4	69,196
5	37,359
6	65,253
7	39,881
8	77,558
9	83,957
10	84,813
11	93,204
12	64,101
13	93,054
14	82,220
15	149,840
16	43,516

TDV Energy savings measured on a kBtu/yr/ft^2 basis vary between -44.8 and 51.7 depending on climate zone for warm climates, as shown in Figure 11. The TDV Energy savings vary between -13.9 kBtu/yr/ft^2 and 16 kBtu/yr/ft^2 depending on the climate zone for cool climates, as shown in Figure 12.

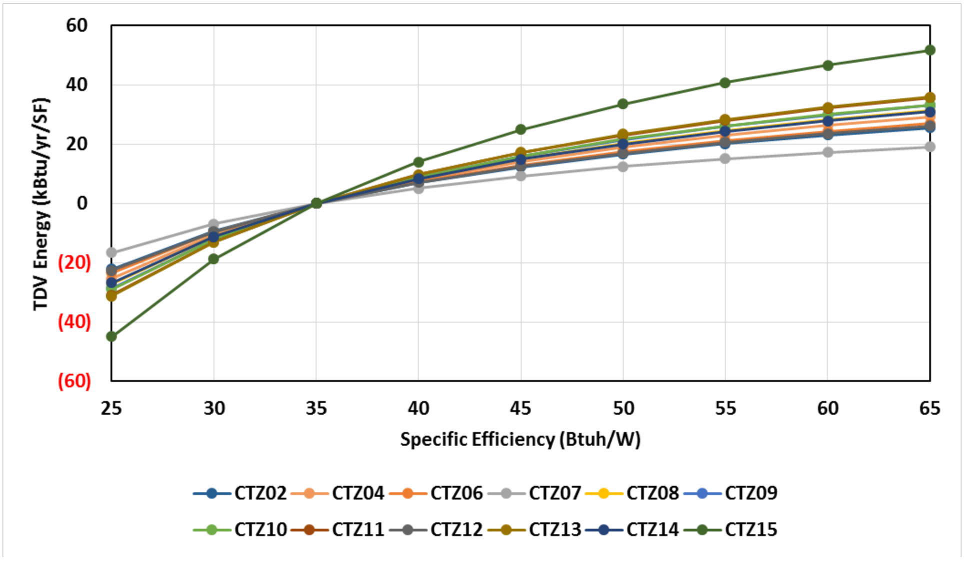

Figure 11: Warm climate TDV energy savings vs. specific efficiency.

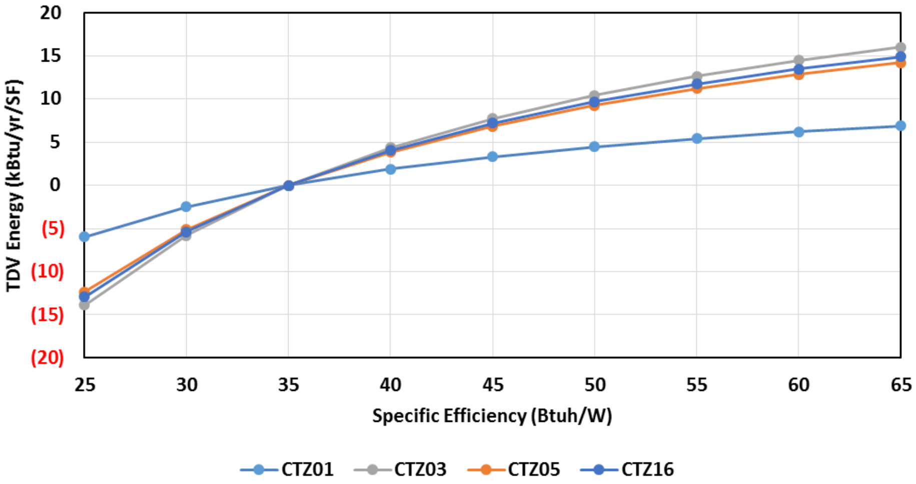

Figure 12: Cool climate TDV energy savings vs. specific efficiency.

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 value (PV) 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 Large Supermarket Prototype

5.2.1.1 Variable SCT Setpoint

Per-unit energy cost savings over the 15-year period of analysis are presented in Table 23 through Table 25 for each of the variable SCT setpoint options. It is estimated that the 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 23: 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
2	$1.70
3	$2.39
4	$2.94
5	$2.07
6	$4.28
7	$4.75
8	$3.08
9	$2.90
10	$1.50
11	$1.30
12	$1.33
13	$1.31
14	$0.76
15	-
16	$0.17

Table 24: 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
2	$0.80
3	$0.96
4	$1.05
5	$0.95
6	$2.35
7	$3.36
8	$2.04
9	$1.64
10	$1.03
11	$0.63
12	$0.81
13	$0.77
14	$0.23
15	$0.38
16	$0.00

Table 25: 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
2	$2.22
3	$2.41
4	$3.36
5	$2.07
6	$4.53
7	$4.83
8	$3.65
9	$3.30
10	$2.11
11	$1.89
12	$1.78
13	$1.86
14	$1.16
15	$1.19
16	$0.53

5.2.1.2 Dry Mode Adiabatic Condenser Sizing

Per-unit energy cost savings over the 15-year period of analysis are presented below. 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, as shown in Figure 13. For cool climate zones, the TDV energy cost savings range from -$0.94 per square foot to $0.15 per square foot with maximum savings at 12/18°F design TD, as shown in Figure 14.

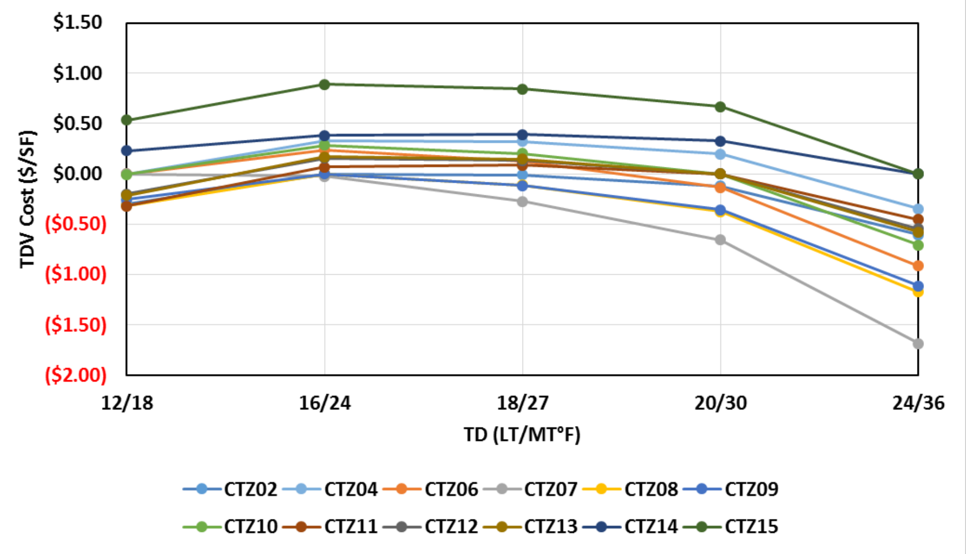

Figure 13: Warm climate TDV energy cost savings vs. dry mode TD.

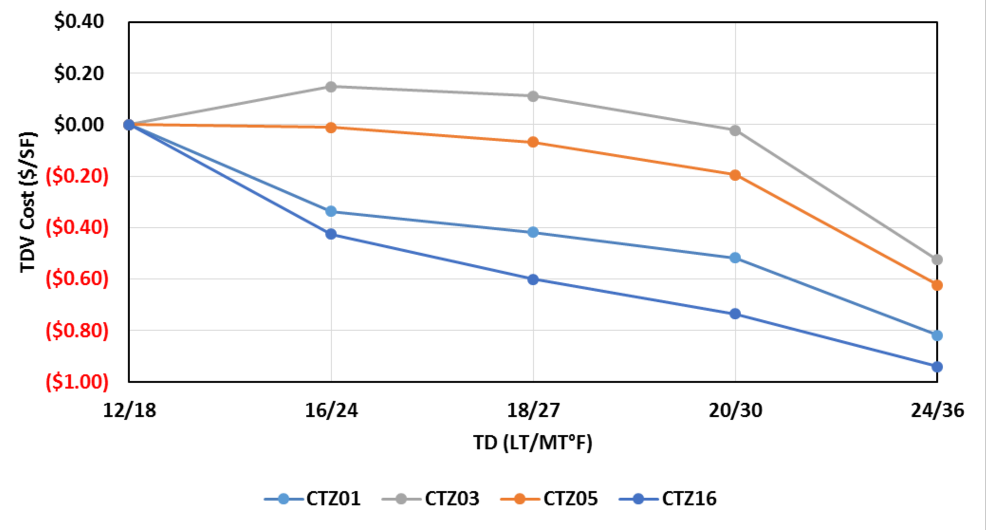

Figure 14: Cool climate TDV energy cost savings vs. dry mode TD.

5.2.1.3 Adiabatic Condenser Specific Efficiency

Per-unit energy cost savings over the 15-year period of analysis are presented in below. It is estimated that the year average TDV energy cost savings for warm climate zones is approximately $0.83 per square foot at a specific efficiency of 65 Btuh/W, as shown in Figure 15. The estimated average first-year TDV energy cost savings for cool climate zones is approximately $0.41 per square foot at a specific efficiency of 65 Btuh/W, as shown in Figure 16.

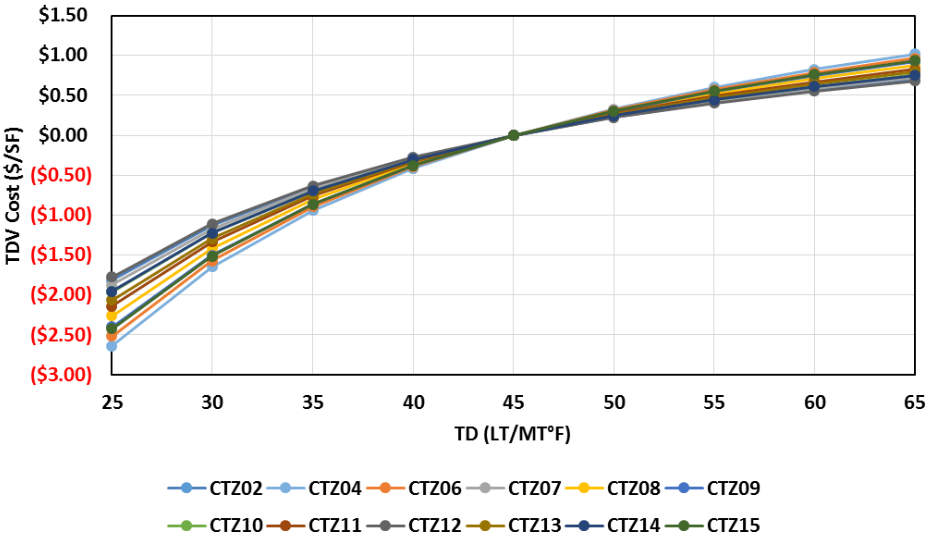

Figure 15: Warm climate TDV energy savings vs. specific efficiency.

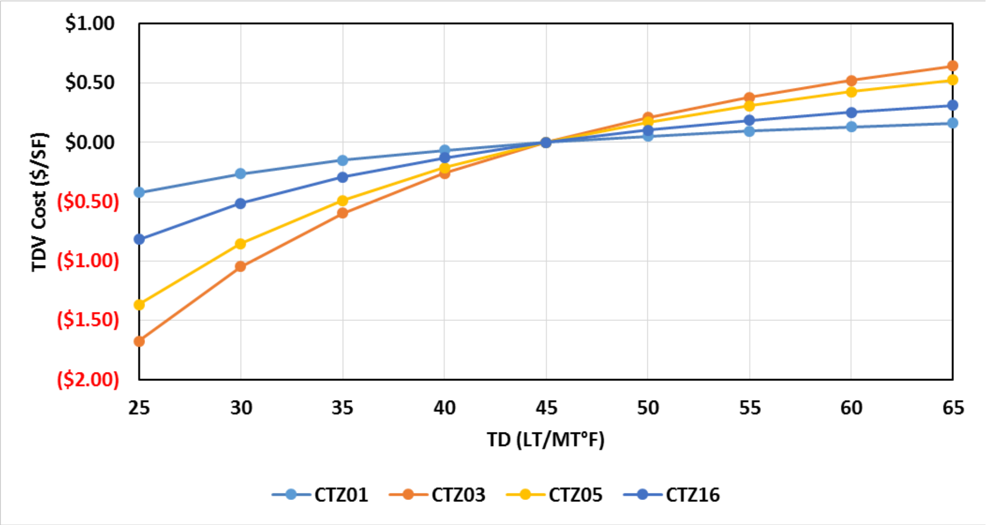

Figure 16: Cool climate TDV energy savings vs. specific efficiency.

5.2.2 Small Refrigerated Warehouse Prototype

5.2.2.1 Variable SCT Setpoint

Per-unit energy cost savings over the 15-year period of analysis are presented in Table 26 through

Table 28 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 26: 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)
2	$0.87
3	$3.42
4	$3.60
5	$2.51
6	$6.91
7	$8.45
8	$4.94
9	$0.32
10	$2.65
11	($5.79)
12	$1.55
13	$1.84
14	$0.06
15	($0.50)
16	($1.89)

Table 27: 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)
2	$1.07
3	$1.31
4	$1.67
5	$1.43
6	$3.77
7	$5.55
8	$2.82
9	$1.79
10	$1.59
11	$0.56
12	$0.63
13	$0.88
14	($0.31)
15	$0.26
16	($0.03)

Table 28: 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
2	$4.11
3	$4.02
4	$6.71
5	$3.04
6	$8.50
7	$8.99
8	$6.56
9	$4.55
10	$4.59
11	$2.93
12	$2.61
13	$3.19
14	$0.55
15	$0.99
16	$0.41

5.2.2.2 Dry Mode Adiabatic Condenser Sizing

Per-unit energy cost savings over the 15-year period of analysis are presented below. 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, as shown in Figure 17. For cool climate zones, the TDV energy cost savings range from -$4.5 per square foot to $0 per square foot, as shown in Figure 18.

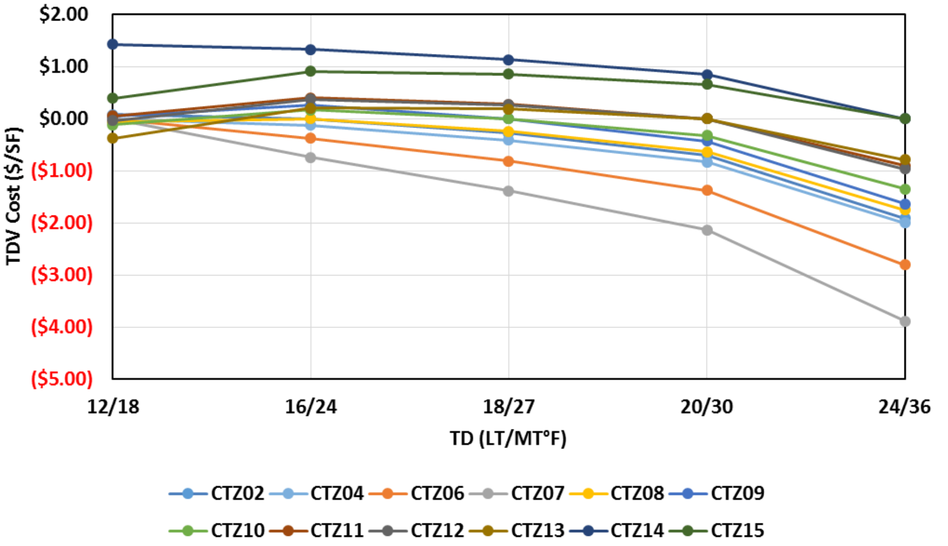

Figure 17: Warm climate TDV energy cost savings vs. dry mode TD.

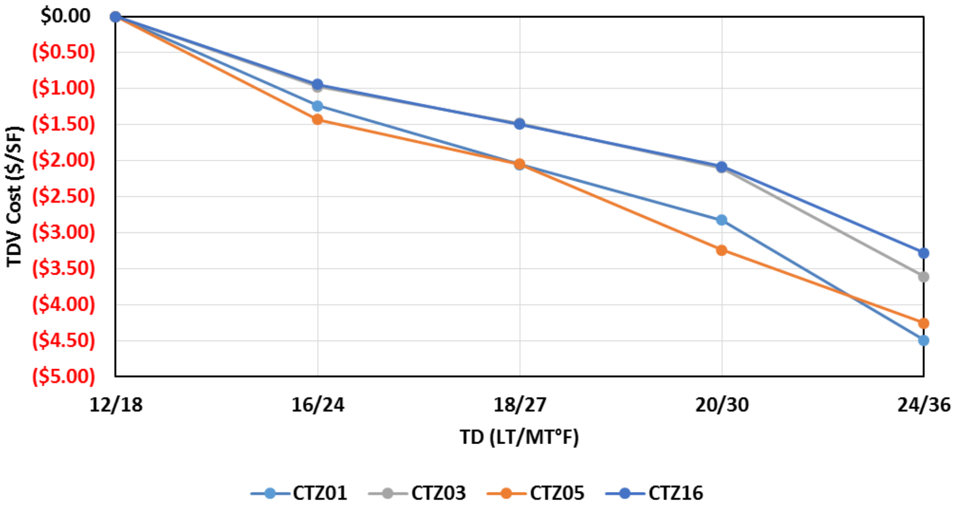

Figure 18: Cool climate TDV energy cost savings vs. dry mode TD.

5.2.2.3 Adiabatic Condenser Specific Efficiency

Per-unit energy cost savings over the 15-year period of analysis are presented in below. It is estimated that the year average TDV energy cost savings for warm climate zones is approximately $1.87 per square foot at a specific efficiency of 65 Btuh/W, as shown in Figure 19. The estimated first-year average TDV energy cost savings for cool climate zones is approximately $0.71 per square foot at a specific efficiency of 65 Btuh/W, as shown in Figure 20.

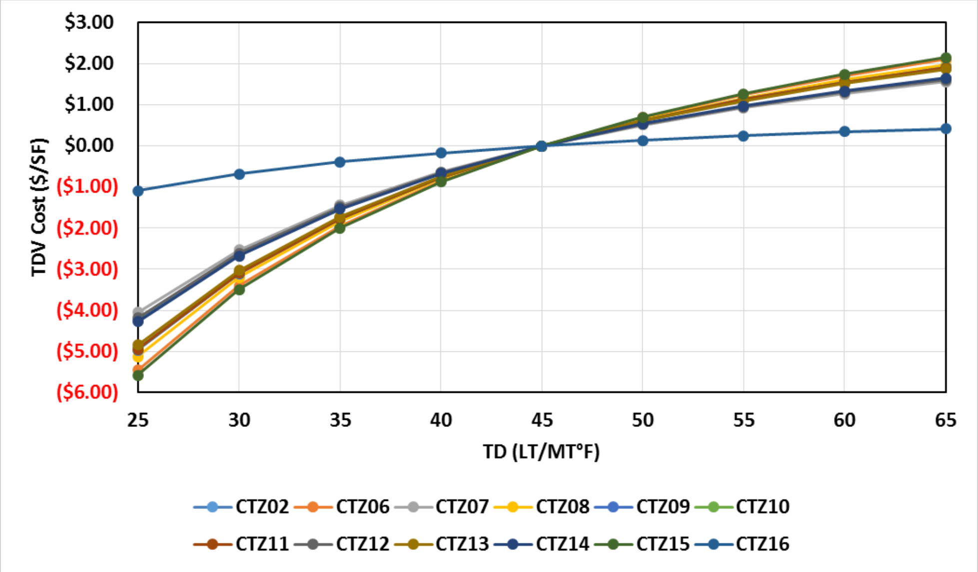

Figure 19: Warm climate TDV energy cost savings vs. specific efficiency.

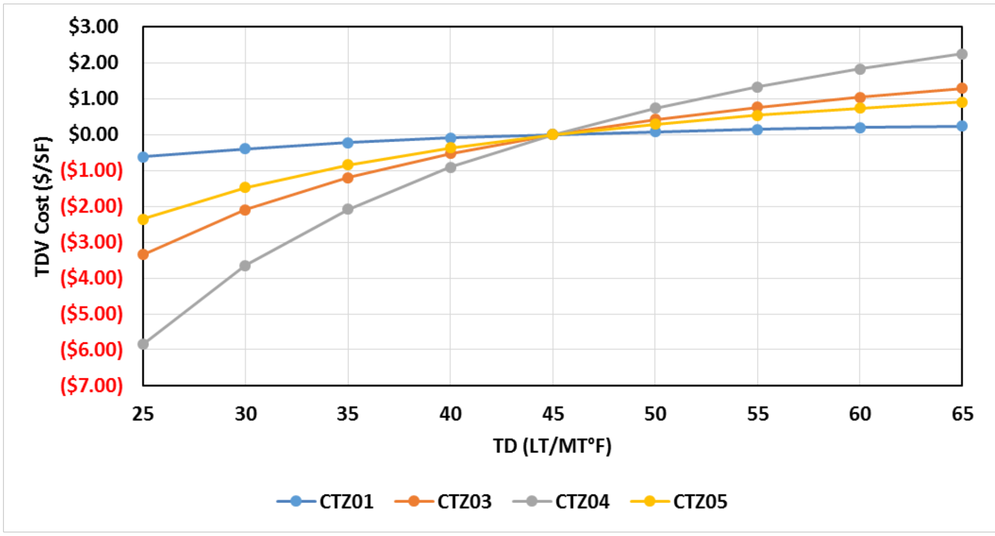

Figure 20: Cool climate TDV energy cost savings vs. specific efficiency.

5.2.3 Large Refrigerated Warehouse Prototype

5.2.3.1 Variable SCT Setpoint

Per-unit energy cost savings over the 15-year period of analysis are presented in Table 29 through Table 31 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 29: 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)
2	($1.11)
3	$0.10
4	($1.32)
5	($0.01)
6	$2.11
7	$4.23
8	$3.42
9	($1.10)
10	$2.24
11	($6.04)
12	$0.40
13	$2.61
14	$0.05
15	$2.27
16	($3.91)

Table 30: 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 $/ft2)
1	($2.19)
2	$0.17
3	($1.06)
4	$0.39
5	($0.93)
6	$1.73
7	$3.09
8	$1.70
9	$1.09
10	$1.01
11	$0.48
12	($0.64)
13	$0.94
14	($0.50)
15	$1.88
16	($0.88)

Table 31: 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 $/ft²)
1	($1.80)
2	$2.46
3	($0.14)
4	$2.95
5	($0.09)
6	$4.15
7	$4.69
8	$4.48
9	$3.59
10	$3.83
11	$3.50
12	$0.25
13	$3.96
14	$0.56
15	$6.49
16	($0.67)

5.2.3.2 Dry Mode Adiabatic Condenser Sizing

Per-unit energy cost savings over the 15-year period of analysis are presented below. 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, as shown in Figure 21. For cool climate zones, the TDV energy cost savings range from $0 per square foot to $4.78 per square foot with maximum savings at 12/18°F, as shown in Figure 22.

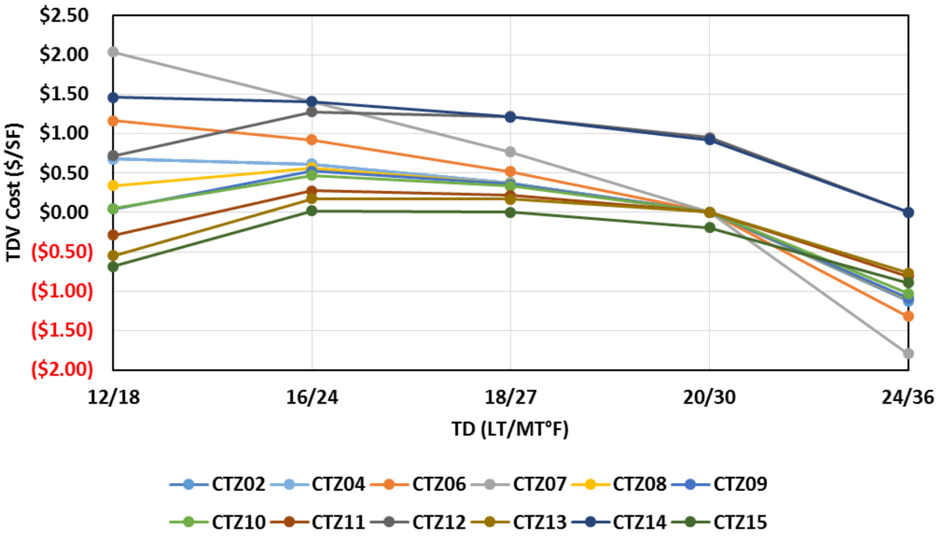

Figure 21: Warm climate TDV energy cost savings vs. dry mode TD.

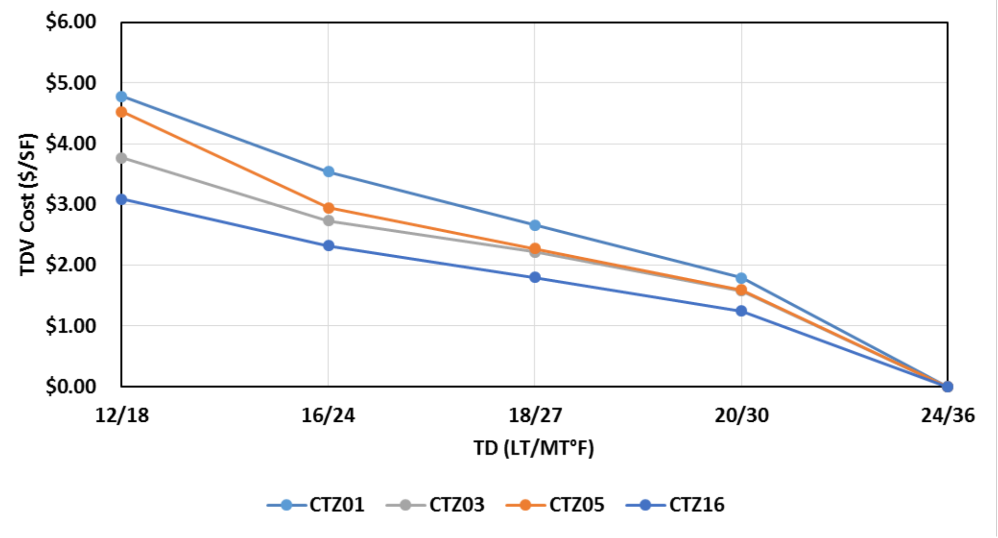

Figure 22: Cool climate TDV energy cost savings vs. dry mode TD.

5.2.3.3 Adiabatic Condenser Specific Efficiency

Per-unit energy cost savings over the 15-year period of analysis are presented in below. It is estimated that the year average TDV energy cost savings for warm climate zones is approximately $2.81 per square foot at a specific efficiency of 65 Btuh/W, as shown in Figure 23. The estimated average first-year average TDV energy cost savings for cool climate zones is approximately $1.16 per square foot at a specific efficiency of 65 Btuh/W, as shown in Figure 24.

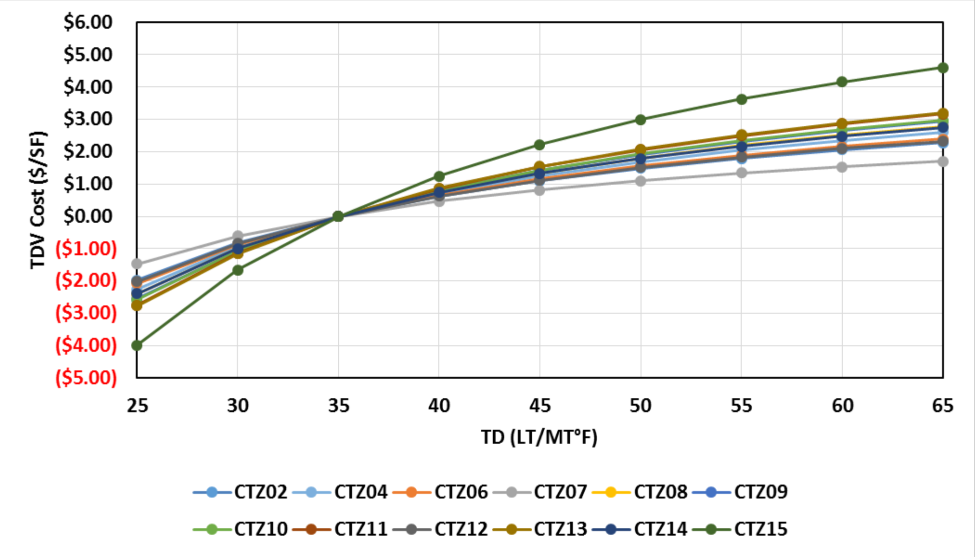

Figure 23: Warm climate TDV energy cost savings vs. specific efficiency.

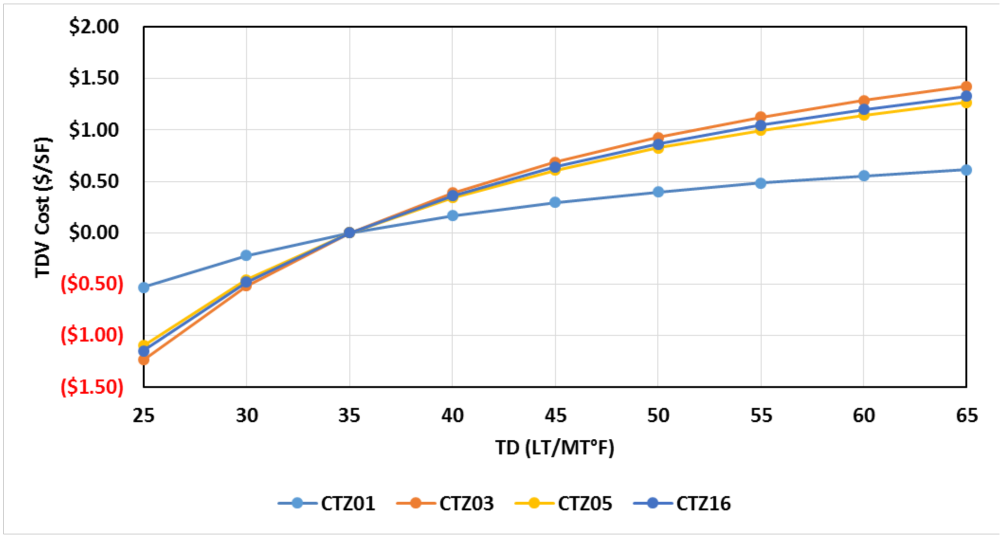

Figure 24: Cool climate TDV energy cost savings vs. specific efficiency.

5.3 Incremental First Cost

The Statewide CASE Team estimated the current incremental construction costs, which represents the incremental cost of the measure if a building meeting the proposed standard were built today.

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 32 below.

Table 32: 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 (2020 PV $)	**$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 33 through Table 35 below.

Table 33: 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 (2020 PV $)	**$1,824**

Table 34: 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 (2020 PV $)	**$2,194**

Table 35: 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 (2020 PV $)	**$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 36 through Table 38 below.

Table 36: 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 37: 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 38: 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 Statewide 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 Statewide 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 39: Incremental Cost for Specific Efficiency Change (LSM 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 40: 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):

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

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 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. For all sections:

- **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 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. If TDV energy cost savings is negative, it is treated as a cost.
- **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 B/C ratio is infinite. Includes TDV energy costs if higher than the TDV energy costs in the base case.

5.5.1 Large Supermarket 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 41 to Table 43. 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 B/C ratio for option B ranges from 0.2 to 235.2 depending on the climate zone.

Table 41: Variable SCT Setpoint Option A: Lifecycle Cost-Effectiveness Summary Per LSM Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2020PV $)	Costs Total Incremental PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$16,687.50	$867	19.2
2	$103,079.80	$867	118.9
3	$145,061.10	$867	167.3
4	$178,320.40	$867	205.6
5	$125,908.30	$867	145.2
6	$259,675.30	$867	299.4
7	$288,493.50	$867	332.7
8	$186,971.20	$867	215.6
9	$176,300.10	$867	203.3
10	$91,029.20	$867	105.0
11	$79,165.50	$867	91.3
12	$80,990.00	$867	93.4
13	$79,752.90	$867	92.0
14	$45,977.40	$867	53.0
15	-	$867	-
16	$10,172.70	$867	11.7

Table 42: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$3,052.70	$867	3.5
2	$48,656.30	$867	56.1
3	$58,384.00	$867	67.3
4	$63,546.00	$867	73.3
5	$57,921.20	$867	66.8
6	$142,497.90	$867	164.3
7	$204,005.80	$867	235.2
8	$124,092.70	$867	143.1
9	$99,279.50	$867	114.5
10	$62,727.20	$867	72.3
11	$38,145.40	$867	44.0
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
16	$160.20	$867	0.2

Table 43: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$15,628.40	$1,824	8.6
2	$134,479.00	$1,824	73.7
3	$146,307.10	$1,824	80.2
4	$203,712.10	$1,824	111.7
5	$125,641.30	$1,824	68.9
6	$274,805.30	$1,824	150.7
7	$293,281.70	$1,824	160.8
8	$221,779.10	$1,824	121.6
9	$200,561.50	$1,824	110.0
10	$128,053.20	$1,824	70.2
11	$114,970.20	$1,824	63.0
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
16	$32,307.00	$1,824	17.7

5.5.1.2 Dry Mode Adiabatic Condenser Sizing

Condensers with lower specific efficiency are less expensive and thus have a negative incremental cost. For condensers 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 44, 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. In the table, the maximum B/C ratio for each climate zone is indicated by bold text.

Table 44: Dry Mode Adiabatic Condenser Sizing: Lifecycle Cost-Effectiveness – LSM prototype [a]

Climate Zone	Dry-mode sizing TD (LT/MT ˚F)				
	12/18	16/24	18/27	20/30	24/36
1	1.00	1.79	**1.92**	1.86	1.47
2	0.00	1.00	**25.82**	3.00	0.99
3	1.00	**Infinite**	**Infinite**	45.23	2.29
4	1.00	**Infinite**	**Infinite**	**Infinite**	3.47
5	1.00	**55.39**	11.99	4.93	1.93
6	1.00	**Infinite**	**Infinite**	7.16	1.31
7	1.00	**25.62**	2.95	1.46	0.71
8	0.00	1.00	**1.77**	0.97	0.51
9	0.00	1.00	**1.72**	1.01	0.54
10	0.00	0.80	**1.27**	1.00	0.34
11	0.00	0.19	0.54	**1.00**	0.53
12	0.00	0.43	0.83	**1.00**	0.44
13	0.00	0.47	0.91	**1.00**	0.42
14	0.19	0.64	0.97	**1.36**	1.00
15	0.45	1.48	2.11	**2.78**	1.00
16	1.00	**1.41**	1.33	1.31	1.28

[a] The maximum B/C ratio for each climate zone is indicated by bold text.

5.5.1.3 Adiabatic Condenser Specific Efficiency

Condensers with lower specific efficiency are less expensive 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 Btuh/W as presented in Figure 25 and Figure 26, 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, which causes very low average fan speeds. Due to this, there is no significant effect of change in specific efficiency for Climate Zone 1.

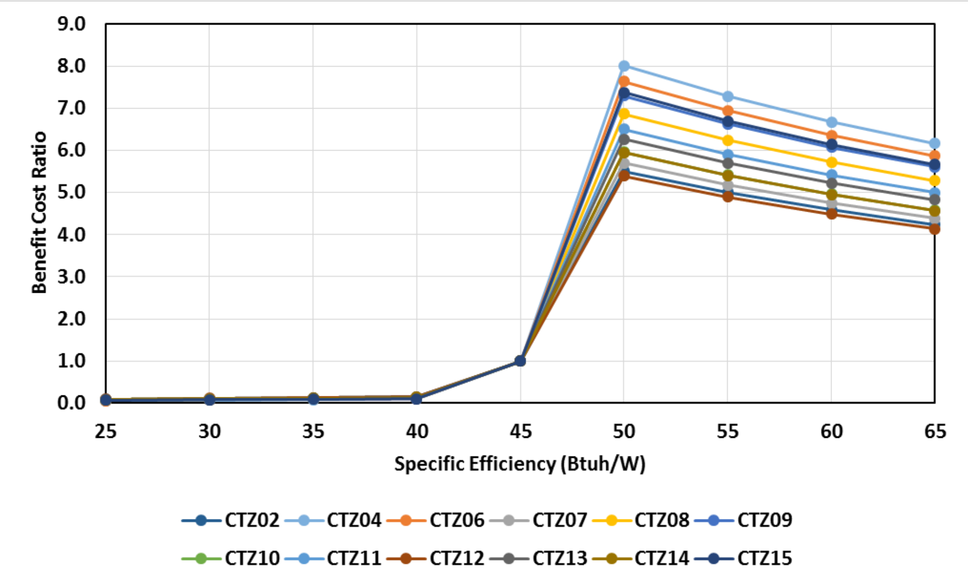

Figure 25: Specific efficiency: lifecycle cost-effectiveness – warm climate (LSM prototype).

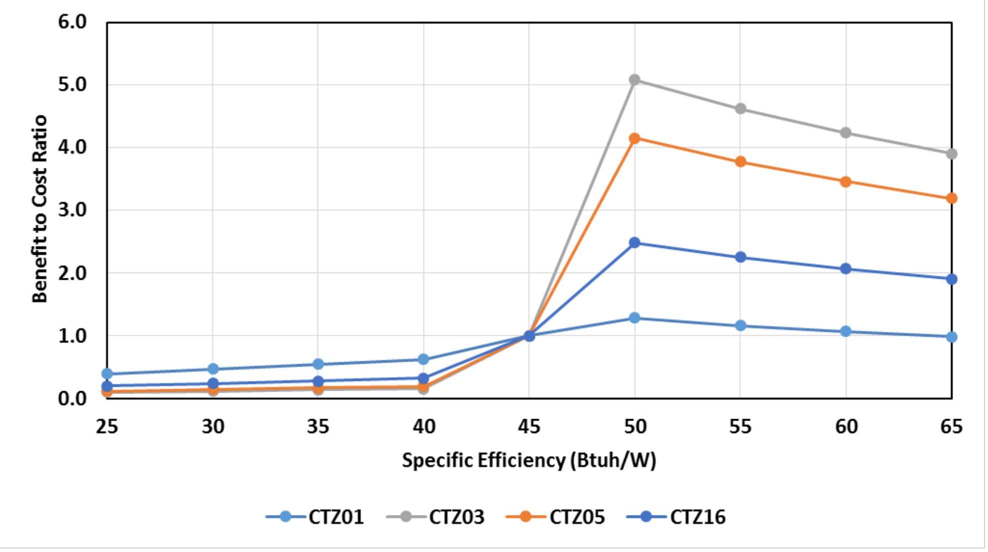

Figure 26: Specific efficiency: lifecycle cost-effectiveness – cool climate (LSM prototype).

5.5.1.4 Minimally Compliant Adiabatic Condenser Comparison

The Statewide CASE Team compared annual energy TDV values between the proposed minimally compliant adiabatic condenser and the minimally compliant air cooled condenser for the Large Supermarket Prototype, based on the proposed cost effective adiabatic condensers measures. The annual TDV values for each system and the percent difference between the two are shown in Table 45 below. The purpose of this comparison is to confirm that annual energy use for these systems, based on Title 24, Part 6 requirements of these, is similar. The results show that, on average, the annual energy TDV values are within two percent.

While this comparison shows the proposed measures for adiabatic condensers result in comparatively efficient system operation, it is not the intent of this CASE Report to determine or recommend a

particular condenser technology. The choice to use air-cooled, evaporative cooled or adiabatic condensing is a function of many factors to be determined by designers and owners.

Table 45: Minimally Compliant Adiabatic Condenser Annual Energy TDV Comparison

Climate Zone	Minimally Compliant Air Cooled (MBTU)	Minimally Compliant Adiabatic (MBTU)	Percent Difference
1	45,223	45,811	1.3%
2	46,213	46,910	1.4%
3	45,623	46,704	2.3%
4	46,720	47,554	1.8%
5	45,368	46,368	2.2%
6	46,523	47,992	3.1%
7	46,538	48,145	3.3%
8	47,012	48,306	2.7%
9	47,562	48,600	2.1%
10	47,562	48,201	1.3%
11	47,932	47,922	(0.0%)
12	47,613	47,831	0.5%
13	48,735	48,941	0.4%
14	47,426	47,585	0.3%
15	50,489	50,004	(0.9%)
16	45,487	46,119	1.4%

5.5.2 Small Refrigerated Warehouse 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, which are presented in Table 46 to Table 48. 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 B/C ratio for option B ranges from 0 to 166.44 depending on the climate zone. Where benefits are presented as $0, the annual TDV energy costs are higher than the base case, with the associated incremental cost included as a cost.

Table 46: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$0.00	$2,140	0.0
2	$22,499.20	$867	25.9
3	$89,000.00	$867	102.6
4	$93,681.40	$867	108.0
5	$65,326.00	$867	75.3
6	$179,664.30	$867	207.2
7	$219,607.50	$867	253.2
8	$128,391.40	$867	148.0
9	$8,232.50	$867	9.5
10	$68,770.30	$867	79.3
11	$0.00	$151,446	0.0
12	$40,361.50	$867	46.5
13	$47,882.00	$867	55.2
14	$1,682.10	$867	1.9
15	$0.00	$13,968	0.0
16	$0.00	$50,084	0.0

Table 47: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$0.00	$3,074	0.0
2	$27,794.70	$867	32.1
3	$34,131.50	$867	39.4
4	$43,351.90	$867	50.0
5	$37,148.60	$867	42.8
6	$97,953.40	$867	113.0
7	$144,322.40	$867	166.4
8	$73,282.60	$867	84.5
9	$46,422.40	$867	53.5
10	$41,385.00	$867	47.7
11	$14,524.80	$867	16.7
12	$16,322.60	$867	18.8
13	$22,997.60	$867	26.5
14	$0.00	$8,806	0.0
15	$6,701.70	$867	7.7
16	$0.00	$1,615	0.0

Table 48: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$1,023.50	$1,824	0.5
2	$106,746.60	$1,824	48.6
3	$104,575.00	$1,824	47.7
4	$174,395.50	$1,824	79.5
5	$78,987.50	$1,824	36.0
6	$220,960.30	$1,824	100.7
7	$233,803.00	$1,824	106.5
8	$170,524.00	$1,824	77.7
9	$118,316.60	$1,824	53.9
10	$119,340.10	$1,824	54.4
11	$76,237.40	$1,824	34.7
12	$67,880.30	$1,824	30.9
13	$82,992.50	$1,824	37.8
14	$14,266.70	$1,824	6.5
15	$25,845.60	$1,824	11.8
16	$10,742.30	$1,824	4.9

5.5.2.2 Dry Mode Adiabatic Condenser Sizing

Smaller sized condensers are less expensive 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 49, 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. In the table, the maximum B/C ratio for each climate zone is indicated by bold text.

Table 49: Dry Mode Adiabatic Condenser Sizing: Lifecycle Cost-Effectiveness (SRWH prototype)[a]

Climate Zone	Dry-mode sizing TD (LT/MT ˚F)				
	12/18	16/24	18/27	20/30	24/36
1	1.00	**1.17**	0.94	0.82	0.64
2	0.06	1.00	**1.73**	1.22	0.76
3	1.00	**1.48**	1.30	1.10	0.80
4	1.00	**11.78**	4.67	2.78	1.45
5	1.00	**1.01**	0.94	0.71	0.68
6	1.00	**3.89**	2.36	1.68	1.03
7	1.00	**1.95**	1.39	1.08	0.74
8	0.00	1.00	**2.00**	1.36	0.83
9	0.02	0.53	**1.00**	0.91	0.59
10	0.00	0.35	1.00	**1.19**	0.72
11	0.02	0.46	0.72	**1.00**	0.64
12	0.00	0.43	0.70	**1.00**	0.60
13	0.00	0.24	0.49	**1.00**	0.73
14	0.49	0.92	1.18	**1.46**	1.00
15	0.13	0.63	0.88	**1.14**	1.00
16	1.00	**1.53**	1.29	1.11	0.88

[a] The maximum B/C ratio for each climate zone is indicated by bold text.

5.5.2.3 Adiabatic Condenser Specific Efficiency

Condensers with lower specific efficiency are less expensive 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 and 16, 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 or 16.

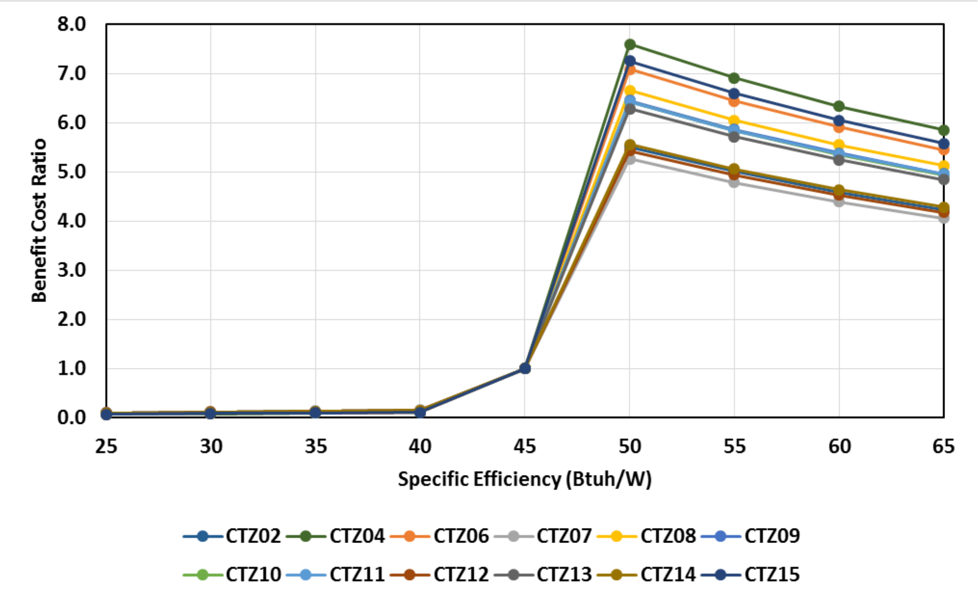

Figure 27: Specific efficiency: lifecycle cost-effectiveness – warm climate (SRWH prototype).

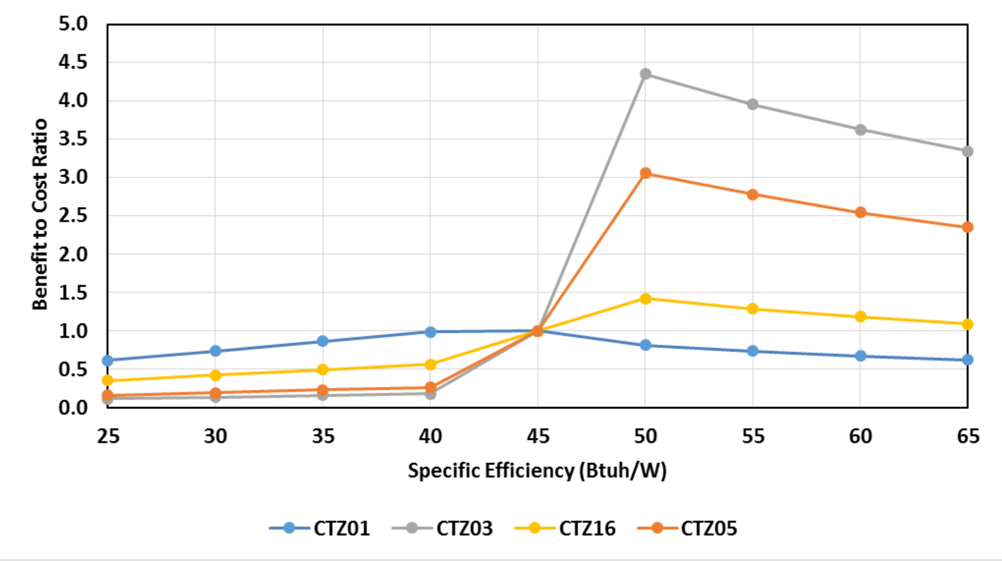

Figure 28: Specific efficiency: lifecycle cost-effectiveness – cool climate (SRWH prototype).

5.5.2.4 Minimally Compliant Adiabatic Condenser Comparison

The Statewide CASE Team compared annual energy TDV values between the proposed minimally compliant adiabatic condenser and the minimally compliant air cooled condenser for the Large Supermarket Prototype, based on the proposed cost effective adiabatic condensers measures. The annual TDV values for each system and the percent difference between the two are shown in Table 50 below. The purpose of this comparison is to confirm that annual energy use for these systems, based on Title 24, Part 6 requirements of these, is similar. The results show that, on average, the annual energy TDV values are within five to ten percent.

While this comparison shows the proposed measures for adiabatic condensers result in comparatively efficient system operation, it is not the intent of this CASE Report to determine or recommend a

particular condenser technology. The choice to use air-cooled, evaporative cooled or adiabatic condensing is a function of many factors to be determined by designers and owners.

Table 50: Minimally Compliant Adiabatic Condenser Annual Energy TDV Comparison

Climate Zone	Minimally Compliant Air Cooled (MBTU)	Minimally Compliant Adiabatic (as proposed in code language) (MBTU)	Percent Difference
1	13,364	14,307	6.6%
2	15,471	16,427	5.8%
3	14,175	15,636	9.3%
4	15,891	17,003	6.5%
5	14,017	15,507	9.6%
6	15,522	17,237	9.9%
7	14,820	16,698	11.2%
8	15,465	16,946	8.7%
9	16,589	17,806	6.8%
10	16,200	17,013	4.8%
11	17,365	17,421	0.3%
12	16,120	16,644	3.1%
13	16,758	17,153	2.3%
14	16,534	16,587	0.3%
15	18,922	18,638	(1.5%)
16	14,430	14,673	1.7%

5.5.3 Large Refrigerated Warehouse 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, which are presented below in Table 51 to Table 53. 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 B/C ratio for option B ranges from 0 to 328 depending on the climate zone.

Table 51: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$0.00	$141,514	0.0
2	$0.00	$102,959	0.0
3	$8,828.80	$867	10.2
4	$0.00	$122,530	0.0
5	$0.00	$1,481	0.0
6	$193,913.20	$867	223.6
7	$389,490.70	$867	449.1
8	$314,606.10	$867	362.8
9	$0.00	$101,677	0.0
10	$206,186.30	$867	237.8
11	$0.00	$556,423	0.0
12	$36,979.50	$867	42.6
13	$239,855.00	$867	276.6
14	$4,903.90	$867	5.7
15	$208,900.80	$867	240.9
16	$0.00	$360,160	0.0

Table 52: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$0.00	$201,945	0.0
2	$15,379.20	$867	17.7
3	$0.00	$98,358	0.0
4	$35,867.00	$867	41.4
5	$0.00	$86,556	0.0
6	$159,372.30	$867	183.8
7	$284,693.20	$867	328.3
8	$156,853.60	$867	180.9
9	$100,561.10	$867	116.0
10	$93,263.10	$867	107.5
11	$43,877.00	$867	50.6
12	$0.00	$59,491	0.0
13	$86,276.60	$867	99.5
14	$0.00	$47,014	0.0
15	$172,588.80	$867	199.0
16	$0.00	$81,670	0.0

Table 53: 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 PV Costs (2020PV $)	Benefit-to-Cost Ratio
1	$0.00	$167,346	0.0
2	$225,908.70	$1,824	88.1
3	$0.00	$14,293	0.0
4	$271,725.90	$1,824	105.9
5	$0.00	$9,950	0.0
6	$381,925.70	$1,824	148.9
7	$431,614.40	$1,824	168.3
8	$412,274.70	$1,824	160.7
9	$329,869.60	$1,824	128.6
10	$351,950.50	$1,824	137.2
11	$321,877.40	$1,824	125.5
12	$22,801.80	$1,824	8.9
13	$364,401.60	$1,824	142.1
14	$51,183.90	$1,824	20.0
15	$597,412.50	$1,824	232.9
16	$0.00	$63,457	0.0

5.5.3.2 Dry Mode Adiabatic Condenser Sizing

Smaller sized condensers are less expensive 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 54, indicate that a condenser sized with TD of 20/30˚F (LT/MT) and 24/36˚F (LT/MT) is most cost-effective among all climate zones. In the table, the maximum B/C ratio for each climate zone is indicated by bold text.

Table 54: Dry Mode Adiabatic Condenser Sizing: Lifecycle Cost-Effectiveness (LRWH prototype)[a]

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
2	0.34	0.82	**1.13**	1.00	0.45
3	1.50	2.18	2.66	**3.15**	1.00
4	0.34	0.81	**1.12**	1.00	0.46
5	1.81	2.35	2.73	**3.18**	1.00
6	0.58	1.23	**1.55**	1.00	0.38
7	1.02	1.86	**2.31**	1.00	0.28
8	0.17	0.75	**1.09**	1.00	0.46
9	0.02	0.70	**1.07**	1.00	0.46
10	0.03	0.63	**1.00**	**1.00**	0.49
11	0.00	0.37	0.65	**1.00**	0.62
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
16	1.23	1.85	2.16	**2.49**	1.00

[a] The maximum B/C ratio for each climate zone is indicated by bold text.

5.5.3.3 Adiabatic Condenser Specific Efficiency

Condensers with lower specific efficiency are less expensive 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 Btuh/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.

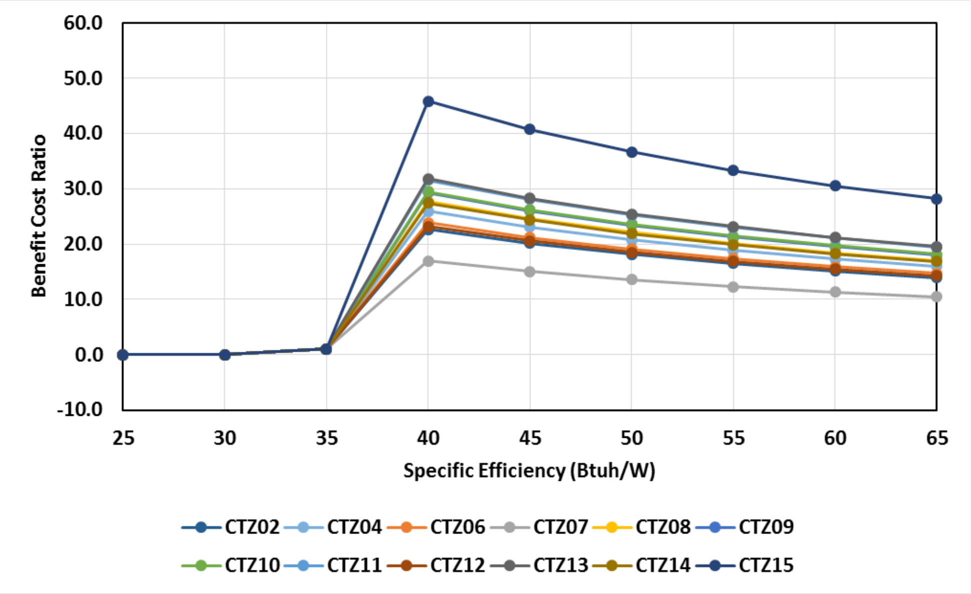

Figure 29: Specific efficiency: lifecycle cost-effectiveness – warm climate (LRWH prototype).

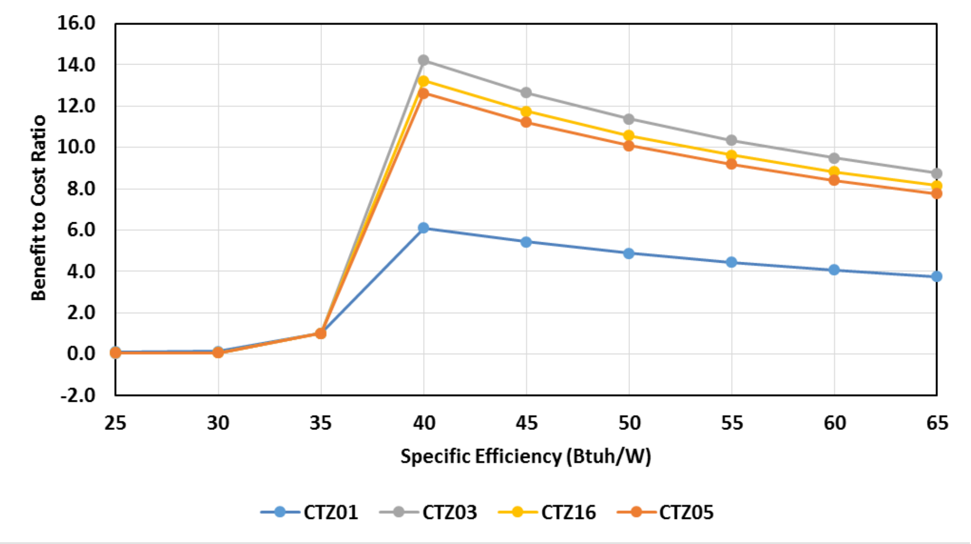

Figure 30: Specific efficiency: lifecycle cost-effectiveness – cool climate (LRWH prototype).

5.5.3.4 Minimally Compliant Adiabatic Condenser Comparison

The Statewide CASE Team compared annual energy TDV values between the proposed minimally compliant adiabatic condenser and the minimally compliant air cooled condenser for the Large Supermarket Prototype, based on the proposed cost effective adiabatic condensers measures. The annual TDV values for each system and the percent difference between the two are shown in Table 55 below. The purpose of this comparison is to confirm that annual energy use for these systems, based on Title 24, Part 6 requirements of these, is similar. The results show that, on average, the annual energy TDV values are within five percent.

While this comparison shows the proposed measures for adiabatic condensers result in comparatively efficient system operation, it is not the intent of this CASE report to determine or recommend a

particular condenser technology. The choice to use air-cooled, evaporative cooled or adiabatic condensing is a function of many factors to be determined by designers and owners.

Table 55: Minimally Compliant Adiabatic Condenser Annual Energy TDV Comparison

Climate Zone	Minimally Compliant Evap Cooled (MBTU)	Minimally Compliant Adiabatic (as proposed in code language) (MBTU)	Percent Difference
1	59,073	53,490	(10.4%)
2	60,141	59,084	(1.8%)
3	60,416	58,432	(3.4%)
4	61,196	61,269	0.1%
5	59,980	57,192	(4.9%)
6	60,961	61,782	1.3%
7	61,091	61,794	1.1%
8	60,768	62,615	2.9%
9	61,918	63,904	3.1%
10	61,535	63,272	2.7%
11	61,488	62,449	1.5%
12	61,223	61,890	1.1%
13	62,047	63,825	2.8%
14	62,682	62,419	(0.4%)
15	64,326	69,312	7.2%
16	59,504	53,065	(12.1%)

5.5.3.5 Specific Efficiency vs. Dry Mode Sizing

Due to the complex interactions between dry mode sizing and specific efficiency as well as its effect on energy savings and overall cost effectiveness, the Statewide CASE Team found that a definitive and quantifiable relationship could not be determined. In addition, the number of products available in the market for refrigerated warehouse applications is still relatively small as compared to supermarkets. This smaller sample size limits the ability to draw definitive conclusions. As this market grows, the additional data will allow for better understanding of the optimization of first cost and energy cost as it relates to specific efficiency and dry mode sizing.

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 for new construction 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 56 for new construction. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

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 680 MWh with an associated demand reduction of 60 kW. 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 56: Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide Construction in 2020 (million ft^2)	First-Year[a] Electricity Savings (MWh)	First-Year[a] Peak Electrical Demand Reduction (kW)	Lifecycle[b] Present Valued Energy Cost Savings (PV$)
1	0.0047	(1)	1	(2,438)
2	0.0332	8	0	20,473
3	0.1348	35	23	107,078
4	0.0795	32	8	90,546
5	0.0154	3	2	9,611
6	0.1127	99	12	246,298
7	0.0776	85	10	210,268
8	0.1611	126	1	272,480
9	0.163	99	(5)	207,232
10	0.1384	68	0	143,488
11	0.043	12	0	25,816
12	0.1689	64	(1)	126,431
13	0.098	39	0	78,965
14	0.0271	7	1	14,978
15	0.0297	14	2	31,793
16	0.0356	(9)	5	(24,837)
TOTAL	**1.3225**	**680**	**60**	**1,558,182**

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

b. Energy cost savings from all alterations completed statewide in 2020 accrued during 15-year period of analysis.

c. Negative energy values are a result of the base case condenser sizing in each climate zone. Some climate zones result in more energy savings and a higher benefit cost ratio using a smaller or larger condenser size, which is not restricted by the proposed code language.

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.

> **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 precools the ambient air by becoming fully wetted during pre-cool mode operation.

TRANSCRITICAL CO_2 REFRIGERATION SYSTEM is a type of refrigeration system that uses CO_2 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 CO_2 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 CO_2 refrigeration systems.

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

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. Used by a CO_2 refrigeration systems in transcritical mode, and normally also capable of operating in subcritical mode.

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, listed in Table 120.6-B:

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 were the design wetbulb temperature is greater than or equal to 78°F.

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

DESIGN WET BULB TEMPERATURE	**DESIGN SATURATED CONDENSING TEMPERATURE**
$T_{WB} \leq 76°F$	$T_{WB} + 20°F$
$76°F < T_{WB} < 78°F$	$T_{WB} + 19°F$
$T_{WB} \geq 78°F$	$T_{WB} + 18°F$

EXCEPTION 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.

B. Design saturated condensing temperatures for air-cooled condensers shall be less than or equal to:
    i. The design drybulb temperature plus 10°F for systems serving freezers
    ii. 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.

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:
    i. The design drybulb temperature plus 20°F for systems serving freezers
    ii. 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.

D. 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.
E. The minimum condensing temperature setpoint shall be less than or equal to 70°F for air-cooled condensers, evaporative-cooled condensers, adiabatic condensers, gas coolers, air or water-cooled fluid coolers or cooling towers.
F. 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 to Section 120.6(a) 4~~G~~F: 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) 4~~G~~F: Systems served by adiabatic condensers in Climate Zones 1, 3, 5, 12, 14, and 16.

G. 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 pumps for evaporative condensers.

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

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

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

TABLE 120.6-C~~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 Capacity < 8,000 MBH and Indoor Evaporative-Cooled	All	160 Btuh/W	
Outdoor Air-Cooled	Ammonia	75 Btuh/W	105°F Saturated Condensing Temperature (SCT), 95°F Outdoor Drybulb Temperature
	Halocarbon	65 Btuh/W	
Adiabatic Dry Mode	Halocarbon	45 Btuh/W	105°F Saturated Condensing Temperature (SCT), 95°F Outdoor Drybulb Temperature
Indoor Air-Cooled	All	Exempt	

EXCEPTION to Section 120.6(a)1A, 1B, 1C, 1E, 1F, 1G: Transcritical CO_2 refrigeration systems.

(b) **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) 1D: Systems served by adiabatic condensers in Climate Zone 16.

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:
  i. The design drybulb temperature plus 20°F for systems serving freezers
  ii. The design drybulb temperature plus 30°F for systems serving coolers
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-D~~C~~.

TABLE 120.6-D~~C~~ FAN-POWERED CONDENSERS-SPECFIC 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
Adiabatic Dry Mode	45 Btuh/W (Halocarbon)	105°F Saturated Condensing Temperature (SCT), 95°F Entering Drybulb Temperature
*See Section 100.1 for definition of condenser specific efficiency		

EXCEPTION 1 to Section 120.6(b)1~~E~~G: Condensers with a Total Heat Rejection capacity of less than 150,000 Btuh at the specific efficiency rating condition.

EXCEPTION 2 to Section 120.6(b)1~~E~~G: Stores located in Climate Zone 1.

EXCEPTION 3 to Section 120.6(b)1~~E~~G: Existing condensers that are reused for an addition or alteration.

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

EXCEPTION 1 to Section 120.6(b)1~~F~~H: Microchannel condensers.

EXCEPTION 2 to Section 120.6(b)1~~F~~H: Existing condensers that are reused for an addition or alteration.

EXCEPTION to Section 120.6(b)1B, 1C, 1D, 1E, 1F, 1G: Transcritical CO_2 refrigeration systems.

7.2 Reference Appendices

Terms will need to be added to JA – Glossary.

The proposed requirements will revise NA7.10.3 to address adiabatic condensers. The acceptance test procedure will be very similar to that of air-cooled condensers and will be able to use the same acceptance test form.

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 throughout to incorporate adiabatic systems. Revisions will include eliminating language in Section 10.5.2.1 that adiabatic condensers are not covered, adding information on adiabatic condenser specific efficiency and sizing requirements from the proposed code language. In addition, the compliance manual updates will include relevant descriptions and diagrams that explain unique features of adiabatic condensers compared to other condenser technology types (i.e., mode switching setpoint, pre-cool pads and coil diagram).

7.5 Compliance Documents

A new form NRCA-PRC will need to be created to address adiabatic condenser requirements. Additionally, NRCC-PRC-05, 06, and 08 will be revised to include adiabatic condensers.

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.

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.

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 Economomy. 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 57.

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 58).
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 60 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 61 and Table 62 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 61 and Table 62 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 57.

Table 57: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2020, by Climate Zone and Building Type (Million ft^2)

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 58: 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%	0.0%	74.9%	0.0%	0.0%	0.0%	12.3%	7.9%	4.9%	100%
	11	0.0%	0.0%	0.0%	0.0%	0.0%	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 59: 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 60: Example of Redistribution of Miscellaneous Category - 2020 New Construction in Climate Zone 1

Building Type	**2020 Forecast (Million ft^2)** **[A]**	**Distribution Excluding Miscellaneous Category** **[B]**	**Redistribution of Miscellaneous Category (Million ft^2)** **[C] = B × 0.11**	**Revised 2020 Forecast (Million ft^2)** **[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 61: Percent of Floorspace Impacted by Proposed Measure, by Building Type

Building Type *Building Sub-Type*	**Composition of Building Type by Sub-types** [a]	**Percent of Square Footage Impacted** [b]	
		New Construction	**Existing Building Stock (Alterations)** [c]
Small Office		0%	0%
Restaurant		0%	0%
Retail		0%	0%
Stand-Alone Retail	*10%*	*0%*	*0%*
Large Retail	*75%*	*0%*	*0%*
Strip Mall	*5%*	*0%*	*0%*
Mixed-Use Retail	*10%*	*0%*	*0%*
Food		12.18%	0%
Non-Refrigerated Warehouse		0%	0%
Refrigerated Warehouse		10%	0%
Schools		0%	0%
Small School	*60%*	*0%*	*0%*
Large School	*40%*	*0%*	*0%*
College		0%	0%
Small Office	*5%*	*0%*	*0%*
Medium Office	*15%*	*0%*	*0%*
Medium Office/Lab	*20%*	*0%*	*0%*
Public Assembly	*5%*	*0%*	*0%*
Large School	*30%*	*0%*	*0%*
High Rise Apartment	*25%*	*0%*	*0%*
Hospital		0%	0%
Hotel/Motel		0%	0%
Large Offices		0%	0%
Medium Office	*50%*	*0%*	*0%*
Large Office	*50%*	*0%*	*0%*

a. 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.

b. 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.

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

Table 62: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone

Climate Zone	Percent of Square Footage Impacted	
	New Construction	Existing Building Stock (Alterations) [a]
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%

a. 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 Statewide 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 63.

This proposal will improve the compliance process for refrigeration systems by clarifying requirements as they apply to adiabatic 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 63: 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 • Revise existing NRCC-PRC-05,06&08 forms to include 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 condenser requirements • Revise existing NRCC-PRC-05,06&08 forms to include adiabatic condensers
Acceptance Test Technician	• Inspect specified equipment after installation and determine how equipment is operating	• Ensure control strategy of installed equipment (condenser) is code compliant and ensure related sensors/equipment are calibrated and functioning properly	• Code change defines compliant control strategy for adiabatic condensers	• Create new compliance document to address adiabatic condensers and align with air cooled condenser acceptance test method • Ensure items like “switching setpoint” and “dry mode” are appropriately defined for the Acceptance Test Technician

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
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 CO_2 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 percent. 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:

- Adiabatic 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.