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Codes and Standards Enhancement (CASE) Initiative 2022 California Energy Code

Air Distribution: High Performance Ducts and Fan Systems

2022-NR-HVAC2-F **|** Nonresidential HVAC **|** September 2020 FINAL CASE REPORT

Prepared by Energy Solutions

Please submit comments to info@title24stakeholders.com.

CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

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Executive Summary

This document presents recommended code changes that the California Energy Commission will be considering for adoption in 2021. If you have comments or suggestions prior to the adoption, please email info@title24stakeholders.com. Comments will not be released for public review or will be anonymized if shared.

Introduction

The Codes and Standards Enhancement (CASE) Initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update the California Energy Code (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. Three California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison – and two Publicly Owned Utilities – Sacramento Municipal Utility District, and Los Angeles Department of Water and Power (herein referred to as the Statewide CASE Team when including the CASE Author) – 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 are 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 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

The overall goal of this Final CASE Report is to present a code change proposal for three air distribution submeasures: fan power budget, fan energy index, and duct leakage. The report contains pertinent information supporting the code change.

Measure Description

Background Information

Air distribution in nonresidential buildings consumes a significant amount of energy, accounting for up to 1.5 percent of total national energy consumption (Department of Energy 2017). Building codes, specifically Title 24, Part 6, have long had standards to encourage better and more efficient design of air distribution systems in nonresidential buildings but no individual fan efficiency requirements or broad requirements for duct sealing. Because every building and air distribution system is unique, the building code regulations covering fan power have historically been structured to give building designers flexibility with standards limiting either watts, fan nameplate horsepower (HP), or fan brake HP (BHP) as a function of airflow. This allows designers to essentially reduce pressure in ductwork through better duct design, larger ducts, better fittings, or choosing a more efficient combination of fans or motors to meet the code.

On January 1, 2020, with the implementation of the 2019 Title 24, Part 6 building code, the fan power limitation standards in California were revised based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1-2016. Most significantly, this code change lowered the threshold of fan systems subject to the standard from 25 fan motor nameplate HP to 5 nameplate HP. It also moved the Title 24, Part 6 Standards from a “watts/cubic feet per minute (CFM)” metric to one where there is a limit on BHP or nameplate HP as a function of supply air flow, depending on whether the system is variable volume or constant volume. If the BHP method is chosen, there are also several additional pressure “allowances” for unique components such as energy recovery ventilators and high efficiency particulate air (HEPA) filters, which allow more fan power to be used and still comply.

The effect of the existing fan power limitation in Title 24, Part 6 is a somewhat stringent requirement for large fan systems but relatively easy to meet with simple smaller fan systems. The key reason is that the underlying fan power limit equation constants have assumptions about what components are in each fan system and how much pressure they present to the fan. For example, a variable-air volume (VAV) fan system may have very short duct runs, but regardless of size (airflow), the fan system is essentially given credit for having three inches of water gauge (in. wg) of total pressure in the duct work. Fan systems are also given credit for an air blender, which are rarely found in temperate California, as well as credited for a cooling coil, regardless if there is cooling or not. The Statewide CASE Team acknowledges assumptions are made throughout the building code, but the Statewide CASE Team believes these assumptions are overdue for re-examination, which would lead to energy savings.

Additionally, the existing fan power limitations do not account for transmission efficiency, meaning the building code largely assumes that all fans have 100 percent efficient transmissions (i.e., direct-drive transmissions). In reality, most fans in buildings use belt-driven transmissions. This has the effect of understating the power consumption of fan systems by roughly 5 percent, as belt-drive transmissions are about 95 percent efficient. There is also no air density correction factor to account for differences of a fan system built at sea level to one built at higher elevations.

Finally, the existing 5 nameplate HP threshold, while lower than the 25 nameplate HP threshold which existed through the end of 2019, still excludes many fan systems where cost-effective energy savings could be realized. Furthermore, there is also no incentive to select more efficient motors and transmissions. In summary, the existing fan power limitations applies a simple "one-size-fits-all" approach to regulating fan power in buildings, which leads to the requirements being easy to meet for many projects. This Final CASE Report proposes a new fan power budget prescriptive requirement to replace the fan power limitations and drive energy savings in all types and sizes of fan systems.

The current Title 24, Part 6 requirements for nonresidential buildings also do not require any specific requirements for individual fan efficiency, only fan systems. This CASE Report proposes requiring certain fans meet a minimum fan energy index (FEI) requirement at the design conditions. FEI is an efficiency metric created by the Air Movement and Control Association (AMCA), an organization that sets standards for commercial and industrial air movement equipment. The metric and subsequent standards to develop FEI ratings have been pursued in collaboration with the United States Department of Energy (U.S. DOE) and energy efficiency advocates, which started during a federal effort to develop commercial and industrial fan efficiency standards. FEI addresses a longstanding problem in characterizing fan efficiency; a fan's peak efficiency is often poorly correlated with its actual efficiency in typical operating conditions. The FEI metric is an easy method to encourage mechanical designers to make fan selections closer to a fan's peak efficiency, where the higher the FEI, the less energy is consumed. Requiring individual fans to be minimally energy efficient using FEI is designed to complement the proposed fan power budget requirements for fan systems. Notably, FEI will apply to fans that move air in unconditioned spaces, whereas the fan power budget submeasure only applies to space conditioning systems covered in Section 140.4. This submeasure is largely based on the recently adopted Addendum ao to ASHRAE Standard 90.1-2016 which sets an FEI of 1.0 for most fans generally not embedded in packaged equipment.

A final important component of high-performance air distribution systems is ensuring the air generated by fan systems is delivered to its intended space in the building with minimal leakage or losses along the way. The proposed code change to require all ducts to be sealed according to Seal Class A (the highest degree of sealing) aligns Title 24, Part 6 with requirements in ASHRAE 90.1 and is a commonsense requirement to minimize duct leakage. The proposed code change will also address duct leakage through leakage limits and duct leakage testing to verify leakage rates are achieved.

Currently, Title 24, Part 6 includes a prescriptive requirement that the entire air distribution system in nonresidential buildings with constant volume systems serving less than 5,000 ft^2 conditioned area that have a significant portion of ductwork in unconditioned or outdoor space be tested to confirm that leakage does not exceed six percent of nominal air handler airflow. This is for simple systems and includes the leakage of all components, including the air handler. In the case of altered existing duct systems that meet the above criteria, the entire system must not exceed of leakage of 15 percent. As a prescriptive requirement, designers that use the performance approach can choose not to pursue achieving leakage limits verified through leakage tests to comply with Title 24, Part 6.

On January 1, 2020, the effective date of the 2019 California Mechanical Code (CMC or Title 24, Part 4), duct leakage limits and duct leakage testing requirements took effect for nonresidential air distribution systems. Maximum permitted leakage requirements and testing to verify leakage rates for all duct systems are now included in Section 603.10.1 of the CMC. The mandatory leakage limits in the CMC are a notable improvement, but the CMC lacks specificity on which sections of ductwork need to be tested, who can execute the testing, and what documentation is needed to demonstrate compliance. The proposed changes would support the existing requirements and could be incorporated into either the CMC or Title 24, Part 6. The current prescriptive duct leakage testing requirements in 140.4(l) would also be moved to the mandatory section, 120.4, in order to be consistent with the mandatory testing requirement in the CMC but would not be changed significantly otherwise.

Proposed Code Change

This code change proposes three air distribution submeasures that modify existing code sections or create new code sections in Title 24, Part 6. First, a new prescriptive fan power budget requirement would replace the existing fan power limitation requirements. Second, a new mandatory requirement would be added to require certain fan types to be selected at an FEI ≥ 1.0. Finally, to address duct leakage, a new mandatory requirement would require new ductwork to be sealed to Seal Class A standards and the existing prescriptive duct leakage limits and duct leakage testing requirements would be moved to mandatory. Nonresidential Appendix 7 (NA7) would also be updated to clarify the sampling requirements for duct leakage testing that is required by the 2019 CMC.

All three of these submeasures would apply to new construction, additions and alterations. For the existing fan power limitations in additions and alterations, additional pressure allowances are currently granted for different air filters. This proposal seeks to simplify the additions and alterations language and simply grant additional pressure allowances (which are directly proportional to fan power) for additions and alterations, knowing there are challenges in meeting fan power requirements in this market segment.

Importantly, the scope of the fan power budget submeasure is changing such that the threshold for fan systems to be subject to the fan power budget is proposed at an electrical input power of 1 kW (which is roughly 1-nameplate HP), as compared to the 5-

nameplate HP threshold for the existing fan power limitations. This submeasure also proposes to separate supply fan systems from return/relief/exhaust/transfer fan systems, such that each fan system must meet the fan power budget separately, not combined as is currently done with the fan power limitations.

Finally, the Statewide CASE Team is also proposing that the fan power budget apply to the healthcare facilities, whereas they currently are exempt from the fan power limitations. However, acknowledging the unique requirements of some healthcare facilities air distribution systems (such as those found in hospitals) the Statewide CASE Team has proposed less stringent requirements for these fan systems, while still requiring they comply with a fan power budget.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, and compliance documents that would be modified as a result of the proposed change(s).

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	Would Compliance Software Be Modified	Modified Compliance Document(s)
Fan Power Budget	Prescriptive	140.4	Nonresidential Appendix NA9	Yes, 5.7.3 Fan and Duct Systems	NRCC-MCH-E, NRCC-PRF-E
Fan Energy Index	Mandatory	120.10 (new section)	N/A	No	NRCC-MCH-E
Duct Leakage	Mandatory	120.4, 120.5, 140.4, 141.0	Nonresidential Appendix NA7	No	NRCC-MCH-E, NRCAV-MCH-04a-H, NRCA-MCH-04a

Source: Statewide CASE Team 2020

Market Analysis and Regulatory Assessment

Nonresidential air distribution systems are designed by mechanical engineers, who must take various considerations into account when developing layouts and specifying fan equipment. This includes but is not limited to space constraints, minimum equipment efficiency requirements, architectural and aesthetic requirements, and ventilation requirements based on building occupancy. The air distribution systems must then be installed according to plan by mechanical contractors.

As previously stated, the existing prescriptive fan power limitations are inherently flexible—a mechanical designer can decrease the pressure the fan must overcome or make the fan system more efficient at overcoming the pressure, or both. In this regard, the fan power budget is similar as a designer can specify lower pressure ductwork systems or higher efficiency equipment (i.e., fans, motors or transmissions) to meet the fan power budget. However, for the purposes of energy and cost analysis in this report the Statewide CASE Team focused exclusively on meeting the fan power budget through lower pressure ductwork, to show that HVAC equipment would not need to be changed to comply with this prescriptive requirement. The Statewide CASE Team leveraged professional mechanical designers and cost estimators to show this was cost effective and technically feasible which is explained in greater detail in Section 5.3.1 and Appendix H. To be clear, a designer can also specify more efficient fans, motors or transmissions, which may often be more cost effective than making changes to ductwork, but it would not be required to comply with the fan power budget.

As with the existing fan power limitations, reducing pressure from ductwork and specifying more efficient fans would remain core strategies for complying with the proposed fan power budget. However, the designers would also have two new opportunities within the code to help meet the proposed fan power budget: more efficient motors and transmissions. In other words, there is currently no credit (or incentive) under the fan power limitations for specifying a more efficient motor (e.g., NEMA premium) or more efficient transmission (e.g., direct-drive transmission). This proposed measure would recognize and credit these energy efficient technologies.

The Statewide CASE Team is proposing the fan power budget submeasure as a prescriptive measure, meaning it can be traded-off in the performance pathway in new construction and additions/alterations. However, the Statewide CASE Team is also proposing two complimentary mandatory measures in this Final CASE Report. The first mandatory measure is the FEI submeasure which would require minimally efficient fan selections for certain fan types (e.g., mostly fans not in packaged equipment) and the second is a requirement to seal all ducts to Seal Class A levels. Compliance with Seal Class A requires sealing all transverse joints, longitudinal seams, and duct wall penetrations and has been mandatory in ASHRAE 90.1 since 2010. The Statewide CASE Team is also proposing adding specifications to comply with the new duct testing requirements in the California Mechanical Code that took effect January 1, 2020. These additions are necessary to standardize testing across projects and provide the necessary compliance documentation and could be incorporated in either the CMC or Title 24, Part 6.

All three of these submeasures are either adopted (FEI in 2019 and Seal Class A in 2010) or proposed in committee (fan power budget) in ASRHAE 90.1. More specifically, the fan power budget mirrors a pending proposal in ASHRAE 90.1, which may also take effect as part of ASHRAE-90.1-2022.

Cost Effectiveness

All three proposed submeasures are found to be cost effective for all climate zones where they would be required. The benefit-to-cost (B/C) ratio compares the benefits or cost savings to the costs over the 15-year period of analysis. Proposed code changes 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 cost savings. The incremental cost for the fan power budget submeasure was conservatively determined to be $0.29/ft^2, and the B/C ratio averaged 3.8 across all building types modeled and all climate zones. The incremental cost to evaluate the FEI submeasure in the large office prototype was determined to be $1,008 per plenum return fan, and the B/C ratio averages 2.56 across all climate zones.[1] The incremental cost for the duct sealing submeasure was determined to be $0.07/ft^2 for supply air systems and $0.30/cfm for exhaust air systems, and the B/C ratio varied from to 3.2 (OfficeLarge in Climate Zone 1) to 33 (OfficeMediumLab in Climate Zone 15) across all building types modeled and all climate zones. See Section 4.3.2 for the methodology, assumptions, and results of the cost-effectiveness analysis.

Statewide Energy Impacts: Energy, Water, and Greenhouse Gas (GHG) Emissions Impacts

Table 2 presents the estimated energy and demand impacts of the proposed code changes that would be realized statewide during the first 12 months that the 2022 Title 24, Part 6 requirements are in effect. First-year statewide energy impacts are represented by the following metrics: electricity savings in gigawatt-hours per year (GWh/yr), peak electrical demand reduction in megawatts (MW), natural gas savings in million therms per year (million therms/yr), and time dependent valuation (TDV) energy savings in kilo British thermal units per year (TDV kBtu/yr). See Section 6 for more details on the first-year statewide impacts calculated by the Statewide CASE Team.

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[1] Note that the incremental cost of $1,008 per plenum return fan is specific to the cost of improving a plenum return fan to achieve an FEI of 1.0 on one floor of the large office prototype. As explained in Section 5.3.1, the shipment-weighted cost for all non-compliant fans to comply with FEI within the scope of this measure is significantly less at $199. (Statewide CASE Team 2018)

Section 4 contains details on the per-unit energy savings calculated by the Statewide CASE Team.

Table 2: First-Year Statewide Energy and Impacts

Measure	Electricity Savings (GWh/yr)	Peak Electrical Demand Reduction (MW)	Natural Gas Savings (MMtherms/yr)	TDV Energy Savings (million TDV kBtu/yr)
Fan Power Budget (Total)	**108.9**	**32.7**	**(0.7)**	**3,039.0**
New Construction	31.1	9.4	(0.2)	870.7
Additions and Alterations	77.8	23.3	(0.5)	2,168.3
FEI (Total)	**1.7**	**0.2**	**(0.0)**	**46.6**
New Construction	0.5	0.1	(0.0)	14.2
Additions and Alterations	1.2	0.1	(0.0)	32.4
Duct Leakage (Total)	**43.4**	**9.1**	**0.6**	**1,373.0**
New Construction	16.5	3.5	0.2	523.2
Additions and Alterations	26.9	5.7	0.4	849.8

Table 2 shows the projected significant savings from the fan power budget measure. These savings were modeled from twelve of the Energy Commission prototype buildings and are a function of 1) reduced fan power due to the fan power budget standard methodology, and 2) an expansion of the lower threshold from 5 nameplate HP to 1 kW. The latter led to significant savings as there are many fan systems between 1 kW and 5 nameplate HP which were previously not subject to the fan power limitations. Electricity savings per fan system in the CEC prototype buildings modeled ranged from 12 percent to 34 percent, leading to ~2 percent electricity savings per building. However, natural gas usage is expected to increase slightly due to less fan motor heat gain. The savings from the FEI measure is more modest, due to the scope of the measure.

The projected energy savings from the duct leakage submeasure are also quite significant, at approximately half the savings of the fan power budget submeasure. The projected savings are from reduced HVAC energy use due to less air needing to be circulated on both the supply and exhaust side when the ducts are tighter.

Table 3 presents the estimated avoided GHG emissions associated with the proposed code change for the first year the standards are in effect. Avoided GHG emissions are measured in metric tons of carbon dioxide equivalent (metric ton CO2e). Assumptions used in developing the GHG savings are provided in Section 6.2 and Appendix C of this report. The monetary value of avoided GHG emissions is included in TDV cost factors and is thus included in the cost-effectiveness analysis.

Table 3: First-Year Statewide GHG Emissions Impacts

Measure	Avoided GHG Emissions (Metric Ton CO2e/yr)	Monetary Value of Avoided GHG Emissions ($2023)
Fan Power Budget	22,582	$677,455
Fan Energy Index	375	$39,875
Duct Leakage	13,943	$1,480,701
Total	36,900	$2,198,031

Water and Water Quality Impacts

The proposed measure is not expected to have any impacts on water use or water quality, excluding impacts that occur at power plants.

Overview of Compliance Process

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process would have on various market actors. The compliance process is described in Section 2.5. Impacts that the proposed measure would have on market actors is described in Section 3.3 and Appendix E. The key issues related to compliance and enforcement are summarized below:

- The fan power budget compliance process would largely mirror the existing process for determining compliance with the fan power limitations.
- A key compliance issue would be for plans examiners to determine whether the designer calculated the correct fan power budget value for each fan system covered by the code, which is now proposed to be a function of air flow, system type, and components.
- The sum of the actual fan system electrical input power is required to be less than that of the fan power budget for each fan system. Plans examiners would be required to verify that the fan input power is determined through one of the four methods in the code. This should be noted in the NRCC-MCH-E forms.
- Designers would need to ensure ≥ 1 kW in-scope fans are being selected at duty points with an FEI ≥ 1.0 and plans examiners would need to verify this on the plan sets and NRCC-MCH-E forms.
- Designers already have to specify maximum permitted leakages and seal classes to be met by mechanical contractors and building owners or their representatives

already need to select sections of ductwork to be leak tested. This proposal mandates a single seal class for all ductwork, which should not impact the work of the designer, and specifies clear parameters for selecting ductwork to be tested, which would help standardize the procedure.

- Additional compliance documentation would be required, because it does not exist currently for the CMC requirements.

Field Verification and Acceptance Testing

The existing fan power limitation standards do not require field verification or acceptance testing, nor would the fan power budget or FEI submeasure. Instead, compliance would be determined during permit review. If duct leakage testing is incorporated into Title 24, Part 6, it requires adding an acceptance testing procedure and field verification to support the existing testing requirements in the CMC. See Section 2.5 for more information.

1. Introduction

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The overall goal of this Final CASE Report is to present a code change proposal for high performance ducts and fan systems, which 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 a number of industry stakeholders including manufacturers, mechanical designers, contractors, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during a public stakeholder workshop that the Statewide CASE Team held on November 5, 2019 (Statewide CASE Team 2019) and March 12, 2020 (Statewide CASE Team 2020).

The following is a brief summary of the contents of this report:

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

- Section 3 –In addition to the Market Analysis section, this section includes a review of the current 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 – Energy Savings presents the per-unit energy, demand reduction, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate per-unit energy, demand reduction, and energy cost savings.
- Section 5 – This section includes a discussion and presents analysis of the materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs, i.e., equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.
- Section 6 – First-Year Statewide Impacts presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2022 code takes effect. This includes the amount of energy that would 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 by the state of California. Statewide water consumption impacts are also reported in this section.
- Section 7 – Proposed Revisions to Code Language 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.
- Section 8 – Bibliography presents the resources that the Statewide CASE Team used when developing this report.
- Appendix A: Statewide Savings Methodology presents the methodology and assumptions used to calculate statewide energy impacts.
- Appendix B: Embedded Electricity in Water Methodology presents the methodology and assumptions used to calculate the electricity embedded in water use (e.g., electricity used to draw, move, or treat water) and the energy savings resulting from reduced water use.
- Appendix C: Environmental Impacts Methodology presents the methodologies and assumptions used to calculate impacts on GHG emissions and water use and

quality.

- Appendix D: California Building Energy Code Compliance (CBECC) Software Specification presents relevant proposed changes to the compliance software (if any).
- Appendix E: Impacts of Compliance Process on Market Actors presents how the recommended compliance process could impact identified market actors.
- Appendix F: Summary of Stakeholder Engagement documents the efforts made to engage and collaborate with market actors and experts.
- Appendix G: FEI Energy Savings Calculation presents additional detail for how energy savings were calculated for the FEI submeasure.
- Appendix H: Duct Costing Details presents greater detail duct costing methodology for the Fan Power Budget submeasure.
- Appendix I: Duct Leakage Calculation shows methodology for calculating the baseline and proposed cases for the duct leakage submeasure.
- Appendix J: Supplemental Energy Savings Impacts Tables presents additional energy savings impacts savings for other building prototypes modelled.
- Appendix K: Supplemental Energy Cost Savings Tables presents additional cost savings for other building prototypes modelled.
- Appendix M: Nominal Energy Savings Tables will present the energy cost savings in nominal dollars by building type and climate zone.
- Appendix N: Fan Power Budget Methodology will show the methodology used to determine the fan power allowances and fan power budget.

2. Measure Description

2.1 Measure Overview

Air distribution systems in nonresidential buildings use a significant amount of energy. According to the United States Department of Energy (U.S. DOE), ventilation systems in commercial buildings use roughly 1.54 quadrillion British thermal units (i.e., quads) of primary energy consumption nationally, or roughly 1.5 percent of energy nation-wide (including transportation, natural gas usage, etc.) (Department of Energy 2017).

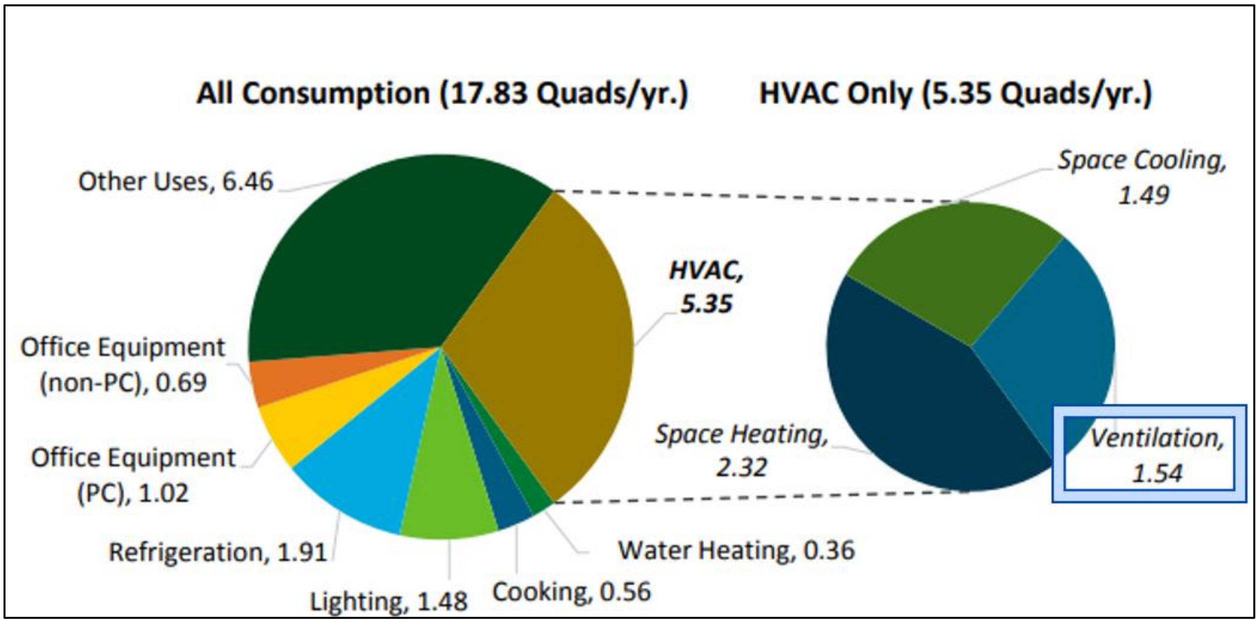

Figure 1: U.S. commercial primary energy consumption.

Source: (Department of Energy 2017)

At a fundamental level, there are a few ways to reduce fan electrical input power in building air distribution systems as shown by Equation 1.

Equation 1: Fan Electrical Input Power Equation

$$Fan\ electrical\ input\ power = \frac{Flow \cdot Pressure}{6343 \cdot \eta_{fan} \cdot \eta_{tran} \cdot \eta_{motor}}$$

This Final CASE Report proposes three submeasures to target each of these variables. To reduce fan electrical input power a fan system must:

1. Reduce the *pressure* the fan must overcome (Fan Power Budget)
2. Improve fan *(η_{fan})*, motor *(η_{motor})*, and transmission *(η_{tran})*, efficiency (Fan Power

Budget/Fan Energy Index)

3. Minimize the *flow* (Duct Leakage)

These proposed submeasures, their applicability and descriptions are shown below in Table 4 and explained in further detail in the following sections.

Table 4: Submeasure Summary

Measure Component	Type of Code Change	New Construction	Additions	Alterations
Fan Power Budget	Prescriptive	X	X	X
Fan Energy Index	Mandatory	X	X	X
Duct Leakage	Mandatory	X	X	X

2.1.1 Fan Power Budget

The fan power budget submeasure would update the current methodology used to calculate prescriptive fan power limitations for fan systems. The submeasure would expand the current scope from all space conditioning fan systems ≥ 5 nameplate HP to ≥ 1 kW (which is roughly 1 nameplate HP). The submeasure would create new, clear definitions for fan systems as the fan power budget would apply separately to supply fan systems and to return/relief/exhaust fan systems.[2] Each fan system would be allocated a fan power budget (kW) as function of the airflow (cfm), system type, and components in the fan system. The fan power budget submeasure would apply to new construction, alterations and additions. As a prescriptive measure it would require changes to the Alternative Calculation Method (ACM) Reference Manual and the compliance software. It should be noted there is a similar proposal being proposed for consideration as an addendum to American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 90.1-2019 (ASHRAE 90.1-2019). At the time the Final CASE Report was posted for public review, the proposal is being discussed within the ASHRAE 90.1 mechanical subcommittee.

2.1.2 Fan Energy Index

Fan Energy Index (FEI) is a straightforward metric to encourage mechanical designers to make fan selections closer to a fan's peak efficiency. The higher the FEI, the less power is consumed at a given duty point (airflow and pressure). FEI is a ratio of the input power of a reference fan and the actual fan at the same duty point. To learn more

2 The supply and return/exhaust side is currently treated as one fan system in Title 24-2019.

about FEI see the Air Movement and Controls Association's (AMCA) webpage on FEI here: https://www.amca.org/advocate/energy-efficiency/about-fan-energy-index/

The FEI submeasure would add a mandatory requirement that certain fans must be selected at an FEI of 1.0 or higher, similar to ASHRAE 90.1-2019, which includes FEI requirements in Section 6.5.3.1.3 (Fan Efficiency).[3] This submeasure would be mandatory and apply to new construction, and alterations and additions but only when a new fan system is being installed. Importantly, FEI would apply to a broad scope of fans than the fan power budget submeasure, such as fans that move unconditioned air. Additionally, as a mandatory submeasure, it would not require changes to the ACM Reference Manual and the compliance software.

2.1.3 Duct Leakage

This submeasure proposes three changes that would minimize air leakage in ducts, align requirements in the California Energy Code and the California Mechanical Code (CMC or Title 24, Part 4), and recommend specifications in support of the mandatory duct leakage testing requirements in the 2019 CMC. The third change could be incorporated into the CMC instead of Title 24, Part 6.

1. Add a mandatory requirement that all ductwork in all nonresidential buildings comply with Seal Class A (the highest degree of sealing) as defined by the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) HVAC Duct Construction Standards – Metal and Flexible (ANSI/SMACNA 2006). This would require sealing of all transverse joints, longitudinal seams, and duct wall penetrations. The proposal would align duct sealing requirements in Title 24, Part 6 with requirements that have been in ASHRAE 90.1 since the 2010 edition.
2. Move existing prescriptive duct leakage testing requirements for buildings under 5,000ft^2 to the mandatory section of Title 24, Part 6.
3. Clarify which sections of ductwork need to be tested, who should execute the testing, and what documentation is needed to demonstrate compliance with existing mandatory duct leakage testing requirements in the 2019 CMC. Clarify with existing mandatory duct leakage testing requirements in the 2019 CMC. The proposal would clarify and standardize which portions of the ductwork would be tested, ensuring that representative portions of all aspects of the system are tested. The following ductwork would be tested to verify the maximum leakage rates defined in the CMC and Title 24, Part 6 are not exceeded:
    - All ductwork that would become inaccessible, to avoid large potential

[3] The FEI requirements approved in ASHRAE as Addendum ao to ASHRAE 90.1-2016. The requirements are published in the 2019 version of ASHRAE 90.1.

mitigation costs if the system fails. This includes all vertical ductwork in shafts and all horizontal ductwork above hard ceilings.

- Supply-air systems upstream and downstream of terminal boxes. For example, in VAV systems 10 percent of the ductwork upstream of VAV valves and 10 percent of the ductwork downstream shall be tested.
- Exhaust systems, and when there are multiple exhaust systems at least two would be tested.
- The Statewide CASE Team is proposing that qualified technicians, certified as Testing, Adjusting, and Balancing (TAB) Technicians by the Associated Air Balance Council (AABC), the National Environmental Balancing Bureau (NEBB), or the Testing, Adjusting and Balancing Bureau (TABB) or as Duct Air Leakage Technicians by the International Certification Board (ICB) perform the testing.

Supporting the duct leakage testing requirement in the 2019 CMC will require coordination with the California Building Standards Commission and potentially other state agencies. At the time this Final CASE Report was published for public review, it is not certain if the revisions to clarify the testing requirements in the 2019 CMC would appear in Nonresidential Appendix 7 (NA7) to Title 24, Part 6 or as revisions to the code language in Section 603.1.10 in the CMC.

2.2 Measure History

2.2.1 Fan Power Budget

2.2.1.1 Fan Power Budget History and Context

Fan power allowances (i.e., watts/cfm) were introduced to Title 24, Part 6 in 1992 and served as the primary mechanism to encourage low pressure duct design and high efficiency fans. These requirements applied to fan systems with a combined nameplate horsepower (HP) over 25 HP. In 1998 the fan power adjustment factor was added to allow filters and other air treatment devices over one inch in water gauge (in. wg) pressure drop to be used without the penalty of added static pressure. Other smaller changes were made over the years, but most recently in the 2019 Title 24, Part 6 code cycle, which took effect January 1, 2020, California updated its fan power requirements based on the ASHRAE 90.1-2019 fan power limitations, which apply to all fan systems (including packaged HVAC equipment) with a combined motor nameplate over 5 HP.

The existing code (2019 Title 24, Part 6) limits the brake horsepower (BHP) or the motor nameplate HP of fan systems, as a function of airflow at the design conditions. There are different fan power limitations (i.e., equations) depending on whether the system is variable air volume (VAV) or a constant air volume (CAV) system. If a designer chooses to comply with the BHP method, several “adjustment credits” are available to allow filters and other air treatment devices over one in. wg pressure drop to be used without the penalty of added static pressure. However, if the motor nameplate method is used, no additional pressure adjustment credits are allowed.

The fan power limitations apply separately to each fan system, where a fan system consists of the fans that must function together to deliver conditioned air to a space and back to the source, or to exhaust air to the outdoors, such as a supply and exhaust fan. Some buildings have multiple fan systems, and the fan power limitations apply to each fan system.

It has been widely acknowledged that the design of the current code requirements is somewhat stringent on larger systems, but less stringent for smaller fan systems. An assumption about the pressure drop a fan must overcome and fan efficiency is built into the fan power limitations equation. Currently, the underlying total static pressure assumption in the fan power limitations is 5.35 in. wg for VAV fan systems and 3.85 in. wg for CAV systems, regardless of the fan system air flow or components. This has the effect of making it easy to meet the standard for smaller buildings with shorter duct runs with lower pressure drop, as compared to larger more complex buildings with longer duct runs (higher pressure drop).

Figure 2 and Figure 3 below show the assumed pressure drop in each fan system for VAV and CAV systems. These component level pressure assumptions were shared by the ASHRAE fan power working group and used by Statewide CASE Team when developing the Final CASE Report to propose adopting the ASHRAE 90.1-2019 fan power limitations approach for the 2019 code cycle The summation of these pressure drop assumptions are also found in default total static pressure assumptions used in the 2019 Title 24 compliance software (Statewide CASE Team 2017). The ASHRAE fan power working group also assumed fan efficiency would be 65 percent for all fan systems, for the purpose of the fan power limitations. Note the figures below are for illustration purposes only, meant to illustrate a generic air handler or packaged HVAC system.

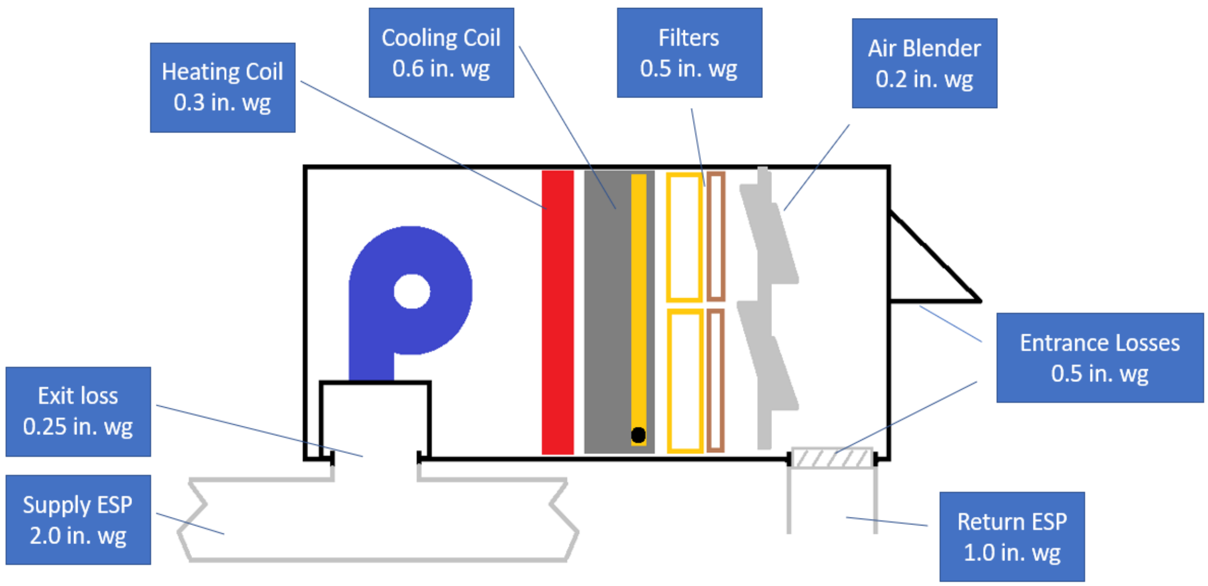

Figure 2: Title 24 pressure allowances for VAV Systems: 5.35 in. wg.

Source: Statewide CASE Team

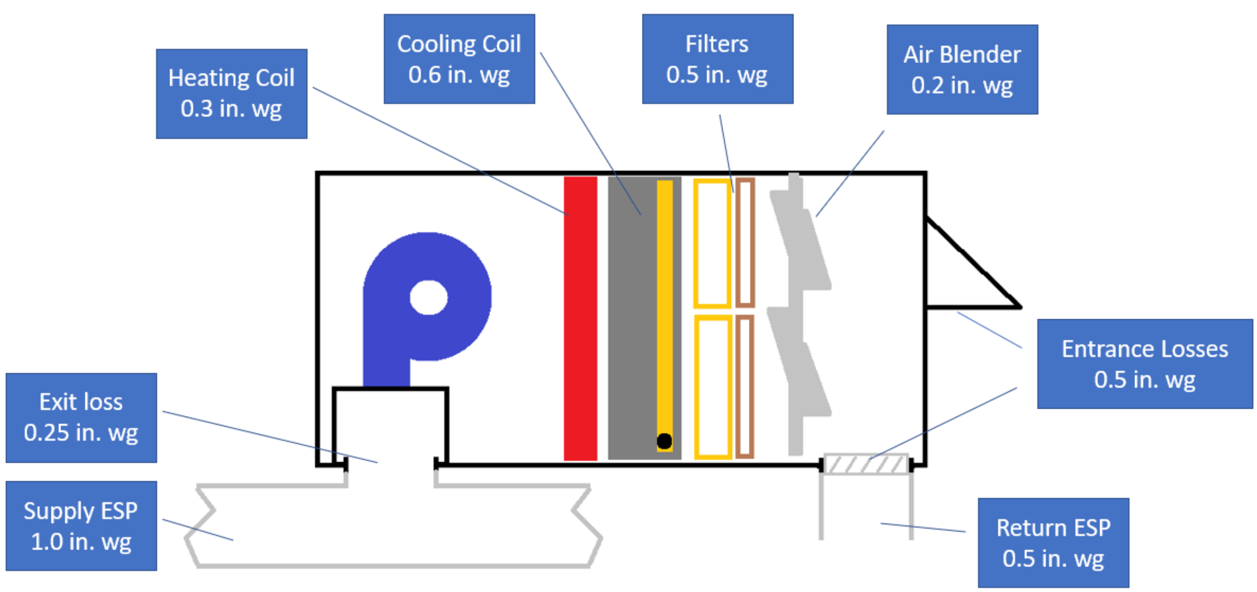

Figure 3: Title 24 pressure allowances for CAV systems: 3.85 in. wg.

Source: Statewide CASE Team

As can be seen in Figure 2 and Figure 3, pressure allowance is accounted for and provided for each component in the system whether the component exists or not in the real-world fan system. For example, a pressure allowance of 0.2 in. wg for an "air blender" is built into the assumption whether fan systems have an air blender or not.

Based on conversations with stakeholders, air blenders are rare in California and typically only used in climates with very cold conditions. However, in Title 24, Part 6, this pressure allowance is granted regardless. Furthermore, a significant allowance is made for the supply and return/exhaust external static pressure, or in other words, there is significant pressure allowance for the ductwork. The data in the figures above is shown in Table 5 below to highlight the pressure assumptions stemming from ductwork and inlet/outlet transitions to the air handler (or other HVAC equipment such as a rooftop packaged unit). The total pressure allowance from the ductwork (including inlet and outlet transitions) is 3.75 in. wg for VAV systems and 2.25 in. wg for CAV systems.

Table 5: Underlying Pressure Assumptions for 2019 Title 24, Part 6 Requirements (in. wg)

Assumed Basic Components	Pressure Assumptions - Variable Air Volume System (in. wg)	Pressure Assumptions – Constant Volume System (in. wg)
Return/Exhaust External Static Pressure	1	0.5
Air Blender	0.2	0.2
Inlet/Mixed Air Section	0.5	0.5
Pre-Filter	0.5	0.5
Heating coil	0.3	0.3
Cooling coil	0.6	0.6
Outlet Transition	0.25	0.25
Supply External Static Pressure	2	1
Total Pressure	5.35	3.85
Total External Static Pressure from Ductwork/Inlets/Outlets	3.75	2.25

Source: (Statewide CASE Team 2017), Title 24 Part 6 (2019)

These total pressure assumptions shown in Figure 2 and Figure 3 are the underlying pressure values that combined with a 65 percent efficient fan, and the constant “6343” that yield the constants in the current fan power limitation standards. For example, Equation 2 shows how BHP is calculated for a fan.

Equation 2: Fan BHP equation

$$Fan\ BHP = \frac{Flow\ (cfm) \cdot Pressure\ (in.wg)}{6343 \cdot \eta_{fan}}$$

Equation 3 below shows VAV total pressure assumption from Table 5 (5.35 in. wg) and a 65 percent efficient fan into the BHP equation.

Equation 3: Title 24, Part 6 Fan power limitation equation (VAV) with assumptions

$$Fan\ power\ limiation\ (BHP)\ \leq \frac{Flow\ (cfm)\ \cdot\ 5.35\ in.wg}{6343\ \cdot\ 65\%}$$

Finally, when solved and simplified, the result is the current fan power limitation equation (for VAV systems using the BHP method) as shown in Equation 4, which matches the language in Title 24, Part 6 Section 140.4(a). Note this does not show the added adjustment factor from additional pressure allowances.

Equation 4: Title 24, Part 6 Fan power limitation equation (VAV)

$$Fan\ power\ limitation\ (BHP)\ \leq Flow\ (cfm) \cdot 0.0013$$

Equation 4 above represents the BHP method for VAV systems. The other option to comply with the fan power limitations is the “fan system motor nameplate HP” method. Here, instead of comparing the BHP of the fan system to the fan power limitation, a user can simply sum the fan motor nameplate values to comply with the fan power limitation. The motor nameplate method makes assumptions about motor efficiency, but the other underlying assumptions are the same. The current fan power limitations in effect in the Title 24, Part 6 code are shown below in Table 6.

Table 6: Current Standards- Table 140.4-A Fan Power Limitations

	Limit	Constant Volume	Variable Volume
Option 1: Fan system motor nameplate hp	Allowable motor nameplate hp	hp ≤ cfms x 0.0011	hp ≤ cfms x 0.0015
Option 2: Fan system bhp	Allowable fan system bhp	bhp ≤ cfms x 0.00094 + A	bhp ≤ cfms x 0.0013 + A
1cfms = maximum design supply airflow rate to conditioned spaces served by the system in cubic feet per minute hp = maximum combined motor nameplate horsepower for all fans in the system bhp = maximum combined fan-brake horsepower for all fans in the system A = sum of (PD x cfmD/4131) PD = each applicable pressure drop adjustment from Table 140.4 – B, in inches of water cfmD = the design airflow through each applicable device from Table 140.4 – B, in cubic feet per minute			

Source: (California Energy Commission 2019)

As noted, an important difference between the BHP and motor nameplate methods, is that that various additional pressure allowances for different devices are made available in Table 140.4-B if the BHP method is used. These pressure allowances are for less common components such as energy recovery systems, unique air filters and more. These pressure allowances have the effect of allowing the fan system to use more power. In general, based on conversations with stakeholders, if a fan system is fairly simple (or small) the nameplate HP method is often used, whereas the BHP method is used for often for more complex systems with devices listed in Table 7.

Table 7: Current Standards- Table 140.4-B Fan Power Limitation Pressure Drop Adjustment

Device	Adjustment Credits
Return or exhaust systems required by code or accreditation standards to be fully ducted, or systems required to maintain air pressure differentials between adjacent rooms	0.5 in. of water
Return and/or exhaust airflow control devices	0.5 in. of water
Exhaust filters, scrubbers, or other exhaust treatment	The pressure drop of device calculated at fan system design condition
Particulate Filtration Credit: MERV 16 and greater and electronically enhanced filters	Pressure drop calculated at 2 x clean filter pressure drop at fan system design condition
Carbon and other gas-phase air cleaners	Clean filter pressure drop at fan system design condition
Biosafety cabinet	Pressure drop of device at fan system design condition
Energy recovery device, other than coil runaround loop	For each airstream [(2.2 x Energy Recovery Effectiveness) – 0.5] in. of water
Coil runaround loop	0.6 in. of water for each airstream
Exhaust systems serving fume hoods	0.35 in. of water

Source: (California Energy Commission 2019)

The current structure of the fan power limitations is well understood by mechanical designers, manufacturers and compliance/enforcement officials, as they have been in existence around the country for many years. There are benefits and drawbacks of the current standard, which are summarized below:

Benefits of current fan power limitation approach:

- Simplicity: The equations are straightforward, as there are only four options to determine compliance depending on if the fan system is variable volume or constant volume and if the nameplate HP or BHP method is used.

- Familiarity: The fan power limitations are familiar to mechanical designers, manufacturers and compliance officials.
- Flexibility: There is inherent flexibility for designers to choose either an improved fan system or ductwork to achieve the desired fan power. It is not overly prescriptive how fan power should be reduced.
- Enforcement: A plans examiner or inspector can fairly easily verify total the nameplate HP of the fans in the field to determine whether the fan system complies, if the nameplate method is used.

Drawbacks of current fan power limitation approach:

- Limited energy savings: The current structure of the existing fan power limitations essentially provides a large power budget, as it assumes a large fan system with significant pressure. (5.35 and 3.85 in. wg is a significant amount of total static pressure for most fan systems, especially considering 3.75 and 2.25 in. wg, respectively, are estimated to be external static pressure.) The effect is that fan power limitations are very easy to meet for smaller and medium size fan systems.
- Transmission efficiency: In the current code, there is no incentive to select more efficient transmission system such as direct-drive over belt driven fan systems, as only fan brake-HP or motor nameplate HP are considered.
- Definitions: The current definitions are vague, and do not clearly denote what is a fan system and how the fan power limitations should apply.
- Air density: The existing approach does not account for changes in air density as a function of elevation.

Based on the reasons listed above, the Statewide CASE Team determined there was an opportunity to save energy by reforming the existing fan power limitation standards. Therefore, in this Final CASE Report, the Statewide CASE Team is proposing a new “fan power budget” requirement, designed to replace the fan power limitations, focusing on the opportunity to save energy through highly efficient fan systems with lower pressure duct systems. This measure is partially inspired by a 2015 ASHRAE-1651 research project which demonstrated that better duct design and duct component selection, can reduce system pressure and lead to significant fan energy savings (Glazer 2015). The new fan power budget methodology builds upon the framework of the existing fan power limitations but includes a number of key changes to realize greater energy savings from all types and sizes of fan systems. These key changes from the fan power limitations to the fan power budget are listed below:

- Change the metric from fan BHP or motor nameplate HP to fan electrical input power to capture transmission and motor efficiency losses. The fan power budget electrical input power calculation is largely based on AMCA-208-18. (AMCA 2018)
- Create new definitions for various fan systems including:
    - Supply-only and single-cabinet fan systems
    - Exhaust, return, and relief fan systems
    - Complex fan systems
    - Transfer fan systems
- Require that fan power budget calculation must be performed separately for each fan system.
- A fan power budget (kW) as a function of airflow (cfm), system type, and the various components in each fan system.
- Expand the scope of fan systems covered by code from 5 motor nameplate HP to 1 kW fan electrical input power.[4]
- Include transmission and motor efficiency to incentivize more efficient motor and transmission selections.
- Remove the healthcare exemption, meaning fan systems in healthcare facilities would be subject to fan power budget requirements for the first time, though additional fan power allowances are available to healthcare facilities.

The methods to determine fan power budget and fan system input power are summarized below. At a high level for each fan system ≥ 1 kW a fan power budget is calculated, and the total fan system input power must be less than the fan power budget to comply. Actual draft code language can be found in Section 7.2.

2.2.1.2 Determining Fan Power Budget

To determine fan power budget (Fan kW_{budget}) for each fan system, a user needs to take the following steps:

1. **Determine the type of fan system:** Using the new fan definitions, determine the type of fan system (Supply-only, single-cabinet, exhaust, return, relief, complex or transfer) that is to comply with the fan power budget.

[4] Note a fan with 1 kW electrical input power can be found in HVAC packaged equipment as small as 3 tons, depending on pressure.

2. **Determine fan system airflow.** Based on the type fan system, the determine the airflow to be used to calculate the fan power budget. Note that Section 140.4-B provides guidance on how to determine the airflow based on the type of fan system. For example, for purposes of determining the fan power budget, supply-only fan systems shall use the airflow at fan system design conditions whereas relief fan systems shall use the design relief airflow.
3. **Sum the fan power allowances (watts/ cfm).** For each fan system, add all the fan power allowances in Tables 140.4-A and 140.4-B as appropriate. Fan power allowances for each component vary by system type (multi-zone VAV vs CV/ single-zone VAV) and by airflow. Each fan system is allocated a "base allowance" plus any allowance from different devices/ components (such as HEPA filters, heating coils, etc.) The fan power allowances are determined based on assumed pressure drop of various components. These pressure drops and the calculation methodology to determine the fan power allowances are documented in Appendix N.
4. **Calculate the fan power budget.** For each fan system, multiply the sum of the fan power allowances (watts/ cfm) (Step 3) by the fan system airflow (Step 2), including dividing by 1000 to get to convert from watts to kW. This is the fan power budget (Fan kW_{budget}) for the given fan system.

The performance approach would similarly calculate the fan power budget for each fan system, based on the approach described above. The energy modeler would need to select the type of fan system, the airflow and which components are part of the fan system for the fan power budget to be determined. This is described in greater detail in Section 7.4.

2.2.1.3 Determining Fan System Input Power

The Statewide CASE Team proposes that four methods be allowed to determine fan input power (Fan $kW_{design,system}$) for each fan system, and that multiple methods could be used for a given fan system if needed:

1. **Calculated using default values in Table 140.4-E (Proposed).** This approach would rely on a lookup table that provides default fan electrical input powers (with and without a motor controller) based on fan motor nameplate HP. This would allow a designer or compliance official to simply sum the motor nameplate HP of all fans in the system to determine total fan electrical input power. The Statewide CASE Team developed the lookup table assuming motor efficiencies that align with minimum U.S. DOE motor efficiency. While this method is simple to use, it is conservative, as credit for high efficiency motors and transmissions (e.g., direct drive) is not possible. In certain cases, another option (as shown below) may

yield a lower electrical input power and be preferable to use, especially if the fan system is close to not complying with the fan power budget.

2. **Provided by manufacturer at design conditions.** The broader HVAC industry is moving towards providing fan input power at design conditions.[5] Similar to how fan manufacturers provide BHP to designers today for use in calculating compliance with the fan power limitations, fan manufacturers are already moving towards providing fan electrical input power at design conditions. This is in part a result of manufacturers starting to publish FEI values per AMCA 208, and the expected adoption of ASRHAE 90.1-2019 by code setting bodies around the country. See Section 7.3 for more details.
3. **Calculated according to methods in Section 5.3 of ANSI/AMCA 208 at design conditions.** This method is the least likely to be used, as it requires more manual calculation by the designer. However, the Statewide CASE Team recognizes the methods in Section 5.3 of ANSI/AMCA 208 are well regarded as accurate methods to determine fan input power and are inclusive of industry recognized procedures for estimating motor and transmission efficiency.
4. **Marked motor maximum electrical input power.** This method is also unlikely to be used often but provides a method for determining input power into the fan motor, should other methods not be available. For motors with maximum electrical input power marked on the nameplate, this value can be used, but would likely be higher relative to how the motor is loaded under design conditions, thus is very conservative.

The Statewide CASE Team recommends users be allowed to mix methods when determining fan electrical input power for a fan system with more than one fan. For example, imagine there is a two-fan system where the supply fan is from a manufacturer that provides fan electrical input power from their selection software, but the return fan is from another manufacturer that does not provide fan electrical input power from their software. In this case, the mechanical designer determining code compliance would likely use the nameplate HP look-up method for the return fan but could use the more accurate input kW value from manufacturer for the supply fan. This would have the benefit of providing a more accurate fan system input power, while allowing flexibility.

[5] AHRI 430, the rating method for central station air handlers recently moved to input power (kW) from BHP.

2.2.2 Fan Energy Index

This submeasure proposes to implement a new efficiency metric in the Title 24, Part 6 code language by requiring certain fans meet a minimum FEI at the design conditions. FEI addresses a longstanding problem in characterizing fan efficiency; a fan's peak efficiency is often poorly correlated with its actual efficiency in typical operating conditions. The FEI metric is an easy method to encourage mechanical designers to make fan selections closer to a fan's peak efficiency, where the higher the FEI, the less energy is consumed. More efficient fans generally have a larger compliant operating range than less efficient fans as shown below Figure 4.

To learn more about FEI, instructional videos and more, see AMCA's informational webpage: https://www.amca.org/advocate/energy-efficiency/about-fan-energy-index/

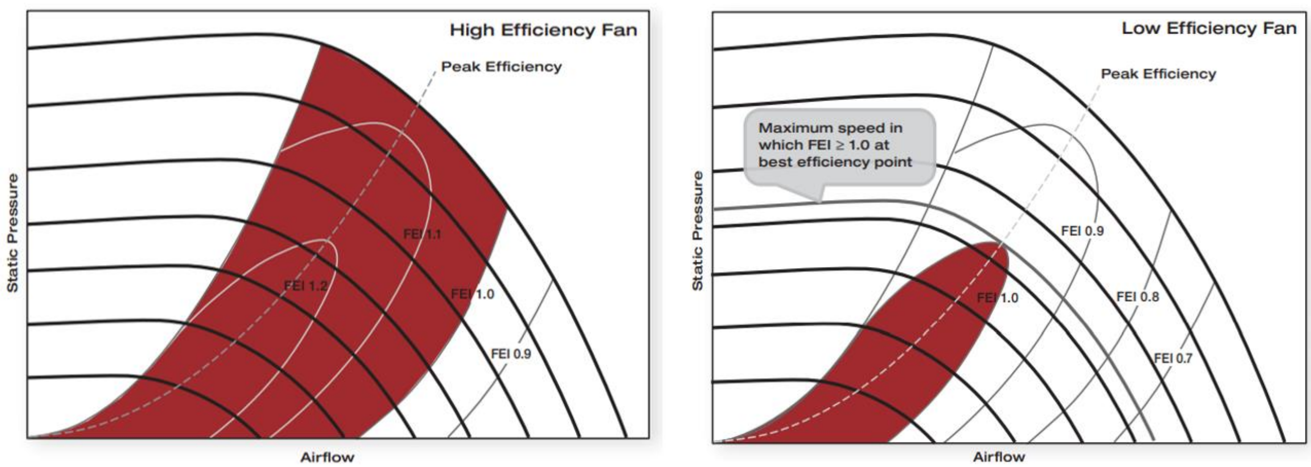

Figure 4: High and low efficiency fans with FEI ratings.

Source: (AMCA 2016)

This submeasure is largely based on the recently adopted Addendum ao to ASHRAE Standard 90.1-2016 which sets a FEI of 1.0 for most fans generally not embedded in packaged equipment. In other words, FEI would primarily apply to supply, return, exhaust fans, etc., but exempts most packaged equipment such as rooftop units. ASHRAE 90.1 also allows a lower FEI of 0.95 for variable air-volume fans. Addendum ao was officially adopted into the ASHRAE 90.1-2019 in late 2019 and identical language was also adopted in the International Energy Conservation Code (IECC)-2022 model building code. The Statewide CASE Team proposes to largely adopt this language with a few changes, briefly noted below. The full draft code language can be found in Section 7.2.

- Removes the lower FEI requirement for VAV systems of 0.95 and sets the FEI requirement at 1.0 across all fan types regardless of whether in variable or constant volume applications

- Adds a clarification and new definition to clarify FEI requirement applies at design conditions
- Removes “exemption #4” to the FEI standard in ASHRAE 90.1-2019 which exempts embedded fans if they are in “equipment bearing a third-party-certified seal for air or energy performance of the equipment package”. The Statewide CASE Team determined an exemption based on seal of “air or energy performance” could create a loophole for manufacturers looking to exempt their equipment from FEI requirements. Furthermore, based on the Statewide CASE Team analysis, in practice this would have the effect of covering additional large air handlers that are currently exempt due to being certified to AHRI-430: Performance Rating of Central Station Air-handling Unit Supply Fans (AHRI 2014), where cost-effective savings are possible.
- Adds language to require third-party certification of FEI values in catalogs and selection software
- Simplifies other exemptions to be clearer to designers and enforcement officials

FEI is an efficiency metric created by the AMCA, an organization that sets standards for commercial and industrial air movement equipment. The metric and subsequent standards to develop FEI ratings were pursued in collaboration with the U.S. DOE and energy efficiency advocates (including the Statewide CASE Team).

In 2019, a proposal was put forward by AMCA to replace the Fan Efficiency Grade (FEG) metric, with the FEI metric, in ASHRAE 90.1, as FEI was ultimately determined to be a superior metric for saving energy in fan systems. (Note: California never adopted the FEG into Title 24, Part 6, though it was briefly considered during the 2016 code cycle.) ASHRAE Addendum ao, which replaced FEG with FEI, was officially adopted in late 2019, and incorporated into ASHRAE 90.1-2019.)

2.2.3 Duct Leakage

2.2.3.1 Seal Class Requirements

Section 603.10 of the 2019 CMC states that joints and seams of ductwork shall comply with SMACNA HVAC Duct Construction Standards – Metal and Flexible (ANSI/SMACNA 2006), which defines sealing classes for ducts. As summarized in Table 8, the seal classes vary depending on the joints and seams that are sealed and the design pressure of the ductwork. Seal Class A is the most stringent sealing class, requiring that all transverse joints, longitudinal seams, and duct wall penetrations be sealed. The SMACNA construction standard recommends Seal Class A for ducts that operate at 4 in. wg or higher and the 2019 CMC requires compliance with the SMACNA construction standards.

Table 8: Seal Classes and Applicable Pressure for Indoor Ductwork from SMACNA HVAC Duct Construction Standards – Metal and Flexible

Seal Class	C	B	A
Sealing Applicable	Transverse joints only	All transverse joints and longitudinal seams only	All transverse joints, longitudinal seams, and duct wall penetrations.
Applicable Pressure Class	2 in. wg; any variable air volume systems duct of 1 in. wg and ½ in. wg construction class that is upstream of the VAV boxes	3 in. wg	4 in. wg and up
Proposed Applicable Pressure Class	NA	NA	All

Source: (ANSI/SMACNA 2006)

ASHRAE 90.1 and IECC have included requirements that all ductwork be sealed since the 1999 and 2000 versions, respectively. IECC-2000 Section 503.3.3.4.2 states: "All longitudinal and transverse joints, seams and connections of low-pressure supply and return ducts shall be securely fastened and sealed… " which is equivalent to Seal Class B, see Table 8 (International Code Consortium 2000). ASHRAE 90.1-2004 Section 6.4.4.2.1 has analogous language: "Ductwork and plenums shall be sealed in accordance with Table 6.4.4.2A…" see

for the relevant table (ASHRAE 2004).

Table 9: Table 6.4.4.2A from ASHRAE 90.1-2004

Duct Location	Supply ≤ 2 in. wg.	Supply >2 in. wg.	Exhaust	Return
Outdoor	A	A	C	A
Unconditioned Spaces	B	A	C	B
Conditioned Spaces	C	B	B	C

Source: (ASHRAE 2004)

Duct sealing requirements were strengthened for ASHRAE 90.1-2010 in which Section 6.4.6.4.2.1 required, “Ductwork and all plenums with pressure class ratings shall be constructed to Seal Class A.” Sealing that would void product listings is not required and neither is sealing for spiral lock seams (ASHRAE 2010). Pressure class rating refers to the static pressure that ductwork is able to withstand under normal conditions at a specified temperature. Typically, all metal ductwork in an air distribution system has a pressure class rating. The proposed code changes would align Title 24, Part 6 requirements with ASHRAE 90.1 in requiring Seal Class A for all ductwork regardless of design pressure.

2.2.3.2 Duct Leakage Limits and Duct Leakage Testing

ASHRAE 90.1 and IECC both include maximum leakage limits for ductwork designed to operate at high pressure (above 3.0 in. wg and equal to or above 3.0 in. wg, respectively), and require testing to verify the maximum leakage rates are not exceeded. The maximum leakage rates in ASHRAE 90.1-2019 and IECC-2018 are defined in Equation 5. Both model codes require tested ductwork to not exceed a leakage class of four cfm/100ft^2 of duct surface area per (in. wg)$^{0.65}$. This is the maximum leakage class for rectangular ductwork that meets Seal Class A – see Table 10. The SMACNA Air Duct Leakage Manual gives equivalences between seal classes and leakage class – essentially the maximum amount that ductwork should leak if it is sealed in accordance with seal class requirements. These equivalencies are shown in Table 10.

Equation 5: Maximum Permitted Leakage in ASHRAE 90.1-2016

$$L_{max} = C_L P^{0.65}$$

Source: (ASHRAE 2016)

Where

L_{max} = maximum permitted leakage, (cfm per 100 ft^2 of duct surface area)

C_L = four, duct leakage class, (cfm per 100 ft^2 of duct surface area) per (in. of water)$^{0.65}$

P = test pressure, which shall be equal to the design duct pressure class rating (in. of water)

Table 10: Maximum Leakage Class for Each Seal Class - SMACNA HVAC Air Duct Leakage Manual (ANSI/SMACNA 2012)

Seal Class	C	B	A
Leakage class for rectangular/oval ductwork (cfm/100ft^2) per (in. wg.)$^{0.65}$	16	8	4
Leakage class for round ductwork (cfm/100ft^2) per (in. wg.)$^{0.65}$	8	4	2

Duct leakage testing requirements were introduced for Title 24, Part 6 for the 2001 code cycle. The requirements, which have not been updated since introduced, require that the entire air distribution system in nonresidential buildings with constant volume systems serving less than 5,000ft^2 conditioned area that have a significant portion of ductwork in unconditioned or outdoor space be tested to confirm that leakage does not exceed six percent of nominal air handler airflow. This is for simple systems and includes the leakage of all components, including the air handler. In the case of altered existing duct systems that meet the above criteria, the entire system must not exceed of leakage of 15 percent.

The maximum duct leakage and duct leakage testing requirements in Title 24, Part 6 are prescriptive so designers that choose to comply using the performance approach do not have to pursue the duct leakage testing requirements. As described below, the 2019 CMC includes a mandatory requirement that all nonresidential buildings confirm maximum leakage rates with a duct leakage test. To align the duct leakage requirements in Title 24, Part 6 and the CMC, the Statewide CASE Team proposes to reference the CMC mandatory duct leakage requirement and move the existing prescriptive requirements to a new mandatory section – Section 120.4(g).

There are now requirements in both the Uniform Mechanical Code (UMC – 2018) and the 2019 CMC (Section 603.10.1) that apply to all nonresidential buildings and require testing of representative sections of ducts totaling not less than 10 percent of the total installed duct area, with permitted leakage class six – note that this is a less stringent leakage requirement than in ASHRAE 90.1 or IECC. This sets an important minimum threshold for the amount of ductwork that must be tested and maximum permitted leakage threshold across all ductwork regardless of design pressure. The International Association of Plumbing and Mechanical Officials Technical Committee (UMC voting body) stated in a response to comments that the 10 percent of installed duct area that is tested should be representative sample of all ductwork, regardless of design pressure, (IAPMO 2019). This is important to emphasize given that the testing requirements in ASHRAE 90.1 and IECC have focused on testing higher pressure class and outdoor ductwork.

The CMC states: “Sections shall be selected by the building owner or designated representative of the building owner.” While the Statewide CASE Team understands the importance of the building owner being satisfied with the performance of the air distribution system, from an energy savings perspective, it is also important that testing be standardized across all projects so that all systems are meet the same standard.

The proposed code changes would provide specifications as to which parts of the ductwork system will need to have representative portions tested with the goal of ensuring that representative portions of all aspects of the system are tested while providing flexibility as to when the testing occurs. The Statewide CASE Team is proposing that for VAV systems, 10 percent of the ductwork upstream of VAV valves and 10 percent of the ductwork downstream shall be tested to balance out the previously mentioned focus on high pressure ductwork. Studies have found an average of 10 percent leakage downstream of VAV boxes, with a variation of close to 50 percent. This supports the need to also test low pressure ductwork (Modera, Wray and Dickerhoff 2014). The Statewide CASE Team is proposing that the following ductwork be tested:

- All ductwork that would become inaccessible, to avoid large potential mitigation costs if the system fails. This includes all vertical ductwork in shafts and all horizontal ductwork above hard ceilings.
- Supply-air systems upstream and downstream of terminal boxes
- Exhaust systems, and when there are multiple exhaust systems at least two would be tested

2.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manuals, and compliance documents would be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.1 Summary of Changes to the Standards

This proposal would modify the following sections of Title 24, Part 6 as shown below. See Section 7.2 of this report for marked-up code language.

Section 100.1(b) – Definitions: Recommends new or revised definitions for the following terms:

"air curtain fan" – The purpose of adding this definition is to classify what constitutes an air curtain fan. It is necessary in order to exclude these types of fans from the FEI requirements.

“AHRI 430” – The purpose of adding this definition is to provide a reference to a standard that provides electrical input power for air handlers. (Draft in progress)

“AHRI 440” – The purpose of adding this definition is to provide a reference to a standard that provides electrical input power for fan coil units.

AMCA – The purpose of adding this definition is to provide a reference to an organization, Air Movement and Controls Association, that creates fan and air movement standards.

“ANSI/AMCA 208” – The purpose of adding this definition is to provide a reference to a standard that provides the rating method for FEI.

“ANSI/AMCA 210” – The purpose of adding this definition is to provide a reference to a standard that provides a method to determine the air power provided by a fan.

“ANSI/ASHRAE 84” – The purpose of adding this definition is to provide a reference to a standard that provides the energy recovery ratios of heat and energy recovery equipment.

"ceiling fan” – The purpose of adding this definition is to classify what constitutes a ceiling fan. It is necessary in order to exclude these types of fans from the FEI requirements.

"circulating fan” – The purpose of adding this definition is to classify what constitutes a circulating fan. It is necessary in order to exclude these types of fans from the FEI requirements.

“duct wall penetrations” – The purpose of adding this definition is to classify what constitutes a duct wall penetration. This is necessary in order to standardize what type of openings must be sealed to be compliant with seal class A.

“fan electrical input power” – The purpose of adding this definition is to provide a general definition that describes the electrical input power needed to operate a fan at design conditions. It is necessary in order to determine a compliant FEI.

“fan system” – The purpose of adding this definition is to classify what constitutes a fan system. It is necessary to be able to properly carry out the fan power budget determination.

"fan system, complex” – The purpose of adding this definition is to classify what constitutes a complex fan system. It is necessary to denote clearly what is a complex fan system in order to properly determine the fan power budget for these fan systems.

“fan system, supply-only” – The purpose of adding this definition is to classify what constitutes a supply-only fan system. It is necessary to denote clearly what is a fan supply system in order to properly determine the fan power budget for these fan systems.

“fan system, single-cabinet” – The purpose of adding this definition is to classify what constitutes a single-cabinet fan system. It is necessary to denote clearly what is a single-cabinet fan system in order to properly determine the fan power budget for these fan systems.

“fan system, exhaust” – The purpose of adding this definition is to classify what constitutes an exhaust fan system. It is necessary to denote clearly what is a fan exhaust system in order to properly determine the fan power budget for these fan systems.
“fan system, return” – The purpose of adding this definition is to classify what constitutes a return fan system. It is necessary to denote clearly what is a fan return system in order to properly determine the fan power budget for these fan systems.
“fan system, relief” – The purpose of adding this definition is to classify what constitutes a relief fan system. It is necessary to denote clearly what is a fan relief system in order to properly determine the fan power budget for these fan systems.
“fan system, transfer” – The purpose of adding this definition is to classify what constitutes a transfer fan system. It is necessary to denote clearly what is a fan transfer system in order to properly determine the fan power budget for these fan systems.
“fan system design conditions” – The purpose of adding this definition is to describe the operating conditions that can be expected to occur during normal system operation.
“fan system electrical input power (kW)” – The purpose of adding this for “fan system electrical input power (kW)” is to describe the sum of the fan electrical input power in kilowatts of all fans that are subject to the fan power limit for a given fan system.
“fan, embedded” – The purpose of adding this definition is to classify what constitutes an embedded fan. This addition is necessary to provide clarity on the type of fans that are subject to the FEI requirements.
“fan array” – The purpose of adding this definition is to classify what constitutes a fan array. This definition is necessary to denote clearly what is a fan array as compared to other fans.
“fan nameplate electrical input power” – The purpose of adding this definition is to provide clarity on what type of electrical input power is denoted on the equipment nameplate. This definition is necessary to properly calculate the fan power budget.
“fan energy index (FEI)” – The purpose of adding this definition is to provide clarity and specificity for a new metric to be regulated. This definition is necessary in order to regulate fans according to the metric.
“ISO 5801” – The purpose of adding this definition is to provide a reference to a standard that provides a method to determine the air power provided by a fan.
“seal class A” – The purpose of adding this definition is to standardize what is expected to be sealed for ductwork and plenums that are pressure rated to comply with the proposed sealing requirement in Section 120.4(b).

Section 120.4(b) Duct and Plenum Materials – The purpose of this change is to ensure the performance of all pressure rated ductwork and plenums and to align the Title 24 requirements with those that have been in ASHRAE 90.1 since 2010. This change is necessary to clearly implement the proposed code change for all ductwork to meet Seal Class A.

Section 120.4(g) – Air Distribution System Duct Leakage Sealing – The purpose of this change is to have a single place in the mandatory section of Title 24, Part 6 with all the different duct leakage testing requirements based on the system and building type. It is important that all duct leakage testing requirements be in the mandatory section of Title 24, Part 6 since the duct leakage testing requirement in the California Mechanical Code is mandatory.

Section 120.5(a) – Required Nonresidential Mechanical System Acceptance – The purpose of this change is to update and properly reference all the instances in which ductwork shall be leakage tested. This change is required to maintain consistency within Title 24, Part 6 and not have conflicting changes.

Section 120.10 – Fan Energy Index – The purpose of this change is to add new mandatory requirements for certain fan types to be installed in all applications. This change is important to ensure a minimum efficiency level. This requirement would apply to all fans with an electrical input power ≥ 1 kW, though numerous exemptions apply. Most notably, fans that are embedded in regulated equipment (such as packaged rooftop units) are exempt, as are all fans embedded with other equipment with a fan electrical input power less than 4.1 kW (or 5 HP). However, certain large embedded fans with a fan electrical input power less than 4.1 kW such as those found in large un-regulated air handlers would be subject to FEI requirements.

Section 140.4(c) – Fan Power Budget – The purpose of this change is to replace the existing fan power limitations section with a new fan power budget standard section where each “fan system” is allocated a power budget (kW) as a function of airflow (cfm), system type, with additional allowances available for various components. Other key changes include creating new definitions, changing the metric from fan brake HP or motor HP to fan electrical input power to capture transmission and motor efficiency losses. Notably the fan power budget would also expand the scope of fan systems covered by code from 5 motor nameplate HP to 1 kW fan electrical input power. This change is necessary to implement the proposed code change for all fan systems.

Section 140.4(l) – Air Distribution System Duct Leakage Sealing – The purpose of this change is to move the duct leakage testing from the prescriptive section to the mandatory section. It is important that all duct leakage testing requirements be in the mandatory section of Title 24, Part 6 since the duct leakage testing requirement in the California Mechanical Code is mandatory.

Section 141.0(b)2C – New or Replacement Space-Conditioning Systems or Components – The purpose of this change is to aligns with the requirements in Section 140.4(c) for fan power budget, with additional power allowances for supply and exhaust systems to account for the challenges of retrofitting fan systems and ductwork. This change is necessary to provide the necessary flexibility for retrofit projects to meet the new fan power budget requirements.

Section 141.0(b)2D – Altered Duct Systems – The purpose of this change is to reference the correct sections based on the changes to 120.4, 120.5,140.4(l), and 141.0(b)2E.

2.3.2 Summary of Changes to the Reference Appendices

The proposed code change would make a minor revision to Nonresidential Appendix 2 by updating the reference to the location of the duct leakage testing requirements in the standards, which would be moved from the prescriptive to mandatory section of the standard.

The proposed code change would modify Nonresidential Appendix 7 by adding a test procedure for duct leakage testing for systems that do not meet the criteria to be tested for duct leakage under the criteria in Section 140.4(l)1. Section 140.4(l) only applies to systems that meet a very particular criteria: under 5,000 ft^2 of conditioned space, single-zone, constant volume systems, with at least 25 percent of ductwork in unconditioned space. The CMC applies to all systems. While the CMC has testing requirements already, the added specificity in Title 24, Part 6 is needed so testing is consistent from project to project and the proper compliance forms are filled out. At the time this Final CASE Report was posted for public review, it was uncertain if the proposed clarifications to the duct leakage testing requirements would appear in Nonresidential Appendix 7 to Title 24, Part 6 or as revisions to the language in the CMC. The proposed changes to Title 24, Part 6 presented in this report can be modified to provide the same clarifications within the CMC.

The Statewide CASE Team is proposing that qualified technicians who are also certified as Testing, Adjusting, and Balancing Technicians (by AABC, NEBB, or TABB) or as Duct Air Leakage Technicians by the International Certification Board (ICB) perform the testing.

Finally, the proposed code change would add a new Nonresidential Appendix 9- Fan Power Budget which includes a table on altitude adjustment. See Section 7.3 of this report for the detailed proposed revisions to the text of the Nonresidential Appendices.

2.3.3 Summary of Changes to the Nonresidential ACM Reference Manual

This proposal would modify the following sections of the Nonresidential ACM Reference Manual as shown below. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

- The fan power budget would require modifications to Section 5.7.3- Fan and Duct Systems.
    - The most significant change would be the calculation of fan power in the Standard Design. The fan power budget (kW) would be calculated for each fan system according to the new methodology as a function of fan system type, design air flow, and components from Tables 140.4-A and 140.4-B.
    - The Proposed Design for fan systems would be modified to account for transmission losses, as belt driven fans are assumed to be the new baseline. Transmissions losses are not currently accounted for in the ACM or CBECC.
- For the FEI, as a mandatory submeasure, the Standard Design would equal the Proposed Design.
- For duct sealing, as a mandatory measure, the Standard Design would equal the Proposed Design.

2.3.4 Summary of Changes to the Nonresidential Compliance Manual

The proposed code change would modify the following section of the Nonresidential Compliance Manual:

- Section 4.6.2.3 Fan Power Consumption- This section is almost entirely re-written to provide guidance to users how to calculate fan power budgets and determine FEI values, in line with the proposed code changes. Numerous examples are provided in this section.
- Section 4.4.1.2 Requirements for Air Distribution System Ducts and Plenums – This section would need to reflect the mandatory requirement for ductwork to meet Seal Class A and detail the duct leakage testing requirements in the CMC, as well as the relevant procedures in NA7.

See Section 7.5 of this report for the detailed proposed revisions to the text of the compliance manuals.

2.3.5 Summary of Changes to Compliance Documents

The proposed code change would modify the compliance documents listed below. Examples of the revised documents are presented in Section 7.6.

- 2019-NRCC-MCH-E – The fan power budget calculation methodology would replace the current fan power limit methodology in determining compliance on the form. Additionally, the mandatory measures section would be modified to allow users to denote where on the plan sheet or construction documents the

FEI, airflow and pressure values (i.e. fan schedule) for each fan is located. Section L would need to be updated with the duct leakage testing requirements in the CMC and the requirement to meet Seal Class A.

- NRCV-MCH-04-H Duct Leakage Test would need to be updated with the leakage testing requirements in the CMC and the duct leakage testing procedure in NA 2
- NRCA-MCH-04-A Air Distribution Duct Leakage would need to be updated with the leakage testing requirements in the CMC and the duct leakage testing procedure in NA7.

2.4 Regulatory Context

2.4.1 Existing Requirements in the California Energy Code

Title 24, Part 6 includes numerous requirements for fan systems. The fan power budget submeasure would replace fan power limitations (Section 140.4(c)1), and the fan energy index submeasure would be a new mandatory requirement for fan selection (a proposed Section 120.10). Both of these measures apply to the fan system design or fan selection at design conditions. However, there are other fan system requirements which neither of these submeasures would impact and would remain in place.

The existing Title 24, Part 6 fan system requirements which would not be modified or altered due to this proposal are briefly summarized below.

- Section 120.4 Requirements for Air Distribution System Ducts and Plenums: Explicitly mandates compliance with relevant sections of CMC that handle duct sealing and leakage testing requirements. It also sets forth what materials may be used for the purpose of sealing.
- Section 140.4(c)2 VAV systems: This is a requirement for static pressure sensor location and setpoint reset conditions for VAV systems.
- Section 140.4(c)3 Fractional HVAC motors and fans: This requirement places minimum motor efficiency requirements and motor speed control requirements for motors between 1/12 and 1 HP.
- Section 140.4(l) Air Distribution System Duct Leakage Sealing: This requirement is for sealing and testing ducts of small single zone systems with portions of ductwork in outdoor or unconditioned space and would not be modified.
- Section 140.4(m) Fan Control: This section sets requirements for fan control schemes depending on cooling system type (DX cooling, or chilled water and evaporative) that essentially require two-speed or variable-speed fan control depending on certain factors including system size.

- Section 140.9 Prescriptive Requirements for Covered Processes: There are numerous fan power and fan control requirements for various covered processes that are exempt from this CASE proposal including requirements for computer rooms, commercial kitchens, and laboratories.

2.4.2 Relationship to Requirements in Other Parts of the California Building Code

There are no relevant requirements in other parts of the California Building Code for fan systems, however there are requirements in the CMC for duct sealing and leakage testing. Section 603.10 of the 2019 CMC requires joints and seams for duct systems to comply with the SMACNA HVAC Duct Construction Standards – Metal and Flexible (ANSI/SMACNA 2006), which requires different seal classes based on duct location and design pressure class rating (see Table 8 for more detail on the seal class).

Section 603.10.1 of the 2019 CMC (Title 24, Part 4) also requires duct leakage testing to confirm leakage rates. Under these new requirements, which took effect on January 1, 2020, the CMC establishes a maximum permitted leakage for all systems and requires testing to verify leakage rates. The CMC requires leak testing in accordance with the SMACNA HVAC Air Duct Leakage Testing Manual (ANSI/SMACNA 2012) and specifies representative sections of ductwork be tested. Specifically, ten percent of the total installed duct area must be tested. If the ten percent of tested duct area fails the test, then 40 percent of the duct area must be tested. If the sample of 40 percent of duct area fails, then 100 percent of the duct area must be tested. The maximum allowable leakage rate is determined using the same equation that is used to determine allowable leakage rate for ASHRAE 90.1-2019 (see Equation 5) but using a leakage class (C_L) of six instead of four.

While the CMC cites the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) Air Duct Leakage Test Manual (ANSI/SMACNA 2012) for the testing procedure, there is a need to clarify which sections of ductwork need to be tested, who should execute the testing, and what documentation is needed to demonstrate compliance.

2.4.3 Relationship to Local, State, or Federal Laws

The fan power limitation building code requirements, which have long been in ASHRAE 90.1 and Title 24, Part 6 Section 140.4(c)1 have applied to fan systems that include HVAC equipment which are federally covered, such as various types of packaged equipment. However, as this CASE Report demonstrates, there are numerous pathways to comply with the proposed fan power budget requirements, including through improved duct design, duct sizing, and duct fittings selection such that fans and HVAC equipment do not need to change. In summary, the fan power budget prescriptive requirement proposed in this CASE Report would not require changes in HVAC equipment that is federally covered. To be sure, more efficient fans in federally-covered and non-federally covered HVAC equipment are one way to comply with the fan power budget requirement (as they are in the current Title 24, Part 6 code 140.4(c)1), but it is not required. The Statewide CASE Team designed this measure to avoid preemption and has demonstrated more efficient fans or HVAC equipment is not needed to comply.

The FEI metric and subsequent standards to develop FEI ratings for commercial and industrial fans were initially developed as part of a Department of Energy led negotiation and rulemaking process (Department of Energy 2015). However, this effort stalled after DOE published a Notice of Data Availability III in late 2016 (Department of Energy 2016). Following the national pause in activity, California is considering an appliance standard through Title 20 for commercial and industrial fans using the FEI metric and is currently in the pre-rulemaking phase (Galdámez 2017).

2.4.4 Relationship to Industry Standards

All three submeasures proposed in this Final CASE Report have significant alignment with existing code or proposed code changes in ASHRAE 90.1.

The 2019 Title 24, Part 6 code changes which took effect January 1, 2020 largely aligned Title 24, Part 6 fan system requirements with the ASHRAE's 90.1-2016 fan power limitation code language. In this code cycle, the Statewide CASE Team's proposed fan power budget submeasure is being proposed simultaneously in ASHRAE for consideration for the 90.1.-2022 code changes. As of March 2020, the fan power budget proposal is currently being reviewed by ASHRAE SSPC 90.1 Mechanical Subcommittee.

The FEI submeasure is largely aligned with ASHRAE 90.1-2016 addendum ao which was incorporated into ASHRAE 90.1-2019 in the fall of 2019.

The Statewide CASE Team is basing the proposed Seal Class A requirement on ASHRAE 90.1 duct sealing requirements, which were introduced in ASHRAE 90.1-2010. Section 6.4.4.2.1 of ASHRAE 90.1-2019 requires ductwork and all plenums with pressure class ratings to be construed to Seal Class A.

Finally, Section 6.4.4.2.1 of ASHRE 90.1-2019 requires ductwork that is designed to operate at static pressure over 3.0 in. wg and all ductwork that is located outdoors to undergo duct leakage testing to confirm the maximum allowable leakage rate is not exceeded. ASHRAE 90.1 references the SMACNA HVAC Air Duct Leakage Testing Manual (Sections 3, 5, and 6) as the test method for duct leakage testing. Representative sections of not less than 25 percent of this ductwork is to be tested and not exceed duct leakage class four.

2.5 Compliance and Enforcement

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 section describes how to comply with the proposed code change for each submeasure. It also describes the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

2.5.1 Fan Power Budget

The activities that need to occur during each phase of the project are described below for compliance with the fan power budget submeasure. At a high level, the fan power budget compliance process would largely mirror the existing compliance process for the fan power limitations.

- **Design Phase:** Mechanical designers, using the prescriptive path for compliance, must first clearly determine which fan systems are in scope, meaning determining whether the fan system ≥ 1 kW and not an exempt process. Next, the designer must categorize each fan system as either single-cabinet, supply-only, exhaust, relief, return or transfer. For each fan system, the designer must then determine the fan power budget for each fan system and compare it to the collective fan system input power at design conditions. If the fan system input power is less than the fan power budget, then the fan system complies. The designer would typically be responsible for populating the NRCC-MCH-E form denoting compliance with the prescriptive path. If the performance path is used, the compliance software would generate the fan power budget based on the type of HVAC system and components selected within the software.
- **Permit Application Phase:** The designer, or designated consultant, is typically responsible for populating the NRCC-MCH-E form accordingly for each fan system to demonstrate compliance. The plans examiner would review the NRCC-MCH-E forms to determine prescriptive compliance with the fan power budget for each fan system. The plans examiner can cross reference the equipment schedules on the plan sets to verify any fan system configurations, system airflow, fan system input power values or other values to double-check the NRCC-MCH-E form has been completed properly if needed. If the performance path is used, the compliance software would generate compliance forms, as is currently done with the fan power limitations.
- **Construction Phase:** For the prescriptive fan power budget component of the measure, the mechanical contractor would build the system to plan, and complete the NRCI form in similar fashion to the existing fan power limitations.

- **Inspection Phase:** During inspection, the prescriptive fan power budget component would largely follow the existing fan power limitation inspection process. The inspector shall determine that all installed equipment and airflows matches the equipment on the NRCI forms.

This compliance process represents some changes from the current compliance process. However, mechanical designers are familiar as it relates to complying with fan power requirements in Title 24, Part 6. For the fan power budget, the compliance process is similar to the fan power limitations, however there are a few key differences highlighted below.

- Instead of performing one fan system power calculation where both supply and return/exhaust/relief were combined as one fan system, this measure would require the fan power budget to be calculated separately for each fan system. This may require some additional effort on the designer’s behalf, and it also may lengthen the NRCC-MCH-E form to show compliance.
- All market actors would need to understand that more fan systems would be subject to the fan power budget requirements than are currently subject to the existing fan power limitations. It is important to note that market actors are currently adjusting to recent scope changes to the fan power limitations. More specifically, prior to 2020, only fan systems greater or equal to 25 motor nameplate HP were subject to the fan power limitations. Then, starting January 1, 2020, with Title 24, Part 6 2019 code taking effect, this threshold was lowered such that all fan systems greater than 5 motor nameplate HP were subject the fan power limitations. This fan power budget proposal would again lower the threshold to 1 kW for any fan system in-scope.
- All market actors would need to understand the shift away from using motor nameplate or BHP to determine whether fan systems are subject to the code, or whether and how fan systems comply with the code. However, this would have the greatest impact on designers and fan manufacturers. Instead of motor nameplate or BHP methods used for determining compliance, input kW at design conditions would become the new key metric. This would require designers to calculate the fan power budget based on kW, whereas BHP or motor nameplate is common today. Importantly, this code change would push manufacturers of fans to provide the input kW at design conditions to designers, such that it can be listed on submittals and plans. While the Statewide CASE Team has accounted for cases where the manufacturer does not provide input kW, it is expected that as function of this submeasure, the FEI submeasure in this Final CASE Report, FEI being in 90.1-2019 and broader industry trends, input kW at design conditions would become commonplace in the fan industry in the coming years.

The existing fan power limitations largely rely on designers to comply with the requirements and this would remain for the fan power budget. Today, enforcement officials are not measuring system pressure or airflow with instruments as it is not feasible, or necessary. The fan power limitations and the proposed fan power budget submeasure require mechanical designers to make certain design choices that ultimately lead to compliance. No instruments or field measurements would be required as a result of this submeasure. This compliance has and would continue to be documented on the NRCC-MCH-E forms for plans examiners to ensure compliance.

2.5.2 Fan Energy Index

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** This submeasure would require the designer to use a manufacturers' software or catalog certified by a third-party certification program (such as the AMCA Certified Ratings Program) to determine FEI when making fan selections (AMCA 2020). Either of these sources should rely on AMCA 208 to properly calculate FEI (AMCA 2018). Typically when designing air distribution systems and making fan selections a mechanical designer would use a fan manufacturer's selection software to input (or look up in a catalog) the duty point and then make a fan selection based on a number of variables provided including cost, size, fan type, BHP, static/total efficiency, etc. FEI is already another variable that many manufacturers are automatically calculating and displaying in fan selection software's (as was shown in Figure 5). This submeasure would require that the in-scope fans be selected by designers with an FEI ≥ 1.0 at design conditions. The designer should denote the associated FEI value and the actual fan electrical input power (FEP_{actual}) with each fan on the plan sets, along with including design pressure, design flow, RPM and BHP which are already typically included on the plan sets.
- **Permit Application Phase:** During permit application, the designer is responsible for populating the NRCC-MCH-E form and denoting in the mandatory measures section where the FEI values are located (e.g., what page on plan set). To determine compliance of the mandatory FEI requirements, the plans examiner would check the plan set to verify FEI values are listed for the in-scope fans and that they are ≥ 1.0 at design conditions. If there are any concerns the plans examiner could request the "cut-sheets" (typically exported from fan selection software) which would show the flow, pressure, and FEI values. The plans examiner could also calculate the FEI manually with basic equations using information from the plan set, though this is less likely.
- **Construction Phase:** The mechanical contractor shall install fans at the pressure, flow and RPM according to the plan set where the FEI is greater than

or equal to one. If fan substitutions are made, as is common, the designer should ask the contractor for a revised FEI calculation (via the fan selection cut-sheet) as part of the submittal process.

- **Inspection Phase:** The inspector shall determine that all installed equipment and airflows matches the equipment on the NRCI forms.

Aside from certain fans used in covered processes, there is not currently an individual fan efficiency requirement in Title 24, Part 6 for fans used for space conditioning or ventilation so FEI represents a new requirement, and thus compliance process. This mandatory requirement would require designers to select in-scope fans at an FEI or 1.0 or greater and providing the proper documentation on the plan sets.

- All market actors, but especially mechanical designers and plans examiners would need to understand the scope of the FEI mandatory requirement. Practically speaking, nearly all packaged HVAC equipment is exempt from the requirement, but the scope is slightly more nuanced. There would need to be a basic understanding of which fans are “in” vs “out” aside from the ≥ 1 kW threshold. The compliance manual would assist with determining compliance.
- Compliance with the mandatory FEI requirements would also require that manufacturers or third parties provide FEI and FEP_{actual} (i.e., input kW) according to AMCA 208 Annex C for designers to use. Designers would then list these values on the plan sets. Several manufacturers are already providing FEI values per AMCA 208 Annex C and have had their catalogs and selection software certified by the AMCA Certified Ratings Program (AMCA 2020). The Statewide CASE Team expects third party certification of fan catalogs and selection software to become commonplace by 2022 as FEI is adopted nationally due its inclusion in ASHRAE 90.1-2019 and IECC-2021 national model codes.

2.5.3 Duct Leakage

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** The designer would explicitly put on the construction documents that all ductwork shall be sealed to meet Seal Class A and that all ductwork must meet the maximum leakage limits. The designer would contribute to the Certificate of Compliance documents, by laying out how the project would achieve the above requirements, both for the permit and inspection.
- **Permit Application Phase:** During permit application, the designer is responsible for populating the NRCC-MCH-E form accordingly and denoting in the mandatory measures section how the project is meeting the requirement to meet Seal Class A and perform duct leakage testing for the ductwork. The plans examiner would review the project plans and NRCC-MCH-E form to confirm that

the necessary documentation is provided to show compliance with the mandatory requirements for ductwork.

- **Construction Phase:** The building owner or building owner's representative, designer, contractor, and testing professional would need to determine which sections of ductwork would be tested to comply with duct leakage testing requirements in a way that fits the construction schedule. The contractor would need to inform the qualified testing technician when the relevant sections of ductwork are accessible for testing and the testing professional would need to go onsite to test those sections. This would likely happen at least two times for supply-air systems with terminal boxes: once when the upstream ductwork is installed and another time once when the downstream ductwork is installed. Stakeholders told the Statewide CASE Team that this second test can likely be scheduled to occur during TAB. The technician would also test all ductwork that would become inaccessible and test parts of the exhaust system. The testing professional would need complete the NRCA-MCH-04-H Duct Leakage Test and NRCA-MCH-04-A Air Distribution Duct Leakage to verify that duct leakage was carried out according to the procedures in NA7.
- **Inspection Phase:** The qualified technician would need to complete the NRCA-MCH-04-A Air Distribution Duct Leakage to demonstrate compliance with the sealing, leakage, and testing requirements in Sections 120.4 and 120.5. The building inspector would review the form to verify compliance. The building inspector would need to ensure that Seal Class A was met on all ductwork.

Sealing and testing requirements for ductwork already exist in the CMC and Title 24, Part 6. The Statewide CASE Team does not expect there to be significant changes to the compliance process in order for all ductwork to meet Seal Class A, as designers already specific sealing requirements, plans examiners are familiar with reviewing construction documents, and contractors are comfortable with that degree of sealing for ductwork.

Market actors are already familiar with duct leakage testing and it is required by the 2019 CMC. However, it is not clear from the requirements who needs to perform the testing, what documentation needs to be provided, and how sections need to be selected. The Statewide CASE Team is recommending incorporating instructions on which ductwork to select in either Section 120.5 and Reference Appendix NA7 to or the CMC to resolve this and has worked closely with industry stakeholders to develop these recommendations. The Statewide CASE Team is also providing recommendations for the compliance manual and compliance documents to further support the existing leakage testing requirements in the CMC. Finally, the Statewide CASE Team is proposing that qualified technicians who are certified as Testing, Adjusting, and

Balancing Technicians (by AABC, NEBB, or TABB) or as Duct Air Leakage Technicians by the International Certification Board (ICB) perform the testing.

The main challenge for compliance and enforcement would be coordinating the construction, testing, and inspection schedules in order to minimize the number of visits. Project teams would need consider the best way to minimize the burden to themselves and to avoid holding up construction. As long as there is clear communication between the installation contractors and testing professionals and a clear outline of when testing would occur it would not impact construction schedules.

3. Market Analysis

3.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. It then considered how the proposed standard may impact the market in general as well as individual market actors. Information was gathered 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 actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during two public stakeholder meetings that the Statewide CASE Team held on November 5, 2019 (Statewide CASE Team 2019), and March 12, 2020 (Statewide CASE Team 2020).

Nonresidential air distribution systems are designed by mechanical engineers, who must take various considerations into account when developing air distribution layouts and specifying parts and equipment. This includes but is not limited to space constraints, minimum equipment efficiency requirements, architectural and aesthetic requirements, and ventilation requirements based on building occupancy. The air distribution systems must then be installed according to plan by mechanical contractors and tested for duct leakage to meet the leakages specified in the mechanical drawings. Once installed, systems are typically commissioned.

3.1.1 Fan Power Budget

Based on conversations with many market actors, including mechanical designers and fan manufacturers, the current fan power limitations in Title 24, Part 6, Section 140.4(c) are generally not difficult to meet when designing most nonresidential buildings. However, the current fan power limitations do tend to “kick in” for larger buildings with longer duct runs, requiring more energy efficient duct systems and/or fan selections.

It should also be noted that, like many improvements to the building code, there is ample good design in the market with many mechanical designers already designing their duct systems and selecting fans for optimum efficiency. This proposed code change aims to raise the quality of duct design and fan selection, such that energy efficient air distribution systems are commonplace across all building types, of all sizes, not just large buildings with long duct runs.

It should be emphasized that there are many avenues to comply with the existing 2019 fan power limitations. Designers can specify design more efficient duct layouts, use larger ducts, specify better fittings, etc. to lower pressure, or reduce the fan power required to overcome that pressure through more efficient fans, motors or transmissions. (A more detailed list and discussion of pressure reduction opportunities is discussed in Section 5.3.1). This proposed measure is no different, in that there are numerous pathways to comply with the fan power budget for each fan system. In many cases, a more efficient fan, motor, or air handler would be the easiest method to comply. However, for the purposes of this analysis, to be conservative, the Statewide CASE Team examined how the fan power budget could be met entirely with better duct layout design, sizing and fittings. In other words, this measure does not require any changes to the fan/equipment-side of the air distribution system.

The Statewide CASE Team estimates that roughly 85 percent of new nonresidential buildings would be impacted by this measure based on state building forecasts (California Energy Commission 2019) and CEC building prototypes which have at least one fan system ≥ 1 kW. The mechanical design community and air distribution industry are very familiar with the fan power limitations; therefore, the Statewide CASE Team expects the market to be able to easily adjust to what is essentially a reform and tightening of the existing standards. The only market actor which may need to make changes or investments in processes is fan and equipment manufacturers as they would be expected to provide input kW at design conditions, as compared to BHP which has been the traditional metric provided to mechanical designers for many years.

As described in Section 2.2.1.3, one option for mechanical designers to determine their fan input power is to receive the value from fan and equipment manufacturers, likely through their fan selection software. Based on conversations with stakeholders, the industry is in the process of moving to input kW, as compared to BHP. This would require manufacturers to essentially add on motor and transmission efficiency values to their selection tools. The addition of FEI to ASHRAE 90.1-2019 is already moving the industry in this direction. Acquiring the fan system input kW at design conditions from manufacturers is not required, as there are other methods as described in Section 2.2.1.3, but the Statewide CASE Team believes there would be market pressure from the mechanical design community to provide this information for ease of compliance with the fan power budget.

3.1.2 Fan Energy Index

The FEI submeasure would impact the fan selection process, a key activity for mechanical designers in designing air distribution systems. At a high level a designer would determine the airflow needed to meet the ventilation/heating/cooling needs at design conditions and then determine the expected pressure needed to be overcome to deliver this airflow (e.g., through ductwork) to the building space. With pressure and airflow values (and altitude), the designer would then select a fan at this design condition duty point for the type of fan system needed. This is often done using a fan manufacturer’s selection software (or a fan catalog) which provides many options of fans to select from often ranging in size, design, cost, etc. A designer would make a fan selection and include the selection on the equipment schedules in the plan set. In fact, some fan selection software tools would export equipment schedules and cut sheets for designers to easily paste into their plan sets. The mechanical contractor would then purchase the equipment and install according to plans. Often equipment substitutions are needed, where the contractor would select a different brand or slightly different fan. In these cases, the designer should ask the contractor for a revised FEI calculation output as part of the submittal process.

3.1.3 Duct Leakage

Ductwork performance requirements are specified by mechanical engineers, which includes the degree of sealing and the maximum permitted leakage. The Statewide CASE Team has had input from mechanical contractors that designers tend to be more concerned with overall system performance, and that it is on the mechanical contractor to ensure that each piece of ductwork meets the necessary specifications. Mechanical contractors have informed the Statewide CASE Team that, especially for factory-fabricated ductwork, it is often simpler to seal all joints and seams during fabrication than vary sealing depending on requirements. Then all penetrations are sealed when installing the ductwork as is required for Seal Class A. Contractors stated that it is oftentimes easier and not comparatively more work to have all ductwork meet the same high standard, rather than having to ensure that specific pieces meet a standard while others meet a lower one. Representatives of SMACNA stated to the Statewide CASE Team that they support the requirement of Seal Class A and have considered updating the SMACNA HVAC Duct Construction Standards to require Seal Class A for all ductwork. While it may be the case that Seal Class A is an accepted level of sealing for all ductwork for certain mechanical contractors, it is important to have this be a consistent requirement throughout the market. The Statewide CASE Team heard from members of SMACNA that it is typical to seal all ductwork to meet Seal Class A in alignment with the ASHRAE 90.1 requirement and that it can be easier to do so sometimes than try to seal different pieces of ductwork to different degrees.

Leakage testing is an important quality control mechanism. Until Jan 1, 2020, only air distribution systems in small commercial buildings that met the specifications laid out in Section 140.4(l)1 were required to be leakage tested. However, requirements for balancing the ventilation system have been in the CMC since at least 2010. Mechanical contractors and testing professionals told the Statewide CASE Team that where in the system the ductwork leakage testing occurs is typically specified by the mechanical designer to confirm the performance of the system and that it is usually only high pressure, supply-air ductwork that gets tested. The testing agent would typically seal any small leaks and inform the contractor if there is a larger leak or systemic leakage issue. The Statewide CASE Team's proposal to add requirements for leakage testing to

Section 120.4 and testing procedures to NA7 in support of the CMC testing requirements would provide specification as to what ductwork needs to be tested to ensure proper quality control and take some of the guesswork out for designers and testing professionals – typically TAB Technicians or Duct Air Leakage Technicians.

3.2 Technical Feasibility, Market Availability, and Current Practices

3.2.1 Fan Power Budget

This measure would require mechanical designers to consider duct layout, duct size, duct fittings, air handler design, fan efficiency, motor efficiency and transmission efficiency when designing fan systems. To meet the proposed fan power budget for each fan system, mechanical designs would have flexibility in how to meet the standard. As mentioned, many designers already design very efficient air distribution systems that exceed the efficiency requirements of the 2019 fan power limitations.

Principal makers of standalone fans, air handlers, and packaged HVAC equipment are listed below, though this list is not exhaustive.

- Greenheck (manufacturing in California)
- Energy Labs Inc. (headquarters and manufacturing in California)
- Alliance Air Products (headquarters in California)
- Nortek Air Solutions
- Twin City Fans
- New York Blower
- Loren Cook
- Trane
- Carrier
- York
- Daikin
- ACME Fans

Ductwork and fittings are manufactured by a variety of companies, including by custom sheet-metal shops that fabricate custom ductwork for local and regional markets. Ductwork in nonresidential buildings is commonly made of galvanized steel, often by custom sheet metal shops. Other materials used in duct work include aluminum (special clean room type applications), stainless steel (kitchen exhaust, other air streams with moisture), carbon steel (industrial applications) or even copper (certain chemical exhaust).

This submeasure does not require new technology, but an approach to the design and selection of equipment, ductwork and components that support energy efficiency while being commonly available in the market. The Statewide CASE Team was able to demonstrate that all of the energy savings could be achieved in the Large Office prototype through ductwork static pressure reduction with better duct fittings and larger ductwork. The Large Office prototype was chosen to determine incremental cost of the fan power budget submeasure as, of the CEC prototype buildings used to evaluate code change proposals, it is likely the prototype building with the most ductwork (i.e., longest duct runs), and thus external static pressure. This is explained further in Section 4 and Section 5.3.

While there are many pathways to meet the fan power budget, energy savings from this measure are expected to persist for numerous reasons. First, if the duct work is designed in an efficient manner, it should not change over time, as there are few, if any moving parts. Similarly, if more efficient fan, motor or transmission selections are made, these savings are likely to persist as well. It should be noted again that the fan power budget, like the existing fan power limitation, only applies to the design conditions. Fan system control strategies have a greater likelihood of being modified over time and are covered by other parts of Title 24, Part 6. With the exception of air filters which increase pressure drop as they become dirty before being replaced, most of the fan system components which impact the fan power budget should not change over time with appropriate normal maintenance.

3.2.2 Fan Energy Index

The FEI submeasure is technically feasible and products are available on the market to meet the proposal. In fact, it is unlikely any fans currently used would be explicitly removed from the market in California as result of the adoption of this submeasure. FEI is a unique metric in that it is a rating at a specific duty point of a given fan (or fan, motor, drive combination), not the entire fan itself. Almost every fan is efficient at *some* flow and pressure, but more efficient fans can typically operate efficiently at a wider array of duty points. From a designer's perspective, the FEI would be a new value to consider when making fan selections. This submeasure would require that each in-scope fan or fan array with a combined motor nameplate HP greater than 1.0 hp or with a combined fan nameplate electrical input power greater than 0.89 kW shall be selected and installed at an FEI of 1.00 or higher.

For example, Greenheck (a fan manufacturer) has already incorporated FEI into their eCAPS (Computer Aided Selection Program) fan selection software (Greenheck Inc. 2020). As shown in Figure 5 below, when searching for an exhaust fan that can produce 5,000 cfm at 0.75 in. wg there are numerous fans to choose from, however not all have an FEI at 1.0 or higher. In this example, the designer could select any of the fans listed except the GB-200 as it has an FEI of 0.98 at this duty point. The designer would then add the compliant selection to their equipment schedule with the accompanied compliant FEI value.[6]

Model Name	Actual CFM	Total External SP (in. wg)	Bhp	FEI ?
GB-220	5,000	0.750	1.29	1.33
GB-200	5,000	0.750	1.75	0.98
GB-240	5,000	0.750	1.29	1.33
CUBE-220	5,000	0.750	1.46	1.18
GB-220HP	5,000	0.750	1.62	1.06

Figure 5: FEI in Greenheck's eCAPS fan selection software.

Source: (Greenheck Inc. 2020)

Due to efforts at U.S. DOE, ASHRAE 90.1, and the IECC, manufacturers are already preparing and adding FEI to their fan selection software and fan catalogs. Furthermore, the AMCA Certified Ratings Program is actively certifying that fan manufacturers' software and catalogs are accurately representing FEI, in accordance with AMCA 208. The Statewide CASE Team expects more manufacturers in the coming years to certify to this program to ensure compliance with ASHRAE 90.1-2019 and IECC-2022 as more states adopt these codes.

In summary, this FEI proposal would not likely require new products to be designed or on the market, though it may broadly encourage the development of new more efficient fans. Furthermore, for designers and contractors, no new engineering or calculations would be required. Instead, it would serve to require designers to make minimally efficient fan selections that meet the minimum FEI of 1.0 during the existing industry standard fan selection process. The greatest impact would be on manufacturers to

[6] Note, the "?" by the FEI is to allow the user of the software to learn more about FEI, as it is a new metric in Greenheck's eCAPs tool.

ensure their products are properly rated and that the FEI is easily displayed for designers to make compliant selections.

3.2.3 Duct Leakage

Duct sealing to a required standard and testing ductwork for leakage are both common practices nationally and in California. Higher pressure ductwork has historically been the focus of testing and sealing requirements because a leak of the same size would have a larger energy impact. However, it has been shown that low pressure ductwork downstream of VAV boxes can leak significantly and also have an impact on energy consumption (Modera, Wray and Dickerhoff 2014).

This proposal seeks to align with ASHRAE 90.1's duct sealing standards that were introduced in 2010 as well as provide specifications to the CMC duct leakage testing requirements. Mechanical contractors are comfortable meeting this sealing class and have informed the Statewide CASE Team that they sometimes already meet Seal Class A for all ductwork. The motivation for this proposal is to create standardized sealing for all ductwork regardless of project or pressure class. Requiring this level of seal class would also increase the likelihood that ductwork does not exceed the maximum permitted leakage when it is tested.

Project teams, particularly designers, contractors, and testing professionals, would have to be made aware of the updates to the compliance documents and the ductwork criteria in Section 120.4 and testing in Section 120.5.Title 24, Part 6 would be providing the compliance support for the testing requirement, so it is especially important to communicate these changes before the effective date so that project teams can become familiar with the criteria and see how it may affect the scheduling of construction and testing. Building inspectors would also need to be in communication with project teams to coordinate the best time for site visits. However, by creating a standard selection criterion, the Statewide CASE Team thinks that it would lead to more regular and predictable scheduling from one project to another.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2022 code cycle. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

California's construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 11).[7] In 2018, total payroll was $80 billion. Nearly 17,000 establishments and 344,000 employees focus on the commercial sector.

Table 11 California Construction Industry, Establishments, Employment, and Payroll

Construction Sectors	Establishments	Employment	Annual Payroll ($ billion)
Commercial	**17,273**	**343,513**	**$27.8**
Commercial Building Construction	4,508	75,558	$6.9
Foundation, Structure, & Building Exterior	2,153	53,531	$3.7
Building Equipment Contractors	6,015	128,812	$10.9
Building Finishing Contractors	4,597	85,612	$6.2

Source: (State of California, Employment Development Department n.d.)

The proposed changes to air distribution would likely affect commercial builders. The effects on the commercial building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors. Table 12 shows the commercial building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report. Chiefly, contractors that focus on HVAC equipment and ductwork would be impacted by this proposal. The Statewide CASE Team's estimates of the magnitude of these impacts are shown in Section 3.4.

Table 12: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code/Standard

Construction Subsector	Establishments	Employment	Annual Payroll ($ billion)
Commercial Building Construction	4,508	75,558	$6.95
Nonresidential plumbing and HVAC contractors	2,394	52,977	$4.45

Source: (State of California, Employment Development Department n.d.)

7 Average total monthly employment in California in 2018 was 18.6 million; the construction industry represented 4.5 percent of 2018 employment.

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the Title 24, Part 6) are typically updated on a three-year revision cycle and building designers and energy consultants engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310).

Table 13 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code changes for the 2022 code cycle would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for this measure to affect firms that focus on nonresidential construction.

There is not a North American Industry Classification System (NAICS)[8] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[9] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in

[8] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy. NAICS was development jointly by the U.S. Economic Classification Policy Committee (ECPC), Statistics Canada, and Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

[9] Establishments in this sector include businesses primarily engaged in evaluating a building’s structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily engaged in providing inspections for pests, hazardous wastes or other environmental contaminates, nor does it include state and local government entities that focus on building or energy code compliance/enforcement of building codes and regulations.

Table 13 provides an upper bound indication of the size of this sector in California.

Table 13: California Building Designer and Energy Consultant Sectors

Sector	Establishments	Employment	Annual Payroll (billion $)
Architectural Services a	3,704	29,611	$2.9
Building Inspection Services b	824	3,145	$0.2

Source: (State of California, Employment Development Department n.d.)

a. Architectural Services (NAICS 541310) comprises private-sector establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;
b. Building Inspection Services (NAICS 541350) comprises private-sector establishments primarily engaged in providing building (residential & nonresidential) inspection services encompassing all aspects of the building structure and component systems, including energy efficiency inspection services.

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 (Cal/OSHA). All existing health and safety rules would 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.

All proposed code changes would apply to healthcare facilities.

3.3.4 Impact on Building Owners and Occupants

The commercial building sector includes a wide array of building types, including offices, restaurants and lodging, retail, and mixed-use establishments, and warehouses (including refrigerated) (Kenney 2019). Energy use by occupants of commercial buildings also varies considerably with electricity used primarily for lighting, space cooling and conditioning, and refrigeration. Natural gas consumed primarily for heating water and for space heating. According to information published in the 2019 California Energy Efficiency Action Plan, there is more than 7.5 billion square feet of commercial floor space in California and consumes 19 percent of California's total annual energy use (Kenney 2019). The diversity of building and business types within this sector creates a challenge for disseminating information on energy and water efficiency solutions, as does the variability in sophistication of building owners and the relationships between building owners and occupants.

Building owners and occupants would 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. The Statewide CASE Team does not expect this proposed code change to impact building owners or occupants adversely.

3.3.5 Impact on Building Component Retailers (Including Manufacturers and Distributors)

The Statewide CASE Team does not expect widespread changes to the air distribution technology markets. As noted in Section 3.2 , the technologies that meet these proposed requirements are mature and only a portion of the market would be impacted due to the respective capacity thresholds.

3.3.6 Impact on Building Inspectors

Table 14 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 14: Employment in California State and Government Agencies with Building Inspectors

Sector	Govt.	Establishments	Employment	Annual Payroll (million $)
Administration of Housing Programs[a]	State	17	283	$29.0
	Local	36	2,882	$205.7
Urban and Rural Development Admin[b]	State	35	552	$48.2
	Local	52	2,446	$186.6

Source: (State of California, Employment Development Department n.d.)

a. Administration of Housing Programs (NAICS 925110) comprises government establishments primarily engaged in the administration and planning of housing programs, including building codes and standards, housing authorities, and housing programs, planning, and development.

b. Urban and Rural Development Administration (NAICS 925120) comprises government establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.
Impact on Statewide Employment

As described in Sections 3.3.1 through 3.3.6, the Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 3.3.7 the Statewide CASE Team estimates that the proposed change would affect statewide employment and economic output directly and indirectly through its impact on builders, designers and energy consultants, and building inspectors. In addition, it is estimated how energy savings associated with the proposed changes in air distribution would lead to modest ongoing financial savings for California residents, which would then be available for other economic activities.

3.3.7 Impact on Statewide Employment

As described in Sections 3.3.1 through 3.3.6, the Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 3.4, the Statewide CASE Team estimated the proposed change in air distribution would affect statewide employment and economic output directly and indirectly through its impact on builders, designers and energy consultants, and building inspectors. In addition, the Statewide CASE Team estimated how energy savings associated with the proposed change in air distribution would lead to modest ongoing financial savings for California residents, which would then be available for other economic activities.

3.4 Economic Impacts

For the 2022 code cycle, the Statewide CASE Team used the IMPLAN model software, along with economic information from published sources, and professional judgement to developed estimates of the economic impacts associated with each proposed code changes.[10] While this is the first code cycle in which the Statewide CASE Team developed estimates of economic impacts using IMPLAN, it is important to note that the economic impacts developed for this report are only estimates and are based on limited and to some extent speculative information. In addition, the IMPLAN model provides a relatively simple representation of the California economy and, though the Statewide CASE Team is confident that direction and approximate magnitude of the estimated economic impacts are reasonable, it is important to understand that the IMPLAN model

[10] IMPLAN (Impact Analysis for Planning) software is an input-output model used to estimate the economic effects of proposed policies and projects. IMPLAN is the most commonly used economic impact model due to its ease of use and extensive detailed information on output, employment, and wage information.

is a simplification of extremely complex actions and interactions of individual, businesses, and other organizations as they respond to changes in energy efficiency codes. In all aspect of this economic analysis, the CASE Authors rely on conservative assumptions regarding the likely economic benefits associated with the proposed code change. By following this approach, the economic impacts presented below represent lower bound estimates of the actual impacts associated with this proposed code change.

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the commercial/ non-residential building industry, architects, energy consultants, and building inspectors. The Statewide CASE Team does not anticipate that money saved by commercial building owners or other organizations affected by the proposed 2022 code cycle regulations would result in additional spending by those businesses.

Table 15: Estimated Impact that Adoption of the Proposed Measure would have on the California Commercial Construction Sector

Type of Economic Impact	Employment (persons)	Labor Income ($ million)	Total Value Added ($ million)	Output ($ million)
Fan Power Budget Economic Impacts	**707.4**	**$45.58**	**$67.07**	**$113.51**
Direct Effects (Additional spending by Commercial Builders)	428.2	$28.31	$37.52	$62.06
Indirect Effect (Additional spending by firms supporting Commercial Builders)	93.1	$6.77	$10.79	$20.82
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	186.2	$10.49	$18.77	$30.64
FEI Economic Impacts	**2.5**	**$0.16**	**$0.23**	**$0.40**
Direct Effects (Additional spending by Commercial Builders)	1.5	$0.10	$0.13	$0.22
Indirect Effect (Additional spending by firms supporting Commercial Builders)	0.3	$0.02	$0.04	$0.07
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	0.6	$0.04	$0.07	$0.11

Duct Leakage Economic Impacts	**91.8**	**$5.92**	**$8.71**	**$14.73**
Direct Effects (Additional spending by Commercial Builders)	55.6	$3.67	$4.87	$8.05
Indirect Effect (Additional spending by firms supporting Commercial Builders)	12.1	$0.88	$1.40	$2.70
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	24.2	$1.36	$2.44	$3.98
Total Economic Impacts	**801.7**	**$51.65**	**$76.01**	**$128.64**

Source: Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software.

3.4.1 Creation or Elimination of Jobs

The Statewide CASE Team does not anticipate that proposed code changes would lead to the creation of new *types* of jobs or the elimination of *existing* types of jobs. In other words, the Statewide CASE Team’s proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 3.4 would lead to modest changes in employment of existing jobs.

3.4.2 Creation or Elimination of Businesses in California

The proposed code changes for the 2022 code cycle would apply to all businesses incorporated in California, regardless of whether the business is located inside or outside of the state.[11] Therefore, the Statewide CASE Team does not anticipate that these measures proposed for the 2022 code cycle regulation would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

11 Gov. Code, §§ 11346.3(c)(1)(C), 11346.3(a)(2); 1 CCR § 2003(a)(3) Competitive advantages or disadvantages for California businesses currently doing business in the state.

3.4.3 Competitive Advantages or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses incorporated in California, regardless of whether the business is incorporated inside or outside of the state.[12] Therefore, the Statewide CASE Team does not anticipate that the proposed measures would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

3.4.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[13] As Table 16 shows, between 2015 and 2019, NPDI as a percentage of corporate profits ranged from 26 to 35 percent, with an average of 31 percent. While only an approximation of the proportion of business income used for net capital investment, the Statewide CASE Team believes it provides a reasonable estimate of the proportion of proprietor income that would be reinvested by business owners into expanding their capital stock.

Table 16: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
2015	$609.2	$1,740.3	35%
2016	$456.0	$1,739.8	26%
2017	$509.3	$1,813.6	28%
2018	$618.2	$1,843.7	34%
2019	$580.9	$1,827.0	32%
		5-Year Average	**31%**

Source: (Federal Reserve Economic Data n.d.)

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to significant change (increase or decrease) in

[12] Gov. Code, §§ 11346.3(c)(1)(C), 11346.3(a)(2); 1 CCR § 2003(a)(3) Competitive advantages or disadvantages for California businesses currently doing business in the state.

[13] Net private domestic investment is the total amount of investment in capital by the business sector that is used to expand the capital stock, rather than maintain or replace due to depreciation. Corporate profit is the money left after a corporation pays its expenses.

investment in any directly or indirectly affected sectors of California's economy. Nevertheless, the Statewide CASE Team is able to derive a reasonable estimate of the change in investment by California businesses by multiplying the sum of Business Income estimated in Table 15 above by 31 percent.

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

The Statewide CASE Team does not expect the proposed code changes to have a measurable impact on the California's General Fund, any state special funds, or local government funds.

3.4.5.1 Cost of Enforcement

3.4.6 Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government would 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 proposal may increase costs to construct state buildings such as large offices, but as shown in Section 5.2, all submeasures are cost effective.

3.4.7 Cost to Local Governments

All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would 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 2022 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 E, 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.

3.4.8 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, there is the potential that a proposed update to the 2022 code cycle may result in unintended consequences. The Statewide CASE Team does not believe there would be negative impacts towards one any specific persons as a result of this code change proposal.

4. Energy Savings

4.1 Key Assumptions for Energy Savings Analysis

The energy and cost analysis presented in this report used the TDV factors that are consistent with the TDV factors presented during the Energy Commission's March 27, 2020 workshop on compliance metrics (California Energy Commission 2020). The electricity TDV factors include the 15 percent retail adder and the natural gas TDV factors include the impact of methane leakage on the building site. The electricity TDV factors used in the energy savings analyses were obtained via email from Energy and Environmental Economics, Inc. (E3), the contractor that is developing the 2022 TDV factors for the Energy Commission, in a spreadsheet titled "Electric TDVs 2022 - 15 pct Retail Adj Scaled by Avoided Costs.xlsx". The natural gas TDV factors used in the energy savings analyses were obtained via email from E3 in a spreadsheet titled "2022_TDV_Policy_Compliant_CH4Leak_FlatRtlAdd_20191210.xlsx". The electricity demand factors used in the energy savings analysis were obtained via email from E3 in a spreadsheet titled "2022 TDV Demand Factors.xlsx". The final TDV factors that the Energy Commission released in June 2020 use 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. The 20-year GWP values increased the TDV factors slightly. As a result, the TDV energy savings presented in this report are lower than the values that are expected if the final TDV that use 20-year GWP values were used in the analysis. The proposed code changes will be more cost effective using the revised TDV. Energy savings presented in kWh and therms are not affected by TDV or demand factors.

The Statewide CASE Team used California Building Energy Code Compliance software for commercial buildings (CBECC-Com) to conduct the energy savings for all code change proposals. Energy models are sourced from the CBECC-Com prototypical building models and are modified to include the proposed changes to the energy standards.

4.1.1 Fan Power Budget

The measure was evaluated using the stated methodology in Section 4.2. The energy savings analysis compares prescriptive proposed design according to the new fan power budgets to the current nonresidential standard design. Energy savings were modeled and quantified the HotelSmall, OfficeLarge, OfficeMedium, OfficeMediumLab, RetailLarge, RetailMixedUse, RetailStandalone, RetailStripMall, SchoolPrimary, SchoolSecondary, and Warehouse prototypes. All other components of the existing conditions are assumed to be minimally comply with the 2019 Title 24, Part 6 Standards.

4.1.2 Fan Energy Index

This measure was evaluated using the stated methodology in Section 4.2. The energy savings analysis compares the mandatory proposed design where the new FEI = 1.0 for a modified fan system (i.e., a two-fan system with a return fan) in the Large Office prototype to the current nonresidential standard design Large Office prototype. Energy savings were not quantified or claimed for any other building type, primarily because most other building prototypes use packaged equipment. Therefore, the energy savings are conservative in nature. All other components of the existing conditions are assumed to be minimally compliant with the 2019 Title 24, Part 6 Standards.

4.1.3 Duct Leakage

An energy and cost analysis is not required to refer to an existing requirement in the CMC.

The Statewide CASE Team is not claiming any savings from providing specifications to the duct leakage testing in the CMC because the objective of the proposal is to improve compliance with the code. However, the Statewide CASE Team has determined that the explicit ductwork selection requirements proposed would increase the cost of testing over current practices and has included those incremental cost in Section 5.4.3.

This measure was evaluated using the stated methodology in Section 4.2. The energy savings analysis compares the proposed mandatory requirement for Seal Class A with a baseline cases of Seal Class B for supply systems and 25 percent leakage for exhaust systems – based on Seal Class C. Table 10 gives the associated Leakage Class for each. Seal Class B was used in the baseline case to both align the SMACNA Duct Construction Standards and the CMC requirement that ducts meet Leakage Class 6.

The Statewide CASE Team is using the same duct layouts and costs for the duct leakage submeasure and fan power budget (Section 5.3.1). The Statewide CASE Team used the VAV proposed design layout (Figure 6) to estimate percent supply air duct leakage for the baseline and proposed cases – Seal Class B and Seal Class A, respectively. OfficeLarge and OfficeMedium protypes have no exhaust system so the Statewide CASE Team modified the prototypes by adding a 1000 cfm toilet exhaust system (two toilets) per floor. The Statewide CASE Team used 25 percent exhaust duct leakage based on the literature and the “SMACNA HVAC Duct Construction Standards – Metal and Flexible,” where exhaust systems are required to meet Seal Class C – see Table 20 (M. P. Modera 2007). This percent leakage was applied to the OfficeLarge, OfficeMedium, and OfficeMediumLab prototypes used to determine the difference in HVAC energy consumption. In each climate zone, the average energy savings per ft^2 among these three prototypes were calculated and weighed based on their 2023 forecasted new construction area (e.g., the OfficeLarge savings were weighed the most because it has the largest forecasted construction of the three). The average energy savings were extrapolated to the remaining prototype buildings. The Statewide CASE team believes this is appropriate since the airflow of all prototype buildings analyzed have supply airflow rates to floor area ratios of approximately 1.0 cfm per ft^2. The Statewide CASE Team did not calculate or include savings for OfficeSmall, RestaurantFastFood, Grocery, Warehouse, and RetailLarge as they would not be significantly impacted by the proposal because there is either no ductwork or very small amounts of ductwork that is often in conditioned space in these building types.

4.2 Energy Savings Methodology

4.2.1 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 17, though not all buildings were used for every measure. For example, the FEI measure was only considered in the Large Office prototype. Additionally, for the fan power budget measure, incremental cost was only calculated for the Large Office, but extrapolated to other building types. This is explained further in Section 5.3.

Table 17: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
HotelSmall	4	42,554	4 story Hotel with 77 guest rooms. Window/wall ratio (WWR) - 11%
OfficeLarge	13	498,589	12 story + 1 basement office building with 5 zones and a ceiling plenum on each floor. WWR - 40%
OfficeMedium	3	53,628	3 story office building with 5 zones and a ceiling plenum on each floor. WWR - 33%
OfficeMediumLab	3	53,628	3 story office building with 5 zones and a ceiling plenum on each floor. WWR- 33%
RetailLarge	1	240,000	Big-box type Retail building with WWR - 12% and SRR-0.82%
RetailMixedUse	1	9,375	Retail building with WWR -10%. Roof is adiabatic
RetailStandAlone	1	24,563	Similar to a Target or Walgreens.7% WWR on the front façade, none on other sides. SRR of 2.1%.
RetailStripMall	1	9,375	Strip Mall building with WWR -10%
SchoolPrimary	1	24,413	Elementary school with WWR of 36%
SchoolSecondary	2	210,866	High school with WWR of 35% and SRR 1.4%
Warehouse	1	49,495	Single story high ceiling warehouse. Includes one office space. WWR- 0.7%, SRR-5%

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of CBECC-Com.

CBECC-Com generates two models based on user inputs: the Standard Design and the Proposed Design.[14] The Standard Design represents the geometry of the design that the builder would like to build and inserts a defined set of features that result in an energy budget that is minimally compliant with 2019 Title 24, Part 6 code requirements. Features used in the Standard Design are described in the 2019 Nonresidential ACM

[14] CBECC-Res creates a third model, the Reference Design, that represents a building similar to the Proposed Design, but with construction and equipment parameters that are minimally compliant with the 2006 IECC. The Statewide CASE Team did not use the Reference Design for energy impacts evaluations.

Reference Manual. The Proposed Design represents the same geometry as the Standard Design, but it assumes the energy features that the software user describes with user inputs. To develop savings estimates for the proposed code changes, the Statewide CASE Team created a Standard Design and Proposed Design for each prototypical building. There is an existing Title 24, Part 6 requirement that covers the building system in question and applies to both new construction and alterations, so the Standard Design is minimally compliant with the 2019 Title 24 requirements.

4.2.1.1 Fan Power Budget

Currently, in Section 140.4(c) Fan Systems at design conditions shall not exceed the allowable fan system power of option 1 or 2 as specified in Table 140.4-A. In other words, the Standard Design is a fan system which exactly meets the fan power limitations. Comparing the energy impacts of the Standard Design (fan power limitations) to the Proposed Design (fan power budget) reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

The Proposed Design was identical to the Standard Design in all ways except for the revisions that represent the proposed changes to the code. Table 18 presents which parameters in CBECC-Com were modified and what values were used in the Standard Design and Proposed Design. The Proposed Design assumes fan power matches the proposed fan power budget.

Although the fan power budget addresses fan power, the energy modeling software does not have a user input for total system fan power measured in kW. To calculate the energy impacts, the Statewide CASE Team used the linear relationship between total fan power and total static pressure and adjusted total static pressure values in CBECC-Com to represent the modifications to fan power. For example, to simulate a 20 percent reduction in power (kW) at design conditions, the total static pressure input can simply be reduced by 20 percent in CBECC-Com. The Statewide CASE Team conducted a spreadsheet analysis to determine the electrical input power for the Proposed Design at design conditions, using Fan Power Budget methodology outlined in Appendix N), where the allowable electrical input power (Fan kW_{budget}) was calculated for each fan system as a function of airflow, system components, and fan system type (e.g., supply, return, relief, or exhaust). For modeling purposes, the fan electrical input power was set to equal the fan power budget. The total static pressure (in. wg) variable was then adjusted in the Proposed Designs in CBECC-Com to match the electrical input power from the spreadsheet analysis.

For example, for one fan in the large office prototype building the total static pressure was changed from 5.362 in. wg in the Standard Design to 4.267 in. wg in the Proposed Design to illustrate the fan power input power going from 30.82 kW under the Standard

Design to 23.44 kW under the Proposed Design. This does not mean the Proposed Design is expected to have its total static pressure at that level, but because pressure has a linear relationship with fan brake HP, it was adjusted to match the input power kW in the Proposed Design. This example is shown below for one fan but was repeated for dozens of fans in-scope (namely all fans with input power greater than 1 kW) for each prototype building modeled. For the purposes of this analysis, transmission efficiency was ignored, as transmission efficiency is not currently in CBECC-Com and it would not impact the energy savings as the Standard Design and Proposed Design in 2022 are both assumed to have belt-drives at the same efficiency level.

Table 18: Example Modifications Made to Standard Design for Large Office Prototype Supply Fan to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
OfficeLarge	All	Total Static Pressure	5.362	4.267
OfficeLarge	All	Fan Total Efficiency	65%	65%
OfficeLarge	All	Motor Efficiency	94.1%	94.1%

4.2.1.2 Fan Energy Index

As stated above, in Section 140.4(c) Fan Systems at design conditions shall not exceed the allowable fan system power of option 1 or 2 as specified in Table 140.4-A. The Standard Design is a fan system which exactly meets the fan power limitations.

To model the energy savings from FEI, changes were made to the fan system in the Large Office prototype to make it a "two-fan" system from the current "single-fan" system. As background, most fan systems in large buildings are two-fan systems, having a supply fan and a return fan. However, the CBECC-Com 2022 prototype buildings model fan systems as one fan systems, likely for modeling simplicity. In general, this is sufficient for estimating overall *fan system* power consumption, but it makes it challenging to quantify power consumption and savings from *individual fans,* where the FEI metric applies. As described previously, the default assumption for the large office prototype (and all VAV systems) is a single fan system with 5.35 in. wg of total static pressure and a 65 percent efficient fan, which equals the maximum allowed power consumption at the fan power limitations. However, when switching to a two-fan system, the Statewide CASE Team had to determine the separate efficiencies for a supply and return fan. The Statewide CASE Team consulted with expert stakeholders to understand the common fan efficiencies and pressures in a large office fan configuration and how fan selections for a two-fan system would be conducted in the real world, keeping power demand at design conditions to equal the power allowed by the fan power limitations. This approach yielded a representative fan system where the supply fan has an FEI greater than 1.0, meeting the proposed standard, but the return fan has an FEI less than 1.0, not meeting the propose standard. In other words, the Standard Design was modified from a single-fan system to a two-fan system where the total power consumption at design conditions is the same (at the fan power limitations). Energy savings are then calculated by increasing the efficiency of the return fan from 38 percent to 42.5 percent to go from an FEI of 0.87 to an FEI of 1.0 which allows the proposed FEI standard to be met, and energy to be saved. For more detailed calculations see Appendix G.

Table 19: Example Modifications Made to Standard Design for Large Office Prototype Supply Fan to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
OfficeLarge	All	Total Static Pressure (Supply)	3.6	3.6
OfficeLarge	All	Fan Total Efficiency (Supply)	66%	66%
OfficeLarge	All	Motor Efficiency (Supply)	93.6%	93.6%
OfficeLarge	All	FEI- Supply fan *(Reference Only)*	1.23	1.23
OfficeLarge	All	Total Static Pressure (Return)	1	1
OfficeLarge	All	Fan Total Efficiency (Return)	37%	42.5%
OfficeLarge	All	Motor Efficiency (Return)	92.4%	92.4%
OfficeLarge	All	FEI- Return Fan *(Reference Only)*	0.88	1.00

To simulate the energy savings in CBECC-Com, the Statewide CASE Team used the linear relationship between total fan power and total static pressure and adjusted total static pressure values in CBECC-Com to represent the modifications to fan power.

The Statewide CASE Team also spoke with manufacturers and other fan experts to confirm it was common practice to select efficient supply fans, but to then pick less efficient return fans. This aligns with general industry commentary that the FEI metric would have the largest impact on the return and exhaust fans.

4.2.1.3 Duct Leakage

The Statewide CASE Team compared the associated leakage of current sealing and testing requirements in the CMC to the proposed mandatory requirement of Seal Class A for ductwork. The Statewide CASE Team used the proposed supply air VAV layout of the OfficeLarge prototype to determine the baseline and proposed percent leakage, and then the associated difference in fan energy consumption to arrive at the energy savings. This difference in leakage was then applied to all building prototypes evaluated. The Statewide CASE Team believes this is appropriate since the airflow of all prototype buildings analyzed have supply airflow rates to floor area ratios of approximately 1.0 cfm per ft^2. The highest design pressure for the ductwork for this layout is 2.25 in. wg, so according to the CMC and "SMACNA HVAC Duct Construction Standards – Metal and Flexible" it would be required to meet Seal Class B – sealing transverse joints and seams – above 2 in. wg and Seal Class C – sealing transverse joints – below 2 in. wg, see Table 20. However, given that the CMC requires portions of all ductwork to be tested and to meet Leakage Class Six, the Statewide CASE Team assumed that all ductwork in the baseline case complied with Seal Class B – the layout has both round and rectangular duct. The Statewide CASE Team also assumed 25 percent leakage in the baseline case for toilet and general exhaust air systems and that exhaust systems be sealed to Seal Class A in the proposed case (M. P. Modera 2007). Two toilets were assumed per floor for the OfficeLarge and OfficeMedium prototypes, with each toilet having an exhaust flow of 500 cfm.

Table 20: Recommended Leakage Classes (ANSI/SMACNA 2006)

Seal Class	**C**	**B**	**A**
Duct Pressure Class	≤2 in. wg	>2 and <4 in. wg	≥4 in. wg
Leakage Class – Rectangular Metal	16	8	4
Leakage Class – Round Metal	8	4	2

The Statewide CASE Team used Leakage Classes 8 and 4 in the baseline case and Leakage Classes 4 and 2 in the proposed case, for rectangular and metal ductwork, respectively. The duct leakage per ft^2 of ductwork surface area was calculated using Equation 5 for both cases.

The associated leakages for Seal Class C, Seal Class B, and Seal Class A were scaled based upon the testing performed by National Energy Management Institute (NEMI), with the difference between the two shown in Table 21. Seal Class C was the baseline case for the exhaust air system because toilets exhausts are typically low pressure ductwork that is not tested, Seal Class B was the baseline case for the supply air system, and Seal Class A was the proposed case for both.

Table 21: Allowable and Measured Leakage for Each Seal Class

Seal Class	SMACNA Duct Construction Standards leakage factor rectangular (at 2 in w.g.)	SMACNA Duct Construction Standards leakage factor round (at 2 in w.g.)	SMACNA Duct Construction Standards total allowable leakage for tested ducts (at 2 in. w.g.)	NEMI total measured leakage (at 2 in. w.g.)	Scalar (measured/ allowable leakage)
C	25 cfm/100ft^2	13 cfm/100ft^2	15 cfm	55 cfm	3.8
B	13 cfm/100ft^2	6.3 cfm/100ft^2	7.4 cfm	11 cfm	1.6
A	6.3 cfm/100ft^2	3.1 cfm/100ft^2	3.7 cfm	1.4 cfm	0.37

Additional leakage was estimated for the VAV boxes and added to both the baseline and proposed cases for the supply systems. The leakage for each VAV box was determined by summing the maximum allowed casing and relevant appurtenance leakages (dependent on whether or not there was terminal heating), as per the example in Table 22.

Table 22: Example Calculation of VAV Box Leakage

	Conference Room 1	Conference Room 9
VAVs Per Zone	2	1
Airflow Per VAV	1030 cfm	185 cfm
Inlet Size	10”	5”
AHRI Nominal Rating	1100 cfm	250 cfm
Casing Max Leakage	11 cfm	4 cfm
Max Appurtenances Leakage	4 cfm	2 cfm
Water Coil Max Leakage	6 cfm	NA
Total VAV Box Leakage	42 cfm	6 cfm

The duct leakage rate and HVAC energy consumption were then determined for the large office prototype with the modifications in Table 23. The total VAV box leakage was added to the baseline and proposed duct leakage levels, resulting in a total leakage of 7.4 percent the baseline case (Seal Class B) and 3.0 percent in the proposed case (Seal Class A). This percent leakage was then applied individually to the ductwork upstream and downstream of the VAV boxes – 7.4 percent upstream and downstream in the baseline case and 3.0 percent upstream and downstream in the proposed case. The full results of the calculations of duct leakage can be found in Appendix I.

Table 23: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
OfficeLarge	All	Nominal Upstream Leakage Fraction	7.4	3.0
OfficeLarge	All	Constant Downstream Leakage Fraction	7.4	3.0
OfficeLarge	All	Fan:ZoneExhaust: Maximum Flow Rate	Calculated based on 25% duct leakage	2.0
OfficeMedium	All	Nominal Upstream Leakage Fraction	7.4	3.0
OfficeMedium	All	Constant Downstream Leakage Fraction	7.4	3.0
OfficeMedium	All	Fan:ZoneExhaust: Maximum Flow Rate	Calculated based on 25% duct leakage	2.0
OfficeMediumLab	All	Nominal Upstream Leakage Fraction	7.4	3.0
OfficeMediumLab	All	Constant Downstream Leakage Fraction	7.4	3.0
OfficeMediumLab	All	Fan:ZoneExhaust: Maximum Flow Rate	Calculated based on 25% duct leakage	2.0

CBECC-Com calculates whole-building energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). It then applies the 2022 TDV factors to calculate annual energy use in thousand British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). CBECC-Com also generates TDV energy cost savings values measured in 2023 present value dollars (2023 PV$) and nominal dollars.

The current version of CBECC-com can’t model duct leakage. The return plenums and duct leakage rates were added to OfficeLarge, OfficeMedium, and OfficeMediumLab building prototypes in EnergyPlus. The Statewide CASE Team simulated the energy impacts in every climate zone and applied the climate-zone specific TDV factors when calculating energy and energy cost impacts.

Upstream and downstream duct leakage is specified in the EnergyPlus IDF using the “ZoneHVAC:AirDistributionUnit” object for each thermal zone. An example for one of the zones simulated is shown below:

ZoneHVAC:AirDistributionUnit,

ADU BaseVAVBox TrmlUnit-2, !- Name

BaseVAVBox TrmlUnit-2 Outlet Node, !- Air Distribution Unit Outlet Node Name

AirTerminal:SingleDuct:VAV:Reheat, !- Air Terminal Object Type

BaseVAVBox TrmlUnit-2, !- Air Terminal Name

0.074, !- Nominal Upstream Leakage Fraction

0.074; !- Constant Downstream Leakage Fraction

Nominal Upstream Leakage Fraction is the leakage upstream of the terminal unit as a fraction of the design flow rate through the unit. It is the leakage fraction at the design flow rate. It is used to calculate a leakage flow rate which is then held constant while the system air flow varies.

Constant Downstream Leakage Fraction is the leakage downstream of the terminal unit as a fraction of the current flow rate through the terminal unit. This fraction is held constant, so the leakage flow rate will vary proportionally with the supply air flow rate.

Normalized energy impacts for nonresidential buildings are presented in savings per square foot of total building floor area – all of the floor area is conditioned. Annual energy and peak demand impacts for each prototype building were translated into impacts per square foot by dividing by the floor area of the prototype building. This step allows for an easier comparison of savings across different building types and enables a calculation of statewide savings using the construction forecast that is published in terms of floor area by building type.

4.2.2 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts that the Energy Commission provided (California Energy Commission n.d.). The Statewide Construction Forecasts estimate new construction that would occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Com, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 24 presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

Appendix A presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 24: Nonresidential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Small Office	OfficeSmall	100%
Large Office	OfficeMedium	50%
" "	OfficeLarge	50%
Restaurant	RestaurantFastFood	100%
Retail	RetailStandAlone	10%
" "	RetailLarge	75%
" "	RetailStripMall	5%
" "	RetailMixedUse	10%
Grocery Store	Grocery	100%
Non-Refrigerated Warehouse	Warehouse	100%
Refrigerated Warehouse	RefrigWarehouse	N/A
Schools	SchoolPrimary	60%
" "	SchoolSecondary	40%
Colleges	OfficeSmall	5%
" "	OfficeMedium	15%
" "	OfficeMediumLab	20%
" "	PublicAssembly	5%
" "	SchoolSecondary	30%
" "	ApartmentHighRise	25%
Hospitals	Hospital	100%
Hotel/Motels	HotelSmall	100%

4.3 Per-Unit Energy Impacts Results

4.3.1 Fan Power Budget

Energy savings and peak demand reductions per unit are presented in Table 25 for new construction, additions and alterations for the fan power budget submeasure in the large office prototype. These are shown in one table as the relative energy savings are estimated to be the same per square foot, as is explained further in Section 6.1. Energy savings and peak demand reductions per unit for other prototype buildings analyzed are in Appendix J. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates. For the OfficeLarge prototype, per-unit savings for the first year are expected to range from 0.15 to 0.217 kWh/ft2 and –0.003 to 0 therms/ft2 depending upon climate zone. Demand decreases are expected to range between 0.059 and 0.392 watts (W)/ft2 depending on climate zone. Gas usage increases as more efficient fan systems generate less waste heat from the fan's motor which is captured in the air stream providing heat to the building. With more efficient fan systems, there is less waste heat, and thus more gas is needed during the heating season.

Table 25: First-Year Energy Impacts Per Square Foot - Fan Power Budget – New Construction/ Additions /Alterations – OfficeLarge

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.150	0.059	(0.003)	3.192
2	0.177	0.079	(0.002)	4.518
3	0.175	0.075	(0.001)	4.290
4	0.186	0.077	(0.001)	4.819
5	0.179	0.080	(0.001)	4.194
6	0.202	0.087	(0.001)	5.255
7	0.195	0.080	(0.001)	4.951
8	0.197	0.079	(0.001)	5.371
9	0.195	0.084	(0.001)	5.343
10	0.202	0.077	(0.001)	5.374
11	0.186	0.081	(0.001)	4.699
12	0.184	0.033	(0.001)	4.598
13	0.193	0.087	(0.001)	4.946
14	0.209	0.093	(0.001)	5.559
15	0.217	0.392	0.000	5.835
16	0.208	0.067	(0.002)	4.742

4.3.2 Fan Energy Index

Energy savings and peak demand reductions per unit are presented in Table 26 for new construction for the fan energy index submeasure. Energy savings and peak demand reductions per unit for other prototype buildings analyzed are in Appendix I. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates. For the large office prototype, per-unit savings for the first year are expected to range from 0.022 to 0.034 kWh/ft2 depending upon climate zone. Demand decreases are expected to be minimal.

Table 26: First-Year Energy Impacts Per Square Foot - Fan Energy Index - OfficeLarge

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.022	0.002	0.000	0.486
2	0.027	0.003	0.000	0.693
3	0.026	0.003	0.000	0.651
4	0.028	0.003	0.000	0.714
5	0.027	0.003	0.000	0.629
6	0.031	0.003	0.000	0.813
7	0.029	0.002	0.000	0.723
8	0.031	0.004	0.000	0.868
9	0.029	0.002	0.000	0.841
10	0.031	0.002	0.000	0.864
11	0.029	0.001	0.000	0.726
12	0.028	0.003	0.000	0.713
13	0.029	0.003	0.000	0.782
14	0.033	0.003	0.000	0.921
15	0.034	0.003	0.000	0.925
16	0.032	0.004	0.000	0.746

4.3.3 Duct Leakage

Energy savings and peak demand reductions per unit are presented in Table 27 for new construction, additions and alterations for the duct leakage submeasure in the large office prototype. These are shown in one table as the relative energy savings are estimated to be the same per ft2, as is explained further in Section 6.1. Energy savings and peak demand reductions per unit for other prototype buildings analyzed are in Appendix I. Energy savings and peak demand reductions per unit for other prototype buildings analyzed are in Appendix I. The per-unit energy savings figures assume a single, average total leakage for supply- and exhaust-air systems in the base case. For the large office prototype, per-unit savings for the first year are expected to range from 2.95 to 5.79 kBtu/ft2 depending upon climate zone. HVAC energy savings are from reducing the amount of air that needs to be moved by the fan. This reduces fan energy and also slightly reduces heating and cooling energy, because less air would need to be conditioned. There is a slight heating penalty because airflow reduction decreases the fan motor heat. That is why there are small negative gas savings in Climate Zone 1, but in every other climate zone the savings from having to condition less air outweigh the reduction in fan motor heat and lead to positive gas savings.

Table 27: First-Year Energy Impacts Per Square Foot – Duct Leakage - OfficeLarge

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.12	0.01	(1.95)	2.95
2	0.15	0.01	0.92	4.61
3	0.16	0.06	2.39	5.10
4	0.16	0.01	2.17	5.14
5	0.15	0.01	0.72	4.33
6	0.17	(0.06)	2.48	5.31
7	0.16	0.00	1.97	4.97
8	0.17	0.01	2.26	5.20
9	0.17	0.02	2.62	5.28
10	0.16	0.01	0.57	4.57
11	0.17	0.01	2.39	5.30
12	0.16	0.01	1.82	5.11
13	0.16	0.01	2.01	5.16
14	0.17	0.01	1.58	5.16
15	0.18	0.01	3.12	5.79
16	0.17	0.02	0.47	4.90

5. Cost and Cost Effectiveness

The Statewide CASE Team found all submeasures to be cost effective. The energy cost savings methodology and results are shown below.

5.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the TDV energy cost factors to the energy savings estimates that were derived using the methodology described in Section 4.2. TDV is a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the period of analysis (30 years for 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 nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 15 years.

The fan power budget, FEI and duct leakage submeasures all also apply to alterations and alterations. For all submeasures, the incremental energy savings and cost per ft^2 were estimated to be the same for new construction and alterations and additions.

It should also be noted that the proposed fan power budget is slightly less stringent for additions and alterations, than for new construction, in line with the relative stringency of the fan power limitations in new construction and additions/alterations. Practically speaking, in the Title 24-2019 building code, alterations get an additional 0.9 in. wg in total to meet the fan power limitations.[15] In line with this current allowance for additions/alterations, the Statewide CASE Team is proposing allowance of 0.6 in. wg for supply systems and 0.3 in. wg for exhaust/return/relief systems (where the combined total equals 0.9 in. wg). These additional pressure allowances align with the existing additional pressure allowances allowed for additions and alterations with the 2019 fan power limitations.

There are no differences in stringency for the duct leakage proposal between new construction and alterations and additions.

5.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings and alterations that are realized over the 15-year period of analysis are presented in nominal dollars in Appendix M and 2023 dollars in Table 28, Table 29, and Table 30. For brevity, only the

15 The additional pressure allowance of 0.9 in. wg is technically allowed when MERV 13 filters are present. However, these filters are required by code in CA, thus giving an extra allowance.

energy cost savings results for one prototype, Large Office, are shown below for each submeasure. All other energy cost savings results for other prototypes are shown in Appendix K.

The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods. In general, because HVAC is a driver of peak demand, especially in the summer months during the cooling season, savings from fan energy during the peak is significant.

5.2.1 Fan Power Budget

Table 28: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – Fan Power Budget – New Construction/Additions/Alterations – OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.34	($0.06)	$0.28
2	$0.44	($0.04)	$0.40
3	$0.41	($0.03)	$0.38
4	$0.45	($0.03)	$0.43
5	$0.41	($0.03)	$0.37
6	$0.48	($0.02)	$0.47
7	$0.45	($0.01)	$0.44
8	$0.49	($0.01)	$0.48
9	$0.49	($0.02)	$0.48
10	$0.50	($0.02)	$0.48
11	$0.45	($0.03)	$0.42
12	$0.44	($0.03)	$0.41
13	$0.47	($0.03)	$0.44
14	$0.53	($0.03)	$0.49
15	$0.53	($0.01)	$0.52
16	$0.48	($0.05)	$0.42

5.2.2 Fan Energy Index

Table 29: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – FEI –New Construction – OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.05	($0.01)	$0.04
2	$0.07	($0.01)	$0.06
3	$0.06	$0.00	$0.06
4	$0.07	$0.00	$0.06
5	$0.06	$0.00	$0.06
6	$0.07	$0.00	$0.07
7	$0.07	$0.00	$0.06
8	$0.08	$0.00	$0.08
9	$0.08	$0.00	$0.07
10	$0.08	$0.00	$0.08
11	$0.07	$0.00	$0.06
12	$0.07	$0.00	$0.06
13	$0.07	$0.00	$0.07
14	$0.09	$0.00	$0.08
15	$0.08	$0.00	$0.08
16	$0.07	($0.01)	$0.07

5.2.3 Duct Leakage

Table 30: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – Duct Leakage – New Construction/ Additions/ Alterations – OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.31	($0.04)	$0.26
2	$0.39	$0.02	$0.41
3	$0.40	$0.05	$0.45
4	$0.41	$0.05	$0.46
5	$0.37	$0.01	$0.39
6	$0.42	$0.05	$0.47
7	$0.40	$0.04	$0.44
8	$0.41	$0.05	$0.46
9	$0.41	$0.06	$0.47
10	$0.40	$0.01	$0.41
11	$0.42	$0.05	$0.47
12	$0.42	$0.04	$0.46
13	$0.42	$0.04	$0.46
14	$0.43	$0.03	$0.46
15	$0.45	$0.07	$0.52
16	$0.43	$0.01	$0.44

5.3 Incremental First Cost

5.3.1 Fan Power Budget

The incremental cost analysis approach for the fan power budget submeasure examined the costs of better duct design and duct component selection required for lower pressure ducts. However, there are many ways to reduce fan power and comply with the existing fan power limitation standards *and* proposed fan power budget standards. Lower pressure ducts are just one of the pathways. It may often be easier and less expensive to comply with the fan power budget through better fan selections, more efficient air-handler/HVAC packaged equipment design and other component selections. However, for the purposes of this measure, cost-effectiveness was pursued strictly through the duct systems (with the boundaries being the inlet and outlet transitions of air-handlers/HVAC packaged equipment to the VAV box and diffusers). The Statewide CASE Team is taking this conservative approach to show all the energy savings from this measure can be realized through improvements to the ductwork resulting in reduced static pressure. This also demonstrates that preemption should not be a concern as changes to regulated equipment would not be necessary to comply with the fan power budget.

As noted in Section 2.2.1, this measure was partially inspired by an ASHRAE research paper titled “Development of Maximum Technically Achievable Energy Targets for Commercial Buildings” which included a section on “High Performance Ducts to Reduce Static Pressure” (Glazer 2015). In this paper, the following strategies were identified for reducing static pressure in duct systems:

- Maximize use of straight ducts
- Focus on critical path
- Duct system symmetry
- Use round ducts
- Reduce number of fittings and joints
- Use conical or 45° taps at VAV boxes
- Sheet metal VAV box inlets (not flex duct)
- Avoid consecutive fittings
- Use only short runs of flex duct
- Larger duct sizes
- Lower air velocities
- Fan discharge into straight duct sections
- Fittings with turning vanes
- Radiused elbow
- Direct routing of ducts
- Central fan location
- Reduce system effects
- Use materials with low friction factors

To estimate the incremental cost for this measure, the Statewide CASE Team developed bottom-up cost estimates for four different large office duct designs for two very different systems. The CAV duct system is for an application where a variable refrigerant flow (VRF) heat pump supplies space heating and cooling, representing a lower airflow fan system. The VAV duct system is a full standalone mixed-air HVAC system, representing a higher airflow fan system. By modeling both of these systems the Statewide CASE team would get a range of results and truly test the approach of achieving all of the pressure out of the ductwork. The matrix of duct designs is shown below in Figure 6.

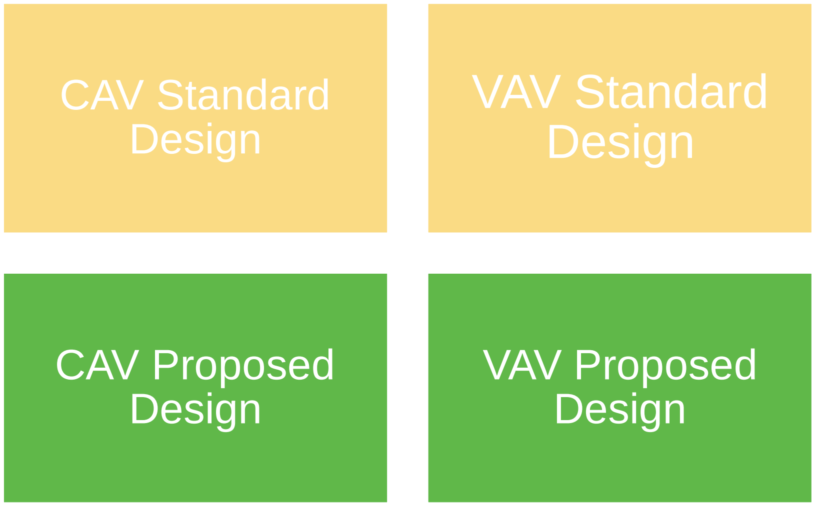

Figure 6: Large office duct designs standard and proposed.

Source: Statewide CASE Team

The first two duct designs (Standard Designs) were created to reflect the external static pressure assumptions in the existing 2019 fan power limitations. Next, two duct designs (Proposed Design) were created using the same general layouts but were modified in various ways to meet the external static pressure required to meet the fan power budget.

It's important to note that there are numerous methods, materials and techniques to designing ductwork. There are also numerous considerations designers must take into account such as aesthetics, sound, space constraints and of course, first cost, aside from static pressure and energy costs. For example, there can be high cost high pressure duct designs, and low-cost high-pressure duct designs. The Statewide CASE Team also understands that the ductwork ultimately installed in a building often depends on the contractor's approach and preference. For example, some contractors rely on more on rectangular ductwork as it allows more on-site fabrication and customization, whereas some contractors use round ductwork which may require more planning and off-site fabrication of components. In summary, there are many variables which can alter the ductwork cost, aside from just pressure loss. The Statewide CASE Team chose to determine the incremental cost to reduce pressure to meet the proposed standard by using the same general duct layout for both the Standard and Proposed Designs, which utilized many good design practices, and only changing the fittings and ductwork diameter. This would allow the most straightforward and conservative approach to determining the incremental cost to meet the fan power budget.

The large office prototype was chosen to determine incremental cost of the fan power budget submeasure as, of the CEC prototype buildings used to evaluate code change proposals, it is likely the prototype building with the most ductwork (i.e., longest duct runs), and thus external static pressure.[16] This approach was important to show that the standard was technically feasible and cost effective by pursuing pressure reductions in the ductwork alone. The incremental cost per ft^2 for large office design could then be conservatively extrapolated to the other prototype buildings. For example, if the incremental cost to comply was $1/$ft^2$ in the large office (with extensive ductwork), then applying this same incremental cost of $1/$ft^2$ to the medium retail prototype (with very little ductwork) would likely overstate the costs to comply, or in other words be a conservative estimate of the cost to comply. Again, more efficient fans, motors and transmissions are likely easier and potentially more cost-effective methods to meet the proposed fan power budget, but the Statewide CASE Team aimed to demonstrate that packaged HVAC equipment would not need to be modified for the prescriptive standard to be met. The incremental cost exercise was designed to be represent a "worst-case scenario" where all the energy savings to meet the new standard are realized by reducing pressure in ductwork.

As mentioned, the Statewide CASE Team developed ductwork layouts based upon two different fan system types commonly found in large office air distribution systems and were designed using underlying total static pressures assumptions in the Standard Design (2019) and the pressure reduction needed to meet the fan power budget for the Proposed Design (2022). The first fan system design modeled is a traditional, mixed-air VAV system, reflecting the CBECC-Com prototype model fan system. Here, conditioned air is delivered to the space via an air-handler with VAV boxes.

The second fan system design is CAV fan system, meant to simulate a 100 percent outside air system with a VRF heat pump. This second system was chosen to be modeled and costed as it represents a lower air flow case, where the ductwork cost per CFM was expected to be the highest. In other words, the ductwork in 100 percent outside-air systems serve primarily to deliver outside air, not heating or cooling functions, meaning the air flows are much lower than a standard mixed-air VAV configuration.

The Statewide CASE Team leveraged their internal engineering resources and subcontractors to develop ductwork designs and cost estimates for each of the two Standard Designs and two Proposed Designs. The external static pressures the ductwork was designed to are shown in Table 31. The VAV Proposed Design is shown below in Figure 7 as an example. Detailed ductwork designs for all four layouts and other information about this incremental cost exercise are located in Appendix G.

[16] Note that the CEC prototype buildings in CBECC-Com do not actually specify any lengths or layouts of ductwork, only the assumed total static pressure. The duct path options include "ducted", "plenum zones" or "direct", but do not correlate to duct pressure, type or design.

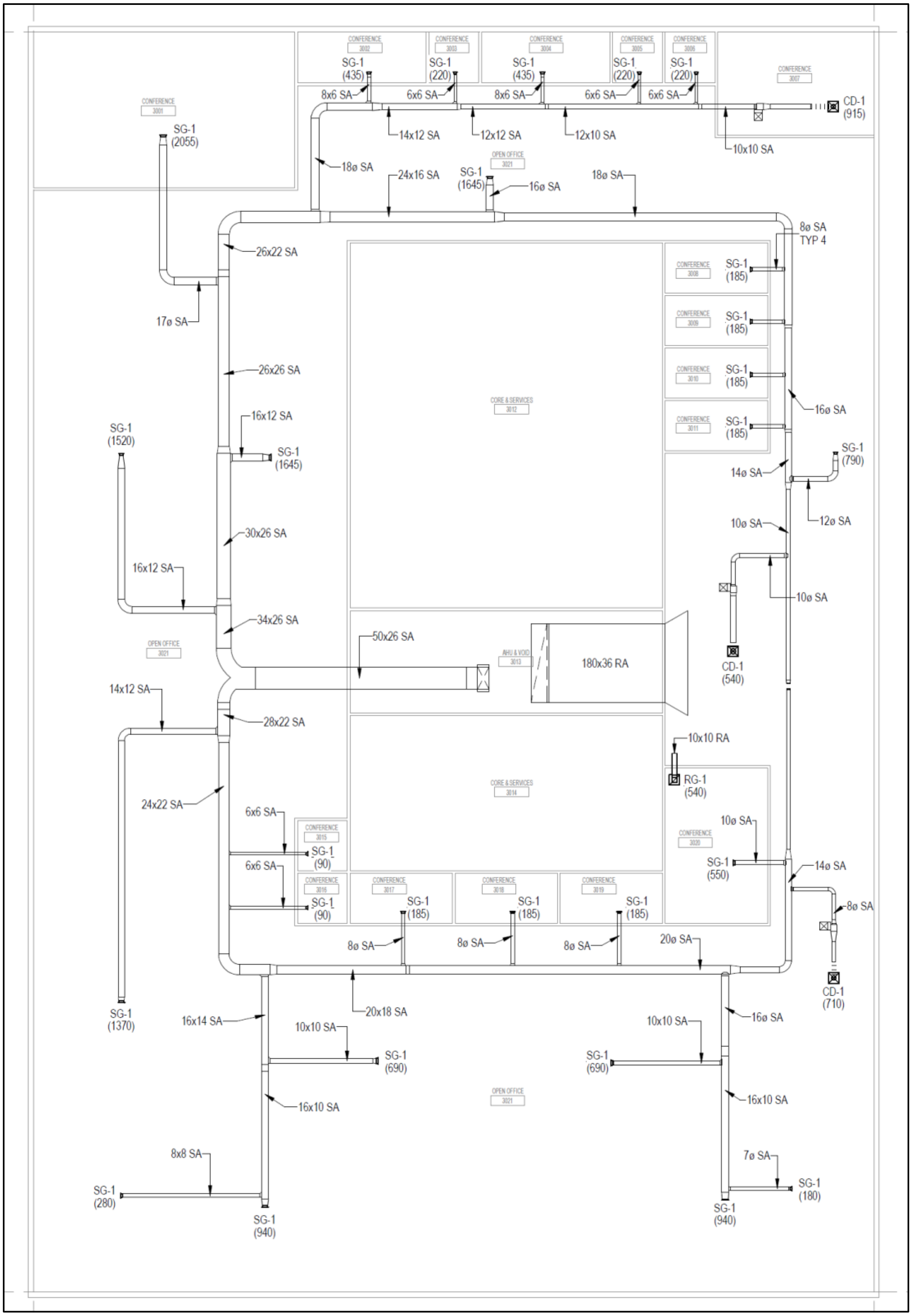

Figure 7: VAV Proposed Design duct layout.

Source: Statewide CASE Team

To develop the duct layouts, the Statewide CASE Team started with the overall area (ft^2) of a single floor from the 38,400 ft^2 Large Office prototype in Los Angeles (Climate Zone 9). From the gross floor plate area, core space, walls and other non-usable areas were subtracted to yield a usable floor area of 32,100 ft^2. The usable space was designed with a standard area layout of open office space (84 percent) and conference rooms (16 percent). Next, using standard occupancy assumptions, ventilation rates, and expected internal heat gains, required airflows were calculated under the VAV and CAV system designs. These design air flows of 18,375 cfm to cover ventilation and space conditioning loads. To cover only ventilation requirements 7,765 cfm is required for the CAV system. Table 31 displays the two systems static pressure details. With these constraints, the Statewide CASE Team designed the duct layouts using best engineering judgement to create two Standard Designs (CAV and VAV) which are representative of the fan power limitation external static pressure assumptions as shown in Table 5. See below for "Standard Design (2019) Target ESP" column in Table 31. These values come from the existing assumptions in the fan power limitations in Table 5. The Statewide CASE Team then calculated how much external static pressure would need to be reduced in order meet the fan power budget requirements, if all other system components stayed the same (i.e., cabinet pressure, fan efficiency, motor efficiency, etc.). The Statewide CASE Team then designed the low pressure Proposed Design ductwork layout to meet the fan power budget at these air flows.[17] (See "Proposed Design (2022) Target ESP" column in Table 31).

Table 31: Modeled Duct External Static Pressure Values for Large Office Prototype

HVAC Type	System Type	Calculated Airflow (cfm)	Standard Design (2019) Target ESP (in. wg)	Proposed Design (2022) Target ESP (in. wg)	2022 Design Layout ESP (in. wg)
Mixed-Air Design	VAV Supply	18,375	2.25	1.78	1.76
	VAV Return	18,375	1.5	1.21	0.46
100% Outside Air Design	CAV Supply	7,765	1.25	1.23 [a]	1.2
	CAV Return	7,765	1	0.84	0.45

Source: Statewide CASE Team

a. In the case of the 100 percent outside air CAV fan system, an extra 0.5 inches of pressure is allocated under the reference pressure tables. See Table 128.

[17] An important distinction in this analysis is that for the Proposed Design, the reference pressures found in Table 128- Reference Pressure Fan System Pressure Losses for Calculating Pref – Supply-Only and Supply/Recirculation and Table 129- Reference Pressure Fan System Pressure Losses for Calculating Pref – Exhaust/Relief/Return/Transfer/Recirculation were not used directly. These reference pressure values were input into the fan power budget equation to determine the allowable fan power. The pressure was then adjusted until the fan power was equal to the fan power budget.

Built into the Proposed Design (2022) Target ESP values are assumptions about what components are included in the air distribution system. For the VAV system, reference pressures are built into the fan power budget equation that include an allowance for supply ductwork ESP, return ductwork ESP, a cooling coil, a gas-fired heating exchanger and a MERV 13 filter. These pressure allowances are the same standard assumptions from Table 128, which underpins Table 140.4-A: Supply Fan Power Allowances. For the CAV system, (as noted in the note to Table 31 above), an additional reference pressure is included into the fan power budget equation as it is a 100 percent outside air system. Without this 0.5 in. wg (from Table 128) it would be difficult, if not impossible, to achieve the fan power budget without this additional allowance. The Statewide CASE Team knew ahead of time that a 100 percent outside air CAV system in the large office layout would be a challenging test case for the technical feasibility of the standard without making significant and unrealistic changes in duct size. In this proposal, the Statewide CASE Team has increased the number of additional component fan power allowances to account for various air distribution components. This allows the fan power budgets to become more stringent overall but create reasonable fan power allowances (and thus extra fan power budget) when needed. See Section 7.3 for a full list of fan power allowances.

The cost of four ductwork designs shown in Figure 6 were then sent to a professional cost estimator. Some key assumptions about the costing analysis are listed below.

- Cost data is inclusive of ductwork, duct insulation, fittings, hangers and other accessories.
- All data comes from RS Means, where labor rates are assumed to be average union standard wages across California.
- Design costs for each system were estimated to be the same for all systems, thus were not included in the total cost or cost/ cfm calculations.

The results shown below in Figure 8 shown represent the total cost for both the standard and proposed designs for the constant volume and variable-air volume systems.

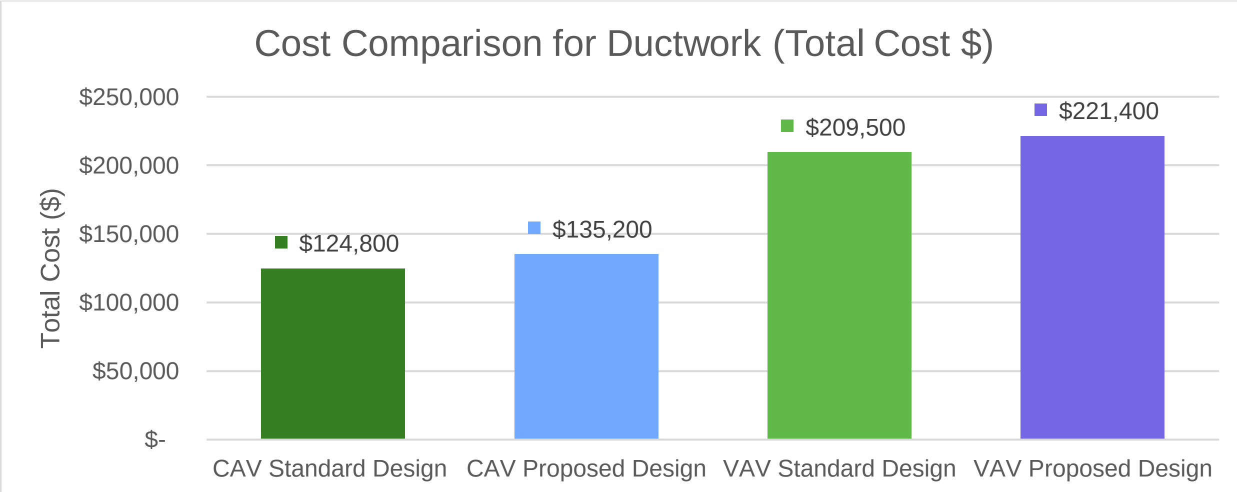

Figure 8: Large Office ductwork total cost ($) for a CAV and a VAV system.

Source: Statewide CASE Team

The results shown below in Figure 9 shown represent cost per ft2 for both the standard and proposed designs for the CAV and VAV systems.

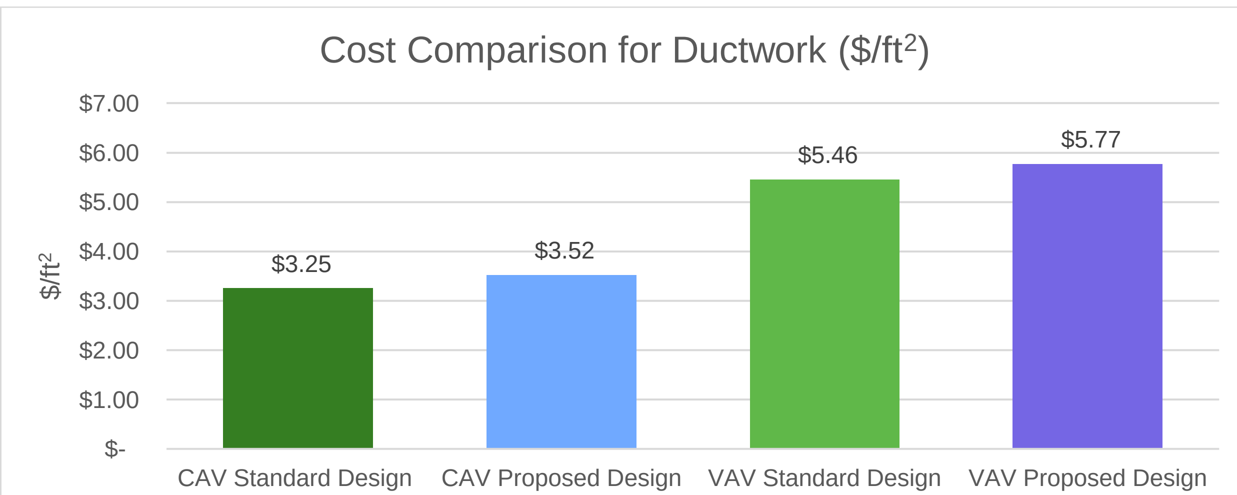

Figure 9: Large Office ductwork cost ($/ft2 building floor area) for a CAV and a VAV system.

Source: Statewide CASE Team

This analysis showed an incremental cost range of $0.31 per ft2 for the VAV system and $0.27 per ft2 for the CAV system. This incremental cost is solely due to larger diameter round ductwork and better fittings selection. The larger round ductwork and fittings uses more sheet metal; therefore, the costs increase. The layouts are geometrically similar, and the critical paths were the same distance. Furthermore, no changes were made between VAV boxes, elbows, length of straight duct. In summary, this analysis shows:

- The external static pressure assumptions underpinning the existing 2019 fan power limitations are generous, and do not require significant care and consideration during the ductwork design process to achieve the prescriptive requirement.
- If the pressure reductions to meet the proposed fan power budget can be achieved in the Large Office prototype for two types of fan systems, then they should be able to be achieved in the other prototype buildings with less ductwork.
- Using basic best practices for duct design and component selection, the external static pressure can be significantly reduced (without new or expensive technologies) for a small incremental cost, or possibly a negative incremental cost.

Given these findings the Statewide CASE Team is proposing to use the average of the incremental costs (between the CAV and VAV systems) for the purposes of cost-effectiveness analysis across all building types and climate zones. Specifically, the Statewide CASE Team is using an incremental cost per \$0.29 per ft^2 to achieve the fan power budget.[18] As has been stated, achieving the fan power budget may be easier and more cost effective to meet through more efficient fans, motors or transmissions, but the Statewide CASE Team chose to focus on ductwork to show the fan power budget could be met without impacting HVAC equipment design.

5.3.2 Fan Energy Index

The Statewide CASE Team explored numerous approaches to determining the incremental cost for the FEI submeasure. This included data derived from the U.S. DOE NODA III documents published in November 2016 (Department of Energy 2016). In September 2018 to support the Title 20 pre-rulemaking activities, the Statewide CASE Team docketed slighted revised/updated values from the U.S. DOE NODA III analysis, which showed an incremental cost of \$199 per standalone fan to achieve an FEI of 1.0 (Statewide CASE Team 2018). More specifically, this incremental cost represents the average incremental cost to achieve an FEI of 1.0 for a shipment weighted average of all "standalone" fans analyzed in the U.S. DOE scope. In the U.S. DOE context,

[18] Note that for Warehouse and the HotelSmall prototypes, the Statewide CASE team did not apply the same incremental cost \$0.29 per ft^2 directly as it was not appropriate. All other prototypes analyzed had a cfm/ ft^2 ratio of 0.94 (or close to 1 cfm/ ft^2 which is common). The airflows, as analyzed for the purpose of this measure for Warehouse and the HotelSmall are significantly lower at cfm/ ft^2, thus the costs were normalized to 0.94 cfm/ ft^2.

standalone fans refer to those fans which are not “embedded” in another piece of equipment, such as packaged HVAC equipment. The scope of coverage in this proposal, is similar to the ASHRAE 90.1-2019 scope, meaning it is mostly fans not embedded in other equipment (commonly referred to as stand-alone fans.) The incremental cost of $199 is a useful value for context but would not necessarily correspond to the incremental cost of a low efficiency return fan in the modified Large Office model achieving an FEI of 1.0. Therefore, the Statewide CASE Team chose to do an actual fan selection to get a better estimate of the incremental cost for the Large Office example explained in Section 4.2.1.2. More specifically, to estimate the cost of going from a plenum return fan with a non-compliant FEI to one with compliant FEI the Statewide CASE Team leveraged Greenheck’s eCAPs online software tool. (Greenheck Inc. 2020) This tool allows a user to enter their duty point (airflow and pressure) for a given fan application and results are returned with fan performance (including FEI) and budget prices for each fan.[19]

The Statewide CASE Team then made fan selections with FEI values as close as possible to those modeled and explained in Section 4.2.1.2. This yielded a budget price of $12,181 (FEI of 0.84) for the Standard Design and $13,189 for the Proposed Design (FEI =0.99) as shown below in Figure 10.[20]

[19] Note that the budget prices on selection software tools are inherently designed to be conservative, for budgeting purposes.

[20] Actual FEI values used in the energy savings calculations are FEI 0.89 (Standard) and FEI = 1.0 (Proposed).

	Model Name	Actual CFM	Total External SP (in. wg)	Budget Price (USD)	Bhp	Fan RPM	Drive Type	FEI	SE (%)
							direct		
☑	APH-36-90	28,000	1.000	$12,181	12.3	1,097	Direct	0.84	36%
☐	APH-40-100	28,000	1.000	$13,189	8.9	778	Direct	1.15	49%
☐	APH-40-100	28,000	1.000	$13,142	8.9	778	Direct	1.16	49%
☐	APH-40-60	28,000	1.000	$10,520	16.2	1,196	Direct	0.66	27%
☑	APH-40-85	28,000	1.000	$13,189	10.4	885	Direct	0.99	42%

Figure 10: Return plenum fan selection.

Source: (Greenheck Inc. 2020)

This incremental cost of $1,008 ($13,189 minus $12,181) was then used by the Statewide CASE Team to determine the incremental cost per floor of the Large Office prototype. This prototype has 13 floors; thus, this value was multiplied by 13 to yield an incremental cost of $13,104 for the purposes of this analysis. It should be noted again that the Statewide CASE Team believes this to be a conservative estimate of incremental cost (meaning a high estimate) as “budget prices” provided by the Greenheck eCAPS tool are inherently conservative and the majority of fans likely already achieve an FEI of 1.0 in newly constructed buildings, due in part to the existing fan power limitations.

5.3.3 Duct Leakage

The Statewide CASE Team has worked with NEMI, SMACNA, and the Western States Council to assess what the incremental cost of testing would be over current practices to comply with Section 603.10.1 of the CMC. Duane Davies of California SMACNA informed the Statewide CASE Team that if TAB is already being performed at the job site and the same technician is performing duct leakage testing, each zone could be tested in 1.5 hours, including time for retesting if a section fails the leakage test. The Statewide CASE Team assumed a total hourly rate of $86.94. This rate is the 90th percentile wage for sheet metal workers in CA (and is inclusive of benefits and labor markups) form by Evergreen Economics (Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software). The Statewide CASE Team used the duct layout in Figure 12 for the OfficeLarge prototype to determine that additional testing of ductwork downstream of terminal boxes in three zones on three floors and two exhaust systems would have to be executed to meet the proposed additions to the testing requirement in the CMC. The Statewide CASE Team performed a similar analysis to determine the additional testing for the OfficeMedium and OfficeMediumLab prototype buildings. See Table 17 for descriptions of the prototype buildings

Table 32: Incremental Duct Leakage Testing Cost

Building Prototype	Number of downstream supply-air zones tested	Number of exhaust-air systems tested	Testing hours	Transportation hours	Incremental testing cost
OfficeLarge	9	2	16.5	6	$1956.15
OfficeMedium	3	1	6	2	$695.52
OfficeMedium Lab	3	1	6	2	$695.52

The Statewide CASE Team used the VAV proposed design layout of the OfficeLarge prototype building (see Section 5.3.1 and Figure 6 for the different duct designs) when determining the leakage in the baseline and proposed cases for the supply side. This layout was chosen from feedback stating that it seemed closest to designs seen the field. The cost for the baseline case is $5.77/ft2 of building floor area (See Figure 9 for the costs of each layout). The Statewide CASE Team received feedback from three California sheet metal fabricators and installers that it is approximately a 1.25 percent increase in labor and materials cost to go from Seal Class B to Seal Class A and used $0.07/ft2 as the incremental cost. See Table 33 for a breakdown of the cost.

For exhaust systems, the Statewide CASE Team took the total VAV system cost in Figure 8 and the total air flow to come up with the cost per cfm for sealing exhaust ducts. The Statewide CASE Team assumed that only the joints of exhaust ducts are sealed in the baseline case (Seal Class C), with an associated leakage of 25 percent. The Statewide CASE Team received feedback from contractors that it is approximately a 2.5 percent increase in labor and materials cost to go from Seal Class C to Seal Class A and therefore used $0.30/cfm as the incremental cost. The Statewide CASE Team estimated that each bathroom exhaust had an airflow of 500 cfm based on feedback from mechanical contractors and two toilets per floor. See Table 33 for a breakdown of the cost.

Table 33: Cost of Duct Sealing

	Total Cost (Large Office)	Airflow (CFM)	Building Gross Area (ft2)	Normalized Cost ($/CFM)	Normalized Cost ($/ft2)
VAV Proposed Design Cost	$221,400	18,375	38,371	$12.05	$5.77
Incremental Cost from Seal Class B to Seal Class A (supply)	$2,768	18,375	38,371	$0.15	$0.07
Incremental Cost from Seal Class C to Seal Class A (exhaust, 1000 cfm)	$300	1000	38,371	$0.30	$0.14

Source: Statewide CASE Team

5.4 Cost Effectiveness

The three submeasures in this CASE Report all require a cost-effectiveness analysis and were evaluated over a 15-year period of analysis.

The Energy Commission establishes the procedures for calculating 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. The 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 were the incremental costs 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 cost benefits realized over 15 years by the total incremental costs, which includes maintenance costs for 15 years. The B/C ratio was calculated using 2023 PV costs and cost savings.

Results of the per-unit cost-effectiveness analyses are presented below for the Large Office prototypes for each submeasure. For fan power budget and duct leakage, where other buildings were analyzed cost effectiveness tables are located in Appendix L.

5.4.1 Fan Power Budget

For fan power budget, the average B/C ratio across all 11 building types analyzed was 3.8. All building and all climate zones were cost-effective, with the exception of 5 prototypes (Warehouse, HotelSmall, OfficeMedium, OfficeLarge RetailLarge, SchoolSecondary) in Climate Zone 1 and one prototype (warehouse) in Climate Zone 4. Generally, extrapolating the incremental cost of \$0.29/ ft^2 from the large office to all building types in all climate zones is conservative, as ductwork is likely significantly less in many buildings (such as warehouses) than in a large office building. Furthermore, Climate Zone 1 is also a heating dominated climate, so many of the prototypes were very close to being cost-effective. The cost-effectiveness results for the OfficeLarge prototype model are shown below in Table 34 and in Appendix L for the rest of the prototype models analyzed.

Table 34: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/Additions and Alterations - Fan Power Budget- OfficeLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$) a	Costs Total Incremental PV Costs per ft2 (2023 PV$)b	Benefit-to-Cost Ratio
1	$0.28	$0.290	0.98
2	$0.40	$0.290	1.38
3	$0.38	$0.290	1.31
4	$0.43	$0.290	1.48
5	$0.37	$0.290	1.29
6	$0.47	$0.290	1.61
7	$0.44	$0.290	1.52
8	$0.48	$0.290	1.65
9	$0.48	$0.290	1.64
10	$0.48	$0.290	1.65
11	$0.42	$0.290	1.44
12	$0.41	$0.290	1.41
13	$0.44	$0.290	1.52
14	$0.49	$0.290	1.70
15	$0.52	$0.290	1.79
16	$0.42	$0.290	1.45

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). 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 PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

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

5.4.2 Fan Energy Index

For the FEI submeasure, all B/C ratios range between 1.6 and 3.1 as shown in Table 35. As explained in Section 5.3.2, the Statewide CASE team believes this is a reasonable, though conservative cost assumption. It is also only representative of one fan type in one building (plenum return fan in a large office).

Table 35: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/Additions and Alterations – Fan Energy Index

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$0.04	$0.026	1.64
2	$0.06	$0.026	2.35
3	$0.06	$0.026	2.20
4	$0.06	$0.026	2.42
5	$0.06	$0.026	2.13
6	$0.07	$0.026	2.75
7	$0.06	$0.026	2.45
8	$0.08	$0.026	2.94
9	$0.07	$0.026	2.85
10	$0.08	$0.026	2.93
11	$0.06	$0.026	2.46
12	$0.06	$0.026	2.41
13	$0.07	$0.026	2.65
14	$0.08	$0.026	3.12
15	$0.08	$0.026	3.13
16	$0.07	$0.026	2.52

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). 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 PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.
b. **Costs: Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation-adjusted) three percent rate and if PV of proposed maintenance costs is greater than PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

5.4.3 Duct Leakage

For the duct leakage submeasure, all B/C ratios for the OfficeLarge prototype range between 3.22 and 6.31 as shown in Table 36. The OfficeMedium and OfficeMediumLab prototype buildings were even more cost effective, see Table 110 and Table 111. Total incremental PV Costs incorporates the incremental cost/ft^2 for sealing the supply air system, the incremental cost/cfm for sealing the exhaust air system, and the additional testing cost.

Table 36: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/Additions and Alterations – Duct Leakage – OfficeLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$0.26	$0.08	3.22
2	$0.41	$0.08	5.02
3	$0.45	$0.08	5.55
4	$0.46	$0.08	5.60
5	$0.39	$0.08	4.72
6	$0.47	$0.08	5.79
7	$0.44	$0.08	5.41
8	$0.46	$0.08	5.66
9	$0.47	$0.08	5.75
10	$0.41	$0.08	4.98
11	$0.47	$0.08	5.77
12	$0.46	$0.08	5.57
13	$0.46	$0.08	5.61
14	$0.46	$0.08	5.61
15	$0.52	$0.08	6.31
16	$0.44	$0.08	5.33

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). 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 PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

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

5.5 Incremental Maintenance and Replacement 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 15-year period of analysis. The present value of equipment maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2022 TDV. The present value of maintenance costs that occurs in the n^{th} year is calculated as follows:

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

The fan power budget, FEI and duct leakage submeasures are not expected to yield any incremental maintenance or replacement costs. In all cases, the changes are primarily related to the design and selection of equipment that of the same materials, but different design. For example, the FEI requirement may require a 14-inch fan as compared to a 12-inch fan, of the same material and design. Similarly, the duct component of the measure may require slightly larger diameter ductwork or radiused elbows instead of 9° elbows. The materials are the same and therefore the maintenance and equipment life is expected to be the same as the base case.

6. First-Year Statewide Impacts

6.1 Statewide Energy and 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 assumptions about the percentage of newly constructed buildings that would be impacted by the proposed code. The statewide new construction forecast for 2023 is presented in Appendix A as are the Statewide CASE Team's assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type).

To determine the statewide savings from additions and alterations for the fan power budget submeasure, the Statewide CASE Team assumed that HVAC and/or ductwork systems in existing buildings would be updated every 20 years, triggering code and thus having to comply with the fan power budget requirements. Currently, in Section 141.0(b)2C, there is language specifying how the fan power limitations apply in additions and alterations. In short, there is an additional pressure allowance of 0.9 in. wg for MERV 13-15 filters if designer choose to comply with the fan power limitations using the BHP method. However, because MERV 13 air filters are now a requirement for buildings complying with Title 24, Part 6, this essentially gives an extra pressure allowance for all additions and alterations. This is a reasonable allowance as it should be not be expected that existing buildings have as efficient fan and ductwork systems as newly constructed buildings. Therefore, in the fan power budget submeasure proposal, the Statewide CASE Team is proposing to continue to incorporate an extra 0.9 in. wg into the fan power budget requirements for additions and alterations. More specifically, 0.6 in. wg for supply side fan systems and 0.3 in. wg for return/ exhaust/ relief side fan systems. (This is shown in Table 128 and Table 129 in Appendix N, but is represented as additional fan power allowances in Table 141.0-D. In summary, the savings for additions and alterations were estimated to be the same per ft^2 as the fan power budget requirements for additions and alterations have been increased in equal stringency as compared the new construction fan power budget requirements.

The FEI submeasure does apply to additions or alterations though only when entirely new fan systems are installed.

For the duct leakage submeasure, the Statewide CASE Team assumed the same savings per ft^2 for new construction and additions and alterations. The CMC and Section 120.5 of Title 24, Part 6 already apply to all replacement ductwork and therefore replacement ductwork would have the same baseline leakage as ductwork in new construction. The Statewide CASE Team assumed that ductwork would be replaced at least every 30 years (ASHRAE 2019) and would comply with code requirements. The

Statewide CASE Team therefore assumed that 3.3 percent of ductwork in existing buildings would be replaced each year and that the new ductwork would meet the specifications of Seal Class A. See Section 4.2.1.3 for the energy savings methodology.

The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2023. The 15-year energy cost savings represent the energy cost savings over the entire 15-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

Table 37 and Table 38 present the first-year statewide energy and energy cost savings of the fan power budget proposal from newly constructed buildings and alterations, respectively, by climate zone. Table 39 presents first-year statewide savings from new construction, additions, and alterations.

Table 40 presents the first-year statewide energy and energy cost savings of the fan energy index proposal from newly constructed buildings by climate zone.

Table 41: Statewide Energy and Energy Cost Impacts – Fan Energy Index – Additions/ Alterations

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft^2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	0.17	0.00	0.00	(0.00)	$0.01
2	1.03	0.03	0.00	(0.00)	$0.06
3	5.63	0.14	0.01	(0.00)	$0.33
4	2.94	0.08	0.01	(0.00)	$0.19
5	0.54	0.01	0.00	(0.00)	$0.03
6	3.81	0.12	0.01	(0.00)	$0.28
7	2.47	0.07	0.01	(0.00)	$0.16
8	5.64	0.17	0.02	(0.00)	$0.44
9	9.94	0.29	0.02	(0.00)	$0.74
10	2.55	0.08	0.01	(0.00)	$0.20
11	0.49	0.01	0.00	(0.00)	$0.03
12	4.51	0.13	0.01	(0.00)	$0.29
13	0.71	0.02	0.00	(0.00)	$0.05
14	0.78	0.03	0.00	(0.00)	$0.06
15	0.24	0.01	0.00	(0.00)	$0.02
16	0.20	0.01	0.00	(0.00)	$0.01

TOTAL	41.64	1.20	0.12	(0.00)	$2.89

a. First-year savings from all buildings completed statewide in 2023.

Table 42: Statewide Energy and Energy Cost Impacts – Fan Energy Index - New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
New Construction	0.52	0.05	(0.00)	1.3
Additions and Alterations	1.20	0.12	(0.00)	2.9
TOTAL	1.72	0.17	(0.01)	4.1

Table 43 and Table 44 present the first-year statewide energy and energy cost savings of the duct leakage proposal from newly constructed buildings and alterations, respectively, by climate zone. Table 45 presents first-year statewide savings from new construction, additions, and alterations.

Table 37: Statewide Energy and Energy Cost Impacts – Fan Power Budget- New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft^2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	0.51	0.09	0.03	(0.00)	$0.16
2	3.05	0.69	0.23	(0.01)	$1.50
3	14.94	2.85	1.00	(0.03)	$6.76
4	7.72	1.78	0.58	(0.01)	$4.61
5	1.47	0.30	0.09	(0.00)	$0.68
6	10.15	2.58	0.70	(0.01)	$5.76
7	7.07	1.83	0.52	(0.01)	$4.78
8	14.70	3.84	1.01	(0.01)	$9.59
9	24.31	5.97	1.95	(0.02)	$14.99
10	12.81	3.27	0.93	(0.01)	$8.66

11	2.64	0.75	0.27	(0.01)	$1.93
12	15.17	3.72	1.07	(0.03)	$9.36
13	5.04	1.68	0.47	(0.01)	$4.01
14	3.05	0.93	0.26	(0.01)	$2.70
15	1.77	0.65	0.17	(0.00)	$1.57
16	0.94	0.22	0.07	(0.00)	$0.44
TOTAL	125.35	31.15	9.35	(0.19)	$77.50

a. First-year savings from all buildings completed statewide in 2023.

Table 38: Statewide Energy and Energy Cost Impacts – Fan Power Budget- Additions/ Alterations

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft^2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	1.17	0.21	0.06	(0.01)	$0.38
2	6.92	1.62	0.55	(0.02)	$3.55
3	33.41	6.66	2.40	(0.08)	$15.73
4	17.20	4.11	1.36	(0.03)	$10.51
5	3.35	0.71	0.22	(0.01)	$1.59
6	24.85	6.63	1.81	(0.02)	$14.86
7	17.38	4.56	1.31	(0.01)	$11.88
8	35.63	9.77	2.58	(0.03)	$24.29
9	57.72	15.05	4.82	(0.06)	$37.64
10	34.18	8.94	2.54	(0.04)	$23.62
11	6.30	1.81	0.66	(0.02)	$4.66
12	34.13	8.75	2.53	(0.08)	$21.85
13	11.94	4.12	1.15	(0.03)	$9.83
14	7.93	2.51	0.70	(0.02)	$7.23
15	4.59	1.73	0.43	(0.00)	$4.19
16	2.39	0.59	0.17	(0.01)	$1.15
TOTAL	299.10	77.79	23.30	(0.47)	$192.98

a. First-year savings from all buildings completed statewide in 2023.

Table 39: Statewide Energy and Energy Cost Impacts – Fan Power Budget- New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
New Construction	31	9.35	(0.19)	77.5
Additions and Alterations	78	23.30	(0.47)	193.0
TOTAL	109	32.66	(0.66)	270.5

a. First-year savings from all alterations completed statewide in 2023.

Table 40: Statewide Energy and Energy Cost Impacts – Fan Energy Index - New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	0.07	0.00	0.00	(0.00)	$0.00
2	0.43	0.01	0.00	(0.00)	$0.03
3	2.42	0.06	0.01	(0.00)	$0.14
4	1.27	0.03	0.00	(0.00)	$0.08
5	0.22	0.01	0.00	(0.00)	$0.01
6	1.68	0.05	0.01	(0.00)	$0.12
7	0.94	0.03	0.00	(0.00)	$0.06
8	2.51	0.08	0.01	(0.00)	$0.19
9	4.65	0.14	0.01	(0.00)	$0.35
10	0.95	0.03	0.00	(0.00)	$0.07
11	0.20	0.01	0.00	(0.00)	$0.01
12	1.97	0.05	0.01	(0.00)	$0.13
13	0.31	0.01	0.00	(0.00)	$0.02
14	0.33	0.01	0.00	(0.00)	$0.03
15	0.10	0.00	0.00	(0.00)	$0.01
16	0.08	0.00	0.00	(0.00)	$0.01
TOTAL	18.14	0.52	0.05	(0.00)	$1.26

a. First-year savings from all buildings completed statewide in 2023.

Table 41: Statewide Energy and Energy Cost Impacts – Fan Energy Index – Additions/ Alterations

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	0.17	0.00	0.00	(0.00)	$0.01
2	1.03	0.03	0.00	(0.00)	$0.06
3	5.63	0.14	0.01	(0.00)	$0.33
4	2.94	0.08	0.01	(0.00)	$0.19
5	0.54	0.01	0.00	(0.00)	$0.03
6	3.81	0.12	0.01	(0.00)	$0.28
7	2.47	0.07	0.01	(0.00)	$0.16
8	5.64	0.17	0.02	(0.00)	$0.44
9	9.94	0.29	0.02	(0.00)	$0.74
10	2.55	0.08	0.01	(0.00)	$0.20
11	0.49	0.01	0.00	(0.00)	$0.03
12	4.51	0.13	0.01	(0.00)	$0.29
13	0.71	0.02	0.00	(0.00)	$0.05
14	0.78	0.03	0.00	(0.00)	$0.06
15	0.24	0.01	0.00	(0.00)	$0.02
16	0.20	0.01	0.00	(0.00)	$0.01
TOTAL	41.64	1.20	0.12	(0.00)	$2.89

b. First-year savings from all buildings completed statewide in 2023.

Table 42: Statewide Energy and Energy Cost Impacts – Fan Energy Index - New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
New Construction	0.52	0.05	(0.00)	1.3
Additions and Alterations	1.20	0.12	(0.00)	2.9
TOTAL	1.72	0.17	(0.01)	4.1

Table 43: Statewide Energy and Energy Cost Impacts – Duct Leakage – New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft^2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	0.31	0.05	0.01	0.00	$0.12
2	1.87	0.37	0.09	0.00	$1.07
3	9.23	1.88	0.76	0.04	$5.47
4	4.78	1.04	0.20	0.02	$2.98
5	0.90	0.18	0.04	0.00	$0.49
6	5.94	1.46	0.16	0.02	$4.12
7	4.37	1.08	0.18	0.02	$2.95
8	8.65	2.07	0.31	0.04	$5.85
9	14.80	3.48	0.72	0.06	$9.97
10	5.80	1.43	0.27	0.01	$3.89
11	1.31	0.32	0.07	0.00	$0.90
12	8.34	1.81	0.38	0.02	$5.08
13	2.53	0.65	0.12	0.01	$1.76
14	1.50	0.37	0.08	0.00	$1.02
15	0.74	0.22	0.05	0.00	$0.64
16	0.46	0.10	0.04	0.00	$0.26
TOTAL	71.54	16.51	3.46	0.25	$46.57

a. First-year savings from all buildings completed statewide in 2023.

Table 44: Statewide Energy and Energy Cost Impacts – Duct Leakage – Additions and Alterations

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million ft^2)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
1	0.50	0.07	0.02	0.00	$0.18
2	2.95	0.59	0.15	0.01	$1.69
3	14.33	2.93	1.21	0.05	$8.51
4	7.41	1.61	0.30	0.03	$4.64
5	1.43	0.29	0.07	0.00	$0.78
6	9.78	2.43	0.30	0.04	$6.83
7	7.29	1.81	0.30	0.03	$4.93
8	14.10	3.41	0.51	0.06	$9.60
9	23.50	5.58	1.15	0.09	$15.97
10	10.31	2.55	0.49	0.02	$6.94
11	2.12	0.53	0.11	0.01	$1.46
12	12.95	2.83	0.59	0.04	$7.92
13	4.11	1.06	0.20	0.01	$2.88
14	2.58	0.64	0.14	0.01	$1.78
15	1.25	0.38	0.09	0.00	$1.09
16	0.78	0.17	0.06	0.00	$0.44
TOTAL	115.39	26.88	5.67	0.39	$75.63

a. First-year savings from all buildings completed statewide in 2023.

Table 45: Statewide Energy and Energy Cost Impacts – Duct Leakage – New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMtherms)	15-Year Present Valued Energy Cost Savings (PV$ million 2023)
New Construction	16.5	3.46	0.25	46.6
Additions and Alterations	26.9	5.67	0.39	75.6
TOTAL	43.4	9.13	0.64	122.2

6.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. In short, this analysis assumes an average electricity emission factor of 240.4 metric tons CO_2e per GWh based on the average emission factors for the CACX EGRID subregion. Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42). See Appendix C for additional details on the methodology used to calculate GHG emissions.

Table 46 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 36,900 metric tons of carbon dioxide equivalents (metric ton CO_2e) would be avoided.

Table 46: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (MMtherms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
Fan Power Budget	109	26,184	(0.66)	(3,602)	22,582
Fan Energy Index	1.7	415	(0.01)	(39.06)	375
Duct Leakage	43	10,429	0.64	3,514	13,943
TOTAL	153.7	37,028	(0.03)	(127.06)	36,900

a. First-year savings from all buildings completed statewide in 2023.

b. Assumes the following emission factors: 240.4 MTCO2e /GWh and 5,454.4 MTCO2e/million therms.

6.3 Statewide Water Use Impacts

The proposed code change would not result in water savings.

6.4 Statewide Material Impacts

There are no significant material impacts expected from the fan power budget or fan energy index submeasures. In certain cases, less ductwork may be used, leading to less steel sheet-metal, however given this is a design standard with numerous technology options (ductwork, fans, motors, transmission changes) and non-technology options (more thoughtful design), it is very challenging to estimate the material impacts. In many cases, a more efficient fan maybe selected to comply, which would not necessarily lead to increased material (e.g., aluminum, steel), but rather this material being more precisely engineered and produced. Finally, there are no significant material impacts expected from the duct leakage measure.

6.5 Other Non-Energy Impacts

The fan power budget submeasure may, in certain cases, result in quieter HVAC systems due to better and lower pressure duct design.

7. Proposed Revisions to Code Language

7.1 Guide to Markup Language

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2019 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions). When the Statewide CASE Team is recommending language move from one section of the code to another, the language is shown in blue underlining in the new recommended location and blue ~~strikethroughs~~ in the location where the language appears in the 2019 code.

Note: The Statewide CASE Team has developed another CASE Report (HVAC Controls[21]) that also alters some of the code sections shown below. While CASE Reports are developed independently, the CASE Authors have been in communication and should the overlapping measures move forward the Statewide CASE Team will support the Energy Commission in resolving overlapping changes.

7.2 Standards

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

(b) Definitions.

Air Curtain Unit means equipment providing a directionally-controlled stream of air moving across the entire height and width of an opening that reduces the infiltration or transfer of air from one side of the opening.

AHRI 430 *(draft/ in-progress)* is the Air-conditioning, Heating and Refrigeration Institute document titled “Performance Rating of Central Station Air-handling Unit Supply Fans”. (AHRI 430-2020)

AHRI 440 is the Air-conditioning, Heating and Refrigeration Institute document titled “Performance Rating of Fan-coil Units”. (AHRI 440-2019)

AMCA is the Air Movement and Controls Association.

ANSI/AMCA 208 is the is the American National Standards Institute / Air Movement and Control Association document titled “Calculation of the Fan Energy Index”. (ANSI/AMCA 208-2018)

ANSI/AMCA 210 is the is the American National Standards Institute / Air Movement and Control Association document titled “Laboratory Methods of Testing Fans for Certified

21 https://title24stakeholders.com/wp-content/uploads/2020/07/2022-T24-Draft-CASE-Report-HVAC-Control.pdf

Aerodynamic Performance Rating". (ANSI/AMCA 210-2016)

ANSI/ASHRAE 84 is the is the American National Standards Institute / American Society of Heating, Refrigeration, and Air-conditioning Engineers document titled "Method of Testing Air-to-Air Heat/Energy Exchanger". (ANSI/ASHRAE 84-2020)

Ceiling Fan means a nonportable device that is suspended from a ceiling or overhead structure for circulating air via the rotation of fan blades as defined in 10 CFR 430.2.

Circulating Fan means a fan that is not a ceiling fan that is used to move air within a space that has no provision for connection to ducting or separation of the fan inlet from its outlet, designed to be used for the general circulation of air.

Duct wall penetrations are openings to the duct wall made by pipes, holes, conduit, tie rods, or wires.

Fan arrays are multiple fans in parallel and in a single enclosure between two plenum sections in an air distribution system, where plenum means a compartment or chamber that forms a part of the air distribution system, and that is not used for occupancy or storage.

Fan, embedded is a fan that is part of a manufactured assembly where the assembly includes functions other than air movement.

Fan energy index (FEI) is the ratio of the electric input power of a reference fan to the electric input power of the actual fan as calculated per ANSI/AMCA 208-18 at fan system design conditions.

Fan electrical input power (Fan kW_{design}) is the electrical input power in kilowatts required to operate an individual fan or fan array at design conditions. It includes the power consumption of motor controllers, if present.

Fan nameplate electrical input power (kW) is the nominal electrical input power rating stamped on a fan assembly nameplate.

Fan system includes all the fans that contribute to the movement of air through a point of a common duct, plenum, or cabinet.

> **Fan system, complex** means a fan system that combines a single-cabinet fan system with other supply fans, exhaust fans, or both.
>
> **Fan system, exhaust** is a fan system dedicated to the removal of air from interior spaces to the outdoors that may operate at times other than economizer operation.
>
> **Fan system, relief** is a fan system dedicated to the removal of air from interior spaces to the outdoors that operates only during economizer operation.
>
> **Fan system, return** is a fan system dedicated to removing air from interior where some or all the air is to be recirculated except during economizer operation.
>
> **Fan system, supply-only** is a fan system that provides supply air to interior spaces

and does not recirculate the air.

Fan system, single-cabinet is a fan system where a single fan, single fan array, a single set of fans operating in parallel, or fans or fan arrays in series and embedded in the same cabinet that both supply air to a space and recirculate the air.

Fan system, transfer is a fan system that exclusively moves air from one occupied space to another.

Fan system airflow (cfm) is the sum of the airflow of all fans with fan electrical input power greater than 1 kW at fan system design conditions, excluding the airflow that passes through downstream fans with fan input power less than 1 kW.

Fan system design conditions are operating conditions that can be expected to occur during normal system operation that result in the highest supply airflow rate to or from the conditioned spaces served by the fan system.

Fan system electrical input power (Fan $kW_{design,system}$) the sum of the fan electrical input power (Fan kW_{design}) in kilowatts of all fans that are required to operate at fan system design conditions to supply air from the heating or cooling source to the conditioned spaces, return it to the source, exhaust it to the outdoors, or transfer it to another space.

ISO 5801 is the International Standards Organization document titled "Fans- Performance testing using standardized airways". (ISO 5801-2017)

Seal Class A is a ductwork sealing category that requires sealing all transverse joints, longitudinal seams, and duct wall penetrations. Duct wall penetrations are openings made by pipes, conduit, tie rods, or wires. Longitudinal seams are joints oriented in the direction of airflow. Transverse joints are connections of two duct sections oriented perpendicular to airflow. Openings for rotating shafts shall be sealed with bushings or other devices that seal off air leakage. All connections shall be sealed, including but not limited to spin-ins, taps, other branch connections, access doors, access panels, and duct connections to equipment. Sealing that would void product listings is not required. All duct pressure class ratings shall be designated in the design documents.

SECTION 120.4 – REQUIREMENTS FOR AIR DISTRIBUTION SYSTEM DUCTS AND PLENUMS

Nonresidential, high-rise residential, and hotel/motel buildings shall comply with the applicable requirements of Sections 120.4(a) through 120.4(fg).

(a) CMC Compliance. All air distribution system ducts and plenums, including, but not limited to, building cavities, mechanical closets, air-handler boxes and support platforms used as ducts or plenums, shall meet the requirements of the CMC Sections 601.0, 602.0, 603.0, 604.0, 605.0, and ANSI/SMACNA-006-2006 HVAC Duct Construction Standards Metal and Flexible 3rd Edition, incorporated herein by reference. Connections of metal ducts and the inner core of flexible ducts shall be mechanically fastened. Openings shall be sealed with mastic, tape, aerosol sealant, or other duct-closure system that meets the applicable requirements of UL 181, UL 181A, or UL 181B. If mastic or tape is used to seal openings greater than one quarter inch, the combination of mastic and either mesh or tape shall be used.

Portions of supply-air and return-air ducts conveying heated or cooled air located in one or more of the following spaces shall be insulated to a minimum installed level of R-8:

1. Outdoors; or
2. In a space between the roof and an insulated ceiling; or
3. In a space directly under a roof with fixed vents or openings to the outside or unconditioned spaces; or
4. In an unconditioned crawlspace; or
5. In other unconditioned spaces.

Portions of supply-air ducts that are not in one of these spaces, including ducts buried in concrete slab, shall be insulated to a minimum installed level of R-4.2 or be enclosed in directly conditioned space.

(b) Duct and Plenum Materials.

1. Factory-fabricated duct systems.

A. All factory-fabricated duct systems shall comply with UL 181 for ducts and closure systems, including collars, connections, and splices, and be labeled as complying with UL 181. UL 181 testing may be performed by UL laboratories or a laboratory approved by the Executive Director.

B. All pressure-sensitive tapes, heat-activated tapes, and mastics used in the manufacture of rigid fiberglass ducts shall comply with UL 181 and UL 181A.

C. All pressure-sensitive tapes and mastics used with flexible ducts shall comply with UL 181 and UL181B.

D. Ductwork and all plenums with pressure class ratings shall be constructed to Seal Class A. Joints and seams of duct systems and their components shall not be sealed with cloth back rubber adhesive duct tapes unless such tape is used in combination with mastic and drawbands.

Exception to Section 120.4(b)1.D: Ductwork located in conditioned space and exposed to view is not required to meet Seal Class A.

2. **Field-fabricated duct systems.**

D. Ductwork and all plenums with pressure class ratings shall be constructed to Seal Class A. Joints and seams of duct systems and their components shall not be sealed with cloth back rubber adhesive duct tapes unless such tape is used in combination with mastic and drawbands.

Exception to Section 120.4(b)2.D: Ductwork located in conditioned space and exposed to view is not required to meet Seal Class A.

(g) Requirements For Air Distribution System Ducts And Plenums. Duct systems shall be tested in accordance with 1, or 2, or 3 below:

1. New duct systems that meet the criteria in Subsections A, B, C, and D below or ductwork that is part of a system that meets the criteria of Section 141.0(b)2D shall be sealed to a leakage rate not to exceed 6 percent of the nominal air handler airflow rate as confirmed through field verification and diagnostic testing, in accordance with the applicable procedures in Reference Nonresidential Appendices NA1 and NA2; or

   A. The duct system does not serve a healthcare facility; and

   B. The duct system provides conditioned air to an occupiable space for a constant volume, single zone, space-conditioning system; and

   C. The space conditioning system serves less than 5,000 square feet of conditioned floor area; and

   D. The combined surface area of the ducts located in the following spaces is more than 25 percent of the total surface area of the entire duct system:

      i. Outdoors; or

      ii. In a space directly under a roof that

         a. Has a U-factor greater than the U-factor of the ceiling, or if the roof does not meet the requirements of Section 140.3(a)1B, or

         b. Has fixed vents or openings to the outside or unconditioned spaces; or

      iii. In an unconditioned crawlspace; or

      iv. In other unconditioned spaces.

Note: The language in 120.4(g)2 is being proposed in CASE Report 2022-MF-IAQ-F and is reproduced here for consistency.

2. Ventilation ducts in multifamily buildings shall meet duct sealing requirements in the California Mechanical Code Section 603.10 and confirmed through field verification and diagnostic testing conducted by a Certified Acceptance Test Technician per NA 2.1.4.2 that leakage is no greater than six percent of the rooftop or central fan design airflow rate if all criteria in Subsections A and B are met. The leakage test shall be conducted using NA 2.1.4.2 at a test pressure of 25 Pa (0.1 inches) for ducts serving six or fewer dwelling units and 50 Pa (0.2 inches) for ducts serving more than six dwelling units, and shall measure the leakage of all ductwork between the central fan and the connection point to the in-unit grille or fan.

   A. The ventilation ducts serve multiple dwelling units.

   B. The ventilation ducts provide continuous airflows or airflows to provide balanced ventilation to meet 120.1(b)2Aivb.

3. All duct systems that do not meet the criteria in Section 120.4(g)1 or Section 120.4(g)2 shall meet the duct leakage testing requirements of CMC Section 603.10.1.

SECTION 120.5 – REQUIRED NONRESIDENTIAL MECHANICAL SYSTEM ACCEPTANCE

Section 120.5(a)3. Duct systems shall be tested in accordance with NA7.5.3 where either:

A. They are new duct systems; or that meet the criteria of Sections 140.4(l)1, 140.4(l)2, and 140.4(l)3; or

B. They are part of an altered system. a system that meets the criteria of Section 141.0(b)2D.

SECTION 120.10 – MANDATORY REQUIREMENTS FOR FANS

(a) Each fan or fan array with a combined motor nameplate horsepower greater than 1.0 hp or with a combined fan nameplate electrical input power greater than 0.89 kW shall have a fan energy index (FEI) of 1.00 or higher at fan system design conditions.

1. The FEI for fan arrays shall be calculated in accordance with ANSI/AMCA 208-18 Annex C.

2. All FEI values shall be provided by a manufacturer, where fan selection software and/or fan catalogs display third party verified FEI values in accordance with ANSI/AMCA 208-18.

EXCEPTION to Section 120.10(a)2: FEI values for embedded fans do not need to be third party verified.

EXCEPTION 1 to Section 120.10(a): Embedded fans that are part of equipment listed under Section 110.2, Section 110.1, or equipment that has an efficiency standard under 10 CFR 431 that takes effect prior to January 1, 2026.

EXCEPTION 2 to Section 120.10(a): Embedded fans and fan arrays with a combined motor nameplate horsepower of 5 hp or less or with a fan system electrical input power of 4.1 kW or less.

EXCEPTION 3 to Section 120.10(a): Circulation fans, ceiling fans and air curtains.

EXCEPTION 4 to Section 120.10(a): Fans that are intended to only operate during emergency conditions.

SECTION 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

(c) Fan Systems. Each fan system moving air into, out of, or between conditioned having a total fan system motor nameplate horsepower 5 HP used for spaces conditioning or circulating air for the purpose of conditioning air within a space shall meet the requirements of Items 1, 2, and 3 below. Total fan system power demand equals the sum of the power demand of all fans in the system that are required to operate at design conditions in order to supply air from the heating or cooling source to the conditioned space, and to return it back to the source or to exhaust it to the outdoors.

1. Fan Power Limitation Budget. At design conditions each fan system shall not exceed the allowable fan system power of option 1 or 2 as specified in Table 140.4-A For each fan system that includes at least one fan or fan array with fan electrical input power ≥ 1 kW, fan system electrical input power (Fan $kW_{design,system}$) at the airflow determined per section 140.4(c)1(B) shall not exceed Fan kW_{budget} as calculated per section 140.4(c)1(B).

A. **Requirements for a Multi-zone VAV Fan System.** A fan system must meet the following requirements to be classified as a multi-zone VAV system. Otherwise its classification shall be a constant volume/single zone VAV system:

i. Fan system must serve three or more space-conditioning zones and airflow to each must be individually controlled based on heating, cooling and/or ventilation requirements.

ii. The sum of the minimum airflows for each space-conditioning zone must be 40% or less of the fan system design conditions.

iii. The fan system meets the requirements of section 140.4 (m).

B. **Calculation of Fan Power Budget (Fan kW_{budget}).** For each fan system:

i. Determine the fan system airflow and choose the appropriate table(s) for fan power allowance.

a. For single-cabinet fan systems, use the fan system airflow and the power allowances in both Tables 140.4-A and Table 140.4-B.

b. For supply-only fan systems, use the fan system airflow and power allowances in Table 140.4-A.

c. For relief fan systems, use the design relief airflow and the power allowances in Table 140.4-B.

d. For exhaust, return and transfer fan systems, use the fan system airflow and the power allowances in Table 140.4-B.

e. For complex fan systems, separately calculate the fan power allowance for the supply and return/exhaust systems and sum them. For the supply airflow, use supply airflow at the fan system design conditions, and the power allowances in Table 140.4-A. For the return exhaust airflow, use return /exhaust airflow at the fan system design conditions, and the power allowances in Table 140.4-B.

ii. For each fan system determine the components included in the fan system and sum the Fan Power Allowances of those components. All fan systems shall include the System Base Allowance. If, for a given component, only a portion of the fan system airflow passes through the component, calculate the Fan Power Allowance for that component per this equation:

$$FPA_{adj} = \frac{Q_{comp}}{Q_{sys}} X\ FPA_{comp}$$

Where

FPA_{adj} = The corrected fan power allowance for the component in w/cfm

Q_{comp} = The airflow through component in cfm

Q_{sys} = The fan system airflow in cfm

FPA_{comp} = The fan power allowance of the component from Table 140.4A or Table 140.4B

iii. Multiply the fan system airflow by the sum of the fan power allowances for the fan system.

iv. Divide by 1000 to convert to Fan kW_{budget}.

v. For building sites at elevations greater than 3,000', multiply Fan kW_{budget} by Correction Factor in Table NA9-4.

Table 140.4-A: Supply Fan Power Allowances (watts/cfm)

	Multi-Zone VAV Systems[1]			**CV and Single-zone VAV Systems**		
Airflow	≥10,000 cfm	≥5,000 and ≤10,000 cfm	≤5,000 cfm	≥10,000 cfm	≥5,000 and ≤10,000 cfm	≤5,000 cfm
Supply System Base Allowance	0.378	0.402	0.362	0.264	0.238	0.239
Particle filtration (select only 1)[3]						
MERV 13 to MERV 16 Filter (mid-life)	0.104	0.108	0.120	0.105	0.109	0.123
MERV 13 to MERV 16 Final filter located	0.173	0.180	0.199	0.174	0.182	0.203

downstream of thermal conditioning equipment. (mid-life)						
HEPA Filter (mid-life)	0.260	0.269	0.298	0.261	0.272	0.302
Heating (select all that apply)						
Hydronic heating coil (central)	0.052	0.036	0.040	0.052	0.037	0.041
Electric heat	0.035	0.036	0.040	0.035	0.037	0.041
Terminal re-heat (hydronic or electric resistance)	0.017	0.018	0.020	0.000	0.000	0.000
Gas heat	0.069	0.054	0.060	0.070	0.055	0.062
Cooling and dehumidification (select all that apply)						
Hydronic/DX cooling coil, or heat pump coil (wet)5	0.104	0.108	0.120	0.105	0.109	0.123
Desiccant system – solid or liquid	0.121	0.126	0.140	0.122	0.128	0.143
Reheat coil for dehumidification	0.035	0.036	0.040	0.035	0.037	0.041
Evaporative humidifier/cooler in series with a cooling coil. Value shown is allowed watts/cfm per 1.0 in. wg. Determine pressure loss (in. wg) at 400 fpm or maximum velocity allowed by the manufacturer, whichever is less.	0.173	0.180	0.199	0.174	0.182	0.203

[Calculation required, see note 4]						
Outdoor Air Systems						
100% Outdoor air system meeting the requirements of Note 2.	0.000	0.000	0.000	0.087	0.091	0.062
Energy recovery (select only 1) where required by code						
0.50 ≤ ERR <0.55 6	0.104	0.108	0.120	0.105	0.109	0.123
0.55 ≤ ERR <0.60 6	0.123	0.128	0.142	0.124	0.129	0.145
0.60 ≤ ERR <0.65 6	0.142	0.148	0.163	0.143	0.149	0.167
0.65 ≤ ERR <0.70 6	0.161	0.167	0.185	0.162	0.169	0.189
0.70 ≤ ERR <0.75 6	0.180	0.187	0.207	0.181	0.189	0.211
0.75 ≤ ERR <0.80 6	0.199	0.207	0.228	0.200	0.209	0.233
ERR ≥ 0.80 6	0.218	0.226	0.250	0.219	0.229	0.255
Sensible-only recovery	0.104	0.108	0.120	0.105	0.109	0.123
Gas-phase filtration (select only 1)						
General odor control	0.087	0.090	0.100	0.087	0.091	0.062
Gas phase filtration required by code or accredited standard. Value shown is allowed w/cfm per 1.0 in. wg air pressure drop. *[Calculation required, see note 4]*	0.173	0.180	0.199	0.174	0.182	0.203
Other						
Air blender	0.035	0.036	0.040	0.035	0.037	0.041

Sound attenuation section [fans serving spaces with design background noise goals below NC35]	0.026	0.027	0.030	0.026	0.027	0.031
Deduction for systems that feed a terminal unit with a fan with electrical input power < 1kW	-0.044	-0.045	-0.051	-0.044	-0.046	-0.052
1. See section 140.4 (c) 1 for requirements to be classified as a Multi-Zone VAV System.						
2. The 100% outdoor air system must serve 3 or more HVAC zones and airflow during non-economizer operating periods must not exceed 135% of minimum requirements in Section 120.1(c)(3).						
3. Filter fan power allowance can only be counted once per fan system, except fan systems in healthcare facilities, which can claim one of the MERV 13 to 16 filter allowances and the HEPA filter allowance if both are included in the fan system.						
4. Power allowance requires further calculation by multiplying the actual in. wg. of the device/ component by the watts/ cfm in Table 140.4-A.						
5. Healthcare facilities can claim this fan power allowance twice per fan system where coil design leaving air temperature is less than 44ºF.						
6. Energy Recovery Ratio (ERR) calculated per ANSI/ASHRAE 84-2020.						

Table 140.4-B: Exhaust, Return, Relief, Transfer Fan Power Allowances (cfm/ watt)

	Multi-Zone VAV Systems[1]	**CV and Single-zone VAV Systems**

Airflow	≥10,000 cfm	≥5,000 and ≤10,000 cfm	≤5,000 cfm	≥10,000 cfm	≥5,000 and ≤10,000 cfm	≤5,000 cfm
Exhaust System Base Allowance	**0.221**	**0.238**	**0.229**	**0.177**	**0.192**	**0.176**
Particle filtration						
Filter (any MERV value)	0.035	0.037	0.041	0.035	0.037	0.042
Energy recovery (select only 1) where required by code						
0.50 ≤ ERR <0.55 [5]	0.105	0.109	0.123	0.105	0.110	0.125
0.55 ≤ ERR <0.60 [5]	0.124	0.129	0.145	0.125	0.130	0.147
0.60 ≤ ERR <0.65 [5]	0.143	0.149	0.167	0.144	0.150	0.169
0.65 ≤ ERR <0.70 [5]	0.162	0.169	0.189	0.163	0.170	0.192
0.70 ≤ ERR <0.75 [5]	0.182	0.189	0.211	0.182	0.190	0.214
0.75 ≤ ERR <0.80 [5]	0.201	0.209	0.233	0.201	0.210	0.236
ERR ≥ 0.80 [5]	0.220	0.229	0.255	0.220	0.230	0.258
Sensible-only recovery	0.105	0.109	0.123	0.105	0.110	0.125
Special exhaust and return system requirements (select all that apply)						
Return or exhaust systems required by code or accreditation standards to be fully ducted, or systems required to maintain air pressure differentials between adjacent rooms	0.088	0.091	0.103	0.088	0.092	0.104
Return and/or exhaust airflow control devices	0.088	0.091	0.103	0.088	0.092	0.104
Laboratory and vivarium exhaust systems in high-rise buildings for vertical duct exceeding 75 ft. Value shown is allowed w/cfm per 0.25 in. wg for each 100 feet	0.044	0.046	0.052	0.044	0.046	0.053

exceeding 75 feet. *[Calculation required, see note 4]*						
Biosafety cabinet. Value shown is allowed w/cfm per 1.0 in. wg air pressure drop. *[Calculation required, see note 4]*	0.175	0.182	0.203	0.175	0.183	0.206
Exhaust filters, scrubbers, or other exhaust treatment required by code or standard. Value shown is allowed w/cfm per 1.0 in. wg air pressure drop. *[Calculation required, see note 4]*	0.175	0.182	0.203	0.175	0.183	0.206
Other						
Healthcare facility allowance[3]	0.175	0.182	0.203	0.175	0.183	0.206
Sound attenuation section [Fans serving spaces with design background noise goals below NC35.]	0.026	0.027	0.031	0.026	0.028	0.032
1. See section 140.4 (c) 1 for requirements to be classified as a Multi-Zone VAV System.						
2. Filter pressure loss can only be counted once per fan system.						
3. This allowance can only be taken for healthcare facilities.						
4. Power allowance requires further calculation, multiplying the actual pressure drop (in. wg.) of the device/ component by the watts/cfm in the Table 140.4-B.						
5. Energy Recovery Ratio (ERR) calculated per ANSI/ASHRAE 84-2020.						

C. Determining Fan System Electrical Input Power (Fan $kW_{design,system}$). Fan $kW_{design,system}$ is the sum of Fan kW_{design} for each fan or fan array included in the fan system with Fan kW_{design} $\geq$ 1 kW. If variable speed drives are used their efficiency losses shall be included. Fan input power shall be calculated with mid-life filter pressure drop, which is the mean of the clean filter pressure drop and design final filter pressure drop. The Fan kW_{design} for each fan or fan array shall be determined using one of the following methods. There is no requirement to use the same method for all fans in a fan system:

i. Use the default Fan kW_{design} in Table 140.4-C for one or more of the fans. This method cannot be used for complex fan systems.

Table 140.4-C: Default values for Fan kW_{design} Based on Motor Nameplate HP

Motor Nameplate HP	Default Fan kW_{design} with variable speed drive (Fan kW_{design})	Default Fan kW_{design} without variable speed drive (Fan kW_{design})
≤1	0.96	0.89
≥1 and <1.5	1.38	1.29
≥1.5 and <2	1.84	1.72
≥2 and <3	2.73	2.57
≥3 and <5	4.38	4.17
≥5 and <7.5	6.43	6.15
≥7.5 and <10	8.46	8.13
≥10 and <15	12.47	12.03
≥15 and <20	16.55	16.04
≥20 and <25	20.58	19.92
≥25 and <30	24.59	23.77
≥30 and <40	32.74	31.70
≥40 and <50	40.71	39.46
≥50 and <60	48.50	47.10
≥60 and <75	60.45	58.87
≥75 and ≤100	80.40	78.17
1. This table cannot be used for Motor Nameplate Horsepower values greater than 100.		
2. This table is to be used only with motors with a service factor ≤1.15. If the service factor is not provided, this table may not be used.		

ii. Use the Fan kW_{design} at fan system design conditions provided by the manufacturer of the fan, fan array, or equipment that includes the fan or fan array calculated per a test procedure included in USDOE 10 CFR Part 430, USDOE 10 CFR Part 431, ANSI/AMCA Standard 208-2018, ANSI/AMCA Standard 210-2016, AHRI Standard 430-2020, AHRI Standard 440-2019, or ISO 5801-2017.

iii. Use the Fan kW_{design} provided by the manufacturer, calculated at fan system design conditions per one of the methods listed in section 5.3 of ANSI/AMCA 208-2018.

iv. Determine the Fan kW_{design} by using the maximum electrical input power provided on the motor nameplate.

~~*TABLE 140.4 - A Fan Power Limitation*~~

	~~Limit~~	~~Constant Volume~~	~~Variable Volume~~
~~Option 1: Fan system motor nameplate hp~~	~~Allowable motor nameplate hp~~	~~$hp \le cfm_s \times 0.0011$~~	~~$hp \le cfm_s \times 0.0015$~~
~~Option 2: Fan system bhp~~	~~Allowable fan system bhp~~	~~$bhp \le cfm_s \times 0.00094 + A$~~	~~$bhp \le cfm_s \times 0.0013 + A$~~

~~[1]cfm$_s$ = maximum design supply airflow rate to conditioned spaces served by the system in cubic feet~~ per ~~minute~~

~~hp = maximum combined motor nameplate horsepower for all fans in the system~~

~~bhp = maximum combined fan-brake horsepower for all fans in the system~~

~~A = sum of (PD x cfm_D/4131)~~

~~PD = each applicable pressure drop adjustment from Table 140.4 – B, in inches of water~~

~~cfm_D = the design airflow through each applicable device from Table 140.4 – B, in cubic feet per minute~~

~~*TABLE 140.4-B – Fan Power Limitation Pressure Drop Adjustment*~~

~~Device~~	~~Adjustment Credits~~
~~Return or exhaust systems required by code or accreditation standards to be fully ducted, or systems required to maintain air pressure differentials between adjacent rooms~~	~~0.5 in. of water~~
~~Return and/or exhaust airflow control devices~~	~~0.5 in. of water~~
~~Exhaust filters, scrubbers, or other exhaust treatment~~	~~The pressure drop of device calculated at fan system design condition~~
~~Particulate Filtration Credit: MERV 16 and greater and electronically enhanced filters~~	~~Pressure drop calculated at 2 x clean filter pressure drop at fan system design condition~~
~~Carbon and other gas-phase air cleaners~~	~~Clean filter pressure drop at fan system design condition~~
~~Biosafety cabinet~~	~~Pressure drop of device at fan system design condition~~
~~Energy recovery device, other than coil runaround loop~~	~~For each airstream [(2.2 x Energy Recovery Effectiveness) – 0.5] in. of water~~
~~Coil runaround loop~~	~~0.6 in. of water for each airstream~~
~~Exhaust systems serving fume hoods~~	~~0.35 in. of water~~

2. Variable air volume (VAV) systems.

A. Static Pressure Sensor Location. Static pressure sensors used to control variable air volume fans shall be placed in a position such that the controller set point is no greater than one-third the total design fan static pressure, except for systems with zone reset control complying with Section140.4(c)2B. If this results in the sensor being located downstream of any major duct split, multiple sensors shall be installed in each major branch with fan capacity controlled to satisfy the sensor furthest below its setpoint; and

B. Setpoint Reset. For systems with direct digital control of individual zone boxes reporting to the central control panel, static pressure setpoints shall be reset based on the zone requiring the most pressure; i.e., the set point is reset lower until one zone damper is nearly wide open.

3. Fractional HVAC Motors for Fans.

HVAC motors for fans that are less than 1 hp and 1/12 hp or greater shall be electronically-commutated motors or shall have a minimum motor efficiency of 70 percent when rated in accordance with NEMA Standard MG 1-2006 at full load rating conditions. These motors shall also have the means to adjust motor speed for either balancing or remote control. Belt-driven fans may use sheave adjustments for airflow balancing in lieu of a varying motor speed.

EXCEPTION 1 to Section 140.4(c)3: Motors in fan-coils and terminal units that operate only when providing heating to the space served.

EXCEPTION 2 to Section 140.4(c)3: Motors in space conditioning equipment certified under Section 110.1 or 110.2.

EXCEPTION 1 to 140.4(c): fan system power caused solely by process loads.

EXCEPTION 2 to 140.4(c): Systems serving healthcare facilities.

…

(l) **Air Distribution System Duct Leakage Sealing.** Duct systems shall be sealed in accordance with 1 or 2 below:

1. Systems serving high-rise residential buildings, hotel/motel buildings and nonresidential buildings other than healthcare facilities, the duct system shall be sealed to a leakage rate not to exceed 6 percent of the nominal air handler airflow rate as confirmed through field verification and diagnostic testing, in accordance with the applicable procedures in Reference Nonresidential Appendices NA1 and NA2 if the criteria in Subsections A, B and C below are met:

    A. The duct system provides conditioned air to an occupiable space for a constant volume, single zone, space-conditioning system; and

    B. The space conditioning system serves less than 5,000 square feet of conditioned floor area; and

    C. The combined surface area of the ducts located in the following spaces is more than 25 percent of the total surface area of the entire duct system:

        i. Outdoors; or

ii. In a space directly under a roof that

a. Has a U-factor greater than the U-factor of the ceiling, or if the roof does not meet the requirements of Section 140.3(a)1B, or

b. Has fixed vents or openings to the outside or unconditioned spaces; or

iii. In an unconditioned crawlspace; or

iv. In other unconditioned spaces.

2. Duct systems serving healthcare facilities shall be sealed in accordance with the California Mechanical Code.

SECTION 141.0 – ADDITIONS, ALTERATIONS, AND REPAIRS TO EXISTING NONRESIDENTIAL, HIGH-RISE RESIDENTIAL, AND HOTEL/MOTEL BUILDINGS, TO EXISTING OUTDOOR LIGHTING, AND TO INTERNALLY AND EXTERNALLY ILLUMINATED SIGNS

(b)1

D. **Fan Energy Index:** New fan systems serving an existing building shall meet the requirements of Section 120.10.

…

(b)2

C. New or Replacement Space-Conditioning Systems or Components other than new or replacement space-conditioning system ducts shall meet the requirements of Section 140.4 applicable to the systems or components being altered, except that additional Fan Power Allowances are available when determining the Fan Power Budget (Fan kW_{budget}) as specified in Table 141.0-D. These values can be added to the Fan Power Allowance values in Tables 140.4-A and Table 140.4-B. For compliance with Section 140.4(c)1 additional fan adjustment credits are available as specified in Table 141.0-D.

Table 141.0-D: Additional Fan Power Allowances

	Multi-Zone VAV System1			Constant Volume/Single-zone VAV		
Airflow	≥10,000 cfm	≥5,000 and ≤10,000 cfm	≤5,000 cfm	≥10,000 cfm	≥5,000 and ≤10,000 cfm	≤5,000 cfm
Supply Fan System Additional Allowance	0.22	0.24	0.28	0.18	0.19	0.18

Exhaust/ Relief/ Return/ Transfer Fan System Additional Allowance	0.06	0.07	0.09	0.06	0.07	0.09
1. See section for requirements 140.4 (c) 1 for Multi-Zone VAV System						

~~*Table 141.0-D Fan Power Limitation Pressure Drop Adjustment*~~

Device	Adjustment Credits
Particulate Filtration Credit: MERV 9 through 12	0.5 in. of water
Particulate Filtration Credit: MERV 13 through 15	0.9 in. of water

EXCEPTION 1 to Section 141.0(b)2C. Subsection (b)2C does not apply to replacements of equivalent or lower capacity electric resistance space heaters for high rise residential apartment units.

EXCEPTION 2 to Section 141.0(b)2C. Subsection (b)2C does not apply to replacement of electric reheat of equivalent or lower capacity electric resistance space heaters, when natural gas is not available.

EXCEPTION 3 to Section 141.0(b)2C. Section 140.4(n) is not applicable to new or replacement space conditioning systems.

D. **Altered Duct Systems.** When new or replacement space-conditioning system ducts are installed to serve an existing building, the new ducts shall meet the requirements of Section 120.4(a) through (f) and meet I or ii below: . If the space conditioning system meets the criteria of Section 140.4(l)1, the duct system shall be sealed as confirmed through field verification and diagnostic testing in accordance with the procedures for duct sealing of an existing duct system as specified in Reference Nonresidential Appendix NA2, to meet one of the following requirements:

i. If the new ducts form an entirely new or replacement duct system directly connected to the air handler, the measured duct leakage shall be equal to, or less than 6 percent of the system air handler airflow as confirmed by field verification and diagnostic testing utilizing the procedures in Reference Nonresidential Appendix Section NA2.1.4.2.1.

i. Entirely new or replacement duct systems installed as part of an alteration shall be leakage tested in accordance with Section 120.4(a). An eEntirely new or replacement duct systems installed as part of an alteration shall be constructed of at least 75 percent new duct material, and up to 25 percent may consist of reused parts from the building's existing duct system, including registers, grilles, boots, air handlers, coils, plenums, and ducts, if the reused parts are accessible and can be sealed to prevent leakage.

ii. If the new ducts are an extension of an existing duct system, the combined new and existing duct system meets the criteria in Subsections 1, 2, 3, and 4 below. The duct system shall be sealed to a leakage rate not to exceed 15 percent of the nominal air handler airflow rate as confirmed through field verification and diagnostic testing, in accordance with the applicable procedures in Reference Nonresidential Appendices NA1 and NA2:

1. The duct system does not serve a healthcare facility; and

2. The duct system provides conditioned air to an occupiable space for a constant volume, single zone, space-conditioning system; and

3. The space conditioning system serves less than 5,000 square feet of conditioned floor area; and

4. The combined surface area of the ducts located in the following spaces is more than 25 percent of the total surface area of the entire duct system:

A. Outdoors; or

B. In a space directly under a roof that

i. Has a U-factor greater than the U-factor of the ceiling, or if the roof does not meet the requirements of Section 140.3(a)1B, or

ii. Has fixed vents or openings to the outside or unconditioned spaces; or

C. In an unconditioned crawlspace; or

D. In other unconditioned spaces.

shall meet one of the following requirements:

a. The measured duct leakage shall be equal to or less than 15 percent of the system air handler airflow as confirmed by field verification and diagnostic testing utilizing the procedures in Reference Nonresidential Appendix Section NA2.1.4.2.1; or

b. If it is not possible to comply with the duct leakage criterion in Subsection 141.0(b)2Diia, then all accessible leaks shall be sealed and verified through a visual inspection and a smoke test performed by a certified HERS Rater utilizing the methods specified in Reference Nonresidential Appendix NA2.1.4.2.2.

EXCEPTION to Section 141.0(b)2Dii: If it is not possible to achieve the duct leakage criterion in Section 141.0(b)2Dii, then all accessible leaks shall be sealed and verified through a visual inspection and a smoke test performed by a certified HERS Rater utilizing the methods specified in Reference Nonresidential Appendix NA2.1.4.2.2a.

EXCEPTION to Section 141.0(b)2Dii: Duct Sealing. Existing duct systems that are extended, which are constructed, insulated or sealed with asbestos are exempt from the requirements of subsection 141.0(b)2Dii.

E. Altered Space-Conditioning Systems. When a space-conditioning system is altered by the installation or replacement of space-conditioning system equipment (including replacement of the air handler, outdoor condensing unit of a split system air conditioner or heat pump, or cooling or heating coil:

i. For all altered units where the existing thermostat does not comply with the requirements for demand responsive controls specified in Section 110.12, the existing thermostat shall be replaced with a demand responsive thermostat that complies with Section 110.12. All newly installed space-conditioning systems requiring a thermostat shall be equipped with a demand responsive thermostat that complies with Section 110.12; and

ii. The duct system that is connected to the new or replaced space-conditioning system equipment shall be sealed in accordance with Section 141.0(b)2Dii, if the duct system meets the criteria of Section 141.0(b)2Dii, as confirmed through field verification and diagnostic testing, in accordance with the applicable procedures for duct sealing of altered existing duct systems as specified in Reference Nonresidential Appendix NA2, and conforming to the applicable leakage compliance criteria in Section 141.0(b)2D.

EXCEPTION 1 to Section 141.0(b)2Eii: Duct Sealing. Buildings altered so that the duct system no longer meets the criteria of Section 141.4(b)2Dii. are exempt from the requirements of Subsection 141.0(b)2Eii.

EXCEPTION 2 to Section 141.0(b)2Eii: Duct Sealing. Duct systems that are documented to have been previously sealed as confirmed through field verification and diagnostic testing in accordance with procedures in the Reference Nonresidential Appendix NA2. are exempt from the requirements of Subsection 141.0(b)2Eii.

7.3 Reference Appendices

The Statewide CASE Team proposes to modify the existing Appendix NA7.5.3 – Air Distribution Systems to support the proposed code change for duct leakage in Section 120.5. There is a slight change to NA1 and NA2 to properly reference the proposed change of moving Section 140.4(l) to 120.4(g). Additionally, a new Appendix NA9 –Fan Power Budget Appendix (Fan kW_{budget}) would be created.

7.3.1 Nonresidential Appendix 1

NA1.1 California Home Energy Rating Systems.

Appendix NA1 provides direction for communication and documentation processes that must be completed for compliance with the HERS verification requirements for multifamily dwelling units (dwelling units), and for HERS verification of duct sealing of HVAC systems covered by §120.4(g)140.4(l)1, §141.0(b)2Dii, and §141.0(b)2E (systems) that require field verification and diagnostic testing by a certified Home Energy Rating System (HERS) Rater, using the testing procedures in Reference Nonresidential Appendix NA2.

7.3.2 Nonresidential Appendix 2

Appendix NA2 – Nonresidential Field Verification and Diagnostic Test Procedures

NA2.1 Procedures for Field Verification and Diagnostic Testing of Air Distribution Systems

NA2.1.1 Purpose and Scope

1. NA2.1 contains procedures for field verification and diagnostic testing for air leakage in single zone, constant volume, nonresidential air distribution systems serving zones with 5000 ft² of conditioned floor area or less as required by Standards section ~~141.0(b)2Dii~~ 140.4(l)1.
2. NA2.1 procedures are applicable to new space conditioning systems in newly constructed buildings and to new or altered space conditioning systems in existing buildings.
3. NA2.1 procedures shall be used by installers, HERS Raters, and others who perform field verification of air distribution systems as required by Standards Section ~~120.4(g) and 141.0(b)2Dii~~ 140.4(l)1.
4. Table NA2.1-1 provides a summary of the duct leakage verification and diagnostic test protocols included in Section NA2.1, and the compliance criteria.

7.3.3 Nonresidential Appendix 7

Appendix NA7 – Installation and Acceptance Requirements for Nonresidential Buildings and Covered Processes

NA7.2 Introduction

Third-party review of the information provided on Certificate of Acceptance documentation is not required, with one exception: duct leakage diagnostic test results for some constant volume space conditioning systems serving less than 5,000 square feet of conditioned floor area are required to be verified by a certified HERS Rater as specified in Standards Section ~~120.4(g)~~ 140.4(l)1.

NA7.5.3 Air Distribution Systems

NA7.5.3.1 Construction Inspection

Prior to Functional Testing on new duct systems, verify and document the following:

(a) Duct connections meet the requirements of Standards §120.4.

(b) Specify choice of drawbands.

(c) Flexible ducts are not constricted in any way.

(d) Duct leakage tests shall be performed before access to ductwork and connections are blocked.

(e) Joints and seams are properly sealed according to the requirements of Standards §120.4.

(f) Joints and seams are not sealed with cloth back rubber adhesive tape unless used in combination with Mastic and drawbands. Cloth backed tape may be used if tape has been approved by the CEC. Ducts are fully accessible for testing.

(g) Insulation R-Values meet the minimum requirements of §120.4(a).Insulation is protected from damage and suitable for outdoor service if applicable as specified by Standards §120.4(f).

Prior to Functional Testing on all new and existing duct systems, visually inspect to verify that the following locations have been sealed:

(h) Connections to plenums and other connections to the forced air unit;

(i) Refrigerant line and other penetrations into the forced air unit;

(j) Air handler door panel (do not use permanent sealing material, metal tape is acceptable);

(k) Register boots sealed to surrounding material; and

(l) Connections between lengths of duct, as well as connections to takeoffs, wyes, tees, and splitter boxes.

NA7.5.3.2 Functional Testing

Duct systems shall be tested in accordance with NA7.5.3.2.1 when they are either new duct systems that meet the criteria of the exception in Section 120.4(g) or they are part of a system that meets the criteria of Section 141.0(b)2Dii. All other duct systems shall be tested in accordance with NA 7.5.3.2.2.

NA 7.5.3.2.1

Step 1: Perform duct leakage test as specified by Reference Nonresidential Appendix NA2 to verify the duct leakage conforms to the requirements of Standards §140.4(l)1 120.4(g) and §141.0(b)2Dii.

Step 2: Obtain HERS Rater field verification as specified in Reference Nonresidential Appendix NA1. Or at the discretion of the enforcement agency, field verification may be satisfied by the ATT as specified in Reference Nonresidential Appendix NA1.9.

NA 7.5.3.2.2

The objective of this procedure is for an installer to determine, and a Mechanical Acceptance Test Technician, who is also a technician certified as a Testing, Adjusting, and Balancing Technician (AABC, NEBB, or TABB) or as a Duct Air Leakage Technician by the International Certification Board (ICB), to verify the leakage of ductwork:

NOTE: The language below up until NA7.5.3.2.2 (a) reproduces parts of CMC Section 603.10.1. This shows how it could be incorporated in Section 603.10.1 instead of this appendix.

Ductwork shall comply with the leakage testing requirements in the California Mechanical Code Section 603.10.1: Ductwork shall be leak-tested in accordance with the SMACNA HVAC Air Duct Leakage Test Manual and NA7.5.3.2.2. Representative sections totaling not less than 10 percent of the total installed duct area shall be tested. Where the tested 10 percent fails to comply with the requirements of this section, then 40 percent of the total installed duct area shall be tested. Where the tested 40 percent fails to comply with the requirements of this section, then 100 percent of the total installed duct area shall be tested. Sections shall be selected by the building owner or designated representative of the building owner. Positive pressure leakage testing shall be permitted for negative pressure ductwork. The permitted duct leakage shall be not more than the following:

$$L_{max} = C_L P^{0.65}$$

Where:

L_{max} = maximum permitted leakage, (ft3/min)/100 square feet [0.0001 (m2/s)/m2] duct surface area.

C_L = four or two, duct leakage class, (ft3/min)/100 square feet [0.0001 (m3/s)/m2] duct surface area at 1 inch water column (0.2 kPa). Rectangular and oval ductwork shall be tested to leakage class four and round ductwork tested to leakage class two.

P = test pressure, which shall be equal to the design duct pressure class rating, inch water column (kPa).

All vertical ductwork that is located in shafts and all horizontal ductwork upstream of a terminal box that is located above hard ceilings shall be tested and counted towards the 10% testing requirement. If more than 10% of the ductwork will be in shafts or above hard ceilings, this requirement will result in more than 10% of the total surface area having to be tested.

In the case of supply-air systems without terminal boxes, 10% of the ductwork as determined by surface area shall be tested.

In the case of supply-air systems with terminal boxes, 10% of ductwork upstream and 10% of ductwork downstream of the terminal boxes as determined by surface area shall be tested and the leakage considered separately.

In the case of exhaust-air systems, 10% of the installed ductwork as determined by surface area shall be tested and the leakage considered separately from the supply-air system. In a building with multiple exhaust systems, at least two systems need to be tested to achieve the minimum 10% of surface area.

(a) Select test pressure equal to the lowest pressure class of any component or ductwork section of the assembly being tested
    a. When testing downstream of VAV air valves, test at 25 Pa (0.1 i.w.c.)

    b. When testing downstream of CAV terminal boxes or branch balancing dampers, test at 50% of the upstream pressure class

(b) When testing 10% of ductwork downstream of VAV air valves, section selection shall be representative of the downstream sections found in the building (e.g., similar type and number of diffusers, similar design flow, similar total duct length)

(c) Calculate maximum permitted leakage according to 603.10.1 of the California Mechanical Code:

    a. Maximum permitted leakage is calculated according to the following equation:

$L_{max} = CL*P_{0.65}$

Where:

L_{max} = maximum permitted leakage, (cfm/min)/100 ft_2 of duct surface area

CL = four or two, duct leakage class (cfm/min)/100 ft_2 duct surface area at 1 inch water column. Rectangular/oval ductwork shall be tested to leakage class four and round ductwork tested to leakage class two.

P = test pressure, equal to the design duct pressure class rating, inch water column

    b. The total leakage flow (cfm) at the pressure conditions specified in a. shall be equal to the sum of the leakage flows from all the sections being tested.
    c. The total leakage flow shall be less than the product of the allowable percentage leakage multiplied by the design flow through the section being tested.
    d. For VAV supply systems, the leakage calculation shall be performed separately for sections upstream and downstream of VAV air valves.
    e. For CAV supply systems with terminal boxes (e.g., with reheat coils), the leakage calculation shall be performed separately for sections upstream and downstream of the terminal boxes.

(d) Connect blower and flow meter to duct or equipment section and temporarily seal open ends of ductwork or equipment

(e) Prevent over pressurizing by starting with the test apparatus inlet damper closed or VFD set to low delivery. Carefully pressurize.

(f) Read flow meter and compare to allowed leakage from c. If it meets the allowed rate continue, otherwise:

    a. Inspect for sensible leaks
    b. Smoke test can be used to identify actual leaks. Soap solution can be applied if necessary:
        i. Inject either theatrical or other non-toxic smoke into a fan pressurization device that is maintaining a duct pressure difference of 25 Pa (0.1 inches water) relative to the duct surroundings, with all grilles and registers in the duct system sealed.

ii. Visually inspect all accessible portions of the duct system during smoke injection.

iii. The system shall pass the test if one of the following conditions is met:

1. No visible smoke exits the accessible portions of the duct system.
2. Smoke only emanates from the furnace cabinet which is gasketed and sealed by the manufacturer and no visible smoke exits from the accessible portions of the duct system.

c. Depressurize and repair leaks. If test pressure could not be reached and significant leak sites were not detected, consider smaller sections or larger test bigger apparatus.

d. Allow seals to cure and retest.

(g) Complete test report and obtain witness signature, if required.

(h) Remove temporary plugs and seals

7.3.4 Nonresidential Appendix 9

Appendix NA9 –Fan Power Budget (Fan kW_{budget})

For building sites 3,000 ft or more above sea level, multiply the fan power budget (Fan kW_{budget}) by the correction factors below in Table NA 9-1.

Table NA9-1 Correction Air Density by Altitude

Altitude (ft)	Correction factor
<3,000	1.000
≥3,000 and <4,000	0.896
≥4,000 and <5,000	0.864
≥5,000 and <6,000	0.832
≥6,000	0.801

7.4 ACM Reference Manual

There are several changes needed to Nonresidential ACM to account for the air distribution submeasures that are specifically related to fan power budget. This section seeks to outline the likely significant changes needed to Section 5.7.3: Fans and Duct Systems to account for the fan power budget submeasure without being directly prescriptive, as further discussion is required between the Statewide CASE team and the Energy Commission. Changes to the ACM for duct leakage and FEI are likely minimum as both are mandatory measures, though this should be discussed further with the Energy Commission as well.

Determining Standard Design fan power based on HVAC system and airflow

In the 2019 ACM, the fan power for the Standard Design is determined using the BHP method, where BHP is calculated as a function of airflow depending on whether the system is a VAV or CAV system. This aligns with the prescriptive requirements for the fan power limitations. Prescriptively, the fan power budget submeasure will be determined for each fan system based on the components and devices in each fan system by totaling the fan power allowances (watts/ cfm) and multiplying the sum by the fan system airflow. However, if the performance path is used, the Statewide CASE team believes a different approach is needed for the fan power budget in the ACM which will better align with the current approach to fan power modeling, while still capturing the new stringency of the fan power budget submeasure.

Whereas the current fan power limitations give two options (CAV or VAV) to determine the allowed BHP/ cfm, the Statewide CASE Team proposes the BHP/ cfm options in the Standard Design expand to become a function of airflow and HVAC system type.

The ACM currently calculates Standard Design airflow for each building based on space conditioning and ventilation requirements. The ACM also determines the Standard Design HVAC system type (13 unique HVAC system types) based on building sector, number of floors and the building ft^2. The fan power budget is already a function of airflow and the components in each system, thus by determining which components are in each default fan system, BHP/ cfm values can be calculated for the Standard Design.

For example, the ACM assigns a Built-up VAV Unit HVAC system (System 6) to buildings with more than five floors or to buildings greater than 150,000 ft^2.

Using the same reference pressure assumptions in Appendix N, and a total pressure can be assigned to each HVAC system, as shown in Table 47.

Table 47: Assumed Pressure Drops for Standard Design Built-up VAV HVAC

System 6- Built up VAV Unit (VAVS)	**>10,000 cfm**	**>5,000 cfm and ≤10,000 cfm**	**≤5,000 cfm**
Total Pressure (in. wg)	**4.50**	**4.40**	**3.65**
Supply System Base Allowance	1.90	1.90	1.40
MERV 13 to MERV 16 Filter (clean)	0.60	0.60	0.60
Hydronic heating coil (central)	0.30	0.25	0.20
Terminal re-heat (gas or electric)	0.10	0.10	0.10

Hydronic/DX cooling coil, or heat pump coil (wet) [Healthcare facilities can select twice]	0.60	0.60	0.60
Exhaust System Base Allowance	1.00	0.95	0.75

With total pressure values for each Standard Design HVAC system (as shown in Table 48), BHP/ cfm values can be determined using the fan power budget methodology in Appendix N for each fan system that may be assigned to a non-residential building (as shown in Table 49).

Table 48: Non-residential HVAC System Types and Total Reference Pressures

ACM HVAC System Type	>10,000 cfm	>5,000 cfm and ≤10,000 cfm	≤5,000 cfm
System 5- Packaged VAV (PVAV)	4.60	4.45	3.75
System 6- Built up VAV Unit (VAVS)	4.50	4.40	3.65
System 7- Packaged Single-zone VAV unit (SZVAV)	3.60	3.25	2.85
System 9 - Heating and Ventilation (HEATVENT)	3.00	2.65	2.25

Table 49: Standard Design Proposed BHP/ cfm Values (Combined/ Single-fan System)

ACM HVAC System Type	>10,000 cfm	>5,000 cfm and ≤10,000 cfm	≤5,000 cfm
System 5- Packaged VAV (PVAV)	0.00101	0.00100	0.00090
System 6- Built up VAV Unit (VAVS)	0.00099	0.00099	0.00088
System 7- Packaged Single-zone VAV unit (SZVAV)	0.00080	0.00074	0.00070
System 9 - Heating and Ventilation (HEATVENT)	0.00067	0.00061	0.00056

Separation of supply side and return/ relief/ exhaust side in the ACM

The Statewide CASE Team understands that the Standard Design for fan systems in the modeling software currently allocates all the pressure, and thus fan power, to a single fan in each system. For example, consider a VAV fan system (Proposed Design) using the static pressure method which has a 9,000 cfm supply fan at 3 in. wg and a

9,000 cfm return fan at 1 in. wg. The current ACM would calculate Standard Design using the brake horsepower method. For this fan system, the standard design BHP would be calculated by multiplying 9,000 cfm by 0.0013 yielding a BHP of 11.7. As explained in Section 2.2.1, the current fan power limitations apply to the entire fan system (supply and return/ exhaust) and the constants in the current fan power limitations (in this case 0.0013) capture the pressure from both the supply and return side (in this case 5.35 in. wg) and a standard fan efficiency of 65%.

The Statewide CASE team understands that the Standard Design is modeled as a one-fan system to align with the current structure of fan power limitations. The fan power budget submeasure as proposed in this Final CASE report will require (at least prescriptively) that the fan power budget be calculated separately and complied with separately for each fan system.

To align the performance method with prescriptive method the fan power budget could apply to each fan system. In other words, there could be a Standard Design calculated for each fan system (i.e. supply, relief, return, exhaust), whereas currently the Standard Design fan power is all allocated to the supply fan.

However, it is possible, and likely simpler, to continue to model fan power using only a single fan. For example, as shown in Table 50, it is possible to represent the fan power as a combined one-fan system, or to have the Standard Design fan power be calculated separately for the supply-side fan and the exhaust/ return-side.

Table 50: Fan Power Modeling Options (BHP/cfm)

Fan System type	>10,000 cfm	>5,000 cfm and ≤10,000 cfm	≤5,000 cfm
Single-cabinet Fan System	0.00100	0.00099	0.00089
Supply-only	0.00075	0.00074	0.00067
Exhaust/ Return	0.00025	0.00025	0.00022

Addition of transmission efficiency (ηtrans)

The addition of transmission efficiency to the ACM will help more accurately model true fan electrical input power in the modeling software, and provide an incentive for designs to select more efficient transmissions (such as direct drives). A transmission efficiency (ηtrans) section needs to be added to the ACM and treated in similar fashion to motor efficiency for each fan, in that the transmission efficiency is determined based upon the BHP of the fan.

The default for all Standard Designs is based on a v-belt drive efficiency and can be determined based on airflow and Standard Design HVAC system type.

Table 51: Standard Design Transmission Efficiency (Combined/ Single-fan System)

Transmission Efficiency (Ƞtrans)	>10,000 cfm	>5,000 cfm and ≤10,000 cfm	≤5,000 cfm
System 5- Packaged VAV (PVAV)	95.5%	94.8%	92.8%
System 6- Built up VAV Unit (VAVS)	95.5%	94.8%	92.7%
System 7- Packaged Single-zone VAV unit (SZVAV)	95.4%	94.4%	92.2%
System 9 - Heating and Ventilation (HEATVENT)	95.3%	94.1%	91.6%

For the Proposed Design users shall be able to select one of three transmission types:

- V-belt drive where: $\eta_{trans} = 0.96\left(\frac{BHP}{\text{BHP+2.2}}\right)^{.05}$
- Synchronous belt drive where:

BHP ≤ 1.34 hp	Ƞtrans = 0.94
1.34 hp < BHP ≤ 6.70 hp	Ƞtrans = 0.007456 * BHP + 0.93
BHP > 6.70 hp	Ƞtrans = 0.98

- Direct-drive where: Ƞtrans equals 1

Altitude Correction

This Final CASE report proposes that fan systems installed at elevations greater than 3,000' above sea level have the fan power budget (Fan kW_{budget}) be corrected for air density. The correction is a straightforward and simple calculation, see NA-9. However, the Statewide CASE team seeks input as to the best location to specify where a user should enter elevation, as it will be needed for the standard design and the proposed design.

7.5 Compliance Manuals

Chapter 4 of the Nonresidential Compliance Manual would need to be revised. Currently, Section 4.6.2.3 "Fan Power Consumption" and Section 4.6.2.4 "Pressure Drop Adjustment Devices" of the Nonresidential Compliance Manual describes how the existing fan power limit code works, including how to determine if fan systems are subject to the code and when pressure drop adjustments can be used. It also includes many examples showing how to comply with the fan power limitations. The code changes proposed in this Final CASE Report would largely require a re-write of these sections, as while the overarching principle is similar to the existing fan power limitations, the approach, and the underlying calculations different. The updated compliance manual would show examples how to determine if fan systems are subject to the code using input kW, how to use the new fan power allowance tables and determine the fan power budget. It would also show how to determine FEI for the in-scope fans subject to the mandatory component of this measure.

Section 4.4.1.2 would need to be revised to include guidance on the mandatory requirement to meet Seal Class A and complying with the California Mechanical Code requirement for duct leakage testing per Section 120.5 and Reference Appendix NA7. Language should be added to further explain ductwork selection, for example: “In the case of CAV supply-air systems, 10% of the ductwork as determined by surface area shall be tested. In the case of VAV supply-air systems, 10% of ductwork upstream of VAV air valves and 10% of ductwork downstream of VAV air valves shall be tested, and the leakage (i.e., compliance with the requirements of Section 120.5) considered separately. Exposed ductwork downstream of VAV air valves shall not be considered as part of the surface area for which 10% needs to be tested. In the case of systems that employ VAV diffusers, testing shall be performed in the same manner as a CAV system. For exhaust ductwork, 10% of the installed ductwork as determined by surface area shall be tested and the leakage considered separately from the supply-air system. In a building with multiple exhaust systems, at least two systems need to be tested to achieve the minimum 10% of surface area.”

7.6 Compliance Documents

Compliance documents NRCC-MCH-E would need to be revised. Specifically, the fan power limitations section in Table H would be replaced with the new fan power budget calculation methodology. Additionally, FEI, as a mandatory requirement would be added to the mandatory measures section in Table Q. Section L. would need to be updated with the duct leakage testing requirements in the CMC and to say that duct systems shall be sealed in accordance with Seal Class A. NRCAV-MCH-04-H Duct Leakage Test and NRCA-MCH-04-A Air Distribution Duct Leakage would need to be updated to reflect the leakage testing requirements in the CMC and Section 120.5.

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Appendix A: Statewide Savings Methodology

To calculate first-year statewide savings, the Statewide CASE Team multiplied the per-unit savings by statewide construction estimates for the first year the standards would be in effect (2023). The projected nonresidential new construction forecast that would be impacted by the proposed code change in 2023 is presented in Table 52. The projected nonresidential existing statewide building stock that would be impacted by the proposed code change as a result of additions and alterations in 2023 is presented in Table 56. This section describes how the Statewide CASE Team developed these estimates.

The Energy Commission Building Standards Office provided the nonresidential construction forecast, which is available for public review on the Energy Commission's website: https://www.energy.ca.gov/title24/participation.html.

The construction forecast presents total floorspace of newly constructed buildings in 2023 by building type and climate zone. The building types included in the Energy Commissions' forecast are summarized in Table 52 through Table 66 below.

This table also identifies the prototypical buildings that were used to model the energy use of the proposed code changes. This mapping was required because the building types the Energy Commission defined in the construction forecast are not identical to the prototypical building types that the Energy Commission requested that the Statewide CASE Team use to model energy use. This mapping is consistent with the mapping that the Energy Commission used in the Final Impacts Analysis for the 2019 code cycle (California Energy Commission 2018).

The Energy Commission's forecast allocated 19 percent of the total square footage of new construction in 2023 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 would 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 so that the percentage of building floorspace in each climate zone, net of the miscellaneous square footage, would remain constant. See Table 57 for a sample calculation for redistributing the miscellaneous square footage among the other building types.

After the miscellaneous floorspace was redistributed, the Statewide CASE Team made assumptions about the percentage of newly constructed floorspace that would be impacted by the proposed code change. Table 58, Table 60 and Table 62 present the assumed percentage of floorspace that would be impacted by the proposed code change by building type. If a proposed code change does not apply to a specific building type, it is assumed that zero percent of the floorspace would be impacted by the proposal. If the assumed percentage is non-zero, but less than 100 percent, it is an indication that no buildings would be impacted by the proposal. Table 59, Table 61 and Table 63 present percentage of floorspace assumed to be impacted by the proposed change by climate zone.

For the fan power budget submeasure, the estimated floorspace that would be impacted was determined by the prototype buildings which had a fan system with an electrical input power ≥ 1 kW. For example, the restaurant fast food prototype does not have a fan system with an electrical input power ≥ 1 kW, therefore the Statewide CASE team did not count saving from this building type in the construction forecast. For alterations and additions, the Statewide CASE team assumed that roughly 5 percent of the existing building stock would be retrofitted each year, triggering the code to comply with the fan power budget. This assumes that fan system equipment life is roughly 20 years. This also aligns with the savings assumptions from the 2019 Statewide CASE team report on updating the fan power limitations to align with ASHRAE 90.1 (Statewide CASE Team 2017).

For the FEI submeasure, only for the office prototypes for the purposes of this analysis. For alterations and additions, the Statewide CASE team assumed that roughly 5 percent of the existing building stock would be retrofitted each year, triggering the code to comply with the FEI. This assumes that fan system equipment life is roughly 20 years. The savings from this measure is conservative, namely because most of the prototypes have packaged HVAC equipment (like rooftop units), and as proposed, FEI does not apply to most of this equipment. There are many in-scope fans in many other building types where FEI would be applicable but is largely dependent on the system design determined by the mechanical designer.

For duct leakage, the estimated floorspace that would be impacted was determined by the prototype buildings which had significant amounts of ductwork and so would be impacted by a sealing requirement. The Statewide CASE Team did not calculate or include savings for OfficeSmall, RestaurantFastFood, Grocery, Warehouse, and RetailLarge as they would not be significantly impacted by the proposal because there is either no ductwork or very small amounts of ductwork in these prototype building models and that ductwork is often in conditioned space – see Section 4.2.1.3. For alterations, the Statewide CASE Team assumed a 30 year life for ductwork based on the ASHRAE HVAC Applications handbook (ASHRAE 2019) and therefore 3.3 percent of the existing building stock was estimated to be impacted each year by the proposal.

Table 52: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2023, by Climate Zone and Building Type (Million Square Feet)- Fan Power Budget

Climate Zone	New Construction in 2023 (Million Square Feet)												
	Apartment High Rise	Hotel Small	Office Large	Office Medium	Office Medium Lab	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	School Primary	School Secondary	Warehouse	Total NR
1	0.01	0.05	0.07	0.08	0.01	0.10	0.01	0.01	0.01	0.04	0.03	0.10	0.52
2	0.05	0.31	0.43	0.46	0.04	0.60	0.08	0.08	0.04	0.22	0.21	0.58	3.10
3	0.22	1.43	2.42	2.55	0.17	2.72	0.36	0.36	0.18	0.89	0.85	3.00	15.16
4	0.11	0.74	1.27	1.34	0.09	1.39	0.19	0.19	0.09	0.45	0.43	1.54	7.83
5	0.02	0.14	0.22	0.24	0.02	0.28	0.04	0.04	0.02	0.09	0.09	0.29	1.49
6	0.11	0.85	1.68	1.74	0.09	1.92	0.26	0.26	0.13	0.49	0.46	2.29	10.26
7	0.10	0.91	0.94	1.00	0.08	1.35	0.18	0.18	0.09	0.52	0.47	1.35	7.17
8	0.16	1.18	2.51	2.61	0.13	2.76	0.37	0.37	0.18	0.67	0.64	3.29	14.86
9	0.30	1.80	4.65	4.83	0.24	4.28	0.57	0.57	0.29	0.89	0.96	5.23	24.62
10	0.16	1.03	0.95	1.04	0.12	2.67	0.36	0.36	0.18	0.95	0.82	4.34	12.97
11	0.04	0.20	0.20	0.23	0.03	0.54	0.07	0.07	0.04	0.25	0.22	0.79	2.69
12	0.20	1.19	1.97	2.09	0.16	2.92	0.39	0.39	0.19	1.03	0.92	3.91	15.37
13	0.09	0.39	0.31	0.36	0.07	1.15	0.15	0.15	0.08	0.55	0.47	1.37	5.12
14	0.03	0.22	0.33	0.35	0.03	0.63	0.08	0.08	0.04	0.19	0.17	0.93	3.09
15	0.01	0.17	0.10	0.11	0.01	0.36	0.05	0.05	0.02	0.13	0.11	0.67	1.79
16	0.01	0.07	0.08	0.09	0.01	0.20	0.03	0.03	0.01	0.07	0.06	0.28	0.95
TOTAL	1.63	10.69	18.14	19.11	1.30	23.86	3.18	3.18	1.59	7.44	6.91	29.95	126.98

Table 53: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2023 (Alterations), by Climate Zone and Building Type (Million Square Feet)- Fan Power Budget

Climate Zone	New Construction in 2023 (Million Square Feet)												
	Apartment High Rise	Hotel Small	Office Large	Office Medium	Office Medium Lab	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	School Primary	School Secondary	Warehouse	Total NR
1	0.02	0.11	0.17	0.19	0.02	0.21	0.03	0.03	0.01	0.10	0.09	0.21	1.19
2	0.13	0.63	1.03	1.11	0.11	1.27	0.17	0.17	0.08	0.58	0.55	1.23	7.06
3	0.57	2.87	5.63	5.97	0.46	5.68	0.76	0.76	0.38	2.39	2.29	6.23	33.99
4	0.29	1.48	2.94	3.12	0.24	2.90	0.39	0.39	0.19	1.22	1.16	3.18	17.49
5	0.06	0.29	0.54	0.57	0.05	0.60	0.08	0.08	0.04	0.25	0.24	0.61	3.41
6	0.37	1.86	3.81	4.03	0.30	4.60	0.61	0.61	0.31	1.63	1.53	5.57	25.21
7	0.30	2.00	2.47	2.65	0.24	3.29	0.44	0.44	0.22	1.28	1.21	3.15	17.68
8	0.52	2.55	5.64	5.95	0.41	6.56	0.87	0.87	0.44	2.27	2.13	7.93	36.15
9	0.94	3.96	9.94	10.50	0.75	10.07	1.34	1.34	0.67	3.36	3.37	12.40	58.67
10	0.48	2.28	2.55	2.84	0.38	7.21	0.96	0.96	0.48	2.66	2.35	11.50	34.66
11	0.12	0.41	0.49	0.56	0.09	1.25	0.17	0.17	0.08	0.64	0.57	1.88	6.42
12	0.53	2.38	4.51	4.82	0.42	6.48	0.86	0.86	0.43	2.70	2.43	8.22	34.65
13	0.23	0.78	0.71	0.85	0.19	2.65	0.35	0.35	0.18	1.48	1.27	3.12	12.17
14	0.11	0.49	0.78	0.84	0.09	1.64	0.22	0.22	0.11	0.60	0.53	2.42	8.04
15	0.04	0.35	0.24	0.27	0.04	0.97	0.13	0.13	0.06	0.36	0.30	1.75	4.64
16	0.04	0.15	0.20	0.22	0.03	0.50	0.07	0.07	0.03	0.22	0.19	0.71	2.43
TOTAL	4.7	22.6	41.6	44.5	3.8	55.9	7.5	7.5	3.7	21.7	20.2	70.1	303.9

Table 54: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023, New Construction/ Alterations/ Addtions by Climate Zone and Building Type (Million Square Feet)- Fan Energy Index

Climate Zone	Altered Floorspace in 2023 (Million Square Feet)		
	Office Large (New Construction)	Office Large (Additions/ Alterations)	Total NR
1	0.07	0.17	0.25
2	0.43	1.03	1.46
3	2.42	5.63	8.05
4	1.27	2.94	4.21
5	0.22	0.54	0.76
6	1.68	3.81	5.48
7	0.94	2.47	3.41
8	2.51	5.64	8.15
9	4.65	9.94	14.59
10	0.95	2.55	3.50
11	0.20	0.49	0.69
12	1.97	4.51	6.48
13	0.31	0.71	1.02
14	0.33	0.78	1.10
15	0.10	0.24	0.34
16	0.08	0.20	0.28
TOTAL	18.1	41.6	59.78

Table 55: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023 (New Construction, by Climate Zone and Building Type (Million Square Feet) – Duct Leakage

Climate Zone	New Construction in 2023 (Million Square Feet)									
	Hotel Small	Office Large	Office Medium	Office Medium Lab	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	School Primary	School Secondary	Total NR
1	0.05	0.07	0.08	0.01	0.01	0.01	0.01	0.04	0.03	0.31
2	0.31	0.43	0.46	0.04	0.08	0.08	0.04	0.22	0.21	1.87
3	1.43	2.42	2.55	0.17	0.36	0.36	0.18	0.89	0.85	9.23
4	0.74	1.27	1.34	0.09	0.19	0.19	0.09	0.45	0.43	4.78
5	0.14	0.22	0.24	0.02	0.04	0.04	0.02	0.09	0.09	0.90
6	0.85	1.68	1.74	0.09	0.26	0.26	0.13	0.49	0.46	5.94
7	0.91	0.94	1.00	0.08	0.18	0.18	0.09	0.52	0.47	4.37
8	1.18	2.51	2.61	0.13	0.37	0.37	0.18	0.67	0.64	8.65
9	1.80	4.65	4.83	0.24	0.57	0.57	0.29	0.89	0.96	14.80
10	1.03	0.95	1.04	0.12	0.36	0.36	0.18	0.95	0.82	5.80
11	0.20	0.20	0.23	0.03	0.07	0.07	0.04	0.25	0.22	1.31
12	1.19	1.97	2.09	0.16	0.39	0.39	0.19	1.03	0.92	8.34
13	0.39	0.31	0.36	0.07	0.15	0.15	0.08	0.55	0.47	2.53
14	0.22	0.33	0.35	0.03	0.08	0.08	0.04	0.19	0.17	1.50
15	0.17	0.10	0.11	0.01	0.05	0.05	0.02	0.13	0.11	0.74
16	0.07	0.08	0.09	0.01	0.03	0.03	0.01	0.07	0.06	0.46
TOTAL	10.7	18.1	19.1	1.3	3.2	3.2	1.6	7.4	6.9	71.5

Table 56: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023 (Alterations), by Climate Zone and Building Type (Million Square Feet)- Duct Leakage

Climate Zone	Existing Floorspace Impacted in 2023 (Million Square Feet)									
	Hotel Small	Office Large	Office Medium	Office Medium Lab	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	School Primary	School Secondary	Total NR
1	0.07	0.12	0.12	0.01	0.02	0.02	0.01	0.07	0.06	0.50
2	0.42	0.69	0.74	0.07	0.11	0.11	0.06	0.39	0.36	2.95

3	1.91	3.75	3.98	0.31	0.51	0.51	0.25	1.60	1.52	14.33
4	0.98	1.96	2.08	0.16	0.26	0.26	0.13	0.81	0.78	7.41
5	0.20	0.36	0.38	0.03	0.05	0.05	0.03	0.17	0.16	1.43
6	1.24	2.54	2.69	0.20	0.41	0.41	0.20	1.08	1.02	9.78
7	1.33	1.65	1.76	0.16	0.29	0.29	0.15	0.85	0.80	7.29
8	1.70	3.76	3.97	0.28	0.58	0.58	0.29	1.51	1.42	14.10
9	2.64	6.63	7.00	0.50	0.90	0.90	0.45	2.24	2.25	23.50
10	1.52	1.70	1.89	0.25	0.64	0.64	0.32	1.77	1.56	10.31
11	0.27	0.32	0.37	0.06	0.11	0.11	0.06	0.43	0.38	2.12
12	1.59	3.01	3.22	0.28	0.58	0.58	0.29	1.80	1.62	12.95
13	0.52	0.47	0.57	0.12	0.24	0.24	0.12	0.99	0.85	4.11
14	0.33	0.52	0.56	0.06	0.15	0.15	0.07	0.40	0.35	2.58
15	0.23	0.16	0.18	0.02	0.09	0.09	0.04	0.24	0.20	1.25
16	0.10	0.13	0.15	0.02	0.04	0.04	0.02	0.15	0.13	0.78
TOTAL	15.1	27.8	29.7	2.5	5.0	5.0	2.5	14.5	13.5	115.4

Table 57: Example of Redistribution of Miscellaneous Category - 2023 New Construction in Climate Zone 1

Building Type	2020 Forecast (Million Square Feet) [A]	Distribution Excluding Miscellaneous Category [B]	Redistribution of Miscellaneous Category (Million Square Feet) [C] = B × [D = 0.145]	Revised 2020 Forecast (Million Square Feet) [E] = A + C
Small Office	0.036	7%	0.010	0.046
Large Office	0.114	21%	0.031	0.144
Restaurant	0.015	3%	0.004	0.020
Retail	0.107	20%	0.029	0.136
Grocery Store	0.029	5%	0.008	0.036
Non-Refrigerated Warehouse	0.079	15%	0.021	0.101
Refrigerated Warehouse	0.006	1%	0.002	0.008
Schools	0.049	9%	0.013	0.062
Colleges	0.027	5%	0.007	0.034
Hospitals	0.036	7%	0.010	0.046
Hotel/Motels	0.043	8%	0.012	0.055
Miscellaneous **[D]**	0.145	N/A	0.000	0.145
TOTAL	0.686	100%	0.147	0.833

Table 58: Percent of Floorspace Impacted by Proposed Measure, by Building Type- Fan Power Budget

Building Type Building sub-type	Composition of Building Type by Subtypes[a]	Percent of Square Footage Impacted[b]	
		New Construction	Existing Building Stock (Alterations)[c]
Small Office	N/A	0%	0%
Restaurant	N/A	0%	0%
Retail	N/A	100%	5%
Stand-Alone Retail	10%	100%	5%
Large Retail	75%	100%	5%
Strip Mall	5%	100%	5%
Mixed-Use Retail	10%	100%	5%
Food	N/A	0%	0%
Non-Refrigerated Warehouse	N/A	100%	5%
Refrigerated Warehouse	N/A	0%	0%
Schools	N/A	100%	5%
Small School	60%	100%	5%
Large School	40%	100%	5%
College	N/A	100%	5%
Small Office	5%	0%	0%
Medium Office	15%	100%	5%
Medium Office/Lab	20%	100%	5%
Public Assembly	5%	N/A	N/A
Large School	30%	100%	5%
High-Rise Apartment	25%	0%	0%
Hospital	N/A	N/A	N/A
Hotel/Motel	N/A	100%	5%
Offices	N/A	100%	5%
Medium Office	50%	100%	5%
Large Office	50%	100%	5%

a. Presents the assumed composition of the main building type category by the building subtypes. All 2022 CASE Reports assumed the same percentages of building subtypes.

b. When the building type is composed of multiple subtypes, the overall percentage for the main building category was calculated by weighing the contribution of each subtype.

c. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 59: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone- Fan Power Budget

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

a. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 60: Percent of Floorspace Impacted by Proposed Measure, by Building Type- Fan Energy Index

Building Type **Building sub-type**	**Composition of Building Type by Subtypes**[a]	**Percent of Square Footage Impacted**[b]	
		New Construction	**Existing Building Stock (Alterations)**[c]
Small Office	N/A	0%	0%
Restaurant	N/A	0%	0%
Retail	N/A	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	N/A	0%	0%
Non-Refrigerated Warehouse	N/A	0%	0%
Refrigerated Warehouse	N/A	0%	0%
Schools	N/A	0%	0%
Small School	60%	0%	0%
Large School	40%	0%	0%
College	N/A	0%	0%
Small Office	5%	0%	0%
Medium Office	15%	0%	0%
Medium Office/Lab	20%	0%	0%
Public Assembly	5%	N/A	N/A
Large School	30%	0%	0%
High-Rise Apartment	25%	0%	0%
Hospital	N/A	N/A	N/A
Hotel/Motel	N/A	0%	0%
Offices	N/A	0%	0%
Medium Office	50%	0%	0%
Large Office	50%	100%	5%

a. Presents the assumed composition of the main building type category by the building subtypes. All 2022 CASE Reports assumed the same percentages of building subtypes.

b. When the building type is composed of multiple subtypes, the overall percentage for the main building category was calculated by weighing the contribution of each subtype.

c. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 61: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone- Fan Power Budget

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

a. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 62: Percent of Floorspace Impacted by Proposed Measure, by Building Type – Duct Leakage

Building Type Building sub-type	Composition of Building Type by Subtypes[a]	Percent of Square Footage Impacted[b]	
		New Construction	Existing Building Stock (Alterations)[c]
Small Office	N/A	0%	0%
Restaurant	N/A	0%	0%
Retail	100%	25%	0.8%
Stand-Alone Retail	10%	100%	3.3%
Large Retail	75%	0%	0%
Strip Mall	5%	100%	3.3%
Mixed-Use Retail	10%	100%	3.3%
Food	N/A	0%	0%
Non-Refrigerated Warehouse	N/A	0%	0%
Refrigerated Warehouse	N/A	0%	0%
Schools	100%	100%	3.3%
Small School	60%	100%	3.3%
Large School	40%	100%	3.3%
College	100%	95%	2.3%
Small Office	5%	0%	0%
Medium Office	15%	100%	3.3%
Medium Office/Lab	20%	100%	3.3%
Public Assembly	5%	N/A	N/A
Large School	30%	100%	3.3%
High-Rise Apartment	25%	0%	0%
Hospital	N/A	N/A	N/A
Hotel/Motel	N/A	100%	3.3%
Offices	100%		
Medium Office	50%	100%	3.3%
Large Office	50%	100%	3.3%

a. Presents the assumed composition of the main building type category by the building subtypes. All 2022 CASE Reports assumed the same percentages of building subtypes.

b. When the building type is composed of multiple subtypes, the overall percentage for the main building category was calculated by weighing the contribution of each subtype.

c. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 63: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone – Duct Leakage

Climate Zone	Percent of Square Footage Impacted	
	New Construction	Existing Building Stock (Alterations)[a]
1	100%	3.3%
2	100%	3.3%
3	100%	3.3%
4	100%	3.3%
5	100%	3.3%
6	100%	3.3%
7	100%	3.3%
8	100%	3.3%
9	100%	3.3%
10	100%	3.3%
11	100%	3.3%
12	100%	3.3%
13	100%	3.3%
14	100%	3.3%
15	100%	3.3%
16	100%	3.3%

a. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Appendix B: Embedded Electricity in Water Methodology

There are no on-site water savings associated with the proposed code change.

Appendix C: Environmental Impacts Methodology

Greenhouse Gas (GHG) Emissions Factors

As directed by Energy Commission staff, GHG emissions were calculated making use of the average emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion (United States Environmental Protection Agency 2018). This ensures consistency between state and federal estimations of potential environmental impacts. The electricity emissions factor calculated from the eGRID data is 240.4 metric tons CO2e per GWh. The Summary Table from eGrid 2016 reports an average emission rate of 529.9 pounds CO_2e/MWh for the WECC CAMX subregion. This value was converted to metric tons CO_2e/GWh.

Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in Chapter 1.4 of the U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (United States Environmental Protection Agency 1995). The U.S. EPA's estimates of GHG pollutants that are emitted during combustion of one million standard cubic feet of natural gas are: 120,000 pounds of CO_2 (Carbon Dioxide), 0.64 pounds of N_2O (Nitrous Oxide) and 2.3 pounds of CH_4 (Methane). The emission value for N_2O assumed that low NOx burners are used in accordance with California air pollution control requirements. The carbon equivalent values of N_2O and CH_4 were calculated by multiplying by the global warming potentials (GWP) that the California Air Resources Board used for the 2000-2016 GHG emission inventory, which are consistent with the 100-year GWPs that the Intergovernmental Panel on Climate Change used in the fourth assessment report (AR4). The GWP for N_2O and CH_4 are 298 and 25, respectively. Using a nominal value of 1,000 Btu per standard cubic foot of natural gas, the carbon equivalent emission factor for natural gas consumption is 5,454.4 metric tons CO2e per million therms.

GHG Emissions Monetization Methodology

The 2022 TDV energy cost factors used in the lifecycle cost-effectiveness analysis include the monetary value of avoided GHG emissions based on a proxy for permit costs (not social costs). To demonstrate the cost savings of avoided GHG emissions, the Statewide CASE Team disaggregated the value of avoided GHG emissions from the other economic impacts. The authors used the same monetary values that are used in the TDV factors – $106.20/metric tons per CO2e.

Water Use and Water Quality Impacts Methodology

There are no impacts to water quality or water use.

Appendix D: California Building Energy Code Compliance (CBECC) Software Specification

Appendix D1: Fan Power Budget

Technical Basis for Software Change

Many designers already design very efficient air distribution systems that exceed the efficiency requirements of the 2019 fan power limitations as addressed in Section 3.2.1. The current Standard Design calculates the fan power based on total static pressure (5.362 in. wg for VAV system and 3.877 in. wg for CAV system), 65% fan efficiency, and motor efficiency. The new prescriptive criteria for fan power budget established in Section 4.1.1 specifies new total static pressure, and outlines other key variables needed to simulate the performance of these systems in energy modeling software.

Description of Software Change

Background Information for Software Change

This section describes how the design minimum outdoor airflow rate can be implemented in CBECC-Com for fan power budget.

Existing CBECC-Com Modeling Capabilities

CBECC-Com currently models the Standard Design fan power based on total static pressure (5.362 in. wg for VAV system and 3.877 in. wg for CAV system), 65% fan efficiency, and motor efficiency.

Summary of Proposed Revisions to CBECC-Com

The proposed change is described in Section 4.1 including primary building types, space types, climate zones, or systems that are predominantly affected by the measure. CBECC-Com would need to be modified to adjust the Standard Design fan power.

User Inputs to CBECC-Com

No changes to user inputs are needed to support this measure.

Simulation Engine Inputs

EnergyPlus/California Simulation Engine Inputs

Table 64 summarizes the relevant EnergyPlus input variable and corresponding variable name in CBECC-Com. In EnergyPlus, this variable is located in the BaseVAVBox TrmlUnit object (Figure 11).

Table 64: EnergyPlus Input Variables Relevant to Fan power budget

Target EnergyPlus Class = FAN:VARIABLEVOLUME			
EnergyPlus Field	**CBECC-Com user input/specified value (if applicable)**	**Units**	**Notes**
Name	**Name**		
Fan Total Efficiency	Total Efficiency	None	
Pressure Rise	Total Static Pressure	Pa/inH2O	
Motor Efficiency	Motor Efficiency	None	
N/A	Transmission Efficiency	None	New Variable

```
!-   ===========  ALL OBJECTS IN CLASS: FAN:VARIABLEVOLUME ===========

Fan:VariableVolume,
    BaseSys6 Fan,            !- Name
    OfficeHVACAvail,         !- Availability Schedule Name
    0.61165,                 !- Fan Total Efficiency
    1385,                    !- Pressure Rise {Pa}
    autosize,                !- Maximum Flow Rate {m3/s}
    Fraction,                !- Fan Power Minimum Flow Rate Input Method
    0.2,                     !- Fan Power Minimum Flow Fraction
    ,                        !- Fan Power Minimum Air Flow Rate {m3/s}
    0.941,                   !- Motor Efficiency
    1.0,                     !- Motor In Airstream Fraction
    0.04076,                 !- Fan Power Coefficient 1
    0.088045,                !- Fan Power Coefficient 2
    -0.072926,               !- Fan Power Coefficient 3
    0.94374,                 !- Fan Power Coefficient 4
    0.0,                     !- Fan Power Coefficient 5
    BaseSys6 CoilHtg Air Outlet Node,  !- Air Inlet Node Name
    BaseSys6 Fan Outlet Node;!- Air Outlet Node Name
```

Figure 11: EnergyPlus object BaseSys6 Fan

Simulation Engine Output Variables

CBECC-Com generates hourly EnergyPlus simulation results to CSV files during analysis. These hourly simulation results can be used by the analyst to debug a building energy model. Variables of particular interest in this case would include:

- Fan Electric Power,hourly; !- HVAC Average [W]
- Fan Rise in Air Temperature,hourly; !- HVAC Average [deltaC]
- Fan Heat Gain to Air,hourly; !- HVAC Average [W]
- Fan Electric Energy,hourly; !- HVAC Sum [J]
- Fan Air Mass Flow Rate,hourly; !- HVAC Average [kg/s]
- Fan Unbalanced Air Mass Flow Rate,hourly; !- HVAC Average [kg/s]
- Fan Balanced Air Mass Flow Rate,hourly; !- HVAC Average [kg/s]
- Fan Runtime Fraction,hourly; !- HVAC Average []

The existing algorithms for calculations, fixed values and limitations are sufficient for the proposed measure. No changes are needed.

Compliance Report

No change needs to be made for the compliance report for this CASE measure.

Compliance Verification

The existing compliance reports are sufficient for the proposed measure. No changes are needed.

Testing and Confirming CBECC-Com Modeling

The existing testing and confirmation process are sufficient for the proposed measure. No changes are needed.

Description of Changes to ACM Reference Manual

This information is available in Section 7.4.

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. Section 3.1 identifies the market actors who would play a role in complying with the proposed change, the tasks for which they would 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. The information contained in Section 3.2 is a summary of key feedback the Statewide CASE Team received when speaking to market actors about the compliance implications of the proposed code changes. Appendix F summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the code change proposal, including gathering information on the compliance process.

Table 65: 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
Testing technician	Duct Leakage: Conduct field testing	Duct Leakage: Easily identify duct leakage requirements, be aware of testing procedures	Duct Leakage: Would need to be aware of new test section selection protocols and coordinate with the project team	Training and outreach
Technician Certification Provider	Duct Leakage: Train Acceptance Test Technicians on section selection	Duct Leakage: Communicate testing procedures easily.	Duct Leakage: Train testing technicians on new requirements and selection protocol	Duct Leakage: Align testing procedures with existing ones, write simplified code language
HVAC Designers	• FEI: Designers must select in-scope fans at a duty points ≥ 1.0 FEI • Fan Power Budget: Design ductwork and select equipment that meets allowed electrical input power according to fan power budget.	• FEI: Show FEI values are ≥ 1.0 for in-scope fans • Fan Power Budget: Easily identify applicable fan power budget requirement and whether fan systems are in scope.	• FEI: Use new metric "FEI" to select fans, include manufacture provided FEI value on mechanical schedule. • Fan Power Budget: Similar to existing fan power limitations, but nature of code means there would be more "fan systems", therefore more calculations.	• FEI: On mandatory measure note block designers would note where FEI values are located (e.g., what page of plan sets) • Fan Power Budget: A look-up table approach was created Statewide CASE to allow determination of fan power budget.

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
Manufacturer	• FEI: Provide FEI value in software, catalogs, etc. • Fan Power Budget: Not required, but there would be market pressure to provide electrical input power at duty point, for more accurate/ less conservative input power ratings. • Duct Leakage: Create equipment with low leakage	FEI: Provide accurate and easy to find FEI values at flows and pressures provided by designers. • Fan Power Budget: Provide electrical input power at duty point (instead of traditional BHP)	• FEI: Need to ensure in-scope fans are rated per AMCA 208 and FEI values are easily accessible. • While not required as there are other methods to determine electrical input power, there would be a strong incentive to provide electrical input power at design conditions.	• FEI: Outreach in CASE process to ensure manufacturers would provide FEI results. • Fan Power Budget: Outreach in CASE process to assess feasibility

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
HVAC Contractor	• FEI: Install equipment as identified on the NRCC-MCH-E, if substitutions are made, as is common, designer should ask contractor for FEI output during submittal process. • Fan Power Budget: Install equipment as identified on the NRCC-MCH-E form. • Duct leakage: comply with Seal Class A, identify testing schedule and sections	• FEI: Ensuring proper fans are installed at compliant duty points. • Fan Power Budget: Ensure specified equipment is installed according to plans	• FEI: During substitutions, contractor would need to generate cutsheet from manufacturer software showing FEI. • Fan Power Budget: No different than workflow for current fan power limitations • Duct leakage: coordinate CMC testing with construction schedule	All submeasures would require training and outreach
Inspector	All submeasures need to ensure all equipment installed matches equipment on NRCI	• FEI/Fan Power Budget: Easily identify equipment that was documented as installed • Inspect duct leakage testing	• FEI: Verify NRCI matches installed equipment for FEI • Fan Power Budget: No different than for existing fan power limitations. • Duct leakage: verifying leakage testing was carried out in accordance with Section 120.5 and NA7	All submeasures would require training and outreach

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
Plans Examiner	• FEI/Fan Power Budget: Ensure design meets requirements as identified on the NRCC-MCH-E forms. • Duct leakage: Ensure Seal Class A is called out	FEI/Fan Power Budget: Easily identify equipment specs on NRCC-MCH-E forms, and	• FEI: Verify in-scope fans have an FEI rating denoted on the plan sets • Fan Power Budget: Verify fan power budget is applied to each fan system in scope, and it is met.	• FEI: Training and outreach, ensuring it is known that cut sheets can easily be requested for a fan subject to FEI from designer or energy consultant. • Fan Power Budget: Build calculations into software and dynamic forms
Energy Consultant	FEI/Fan Power Budget: create energy model and advise on efficient fan power selection if necessary	FEI/Fan Power Budget: Quickly identify fan power and FEI requirements	FEI/Fan Power Budget: Ensure fans comply with FEI and new fan power requirements.	FEI/Fan Power Budget: Build fan power budget calcs into model and dynamic forms, outreach and training

Appendix F: Summary of Stakeholder Engagement

Collaborating with stakeholders that might be impacted by proposed changes is a critical aspect of the Statewide CASE Team's efforts. The Statewide CASE Team aims to work with interested parties to identify and address issues associated with the proposed code changes so that the proposals presented to the Energy Commission in this Final CASE Report are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including cost effectiveness; market barriers; technical barriers; compliance and enforcement challenges; or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

This appendix summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the recommendations presented in this report.

Utility-Sponsored Stakeholder Meetings

Utility-sponsored stakeholder meetings provide an opportunity to learn about the Statewide CASE Team's role in the advocacy effort and to hear about specific code change proposals that the Statewide CASE Team is pursuing for the 2022 code cycle. The goal of stakeholder meetings is to solicit input on proposals from stakeholders early enough to ensure the proposals and the supporting analyses are vetted and have as few outstanding issues as possible. To provide transparency in what the Statewide CASE Team is considering for code change proposals, during these meetings the Statewide CASE Team asks for feedback on:

- Proposed code changes
- Draft code language
- Draft assumptions and results for analyses
- Data to support assumptions
- Compliance and enforcement, and
- Technical and market feasibility

The Statewide CASE Team hosted two stakeholder meetings for Air Distribution via webinar. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting. Such as slide presentations, proposal summaries with code language, and meeting notes, are included in the bibliography section of this report (Statewide CASE Team 2019) (Statewide CASE Team 2020).

Meeting Name	Meeting Date	Event Page from Title24stakeholders.com
First Round of Non-residential HVAC and Enveloped Part 2- Utility-Sponsored Stakeholder Meeting	Tuesday, November 5, 2019	https://title24stakeholders.com/event/nonresidential-hvac-air-distribution-controls-reduced-infiltration-utility-sponsored-stakeholder-meeting/
Second Round of Nonresidential and Single-Family HVAC Part 1- Utility-Sponsored Stakeholder Meeting	Thursday, March 12, 2020	https://title24stakeholders.com/event/nonresidential-and-single-family-hvac-part-1-data-centers-boilers-air-distribution-variable-capacity/

The first round of utility-sponsored stakeholder meetings occurred from September to November 2019 and were important for providing transparency and an early forum for stakeholders to offer feedback on measures being pursued by the Statewide CASE Team. The objectives of the first round of stakeholder meetings were to solicit input on the scope of the 2022 code cycle proposals; request data and feedback on the specific approaches, assumptions, and methodologies for the energy impacts and cost-effectiveness analyses; and understand potential technical and market barriers. The Statewide CASE Team also presented initial draft code language for stakeholders to review.

The second round of utility-sponsored stakeholder meetings occurred from March to May 2020 and provided updated details on proposed code changes. The second round of meetings introduced early results of energy, cost-effectiveness, and incremental cost analyses, and solicited feedback on refined draft code language.

Utility-sponsored stakeholder meetings were open to the public. For each stakeholder meeting, two promotional emails were distributed from info@title24stakeholders.com One email was sent to the entire Title 24 Stakeholders listserv, totaling over 1,900 individuals, and a second email was sent to a targeted list of individuals on the listserv depending on their subscription preferences. The Title 24 Stakeholders' website listserv is an opt-in service and includes individuals from a wide variety of industries and trades, including manufacturers, advocacy groups, local government, and building and energy professionals. Each meeting was posted on the Title 24 Stakeholders' LinkedIn page[22] (and cross-promoted on the Energy Commission LinkedIn page) two weeks before each meeting to reach out to individuals and larger organizations and channels outside of the listserv. The Statewide CASE Team conducted extensive personal outreach to stakeholders identified in initial work plans who had not yet opted in to the listserv. Exported webinar meeting data captured attendance numbers and individual comments,

[22] Title 24 Stakeholders' LinkedIn page can be found here: https://www.linkedin.com/showcase/title-24-stakeholders/.

and recorded outcomes of live attendee polls to evaluate stakeholder participation and support.

Statewide CASE Team Communications

The Statewide CASE Team held personal communications over email and phone with numerous stakeholders when developing this report. The Statewide CASE Team engaged with trade organizations including AMCA, AHRI, California Energy Alliance, and SMACNA, and many of their members which include manufacturers and contractors throughout the development of this CASE Report. The Statewide CASE Team also engaged extensively with ASHRAE committee members who have developed or are developing measures similar to those proposed in this CASE Report. The Statewide CASE Team submitted comments to SMACNA in regard to the draft publication of the System Air Leakage Test Manual.

Conferences and In-Person Meetings

The Statewide CASE Team leveraged other venues to seek feedback on the Air Distribution measures.

- The Statewide CASE Team attended the ASHRAE Winter Meeting in Orlando in February and received feedback on the fan power budget proposal.
- The Statewide CASE Team attended the International Association of Plumbing and Mechanical Officials (IAMPO) 90th Annual Education and Business Conference on September 23-24, 2019 in order to observe the final voting of the 2021 Universal Mechanical and Plumbing Codes and speak with IAPMO attendees about the model codes and the CMC.
- The Statewide CASE Team also had two in person meetings with members of SMACNA (National and California) and the Energy Commission in order to discuss the duct leakage proposal.

Appendix G: FEI Energy Savings Calculation

As described in Section 4.2.1.2, to calculate savings from the proposed FEI requirement from one floor of the CBECC-Com large office prototype the default single fan system (e.g., supply fan) in the Standard Design was first converted to a two-fan system with a supply and return fan. The total power demand remained the same at 30.1 kW at design conditions. In this modified Standard Design, the supply fan has a fan efficiency of 66 percent yielding an FEI of 1.23, while the return fan has a fan efficiency of 37 percent yielding an FEI of 0.88. Energy savings could then be calculated by increasing the fan efficiency of the return fan in the Proposed Design until an FEI of 1.0 was achieved. The supply fan efficiency remained constant.

As described in Section 2.2.2, FEI is a ratio of the electrical input power of a given fan at the duty point (pressure and flow), as compared to a reference fan at the same duty point, as calculated per the AMCA 208 rating method (AMCA 2018). Dividing the reference fan electrical input power (FEPref) by the actual fan electrical input power (FEPact) yields the FEI ratio. The lower the FEPact, the higher the FEI at a given duty point.

As shown in Table 66 below, by increasing the efficiency of the return fan in the proposed design to an FEI =1.0, the power demand at design conditions decreases from 30.1 kW to 28.9 kW, saving 1.2 kW for one floor of the Large Office. The Large Office has 13 floors, which each have slightly different airflows, thus this analysis was replicated to capture energy savings for the entire building.

Table 66: FEI Energy Savings Calculation

	Standard Design			Proposed Design	
	Single-fan System (CBECC-Default)	Two-fan system (same power demand) with non-FEI compliant return fan		Two-fan system with FEI compliant return fan	
Fan Configuration	Supply Only	Supply	Return	Supply	Return
Airflow (CFM)	28,000	28,000	28,000	28,000	28,000
Total Static Pressure (in. wg)	5.35	3.60	1.00	3.60	1.00
Fan Efficiency (Static)	65%	66%	37%	66%	43%
Brake Horsepower (BHP)	36.4	24.1	11.9	24.1	10.4
Motor efficiency [a]	94.1%	93.6%	92.4%	93.6%	92.4%
Transmission efficiency [b]	95.7%	95.6%	95.2%	95.6%	95.1%
Fan Electrical Power (FEPactual) (kW)	30.1	20.1	10.1	20.1	8.8
Fan System Electrical Power (kW)	30.1		30.1		28.9
Reference Fan Electrical Power (FEPref) (kW)	35.3	24.7	8.8	24.7	8.8
FEI [c]	1.17	1.23	0.88	1.23	1.00

a. Motor efficiency values are defaults from CBECC-Com, varying by motor size

b. Transmission efficiency calculated per AMCA 208 (AMCA 2018)

c. FEI is calculated by divide FEPref by FEPact

Appendix H: Duct Costing Details

The Statewide CASE team conducted incremental cost analysis for ductwork for the fan power budget submeasure using the Large Office prototype building. Assumptions for the large office building (in Los Angeles Climate Zone 9) and the ductwork layouts for the Standard and Proposed Designs are below.

Table 67: Large Office Layout Assumptions

Type	Area (ft^2)
Overall square footage	38,400
Usable Square Footage	31,200
Conference Room Square Footage	5,100
Open Office Square Footage	26,100

Table 68: Occupancy, Ventilation, Heat gain and Infiltration Assumptions

	Occupancy			Ventilation Rate		Equipment	Lighting	Infiltration
Space Type	ft^2/ person	Sensible [btuh]	Latent [btuh]	CFM/ ft2	CFM/ person	[W/ person]	[W/ ft^2]	[cfm/ ft^2 wall]
Conference Room	20	250	200	0	15	15	.65	.06
Open Office	200	250	200	.15	0	150	.65	.06
Core	0	0	0	0	0	0	0	0

Table 69: Envelope Assumptions

Opaque envelope[a]		
Type	**Title 24 2019 U-value [Btu/h-ft^2-°F]**	
Opaque Exterior Wall	0.061	
GLAZED ENVELOPE		
	Title 24 2019 U-value	
Type	**U-Value [Btu/h-ft^2-°F]**	**SHGC**
Vertical Glazing	0.36	0.25

a. Note window to wall ratio assumed to be 40%

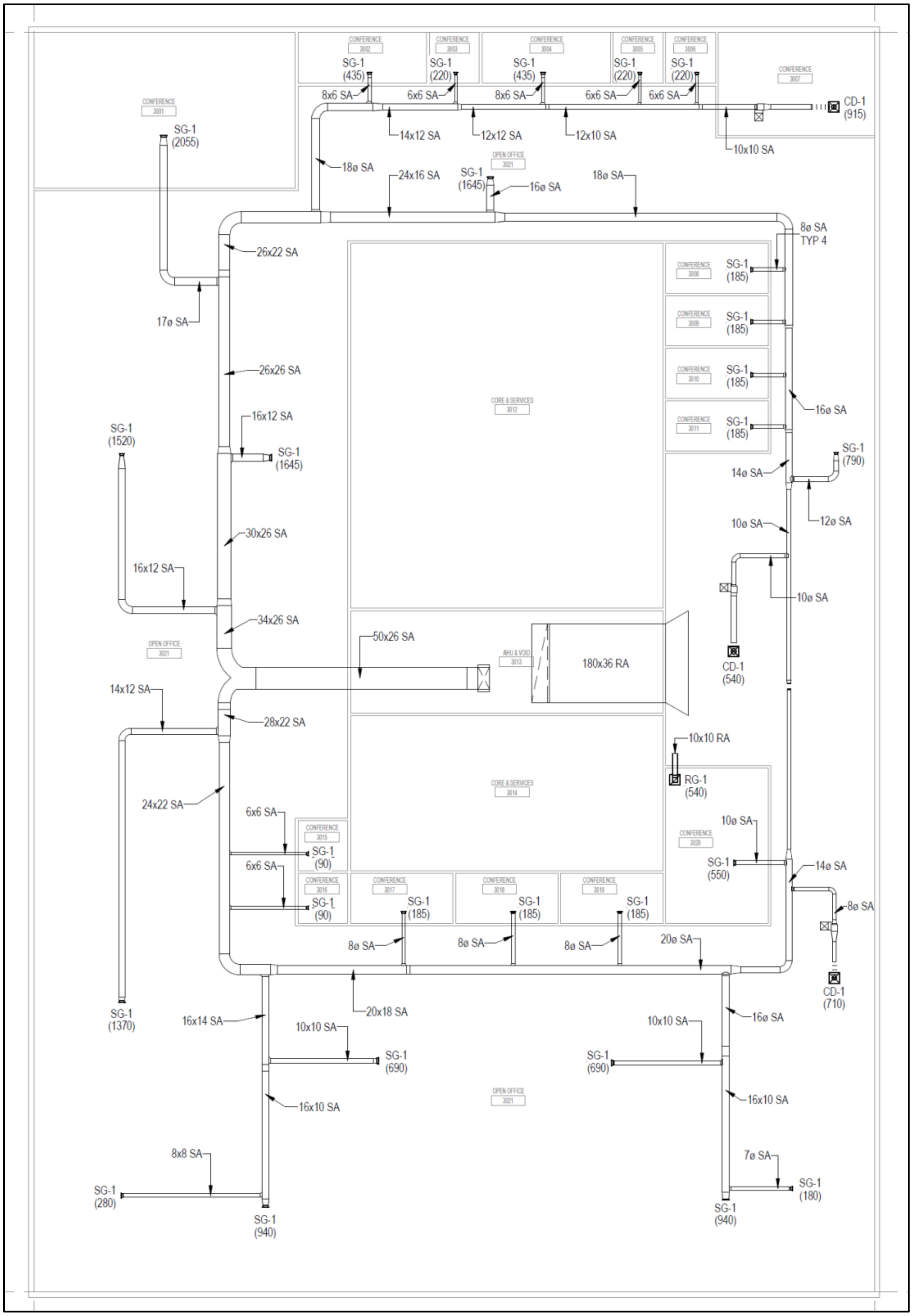

Figure 12: Large Office VAV Proposed Design.

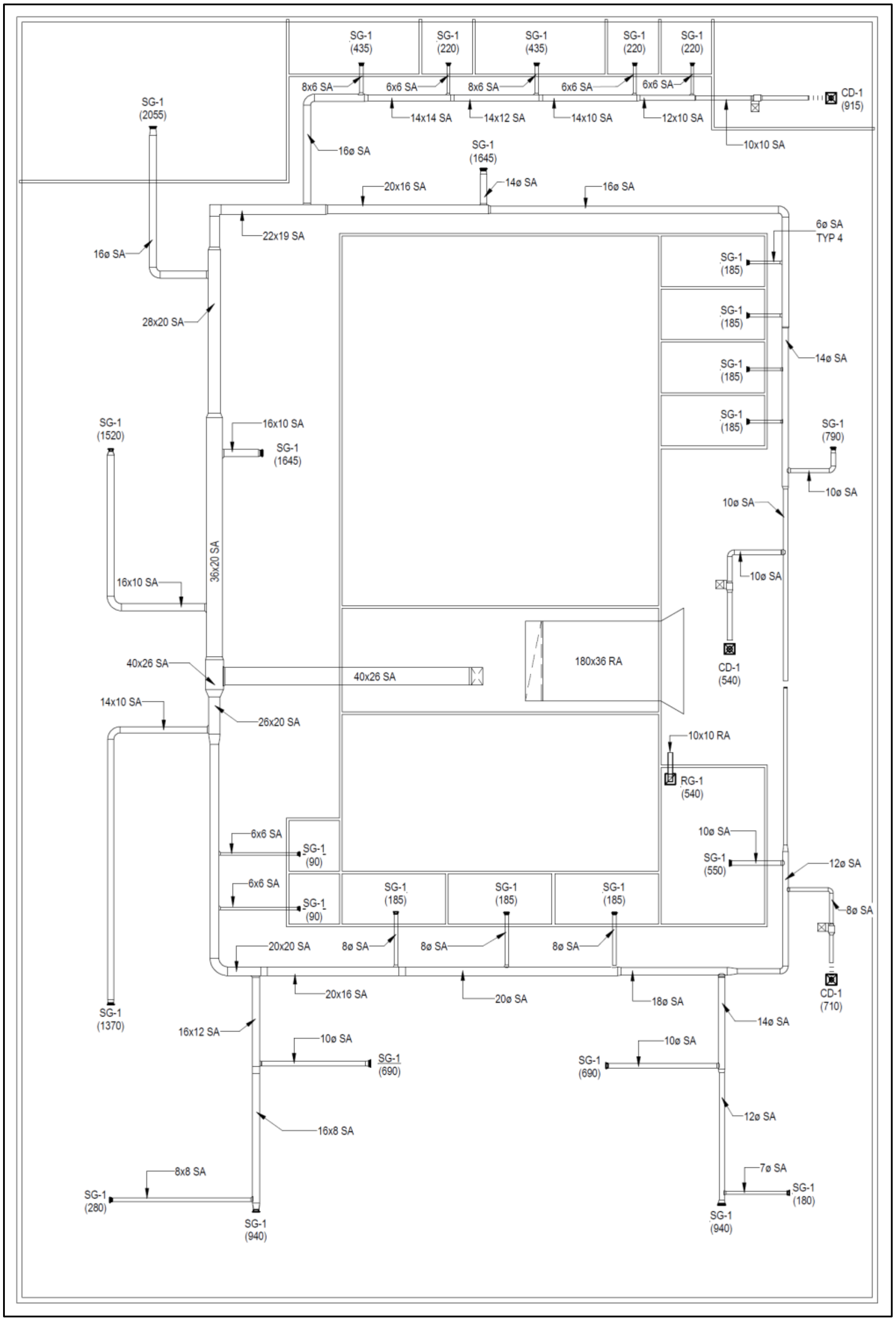

Figure 13: Large Office VAV Standard Design.

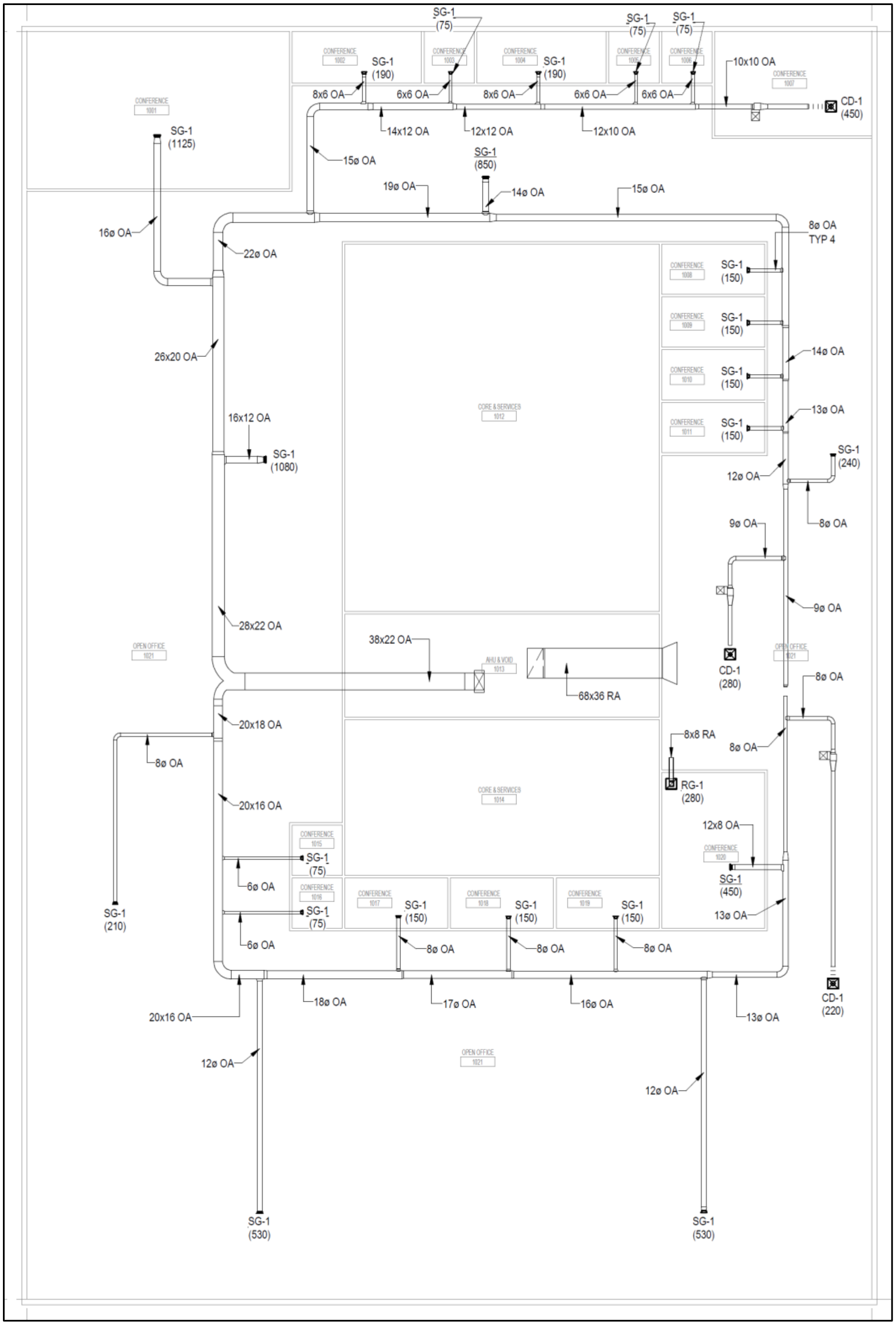

Figure 14: Large Office CAV Proposed Design.

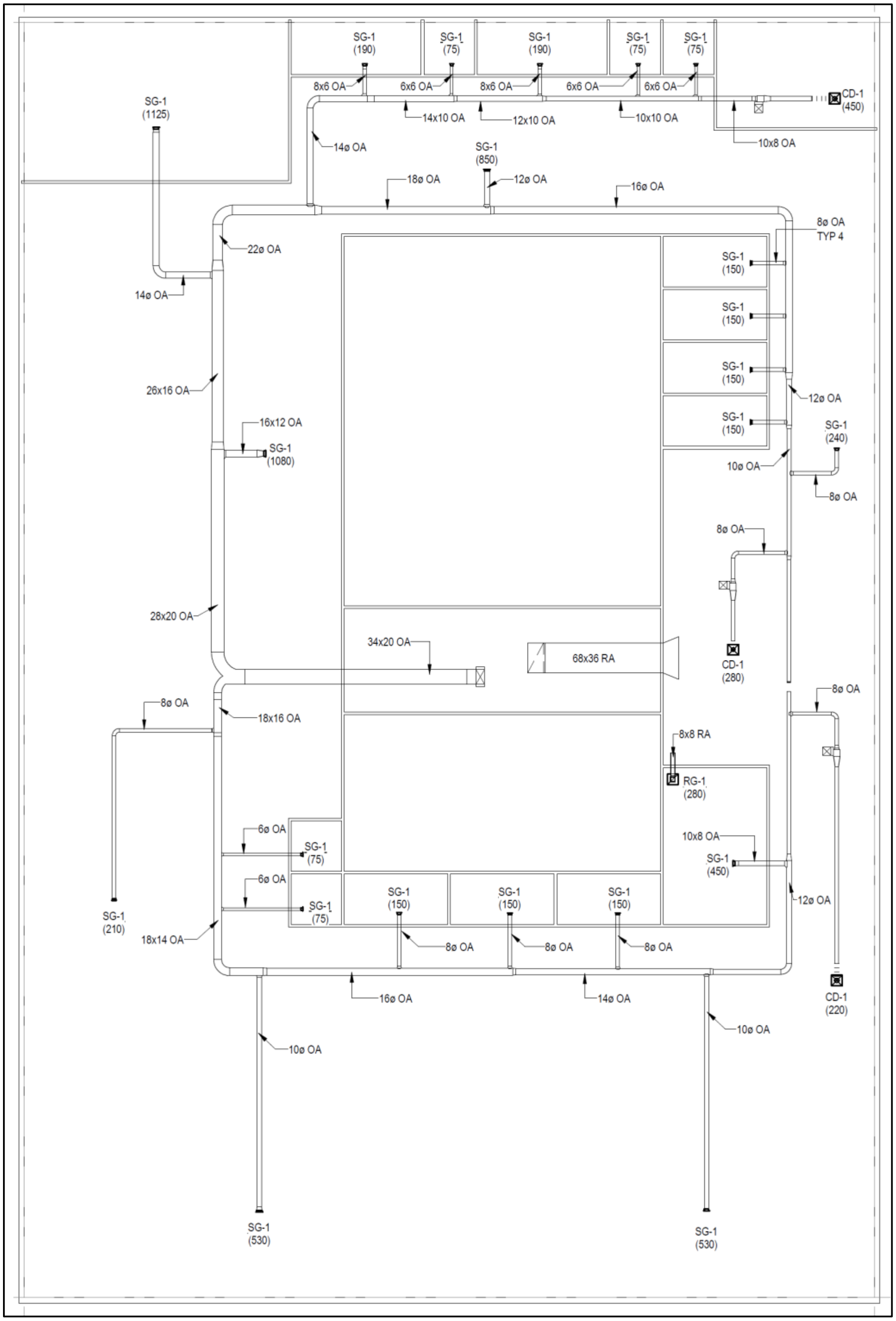

Figure 15: Large Office CAV Proposed Design.

Appendix I: Duct Leakage Calculation

The Statewide CASE Team calculated the duct leakage and leakage from the VAV boxes for the OfficeLarge building prototype using the VAV Proposed Design layout (see Figure 12 for the layout) as shown for the fan power budget submeasure. The leakage rate per ft^2 of surface area was calculated for the critical path and then extrapolated for the entire floor. See Table 70 for the calculation for the duct leakage of the critical path. Note that the individual transition components are omitted (for calculation purposes) because while the pressure drops are included there is no associated surface area because there is no duct length, and duct leakage is calculated as a function of duct length. See Section 4.2.1.3 for the calculation methodology.

Table 70: Duct Leakage Calculation for Critical Path of OfficeLarge

Section	Duct Shape / Component	Type	Total Section Pressure Loss (in. wg)	Surface Area (ft^2)	Duct pressure (in. wg)	Permitted Leakage Seal Class B (cfm)	Permitted Leakage Seal Class A (cfm)
1	Entry Ductwork	Entry	0.375	N/A	1.88	N/A	N/A
3	Rectangular	Straight	0.001	13.7	1.85	1.6	0.8
5	Rectangular	Straight	0.045	507.7	1.76	58.7	29.3
7	Rectangular	Straight	0.009	73.4	1.61	8.0	4.0
9	Rectangular	Straight	0.001	8.8	1.59	0.9	0.5
11	Rectangular	Straight	0.033	250.6	1.55	26.7	13.3
13	Rectangular	Straight	0.001	7.8	1.53	0.8	0.4
15	Rectangular	Straight	0.039	273.0	1.49	28.3	14.1
17	Rectangular	Straight	0.001	8.1	1.47	0.8	0.4
19	Rectangular	Straight	0.007	54.2	1.46	5.6	2.8
21	Rectangular	Straight	0.015	113.4	1.42	11.4	5.7
23	Rectangular	Straight	0	7.9	1.41	0.8	0.4
25	Rectangular	Straight	0.034	202.4	1.37	19.9	9.9
27	Rectangular	Straight	0	6.1	1.36	0.6	0.3
29	Round	Straight	0.052	246.6	1.31	11.7	5.9
31	Round	Straight	0.008	40.5	1.29	1.9	1.0
33	Round	Straight	0.008	50.4	1.27	2.4	1.2
35	Round	Straight	0	6.2	1.26	0.3	0.1
37	Round	Straight	0.012	41.5	1.24	1.9	1.0
39	Round	Straight	0.001	5.4	1.22	0.2	0.1
41	Round	Straight	0.009	40.1	1.21	1.8	0.9

Section	Duct Shape / Component	Type	Total Section Pressure Loss (in. wg)	Surface Area (ft^2)	Duct pressure (in. wg)	Permitted Leakage Seal Class B (cfm)	Permitted Leakage Seal Class A (cfm)
43	Round	Straight	0	5.2	1.20	0.2	0.1
45	Round	Straight	0.014	35.4	1.19	1.6	0.8
47	Round	Straight	0	4.8	1.15	0.2	0.1
49	Round	Straight	0.019	34.1	1.13	1.5	0.7
51	Round	Straight	0.013	23.3	1.09	1.0	0.5
53	Round	Straight	0.006	12.2	1.08	0.5	0.3
56	Round	Straight	0.006	29.4	1.07	1.2	0.6
Total	**-**	**-**	**1.16**	**2102**		**191**	**95.3**

The leakage of each VAV boxes was also calculated (see Table 72) and then added as a constant leakage to the duct leakage calculated in Table 73. The leakage for each VAV box was determined by summing the maximum allowed casing and relevant appurtenance leakages (dependent on whether or not there was terminal heating). Table 71 was used as a resource for the VAV box leakage.

Table 71: Single Duct Air Terminal Unit Leakage from Proposed Addendum to ASHRAE 90.1 – 2010 (Sipes 2011)

Inlet Size	AHRI Nominal Rating (CFM	Casing Max Leakage (CFM)	Max Appurtenance Leakage (CFM)	Water Coil Max. Leakage Per Additional Row (CFM)
4”	150	4	2	2
5”	250	4	2	2
6”	400	4	2	2
7”	550	7	3	2
8”	700	7	3	2
9”	900	11	4	6
10”	1100	11	4	6
12”	1600	16	8	12
14”	2100	21	10	15
16”	2800	28	12	18
16”x24”	5350	53	15	21

The table above was used to calculate the leakage of each VAV box on the floor in Table 72.

Table 72: VAV box leakage for OfficeLarge.

Zone	VAVs Per Zone	Airflow Per VAV (CFM)	Total Zone Airflow (CFM)	AHRI Nominal Rating (CFM)	Total Leakage (CFM)
Conference 1001	2	1030	2060	1100	42
Conference 1002	1	435	435	550	12
Conference 1003	1	220	220	250	8
Conference 1004	1	435	435	550	12
Conference 1005	1	220	220	250	8
Conference 1006	1	220	220	250	8
Conference 1007	1	915	915	1100	21
Conference 1009	1	185	185	250	6
Conference 1010	1	185	185	250	6
Conference 1011	1	185	185	250	6
Conference 1012	1	185	185	250	6
Conference 1015	1	90	90	150	6
Conference 1016	1	90	90	150	6
Conference 1017	1	185	185	250	6
Conference 1018	1	185	185	250	6
Conference 1019	1	185	185	250	6
Conference 1020	1	550	550	700	10
Open Office 1021	2	690	1380	700	20
Open Office 1022	1	1645	1645	2100	31
Open Office 1023	1	540	540	550	10
Open Office 1024	1	1645	1645	2100	31
Office Perimeter 1025	2	940	1880	1100	42
Office Perimeter 1026 (West)	1	1520	1520	1600	36
Office Perimeter 1026 (East)	1	1370	1370	1600	36
Office Perimeter 1027 (West)	1	790	790	900	21
Office Perimeter 1027 (East)	1	710	710	900	21
Southeast Corner	1	280	280	400	8
Northeast Corner	1	180	180	250	8
Total	**31**	**-**	**-**	**-**	**439**

The duct leakage (cfm/ft_2 of duct surface area) for the critical path was adjusted used the field testing data provide by NEMI for Seal Class B and Seal Class A (see Table 21) and the VAV box leakage was added to get the percent leakages in Table 73. This percent leakage was applied for the ductwork upstream and downstream of the VAV boxes.

Table 73: OfficeLarge Duct Leakage Calculation

	Baseline Leakage	Proposed Leakage
Duct Leakage Rate using Table 21 (cfm/ft2)	0.09	0.05
Duct leakage rate adjusted with field testing from NEMI (cfm/ft2)	0.14	0.02
Total Duct Area (ft2)	5,962	5,962
Total Fitting Area (ft2)	551	551
Total Duct System Area (ft2)	6,513	6,513
Total SA (CFM)	18,375	18,375
Duct Leakage Rate (%)	4.97%	0.60%
VAV Leakage (cfm)	439.00	439.00
Leakage Upstream and Downstream of VAV boxes (%)	7.4%	3.0%

Appendix J: Supplemental Energy Savings Impacts Tables

First-year energy savings impacts are shown below, separately each submeasure. Only large office examples are shown in the main body of the report. All other building types are shown here.

Fan Power Budget

See below for Fan Power Budget energy impacts per square foot.

Table 74: First-Year Energy Impacts Per Square Foot – HotelSmall

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.031	0.021	(0.001)	0.460
2	0.042	0.051	(0.001)	1.109
3	0.040	0.028	(0.001)	0.892
4	0.051	0.047	0.000	1.377
5	0.041	0.032	(0.001)	0.856
6	0.057	0.033	0.000	1.518
7	0.054	0.036	0.000	1.325
8	0.058	0.037	0.000	1.684
9	0.057	0.038	0.000	1.780
10	0.060	0.051	0.000	1.746
11	0.056	0.053	(0.001)	1.446
12	0.050	0.055	(0.001)	1.285
13	0.059	0.060	0.000	1.577
14	0.061	0.050	0.000	1.839
15	0.077	0.060	0.000	2.311
16	0.049	0.048	(0.001)	1.054

Table 75: First-Year Energy Impacts Per Square Foot – OfficeMedium

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.114	0.075	(0.003)	2.289
2	0.163	0.118	(0.002)	4.241
3	0.143	0.094	(0.001)	3.513
4	0.180	0.120	(0.001)	4.849
5	0.147	0.083	(0.002)	3.353
6	0.195	0.092	(0.001)	5.124
7	0.176	0.086	0.000	4.448
8	0.207	0.113	(0.001)	5.868
9	0.209	0.125	(0.001)	6.107
10	0.217	0.133	(0.001)	6.059
11	0.200	0.147	(0.001)	5.310
12	0.186	0.120	(0.001)	4.853
13	0.216	0.131	(0.001)	5.831
14	0.224	0.134	(0.001)	6.579
15	0.267	0.140	0.000	7.466
16	0.179	0.119	(0.002)	3.942

Table 76: First-Year Energy Impacts Per Square Foot – OfficeMediumLab

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.488	0.100	(0.020)	8.613
2	0.556	0.181	(0.014)	12.497
3	0.567	0.134	(0.013)	12.481
4	0.590	0.165	(0.010)	14.755
5	0.553	0.107	(0.013)	12.062
6	0.637	0.145	(0.006)	16.298
7	0.627	0.136	(0.005)	16.146
8	0.639	0.171	(0.006)	16.687
9	0.621	0.215	(0.007)	16.275
10	0.628	0.224	(0.007)	16.149
11	0.614	0.221	(0.010)	16.212
12	0.587	0.227	(0.011)	14.890
13	0.622	0.228	(0.008)	17.399
14	0.627	0.255	(0.010)	17.729
15	0.738	0.148	(0.004)	18.766
16	0.588	0.172	(0.015)	12.524

Table 77: First-Year Energy Impacts Per Square Foot – RetailLarge

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.143	0.004	(0.004)	2.696
2	0.255	0.006	(0.003)	5.369
3	0.176	0.009	(0.002)	6.019
4	0.296	0.017	(0.002)	11.911
5	0.211	0.010	(0.002)	6.668
6	0.387	0.008	(0.001)	8.332
7	0.363	0.020	(0.001)	13.541
8	0.418	0.018	(0.001)	12.466
9	0.367	0.008	(0.001)	10.585
10	0.409	0.019	(0.001)	14.239
11	0.406	0.023	(0.003)	14.627
12	0.357	0.018	(0.002)	12.795
13	0.473	0.021	(0.002)	13.321
14	0.520	0.019	(0.002)	22.179
15	0.781	0.020	(0.001)	20.792
16	0.266	0.010	(0.005)	5.884

Table 78: First-Year Energy Impacts Per Square Foot – RetailMixedUse

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.862	0.186	(0.011)	20.351
2	0.905	0.197	(0.006)	23.490
3	0.917	0.190	(0.003)	24.257
4	0.927	0.197	(0.003)	24.869
5	0.919	0.190	(0.003)	24.210
6	0.972	0.191	(0.000)	26.399
7	0.966	0.189	(0.000)	26.308
8	0.955	(0.014)	(0.001)	25.921
9	0.956	0.202	(0.001)	26.112
10	0.934	0.201	(0.002)	25.282
11	0.927	0.263	(0.006)	26.678
12	0.922	0.198	(0.005)	23.958
13	0.938	0.298	(0.005)	26.624
14	0.964	0.216	(0.005)	25.559
15	1.027	0.292	(0.001)	29.556
16	0.865	0.239	(0.013)	19.531

Table 79: First-Year Energy Impacts Per Square Foot – RetailStandAlone

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.239	0.065	(0.006)	5.008
2	0.355	0.218	(0.004)	9.527
3	0.290	0.159	(0.003)	6.738
4	0.385	0.167	(0.003)	11.298
5	0.287	0.109	(0.003)	6.966
6	0.423	0.142	(0.001)	10.968
7	0.410	0.146	(0.002)	10.729
8	0.496	0.176	(0.002)	15.098
9	0.561	0.308	(0.002)	16.117
10	0.605	0.167	(0.002)	17.833
11	0.277	0.422	(0.002)	9.246
12	0.383	0.158	(0.003)	8.331
13	0.500	0.212	(0.003)	13.228
14	0.483	0.440	(0.003)	13.891
15	0.419	0.160	(0.001)	11.361
16	0.436	0.244	(0.006)	9.873

Table 80: First-Year Energy Impacts Per Square Foot – SchoolPrimary

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.669	0.185	(0.024)	13.020
2	0.779	0.219	(0.014)	19.970
3	0.736	0.296	(0.012)	19.638
4	0.798	0.213	(0.009)	20.053
5	0.736	0.225	(0.011)	17.698
6	0.855	0.239	(0.004)	23.175
7	0.830	0.276	(0.004)	22.979
8	0.866	0.249	(0.004)	22.694
9	0.860	0.236	(0.005)	23.038
10	0.792	0.208	(0.006)	21.284
11	0.884	0.241	(0.012)	22.596
12	0.812	0.231	(0.011)	20.669
13	0.898	0.249	(0.010)	23.513
14	0.930	0.238	(0.010)	24.177
15	0.974	0.247	(0.003)	26.881
16	0.828	0.238	(0.020)	17.343

Table 81: First-Year Energy Impacts Per Square Foot – SchoolSecondary

Climate Zone	Electricity Savings (kWh/ft_2)	Peak Electricity Demand Reductions (W/ft_2)	Natural Gas Savings ($therms/ft_2$)	TDV Energy Savings (TDV $kBtu/ft_2$)
1	0.114	0.055	(0.004)	2.022
2	0.155	0.092	(0.002)	3.660
3	0.145	0.068	(0.002)	3.268
4	0.172	0.088	(0.002)	4.187
5	0.150	0.047	(0.002)	3.319
6	0.177	0.087	(0.001)	4.504
7	0.168	0.078	(0.001)	4.207
8	0.180	0.088	(0.001)	4.809
9	0.182	0.084	(0.001)	4.945
10	0.187	0.086	(0.001)	4.870
11	0.181	0.111	(0.002)	4.299
12	0.169	0.099	(0.002)	4.059
13	0.192	0.120	(0.002)	4.754
14	0.195	0.120	(0.002)	5.228
15	0.232	0.135	(0.001)	6.255
16	0.179	0.104	(0.003)	4.140

Table 82: First-Year Energy Impacts Per Square Foot – Warehouse

Climate Zone	Electricity Savings (kWh/ft_2)	Peak Electricity Demand Reductions (W/ft_2)	Natural Gas Savings ($therms/ft_2$)	TDV Energy Savings (TDV $kBtu/ft_2$)
1	0.005	0.001	(0.000)	0.058
2	0.013	0.002	(0.000)	0.247
3	0.012	0.002	(0.000)	0.301
4	0.018	0.014	(0.000)	0.216
5	0.012	0.002	(0.000)	0.226
6	0.021	0.018	(0.000)	0.494
7	0.016	0.017	(0.000)	0.327
8	0.019	0.020	(0.000)	0.403
9	0.019	0.026	(0.000)	0.669
10	0.021	0.032	(0.000)	0.602
11	0.032	0.062	(0.000)	0.761
12	0.018	0.020	(0.000)	0.433
13	0.037	0.027	(0.000)	0.712
14	0.049	0.023	(0.000)	1.348
15	0.061	0.026	(0.000)	1.621
16	0.020	0.003	(0.000)	0.376

Duct Leakage

See below for Duct Leakage energy impacts per square foot.

Table 83: First-Year Energy Impacts Per Square Foot – OfficeMedium

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (W/ft^2)	Natural Gas Savings ($millitherms/ft^2$)	TDV Energy Savings ($TDV\ kBtu/ft^2$)
1	0.16	0.05	3.00	4.90
2	0.22	0.07	4.57	7.39
3	0.23	0.06	6.20	7.93
4	0.25	0.06	5.88	8.23
5	0.23	0.05	5.74	7.63
6	0.30	0.08	6.65	9.86
7	0.30	0.06	6.89	9.71
8	0.29	0.06	6.78	9.51
9	0.28	0.08	6.30	9.35
10	0.28	0.07	5.77	8.96
11	0.26	0.08	4.46	8.55
12	0.24	0.07	4.95	7.91
13	0.26	0.07	4.64	8.32
14	0.28	0.06	4.52	8.97
15	0.33	0.10	6.16	10.90
16	0.24	0.06	1.75	6.78

Table 84: First-Year Energy Impacts Per Square Foot – OfficeMediumLab

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (W/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.31	0.17	(4.02)	7.59
2	0.45	0.18	(5.39)	14.50
3	0.42	0.85	(11.65)	9.81
4	0.51	0.09	(11.60)	15.38
5	0.43	0.48	(9.72)	9.46
6	0.59	0.65	(15.29)	13.95
7	0.56	0.24	(16.52)	11.92
8	0.61	0.10	(15.12)	15.52
9	0.58	0.09	(14.10)	16.01
10	0.63	0.13	(12.19)	18.12
11	0.63	0.09	(7.74)	16.50
12	0.54	0.11	(8.52)	14.47
13	0.67	0.10	(9.83)	17.27
14	0.68	0.36	(6.06)	21.37
15	1.01	0.27	(15.96)	30.80
16	0.43	0.78	2.16	12.51

Appendix K: Supplemental Energy Cost Savings Tables

Energy cost savings are shown below, separately each submeasure. Only large office examples are shown in the main body of the report. All other building types are shown here.

Fan Power Budget

Table 85: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – HotelSmall

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.07	($0.03)	$0.04
2	$0.11	($0.02)	$0.10
3	$0.09	($0.01)	$0.08
4	$0.13	($0.01)	$0.12
5	$0.09	($0.01)	$0.08
6	$0.14	($0.01)	$0.14
7	$0.12	($0.01)	$0.12
8	$0.16	($0.01)	$0.15
9	$0.17	($0.01)	$0.16
10	$0.16	($0.01)	$0.16
11	$0.14	($0.01)	$0.13
12	$0.13	($0.01)	$0.11
13	$0.15	($0.01)	$0.14
14	$0.18	($0.01)	$0.16
15	$0.21	($0.00)	$0.21
16	$0.11	($0.02)	$0.09

Table 86: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.26	($0.06)	$0.20
2	$0.42	($0.04)	$0.38
3	$0.35	($0.03)	$0.31
4	$0.46	($0.03)	$0.43

5	$0.33	($0.03)	$0.30
6	$0.47	($0.01)	$0.46
7	$0.41	($0.01)	$0.40
8	$0.54	($0.01)	$0.52
9	$0.56	($0.02)	$0.54
10	$0.56	($0.02)	$0.54
11	$0.50	($0.03)	$0.47
12	$0.46	($0.03)	$0.43
13	$0.55	($0.03)	$0.52
14	$0.61	($0.03)	$0.59
15	$0.67	($0.01)	$0.66
16	$0.40	($0.05)	$0.35

Table 87: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – OfficeMediumLab

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$1.20	($0.43)	$0.77
2	$1.42	($0.31)	$1.11
3	$1.40	($0.29)	$1.11
4	$1.53	($0.22)	$1.31
5	$1.36	($0.29)	$1.07
6	$1.58	($0.13)	$1.45
7	$1.55	($0.11)	$1.44
8	$1.62	($0.13)	$1.49
9	$1.61	($0.16)	$1.45
10	$1.61	($0.17)	$1.44
11	$1.67	($0.22)	$1.44
12	$1.57	($0.24)	$1.33
13	$1.75	($0.20)	$1.55
14	$1.80	($0.23)	$1.58
15	$1.76	($0.09)	$1.67
16	$1.45	($0.34)	$1.11

Table 88: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – RetailLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.34	($0.10)	$0.24
2	$0.54	($0.06)	$0.48

3	$0.59	($0.05)	$0.54
4	$1.10	($0.04)	$1.06
5	$0.64	($0.04)	$0.59
6	$0.77	($0.03)	$0.74
7	$1.23	($0.02)	$1.21
8	$1.13	($0.02)	$1.11
9	$0.97	($0.03)	$0.94
10	$1.30	($0.03)	$1.27
11	$1.37	($0.06)	$1.30
12	$1.19	($0.06)	$1.14
13	$1.24	($0.05)	$1.19
14	$2.03	($0.05)	$1.97
15	$1.87	($0.02)	$1.85
16	$0.65	($0.13)	$0.52

Table 89: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – RetailMixedUse

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$2.06	($0.25)	$1.81
2	$2.23	($0.14)	$2.09
3	$2.24	($0.08)	$2.16
4	$2.28	($0.07)	$2.21
5	$2.23	($0.07)	$2.15
6	$2.36	($0.01)	$2.35
7	$2.35	($0.01)	$2.34
8	$2.32	($0.02)	$2.31
9	$2.35	($0.03)	$2.32
10	$2.29	($0.04)	$2.25
11	$2.52	($0.15)	$2.37
12	$2.26	($0.13)	$2.13
13	$2.49	($0.12)	$2.37
14	$2.38	($0.11)	$2.27
15	$2.64	($0.01)	$2.63
16	$2.05	($0.31)	$1.74

Table 90: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – RetailStandAlone

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.58	($0.13)	$0.45

2	$0.94	($0.09)	$0.85
3	$0.68	($0.08)	$0.60
4	$1.08	($0.07)	$1.01
5	$0.69	($0.07)	$0.62
6	$1.01	($0.03)	$0.98
7	$0.99	($0.04)	$0.95
8	$1.38	($0.04)	$1.34
9	$1.48	($0.05)	$1.43
10	$1.63	($0.04)	$1.59
11	$0.87	($0.05)	$0.82
12	$0.82	($0.08)	$0.74
13	$1.25	($0.08)	$1.18
14	$1.30	($0.06)	$1.24
15	$1.03	($0.01)	$1.01
16	$1.03	($0.15)	$0.88

Table 91: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – RetailStripMall

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$2.06	($0.41)	$1.64
2	$2.55	($0.25)	$2.31
3	$2.38	($0.19)	$2.19
4	$2.40	($0.17)	$2.23
5	$2.44	($0.17)	$2.27
6	$3.01	($0.07)	$2.94
7	$2.79	($0.07)	$2.72
8	$2.94	($0.09)	$2.85
9	$2.84	($0.10)	$2.73
10	$1.01	($0.04)	$0.97
11	$2.79	($0.24)	$2.55
12	$2.67	($0.22)	$2.45
13	$2.71	($0.20)	$2.51
14	$2.97	($0.19)	$2.78
15	$3.28	($0.05)	$3.23
16	$2.55	($0.45)	$2.10

Table 92: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – SchoolPrimary

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$1.67	($0.52)	$1.16
2	$2.09	($0.31)	$1.78
3	$2.02	($0.27)	$1.75
4	$1.99	($0.21)	$1.78
5	$1.82	($0.25)	$1.58
6	$2.17	($0.10)	$2.06
7	$2.14	($0.09)	$2.05
8	$2.12	($0.10)	$2.02
9	$2.18	($0.13)	$2.05
10	$2.03	($0.14)	$1.89
11	$2.29	($0.28)	$2.01
12	$2.10	($0.26)	$1.84
13	$2.32	($0.23)	$2.09
14	$2.39	($0.24)	$2.15
15	$2.46	($0.07)	$2.39
16	$2.01	($0.47)	$1.54

Table 93: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – SchoolSecondary

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.27	($0.09)	$0.18
2	$0.38	($0.05)	$0.33
3	$0.34	($0.05)	$0.29
4	$0.41	($0.04)	$0.37
5	$0.34	($0.05)	$0.30
6	$0.42	($0.02)	$0.40
7	$0.39	($0.02)	$0.37
8	$0.45	($0.02)	$0.43
9	$0.47	($0.03)	$0.44
10	$0.46	($0.03)	$0.43
11	$0.43	($0.05)	$0.38
12	$0.41	($0.04)	$0.36
13	$0.46	($0.04)	$0.42
14	$0.51	($0.04)	$0.47
15	$0.57	($0.02)	$0.56
16	$0.45	($0.08)	$0.37

Table 94: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction/ Additions/ Alterations – Warehouse

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.01	($0.00)	$0.01
2	$0.03	($0.00)	$0.02
3	$0.03	($0.00)	$0.03
4	$0.02	($0.00)	$0.02
5	$0.02	($0.00)	$0.02
6	$0.05	($0.00)	$0.04
7	$0.03	($0.00)	$0.03
8	$0.04	($0.00)	$0.04
9	$0.06	($0.00)	$0.06
10	$0.06	($0.00)	$0.05
11	$0.07	($0.00)	$0.07
12	$0.04	($0.00)	$0.04
13	$0.07	($0.00)	$0.06
14	$0.12	($0.00)	$0.12
15	$0.15	($0.00)	$0.14
16	$0.04	($0.01)	$0.03

Duct Leakage

Table 95: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction, Additions, and Alterations – OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.31	($0.04)	$0.26
2	$0.39	$0.02	$0.41
3	$0.40	$0.05	$0.45
4	$0.41	$0.05	$0.46
5	$0.37	$0.01	$0.39
6	$0.42	$0.05	$0.47
7	$0.40	$0.04	$0.44
8	$0.41	$0.05	$0.46
9	$0.41	$0.06	$0.47
10	$0.40	$0.01	$0.41
11	$0.42	$0.05	$0.47
12	$0.42	$0.04	$0.46
13	$0.42	$0.04	$0.46
14	$0.43	$0.03	$0.46
15	$0.45	$0.07	$0.52
16	$0.43	$0.01	$0.44

Table 96: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction, Alterations, and Additions – OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.38	$0.05	$0.44
2	$0.57	$0.09	$0.66
3	$0.58	$0.13	$0.71
4	$0.61	$0.12	$0.73
5	$0.56	$0.12	$0.68
6	$0.74	$0.14	$0.88
7	$0.72	$0.15	$0.86
8	$0.70	$0.14	$0.85
9	$0.70	$0.13	$0.83
10	$0.68	$0.12	$0.80
11	$0.67	$0.09	$0.76

12	$0.60	$0.10	$0.70
13	$0.65	$0.09	$0.74
14	$0.71	$0.09	$0.80
15	$0.84	$0.13	$0.97
16	$0.58	$0.03	$0.60

Table 97: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction, Additions, and Alterations – OfficeMediumLab

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.74	($0.07)	$0.68
2	$1.39	($0.09)	$1.29
3	$1.11	($0.23)	$0.87
4	$1.60	($0.23)	$1.37
5	$1.03	($0.19)	$0.84
6	$1.56	($0.32)	$1.24
7	$1.41	($0.35)	$1.06
8	$1.70	($0.31)	$1.38
9	$1.72	($0.29)	$1.43
10	$1.86	($0.24)	$1.61
11	$1.61	($0.14)	$1.47
12	$1.45	($0.16)	$1.29
13	$1.72	($0.19)	$1.54
14	$2.00	($0.10)	$1.90
15	$3.07	($0.33)	$2.74
16	$1.03	$0.08	$1.11

Appendix L: Supplemental Cost Effectiveness Tables

Energy cost savings are shown below, separately each submeasure. Only large office examples are shown in the main body of the report. All other building types are shown here.

Supplemental Cost Effectiveness Tables – Fan Power Budget

Table 98: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – Hotel Small

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft^2 (2023 PV$)	Costs Total Incremental PV Costs per ft^2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.04	$0.051	0.80
2	$0.10	$0.057	1.73
3	$0.08	$0.057	1.40
4	$0.12	$0.058	2.12
5	$0.08	$0.056	1.37
6	$0.14	$0.059	2.27
7	$0.12	$0.058	2.04
8	$0.15	$0.061	2.46
9	$0.16	$0.062	2.56
10	$0.16	$0.061	2.54
11	$0.13	$0.062	2.06
12	$0.11	$0.059	1.95
13	$0.14	$0.062	2.28
14	$0.16	$0.066	2.47
15	$0.21	$0.068	3.05
16	$0.09	$0.068	1.38

Table 99: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – OfficeLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.28	$0.290	0.98
2	$0.40	$0.290	1.38
3	$0.38	$0.290	1.31
4	$0.43	$0.290	1.48
5	$0.37	$0.290	1.29
6	$0.47	$0.290	1.61
7	$0.44	$0.290	1.52
8	$0.48	$0.290	1.65
9	$0.48	$0.290	1.64
10	$0.48	$0.290	1.65
11	$0.42	$0.290	1.44
12	$0.41	$0.290	1.41
13	$0.44	$0.290	1.52
14	$0.49	$0.290	1.70
15	$0.52	$0.290	1.79
16	$0.42	$0.290	1.45

Table 100: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – OfficeMedium

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.20	$0.290	0.70
2	$0.38	$0.290	1.30
3	$0.31	$0.290	1.08
4	$0.43	$0.290	1.49
5	$0.30	$0.290	1.03
6	$0.46	$0.290	1.57
7	$0.40	$0.290	1.36
8	$0.52	$0.290	1.80
9	$0.54	$0.290	1.87
10	$0.54	$0.290	1.86
11	$0.47	$0.290	1.63
12	$0.43	$0.290	1.49
13	$0.52	$0.290	1.79
14	$0.59	$0.290	2.02
15	$0.66	$0.290	2.29
16	$0.35	$0.290	1.21

Table 101: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – OfficeMediumLab

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.77	$0.290	2.64
2	$1.11	$0.290	3.83
3	$1.11	$0.290	3.83
4	$1.31	$0.290	4.52
5	$1.07	$0.290	3.70
6	$1.45	$0.290	5.00
7	$1.44	$0.290	4.95
8	$1.49	$0.290	5.11
9	$1.45	$0.290	4.99
10	$1.44	$0.290	4.95
11	$1.44	$0.290	4.97
12	$1.33	$0.290	4.56
13	$1.55	$0.290	5.33
14	$1.58	$0.290	5.43
15	$1.67	$0.290	5.75
16	$1.11	$0.290	3.84

Table 102: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – RetailLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.24	$0.290	0.83
2	$0.48	$0.290	1.65
3	$0.54	$0.290	1.84
4	$1.06	$0.290	3.65
5	$0.59	$0.290	2.04
6	$0.74	$0.290	2.55
7	$1.21	$0.290	4.15
8	$1.11	$0.290	3.82
9	$0.94	$0.290	3.24
10	$1.27	$0.290	4.36
11	$1.30	$0.290	4.48
12	$1.14	$0.290	3.92
13	$1.19	$0.290	4.08
14	$1.97	$0.290	6.80
15	$1.85	$0.290	6.37
16	$0.52	$0.290	1.80

Table 103: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – RetailMixedUse

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$1.81	$0.290	6.24
2	$2.09	$0.290	7.20
3	$2.16	$0.290	7.43
4	$2.21	$0.290	7.62
5	$2.15	$0.290	7.42
6	$2.35	$0.290	8.09
7	$2.34	$0.290	8.06
8	$2.31	$0.290	7.94
9	$2.32	$0.290	8.00
10	$2.25	$0.290	7.75
11	$2.37	$0.290	8.18
12	$2.13	$0.290	7.34
13	$2.37	$0.290	8.16
14	$2.27	$0.290	7.83
15	$2.63	$0.290	9.06
16	$1.74	$0.290	5.99

Table 104: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/ Alterations – Fan Power Budget – RetailStandalone

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.45	$0.290	1.54
2	$0.85	$0.290	2.92
3	$0.60	$0.290	2.07
4	$1.01	$0.290	3.46
5	$0.62	$0.290	2.14
6	$0.98	$0.290	3.36
7	$0.95	$0.290	3.29
8	$1.34	$0.290	4.63
9	$1.43	$0.290	4.94
10	$1.59	$0.290	5.47
11	$0.82	$0.290	2.83
12	$0.74	$0.290	2.55
13	$1.18	$0.290	4.05
14	$1.24	$0.290	4.26
15	$1.01	$0.290	3.48
16	$0.88	$0.290	3.03

Table 105: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/ Alterations – Fan Power Budget – RetailStripMall

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$1.64	$0.290	5.66
2	$2.31	$0.290	7.94
3	$2.19	$0.290	7.53
4	$2.23	$0.290	7.69
5	$2.27	$0.290	7.83
6	$2.94	$0.290	10.14
7	$2.72	$0.290	9.36
8	$2.85	$0.290	9.81
9	$2.73	$0.290	9.41
10	$0.97	$0.290	3.34
11	$2.55	$0.290	8.79
12	$2.45	$0.290	8.43
13	$2.51	$0.290	8.63
14	$2.78	$0.290	9.57
15	$3.23	$0.290	11.12
16	$2.10	$0.290	7.23

Table 106: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – SchoolPrimary

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$1.16	$0.290	3.99
2	$1.78	$0.290	6.12
3	$1.75	$0.290	6.02
4	$1.78	$0.290	6.15
5	$1.58	$0.290	5.42
6	$2.06	$0.290	7.10
7	$2.05	$0.290	7.04
8	$2.02	$0.290	6.96
9	$2.05	$0.290	7.06
10	$1.89	$0.290	6.52
11	$2.01	$0.290	6.93
12	$1.84	$0.290	6.34
13	$2.09	$0.290	7.21
14	$2.15	$0.290	7.41
15	$2.39	$0.290	8.24
16	$1.54	$0.290	5.32

Table 107: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – SchoolSecondary

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.18	$0.290	0.62
2	$0.33	$0.290	1.12
3	$0.29	$0.290	1.00
4	$0.37	$0.290	1.28
5	$0.30	$0.290	1.02
6	$0.40	$0.290	1.38
7	$0.37	$0.290	1.29
8	$0.43	$0.290	1.47
9	$0.44	$0.290	1.52
10	$0.43	$0.290	1.49
11	$0.38	$0.290	1.32
12	$0.36	$0.290	1.24
13	$0.42	$0.290	1.46
14	$0.47	$0.290	1.60
15	$0.56	$0.290	1.92
16	$0.37	$0.290	1.27

Table 108: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Fan Power Budget – Warehouse

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.01	$0.013	0.39
2	$0.02	$0.020	1.08
3	$0.03	$0.019	1.44
4	$0.02	$0.021	0.92
5	$0.02	$0.018	1.14
6	$0.04	$0.020	2.24
7	$0.03	$0.019	1.53
8	$0.04	$0.022	1.66
9	$0.06	$0.023	2.63
10	$0.05	$0.022	2.39
11	$0.07	$0.024	2.80
12	$0.04	$0.022	1.77
13	$0.06	$0.024	2.65
14	$0.12	$0.025	4.81
15	$0.14	$0.028	5.17
16	$0.03	$0.024	1.39

Supplemental Cost Effectiveness Tables – Duct Leakage

Table 109: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Duct Leakage – OfficeLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.26	$0.08	3.22
2	$0.41	$0.08	5.02
3	$0.45	$0.08	5.55
4	$0.46	$0.08	5.60
5	$0.39	$0.08	4.72
6	$0.47	$0.08	5.79
7	$0.44	$0.08	5.41
8	$0.46	$0.08	5.66
9	$0.47	$0.08	5.75
10	$0.41	$0.08	4.98
11	$0.47	$0.08	5.77
12	$0.46	$0.08	5.57
13	$0.46	$0.08	5.61
14	$0.46	$0.08	5.61
15	$0.52	$0.08	6.31
16	$0.44	$0.08	5.33

Table 110: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Duct Leakage – OfficeMedium

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.44	$0.10	4.37
2	$0.66	$0.10	6.59
3	$0.71	$0.10	7.07
4	$0.73	$0.10	7.34
5	$0.68	$0.10	6.81
6	$0.88	$0.10	8.79
7	$0.86	$0.10	8.66
8	$0.85	$0.10	8.48
9	$0.83	$0.10	8.34
10	$0.80	$0.10	7.99
11	$0.76	$0.10	7.63
12	$0.70	$0.10	7.05
13	$0.74	$0.10	7.42
14	$0.80	$0.10	8.00

15	$0.97	$0.10	9.72
16	$0.60	$0.10	6.05

Table 111: 15-Year Cost-Effectiveness Summary Per Square Foot – New Construction/ Additions/Alterations – Duct Leakage – OfficeMediumLab

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings per ft2 (2023 PV$)	Costs Total Incremental PV Costs per ft2 (2023 PV$)	Benefit-to-Cost Ratio
1	$0.68	$0.08	8.14
2	$1.29	$0.08	15.55
3	$0.87	$0.08	10.52
4	$1.37	$0.08	16.49
5	$0.84	$0.08	10.15
6	$1.24	$0.08	14.96
7	$1.06	$0.08	12.79
8	$1.38	$0.08	16.65
9	$1.43	$0.08	17.18
10	$1.61	$0.08	19.43
11	$1.47	$0.08	17.70
12	$1.29	$0.08	15.53
13	$1.54	$0.08	18.52
14	$1.90	$0.08	22.93
15	$2.74	$0.08	33.04
16	$1.11	$0.08	13.42

Appendix M: Nominal Energy Savings Tables

In Section 5, the energy cost savings of the proposed code changes over the 15-year period of analysis are presented in 2023 present value dollars.

This appendix presents energy cost savings in nominal dollars. Energy costs are escalating as in the TDV analysis, but the time value of money is not included so the results are not discounted.

Fan Power Budget

Table 112: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - HotelSmall

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.09	-$0.04	$0.06
2	$0.16	-$0.02	$0.14
3	$0.13	-$0.02	$0.11
4	$0.19	-$0.02	$0.17
5	$0.13	-$0.02	$0.11
6	$0.20	-$0.01	$0.19
7	$0.17	-$0.01	$0.17
8	$0.22	-$0.01	$0.21
9	$0.23	-$0.01	$0.22
10	$0.23	-$0.01	$0.22
11	$0.20	-$0.02	$0.18
12	$0.18	-$0.02	$0.16
13	$0.21	-$0.02	$0.20
14	$0.25	-$0.02	$0.23
15	$0.30	-$0.01	$0.29
16	$0.16	-$0.03	$0.13

Table 113: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.48	-$0.08	$0.40

2	$0.62	-$0.06	$0.57
3	$0.58	-$0.04	$0.54
4	$0.64	-$0.04	$0.60
5	$0.57	-$0.05	$0.53
6	$0.68	-$0.02	$0.66
7	$0.64	-$0.02	$0.62
8	$0.69	-$0.02	$0.67
9	$0.69	-$0.02	$0.67
10	$0.70	-$0.03	$0.67
11	$0.64	-$0.05	$0.59
12	$0.62	-$0.04	$0.58
13	$0.66	-$0.04	$0.62
14	$0.74	-$0.04	$0.70
15	$0.75	-$0.01	$0.73
16	$0.67	-$0.08	$0.59

Table 114: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.37	-$0.08	$0.29
2	$0.59	-$0.06	$0.53
3	$0.49	-$0.05	$0.44
4	$0.64	-$0.04	$0.61
5	$0.47	-$0.05	$0.42
6	$0.66	-$0.02	$0.64
7	$0.57	-$0.02	$0.56
8	$0.76	-$0.02	$0.74
9	$0.79	-$0.02	$0.77
10	$0.79	-$0.03	$0.76
11	$0.71	-$0.04	$0.67
12	$0.65	-$0.04	$0.61
13	$0.77	-$0.04	$0.73
14	$0.87	-$0.04	$0.83
15	$0.95	-$0.01	$0.94
16	$0.57	-$0.08	$0.49

Table 115: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - OfficeMediumLab

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$1.69	-$0.61	$1.08
2	$2.01	-$0.44	$1.57
3	$1.98	-$0.42	$1.56
4	$2.16	-$0.31	$1.85
5	$1.92	-$0.41	$1.51
6	$2.23	-$0.18	$2.04
7	$2.18	-$0.16	$2.03
8	$2.28	-$0.19	$2.09
9	$2.27	-$0.23	$2.04
10	$2.26	-$0.24	$2.02
11	$2.35	-$0.32	$2.03
12	$2.21	-$0.35	$1.87
13	$2.46	-$0.28	$2.18
14	$2.54	-$0.32	$2.22
15	$2.49	-$0.13	$2.35
16	$2.05	-$0.48	$1.57

Table 116: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - RetailLarge

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.48	-$0.14	$0.34
2	$0.76	-$0.09	$0.67
3	$0.83	-$0.07	$0.75
4	$1.55	-$0.06	$1.49
5	$0.90	-$0.06	$0.84
6	$1.08	-$0.04	$1.05
7	$1.73	-$0.03	$1.70
8	$1.60	-$0.03	$1.56
9	$1.37	-$0.04	$1.33

10	$1.83	-$0.04	$1.79
11	$1.92	-$0.09	$1.83
12	$1.68	-$0.08	$1.61
13	$1.74	-$0.07	$1.67
14	$2.86	-$0.07	$2.78
15	$2.63	-$0.02	$2.61
16	$0.92	-$0.18	$0.74

Table 117: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - RetailMixedUse

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$2.90	-$0.35	$2.55
2	$3.14	-$0.19	$2.95
3	$3.16	-$0.12	$3.04
4	$3.22	-$0.10	$3.12
5	$3.14	-$0.10	$3.04
6	$3.33	-$0.02	$3.31
7	$3.31	-$0.01	$3.30
8	$3.27	-$0.02	$3.25
9	$3.32	-$0.04	$3.28
10	$3.23	-$0.06	$3.17
11	$3.56	-$0.21	$3.35
12	$3.19	-$0.18	$3.01
13	$3.52	-$0.18	$3.34
14	$3.36	-$0.16	$3.21
15	$3.73	-$0.02	$3.71
16	$2.89	-$0.44	$2.45

Table 118: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - RetailStandAlone

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.82	-$0.19	$0.63

2	$1.32	-$0.13	$1.19
3	$0.95	-$0.11	$0.84
4	$1.52	-$0.10	$1.42
5	$0.97	-$0.10	$0.87
6	$1.42	-$0.05	$1.38
7	$1.40	-$0.06	$1.35
8	$1.95	-$0.06	$1.89
9	$2.09	-$0.06	$2.02
10	$2.29	-$0.06	$2.24
11	$1.23	-$0.07	$1.16
12	$1.16	-$0.11	$1.04
13	$1.77	-$0.11	$1.66
14	$1.83	-$0.09	$1.74
15	$1.45	-$0.02	$1.43
16	$1.45	-$0.21	$1.24

Table 119: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - RetailStripMall

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$2.90	-$0.59	$2.31
2	$3.60	-$0.35	$3.25
3	$3.35	-$0.27	$3.08
4	$3.38	-$0.24	$3.15
5	$3.44	-$0.23	$3.20
6	$4.24	-$0.09	$4.15
7	$3.93	-$0.10	$3.83
8	$4.14	-$0.13	$4.02
9	$4.00	-$0.15	$3.85
10	$1.42	-$0.05	$1.37
11	$3.93	-$0.33	$3.60
12	$3.77	-$0.32	$3.45
13	$3.82	-$0.29	$3.53
14	$4.18	-$0.26	$3.92
15	$4.62	-$0.07	$4.55
16	$3.59	-$0.64	$2.96

Table 120: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - SchoolPrimary

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$2.36	-$0.73	$1.63
2	$2.94	-$0.44	$2.50
3	$2.84	-$0.38	$2.46
4	$2.81	-$0.30	$2.51
5	$2.57	-$0.35	$2.22
6	$3.05	-$0.15	$2.91
7	$3.01	-$0.13	$2.88
8	$2.99	-$0.14	$2.85
9	$3.07	-$0.18	$2.89
10	$2.87	-$0.20	$2.67
11	$3.22	-$0.39	$2.83
12	$2.96	-$0.37	$2.59
13	$3.28	-$0.33	$2.95
14	$3.37	-$0.34	$3.03
15	$3.47	-$0.10	$3.37
16	$2.83	-$0.66	$2.17

Table 121: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - SchoolSecondary

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.38	-$0.12	$0.25
2	$0.54	-$0.08	$0.46
3	$0.48	-$0.07	$0.41
4	$0.58	-$0.06	$0.53
5	$0.48	-$0.07	$0.42
6	$0.60	-$0.03	$0.56
7	$0.56	-$0.03	$0.53
8	$0.63	-$0.03	$0.60
9	$0.66	-$0.04	$0.62

10	$0.65	-$0.04	$0.61
11	$0.60	-$0.06	$0.54
12	$0.57	-$0.06	$0.51
13	$0.65	-$0.06	$0.60
14	$0.72	-$0.06	$0.66
15	$0.81	-$0.02	$0.78
16	$0.63	-$0.11	$0.52

Table 122: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - Warehouse

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.01	-$0.01	$0.01
2	$0.04	-$0.01	$0.03
3	$0.04	$0.00	$0.04
4	$0.03	$0.00	$0.03
5	$0.03	$0.00	$0.03
6	$0.06	$0.00	$0.06
7	$0.04	$0.00	$0.04
8	$0.05	$0.00	$0.05
9	$0.09	$0.00	$0.08
10	$0.08	$0.00	$0.08
11	$0.10	-$0.01	$0.10
12	$0.06	-$0.01	$0.05
13	$0.09	$0.00	$0.09
14	$0.17	-$0.01	$0.17
15	$0.21	$0.00	$0.20
16	$0.06	-$0.01	$0.05

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Table 123: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - HotelSmall

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.07	-$0.01	$0.06
2	$0.10	-$0.01	$0.09
3	$0.09	$0.00	$0.08
4	$0.09	$0.00	$0.09
5	$0.08	-$0.01	$0.08
6	$0.10	$0.00	$0.10
7	$0.09	$0.00	$0.09
8	$0.11	$0.00	$0.11
9	$0.11	$0.00	$0.11
10	$0.11	$0.00	$0.11
11	$0.10	-$0.01	$0.09
12	$0.10	-$0.01	$0.09
13	$0.10	-$0.01	$0.10
14	$0.12	-$0.01	$0.12
15	$0.12	$0.00	$0.12
16	$0.10	-$0.01	$0.09

Duct Leakage

Table 124: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations - OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.43	($0.06)	$0.37
2	$0.55	$0.02	$0.58
3	$0.57	$0.07	$0.64
4	$0.58	$0.07	$0.65
5	$0.52	$0.02	$0.54
6	$0.59	$0.08	$0.67
7	$0.56	$0.06	$0.62
8	$0.58	$0.07	$0.65
9	$0.58	$0.08	$0.66

10	$0.56	$0.02	$0.57
11	$0.60	$0.07	$0.67
12	$0.59	$0.05	$0.64
13	$0.59	$0.06	$0.65
14	$0.60	$0.04	$0.65
15	$0.63	$0.10	$0.73
16	$0.61	$0.01	$0.61

Table 125: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations – OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.54	$0.08	$0.62
2	$0.80	$0.13	$0.93
3	$0.81	$0.18	$1.00
4	$0.86	$0.17	$1.03
5	$0.79	$0.17	$0.96
6	$1.04	$0.20	$1.24
7	$1.01	$0.21	$1.22
8	$0.99	$0.20	$1.19
9	$0.98	$0.19	$1.17
10	$0.95	$0.17	$1.12
11	$0.95	$0.13	$1.07
12	$0.85	$0.14	$0.99
13	$0.91	$0.13	$1.05
14	$1.00	$0.13	$1.13
15	$1.18	$0.19	$1.37
16	$0.81	$0.04	$0.85

Table 126: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Square Foot – New Construction/ Additions/Alterations – OfficeMediumLab

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$1.05	($0.09)	$0.95

2	$1.95	($0.13)	$1.82
3	$1.56	($0.33)	$1.23
4	$2.26	($0.33)	$1.93
5	$1.46	($0.27)	$1.19
6	$2.20	($0.45)	$1.75
7	$1.99	($0.49)	$1.49
8	$2.39	($0.45)	$1.94
9	$2.42	($0.41)	$2.01
10	$2.62	($0.35)	$2.27
11	$2.27	($0.20)	$2.07
12	$2.04	($0.22)	$1.81
13	$2.43	($0.27)	$2.17
14	$2.83	($0.15)	$2.68
15	$4.33	($0.47)	$3.86
16	$1.46	$0.11	$1.57

Appendix N: Fan Power Budget Methodology

This appendix shows the methodology used to develop the fan power allowances and the fan power budget (Fan kW_{budget}). As shown in the standards language, there are twelve buckets a given fan system could be classified into depending on whether:

- The fan system is:
  - A supply fan system or;
  - an exhaust, return, relief, or transfer fan system
- The fan system is:
  - a multi-zone VAV system or;
  - a CAV or single-zone VAV system
- The airflow is below 5,000 cfm, between 5,000 and 10,000 cfm, or above 10,000 cfm.

For each component of a fan system that creates pressure drop, the maximum allowable fan power was calculated using fan power methodology below at a representative airflow. Representative airflows were determined based on knowledge of common airflows combined with sensitivity analysis to ensure uniformity. The maximum fan power is then divided by the representative airflow to arrive at the fan power allowance in w/cfm for a given component. The user would sum the fan power allowances and multiply by the design airflow to determine the fan power budget for a fan system (Fan kW_{budget}).

Table 127: Fan Power Budget Representative Airflows

	Multi-zone VAV System			**CV or Single-zone VAV**		
Airflow	>10,000 cfm	>5,000 and ≤10,000 cfm	≤5,000 cfm	>10,000 cfm	>5,000 and ≤10,000 cfm	≤5,000 cfm
Supply system representative airflow (cfm)	20,000	7,500	2,500	20,000	7,500	2,500
Exhaust/ return/ relief/ transfer systems	20,000	7,500	2,500	20,000	7,500	2,500

representative airflow (cfm)						

Base Fan Power Allowances

For both supply-side fan systems and exhaust/ relief/ return/ transfer fan systems, a "base" fan power allowance is calculated and available to each fan system. This is the first fan power allowance in each of Table's 140.4-A and 140.4-B, which corresponds to the first rows in Table 128 and Table 129 below and is based on a reference pressure drop for each fan system. The base fan power allowances are calculated using the fan power budget methodology below, and then dividing by the representative airflows from Table 127. For example, as shown in Table 128, the supply-side base allowance reference pressure (P_{ref}) for a multi-zone VAV fan system ≥10,000 cfm is 2 in. wg, thus the representative airflow would be 20,000 cfm according to Table 127. Using the fan power budget methodology below this yields a fan power of 7.905 kW. This maximum fan power divided by 20,000 cfm, converted to watts yields a fan power allowance of 0.395 watts/ cfm, aligning the value in Table 140.4-A.

Component Fan Power Allowances

In addition to the "base" fan power allowance there are many other fan power allowances depending on which components are in each fan system. The component fan power allowances are determined in a similar way to the base fan power allowances described above, with one key difference. For components, the fan power (kW) of a component is calculated at the pressure drop of the component and the base allowance combined, then the base fan power is subtracted.

For example, as shown in Table 128, the reference pressure (P_{ref}) for a MERV 13 to MERV 16 clean filter for multi-zone VAV fan system ≥10,000 cfm is 0.4 in. wg. Adding this to the baseline P_{ref} of 2.0 in. wg yields a total of 2.4 in wg. The maximum fan power for the filter would be calculated at 2.4 in. wg (base + filter) minus the fan power at 2.0 in. wg (base) at the representative airflow of 20,000 cfm. Using the fan power budget methodology below, the output is 9.295 kW minus 7.905 kW. Dividing each maximum fan power by 20,000 cfm, and converting to watts yields 0.069 watts/ cfm (0.465 - 0.395 watts/ cfm), aligning with the filter fan power allowance value in Table 140.4-A.

The reasoning behind this approach is to not overstate the motor and transmission losses (see steps 4 and 6 in the Fan Power Budget Methodology below). The motor and transmission efficiency equations yield higher efficiency motors and transmissions as power is increased. As shown in the example above, only calculating the fan power at 0.4 in. wg for the air filter would essentially cause the fan to have a small input power, thus a smaller, less efficient motor and transmission, reducing the fan power allowance. Calculating the fan power at 2.4 in. wg and subtracting the fan power at 2.0 in. wg minimizes this effect and more accurately represents the losses of more efficient motors and transmissions.

Fan Power Budget Methodology

The following steps are illustrate how to manually calculate the fan power budget (Fan kW_{budget}) values which underpin the Fan Power Allowances in Table 140.4-A and Table 140.4-B, when divided by the representative airflows in Table 127.

Step 1: Calculate the fan system airflow

The fan system airflow (cfm) is the sum of the airflow of all fans at fan system design conditions with fan input power greater than 1 kW, excluding the airflow that passes through downstream fans with fan input power less than 1 kW. A common example of a system with < 1kW fans downstream of the larger fans is a DOAS system where the air is ducted to a fan coil in each space.

Step 2: Determine the reference pressure losses for the system.

For each fan system, sum the reference pressure losses for each system device/ component in Table 128 and Table 129 using the appropriate columns for fan system classification and airflow.

Table 128: Supply Fan System Reference Pressures (P_{ref}) in. wg

	Multi-zone VAV System[1]			**CAV or Single-zone VAV**		
Airflow	>10,000 cfm	>5,000 and ≤10,000 cfm	≤5,000 cfm	>10,000 cfm	>5,000 and ≤10,000 cfm	≤5,000 cfm
Supply System Base Allowance (supply fan system duct and outlet losses)	1.9	1.9	1.4	1.25	1.00	0.80
Particle filtration (select only 1)[3]						
MERV 13 to MERV 16 Filter (mid-life)	0.60	0.60	0.60	0.60	0.60	0.60
MERV 13 to MERV 16 Final filter located	1.00	1.00	1.00	1.00	1.00	1.00

downstream of thermal conditioning equipment. (mid-life)						
HEPA Filter (mid-life)	1.50	1.50	1.50	1.50	1.50	1.50
Heating (select all that apply)						
Hydronic heating coil (central)	0.30	0.20	0.20	0.30	0.20	0.20
Electric heat	0.20	0.20	0.20	0.20	0.20	0.20
Terminal re-heat (hydronic or electric resistance)	0.10	0.10	0.10	0.10	0.10	0.10
Gas heat	0.40	0.30	0.30	0.40	0.30	0.30
Cooling and dehumidification (select all that apply)						
Hydronic/DX cooling coil, or heat pump coil (wet)[5]	0.60	0.60	0.60	0.60	0.60	0.60
Desiccant system – solid or liquid	0.70	0.70	0.70	0.70	0.70	0.70
Reheat coil for dehumidification	0.20	0.20	0.20	0.20	0.20	0.20
Evaporative humidifier/cooler in series with a cooling coil (Pressure loss at 400 fpm or maximum velocity allowed by the manufacturer, whichever is less)[4]	1	1	1	1	1	1
Outdoor Air Systems						
100% Outdoor air system meeting the requirements of Note 2.	0.00	0.00	0.00	0.5	0.5	0.30

Energy recovery (select only 1) where required by code[6]						
Enthalpy Recovery Ratio ≥ 0.50 and <0.55)	0.6	0.6	0.6	0.6	0.6	0.6
Enthalpy Recovery Ratio ≥ 0.55 and <0.60)	0.71	0.71	0.71	0.71	0.71	0.71
Enthalpy Recovery Ratio ≥ 0.60 and <0.65)	0.82	0.82	0.82	0.82	0.82	0.82
Enthalpy Recovery Ratio ≥ 0.65 and <0.70)	0.93	0.93	0.93	0.93	0.93	0.93
Enthalpy Recovery Ratio ≥ 0.70 and <0.75)	1.04	1.04	1.04	1.04	1.04	1.04
Enthalpy Recovery Ratio ≥ 0.75 and <0.80)	1.15	1.15	1.15	1.15	1.15	1.15
Enthalpy Recovery Ratio ≥ 0.8)	1.26	1.26	1.26	1.26	1.26	1.26
Sensible-only recovery	0.60	0.60	0.60	0.60	0.60	0.60
Gas-phase filtration (select only 1)						
General odor control	0.50	0.50	0.50	0.50	0.50	0.30
Gas phase filtration required by code or accredited standard per in wg. of pressure[4]	1	1	1	1	1	1
Other						
Air blender	0.20	0.20	0.20	0.20	0.20	0.20
Sound attenuation section [fans serving spaces with design background noise goals below NC35]	0.15	0.15	0.15	0.15	0.15	0.15
Deduction for systems that feed a terminal unit	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25

with a fan with electrical input power < 1kW						
1. See section 140.4 (c) 1 for requirements to be classified as a Multi-Zone VAV System.						
2. The 100% outdoor air system must serve 3 or more HVAC zones and airflow during non-economizer operating periods must not exceed 135% of minimum requirements in Section 120.1(c)(3).						
3. Filter fan power allowance can only be counted once per fan system, except fan systems in healthcare facilities, which can claim one of the MERV 13 to 16 filter allowances and the HEPA filter allowance if both are included in the fan system.						
4. Power allowance requires further calculation by multiplying the actual in. wg. of the device/ component by the watts/ cfm in Table 140.4-A.						
5. Healthcare facilities can claim this fan power allowance twice per fan system where coil design leaving air temperature is less than 44ºF.						
6. Energy Recovery Ratio (ERR) calculated per ANSI/ASHRAE 84-2020.						

Table 129: Exhaust, Relief, Return and Transfer Fan System Reference Pressures (P_{ref}) in. wg

	Multi-zone VAV System			**CV or Single-zone VAV**		
Airflow	>10,000 cfm	>5,000 and ≤10,000 cfm	≤5,000 cfm	>10,000 cfm	>5,000 and ≤10,000 cfm	≤5,000 cfm
Exhaust System Base Allowance (exhaust system duct, plenum, inlet, and outlet)	1	1	0.75	0.75	0.75	0.5
Particle filtration						
Filter - any MERV value	0.2	0.2	0.2	0.2	0.2	0.2
Energy recovery (select only 1) where required by code[5]						
Enthalpy Recovery Ratio ≥ 0.50 and <0.55)	0.6	0.6	0.6	0.6	0.6	0.6

Enthalpy Recovery Ratio ≥ 0.55 and <0.60)	0.71	0.71	0.71	0.71	0.71	0.71
Enthalpy Recovery Ratio ≥ 0.60 and <0.65)	0.82	0.82	0.82	0.82	0.82	0.82
Enthalpy Recovery Ratio ≥ 0.65 and <0.70)	0.93	0.93	0.93	0.93	0.93	0.93
Enthalpy Recovery Ratio ≥ 0.70 and <0.75)	1.04	1.04	1.04	1.04	1.04	1.04
Enthalpy Recovery Ratio ≥ 0.75 and <0.80)	1.15	1.15	1.15	1.15	1.15	1.15
Enthalpy Recovery Ratio ≥ 0.8)	1.26	1.26	1.26	1.26	1.26	1.26
Sensible-only recovery	0.60	0.60	0.60	0.60	0.60	0.60
Special exhaust and return system requirements						
Return or exhaust systems required by code or accreditation standards to be fully ducted, or systems required to maintain air pressure differentials between adjacent rooms	0.5	0.5	0.5	0.5	0.5	0.5
Return and/or exhaust airflow control devices	0.50	0.50	0.50	0.50	0.50	0.50
Laboratory and vivarium exhaust systems in high-rise buildings [0.25 per 100 ft of vertical duct exceeding 75 ft]	0.25	0.25	0.25	0.25	0.25	0.25
Biosafety cabinet[4]	Pressure drop of device at fan system design condition.					
Exhaust filters, scrubbers, or other	Pressure loss at 400 sfpm or maximum velocity allowed by the manufacturer, whichever is less.					

exhaust treatment required by code or standard [4]						
Other						
Healthcare facility allowance[3]	1	1	1	1	1	1
Sound attenuation section [fans serving spaces with design background noise goals below NC35]	0.15	0.15	0.15	0.15	0.15	0.15
1. See section for requirements 140.4 (c) 1 for Multi-Zone VAV System						
2. Filter pressure loss can only be counted once per fan system.						
3. This allowance can only be taken for healthcare facilities.						
4. Note that for purposes of determining the Fan Power Allowances in Table 140.4-B, 1 in. wg pressure was used, though calculation is required by end-user to determine actual Fan Power Allowance in watts/ cfm based on actual pressure drop of the device/ component.						
5. Energy Recovery Ratio determined by ANSI/ ASHRAE 84-2020.						

Step 3: Calculate the reference fan brake HP (bhp_{ref})

$$bhp_{ref} = \frac{(Q_i + Q_o)(P_{ref} + P_o)C_A}{6343 \cdot 0.66 \cdot EF}$$

Where

bhp_{ref} = Reference Fan system brake HP (hp)

Q_i = Actual airflow at fan system design conditions (cfm)

Q_o= 250 cfm

P_{ref} = The sum of the reference fan system pressure losses of system components determined from Table 128 and Table 129 (in. wg), or from the equation in Step 2.

P_o = 0.2 in. H_2O

C_A= Altitude density correction from Table NA9-1

EF = 1.15 - The Efficiency Factor

Step 4: Calculate the reference belt-drive transmission efficiency.

$$n_{t,ref} = \left(\frac{bhp_{ref}}{bhp_{ref} + 2.2}\right)^{0.05}$$

Where

$\eta_{t,ref}$ = The calculated efficiency of the reference transmission.

bhp_{ref} = Reference Fan system brake HP (hp)

Step 5: Calculate the reference transmission HP input.

$$H_{t,ref} = \frac{bhp_{ref}}{\eta_{t,ref}}$$

Where

$H_{t,ref}$ = The reference transmission HP input.

bhp_{ref} = Reference Fan system brake HP (hp)

$\eta_{t,ref}$ = The calculated efficiency of the reference transmission.

Step 6: Calculate the reference motor efficiency.

$$\eta_{mtr,ref} = \mathrm{A} \cdot \left[\log_{10}\left(H_{t,ref} \times 0.7457\right)\right]^4 + \mathrm{B} \cdot \left[\log_{10}\left(H_{t,ref} \times 0.7457\right)\right]^3 + \mathrm{C} \cdot \left[\log_{10}\left(H_{t,ref} \times 0.7457\right)\right]^2 + \mathrm{D} \cdot \left[\log_{10}\left(H_{t,ref} \times 0.7457\right)\right]^1 + \mathrm{E}$$

Where

$\eta_{mtr,ref}$ = The reference motor efficiency.

$H_{t,ref}$ = The reference transmission HP input.

Constants are found in Table 130.

Table 130: Constants for Reference Motor Efficiency Equation

Constants	$H_{t,reference}$ <250 hp	$H_{t,reference}$ ≥250 hp
A	-0.003812	0
B	0.025834	0
C	-0.072577	0
D	0.125559	0

E	0.850274	0.962

Step 7: Calculate the budget fan system electrical power input

$$Fan\ kW_{budget} = \frac{H_{t,ref}}{\eta_{mtr,ref}}\ X\ 0.7457$$

Where

Fan kW_{budget} = Maximum allowed fan system electrical input power

$H_{t,ref}$ = The reference transmission HP input.

$\eta_{mtr,ref}$ = The reference motor efficiency.

0.7457 = Conversion factor for hp to kW