California Energy Commission
DRAFT STAFF REPORT

STAFF ANALYSIS OF HVAC AIR FILTERS, DIMMING FLUORESCENT BALLASTS, AND HEAT PUMP WATER CHILLING PACKAGES

California Energy Commission

2014 Appliance Efficiency Pre-Rulemaking

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PREFACE

On March 14, 2012, the California Energy Commission issued an Order Instituting Rulemaking (OIR) to begin considering standards, test procedures, labeling requirements, and other efficiency measures to amend the Appliance Efficiency Regulations (California Code of Regulations, Title 20, Sections 1601 through Section 1608). In this OIR, the Energy Commission identified a variety of appliances with the potential to save energy and/or water. The goal of this pre-rulemaking is to develop the proposed appliance efficiency standards and measures to realize these energy savings opportunities.

On March 25, 2013, the Energy Commission released an "Invitation to Participate" to provide interested parties with the opportunity to inform the Energy Commission about the product, market, and industry characteristics of the appliances identified in the OIR. The Energy Commission reviewed the information and data received in the docket and hosted staff workshops on May 28 through 31, 2013, to vet this information publicly.

On June 13, 2013, the Energy Commission released an "Invitation to Submit Proposals" to seek proposals for standards, test procedures, labeling requirements, and other measures to improve the efficiency and reduce the energy or water consumption of the appliances identified in the OIR.

The Energy Commission reviewed all information received to determine which appliances were strong candidates for the development of efficiency standards and measures. Based on its assessment, the Energy Commission will proceed with appliances in phases for the remainder of the rulemaking. The first phase of rulemaking commences with the development of staff reports and proposed regulations for faucets, toilets, urinals, fluorescent dimming ballasts, air filters, and heat-pump water chillers.

ABSTRACT

Air filters ensure the proper operation of heating, ventilation, and air-conditioning (HVAC) equipment by keeping internal components clean and free of particulates that build up and lower equipment efficiency by preventing the effective transfer of heat. As an air stream passes through the filter, the air decreases its velocity due to the resistance of the air filter. If this decrease is excessive, HVAC equipment performs less efficiently and can suffer damage. To prevent this from occurring, consumers should purchase air filters with the performance specifications that meet their HVAC system requirements. However, air filters in the market currently aren't labeled with this information. In addition, this information isn't available online for HVAC system designers to use in system design. The proposed air filter labeling measure would empower consumers and HVAC designers with the information they need to make energy-efficient decisions.

Deep dimming fluorescent ballasts are designed to dim fluorescent bulbs below 50 percent of their maximum output. These ballasts are currently unregulated, and information on the performance of these bulbs is not readily available or verifiable in dimmed states of operation. Proposed regulations will add these ballasts to the California Energy Commission's database and require them to meet minimum performance requirements based on calculated annual energy use.

Heat-pump water chilling packages are an innovative and efficient way to provide hot water and heating or cooling to a building. It is difficult to use this equipment to its full potential because of a lack of verifiable testing and performance data. Proposed regulations would require that these products provide such information to be sold or installed in California.

Keywords: Appliance Efficiency Regulations, energy efficiency, air filters, labeling, HVAC, particle efficiency, MERV, pressure drop, ballast, fluorescent, heat-pump water chilling package, deep dimming fluorescent ballast

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Legislative Criteria

Section 25402, Subdivision (c)(1), of the Public Resources Code[1] mandates the California Energy Commission to reduce the inefficient consumption of energy and water by prescribing efficiency standards and other cost-effective measures[2] for appliances that require a significant amount of energy and water to operate on a statewide basis. Such standards must be technologically feasible and attainable and must not result in any added total cost to the consumer over the designed life of the appliance.

In determining cost-effectiveness, the Energy Commission considers the value of the water or energy saved, the effect on product efficacy for the consumer, and the life-cycle cost to the consumer of complying with the standard. The Energy Commission also considers other relevant factors, including but not limited to the effect on housing costs, the total statewide costs and benefits of the standard over its lifetime, the economic impact on California businesses, and alternative approaches and their associated costs.

In addition, the California Lighting Efficiency and Toxics Reductions Act of 2007[3] requires the Energy Commission to adopt minimum energy efficiency standards for general purpose lighting. These standards, in combination with other programs and activities, must be structured to reduce average statewide electrical energy consumption by not less than 50 percent from 2007 levels for indoor home lighting and not less than 25 percent from the 2007 levels for indoor commercial and outdoor lighting by 2018.

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1 Warren-Alquist State Energy Resources Conservation and Development Act, Division 15 of the Public Resources Code, § 25000 et seq.. Retrieved from: http://www.energy.ca.gov/2014publications/CEC-140-2014-001/CEC-140-2014-001.pdf .

2 Including energy and water consumption labeling, fleet averaging, incentive programs, and consumer education programs.

3 Assembly Bill 1109 (Huffman, Chapter 534, Statutes of 2007), codified in relevant part at Pub. Resources Code, § 25402.5.4.

Efficiency Policy

The Warren Alquist Act establishes the California Energy Commission as California's primary energy policy and planning agency and mandates the Commission reduce the wasteful and inefficient consumption of energy and water in the state by prescribing standards for minimum levels of operating efficiency for appliances that consume a significant amount of energy or water statewide.

For nearly four decades, appliance standards have shifted the marketplace toward more efficient products and practices, reaping large benefits for California's consumers. The state's appliance efficiency regulations saved an estimated 22,923 gigawatt hours (GWh) of electricity and 1,626 million therms of natural gas in 2012[4] alone, resulting in about $5.24 billion in savings to California consumers in 2012 from these regulations.[5] Since 1975, California's building and appliance energy efficiency standards have saved consumers an estimated $75 billion in reduced electricity bills. The recently adopted appliance standards for battery chargers are expected to save 2,200 GWh annually, which is enough energy to power 350,000 California households each year.[6] Still, there remains huge potential for additional savings by increasing the energy efficiency and improving the use of appliances.

Reducing Electrical Energy Consumption to Mitigate Climate Change

Appliance energy efficiency is identified as a key to achieving the greenhouse gas (GHG) emission goals of Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006)[7] (AB 32), as well as the recommendations contained in the California Air Resources Board's *Climate Change Scoping Plan*.[8] Energy efficiency regulations are also identified as key components in reducing electrical energy consumption in the Energy Commission's *2013 Integrated Energy Policy Report (IEPR)*[9]

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4 California Energy Commission. *California Energy Demand 2014-2024 Revised Forecast*, September 2013. Retrieved from http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC_200-2013-004-SD-V1-REV.pdf.
5 Using current average electric power and natural gas rates of: residential electric rate of $0.164 per kilowatt-hour, commercial electric rate of $0.147 per kilowatt-hour, residential gas rate of $0.98 per therm and commercial gas rate of $0.75 per therm.
6 California Energy Commission, Energy Efficiency Standards for Battery Charger Systems Frequently Asked Questions, January 2012. Retrieved from http://www.energy.ca.gov/appliances/battery_chargers/documents/Chargers_FAQ.pdf
7 Assembly Bill 32, California Global Warming Solutions Act of 2006. Retrieved from http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.html.
8 California Air Resources Board, *Climate Change Scoping Plan*, December 2008. Retrieved from http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.
9 California Energy Commission, *2013 Integrated Energy Policy Report*, January 2014. Retrieved from http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf.

and the California Public Utilities Commission's (CPUC) 2011 update to its *Energy Efficiency Strategic Plan.*[10]

Loading Order for Meeting the State's Energy Needs

California's loading order places energy efficiency as the top priority for meeting the state's energy needs. Increases in state energy demand should be met by improving the efficiency of equipment and buildings in the state before resorting to building new power plants. Not only is energy efficiency the cleanest form of meeting demand, the cost-effectiveness of energy efficiency as a resource is better than any known generation source.

Zero-Net-Energy Goals

The *California Long-Term Energy Efficiency Strategic Plan*,[11] adopted in 2008 by the CPUC, and developed with the Energy Commission, the California Air Resource Board, the state's utilities, and other key stakeholders, is California's roadmap to achieving maximum energy savings in the state between 2009 and 2020, and beyond. It includes four "big bold strategies" as cornerstones for significant energy savings with widespread benefit for all Californians:

- All new home construction in California will be zero net energy by 2020.
- All new commercial construction in California will be zero net energy by 2030.
- Heating, ventilation, and air conditioning (HVAC) will be transformed to ensure that the energy performance is optimal for California's climate.
- All eligible low-income customers will be given the opportunity to participate in the low-income energy efficiency program by 2020.

These strategies were selected based on the ability to achieve significant energy efficiency savings and bring energy-efficient technologies and products into the market.

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10 California Public Utilities Commission, *Energy Efficiency Strategic Plan,* updated January 2011. Retrieved from http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

11 California Energy Commission and California Public Utilities Commission, *Long-Term Energy Efficiency Strategic Plan,* updated January 2011. Retrieved from http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

On April 25, 2012, Governor Edmund G. Brown Jr. further targeted zero-net-energy consumption for state-owned buildings. Executive Order B-18-12[12] requires zero-net-energy consumption for 50 percent of the square footage of existing state-owned buildings by 2025 and zero-net0energy consumption from all new or renovated state buildings beginning design after 2025.

To achieve these zero-net-energy goals, the Energy Commission has committed to adopting and implementing building and appliance regulations that reduce the wasteful power and water consumption. The *Long-Term Energy Efficiency Strategic Plan* calls on the Energy Commission to develop a phased and accelerated "top-down" approach to more stringent codes and standards.[13] It also calls for expanding the scope of appliance standards to plug loads, process loads, and water use. The Energy Commission adopted its detailed plan for fulfilling these zero-net-energy objectives in its *2013 IEPR*.[14]

Governor's *Clean Energy Jobs Plan*

On June 15, 2010, as a part of his election campaign, Governor Brown proposed a *Clean Energy Jobs Plan*,[15] which called on the Energy Commission to strengthen appliance efficiency standards for lighting, consumer electronics, and other products. Governor Brown noted that energy efficiency is the cheapest, fastest, and most reliable way to create jobs, save consumers money, and cut pollution from the power sector. He stated that California's efficiency standards and programs have triggered innovation and creativity in the market. Today's appliances are not only more efficient, but they are cheaper and more versatile than ever.

12 Office of Edmund G. Brown Jr., Executive Order B-18-12, April 25, 2012. Retrieved from http://gov.ca.gov/news.php?id=17506.

13 California Energy Commission and California Public Utilities Commission, *Long-Term Energy Efficiency Strategic Plan*, p. 64.

14 California Energy Commission, *2013 IEPR*, pp. 21-26.

15 Office of Edmund G. Brown Jr., *Clean Energy Jobs Plan*. Retrieved from http://gov.ca.gov/docs/Clean_Energy_Plan.pdf.

HVAC Air Filters

Background

Product Description

Air filters remove particulates from the air stream in ducted heating, ventilation, and air-conditioning (HVAC) systems in residential and commercial buildings. The removal of particulates, such as dust, from the air stream protects HVAC equipment from degradation and benefits efficiency. Air filters ensure the proper operation of HVAC equipment by keeping internal components clean and free of particulate build up that causes lower equipment efficiency, reduced reliability, and diminished heat transfer.

Air filters are typically placed in the return duct line adjacent to the air handler in HVAC equipment for easy installation and maintenance. The air handler pulls air through the return ducts and, consequently, through the filter. Air filters are made in a range of styles, materials, and sizes. They're generally one to four inches thick, made of polyester and/or fiberglass, and styled in a flat or pleated pattern.

Air filters use either mechanical filtration or electrostatic filtration to remove particulates from the air. Mechanical or surface media filtration is the capture of particulates through a dense fiber medium. Typically, the air filter media are pleated, allowing more surface area to capture debris. Electrostatic filtration uses electrostatic precipitation to remove particulates. Electrostatic precipitators charge particles and pull them out of the air stream. This can be done in a one- or two-stage system. In a one-stage system, a plate or other surface charges and attracts the particles. In a two-stage system, the particles are charged in the first stage as they flow past a set of charged wires or corona fields, and then are attracted to an oppositely charged plate or grounded media filter as they flow through in stage two.[16] Some air filter models in the market combine mechanical and electrostatic filtration.

There are two elements of air filter performance: (1) the effectiveness at removing particles from the air and (2) resistance to airflow (or pressure drop) across the filter. The minimum efficiency reporting value (MERV) rating is one measurement of an air filter's ability to capture particles sized from 0.3 to 10 micrometers (μm) from the air stream. It is determined by the test method in the ASHRAE 52.2 Standard. MERV rating corresponds to a level of performance, ranging from 1 to 20. The higher the MERV rating, the more effective an air filter is at capturing particles passing through it. Another measurement of an air filter's effectiveness at removing particles is *particle size efficiency*, which is the fraction (percentage) of particles captured on an air filter, as determined by the test method in AHRI Standard 680. Particle size efficiency is measured across

16 Home Innovation Research Labs, High-Efficiency Whole-House Air Filtration System. Retrieved from http://toolbase.org/Techinventory/TechDetails.aspx?ContentDetailID=3794&BucketID=2&CategoryID=60

three particle-size bins: 0.3 to 1.0 μm, 1.0 to 3.0 μm, and 3.0 to 10.0 μm. The percentages can be converted to a MERV rating using the reference table in Appendix A.

The other aspect of air filter performance is the pressure drop or resistance to airflow. As the air stream passes through the air filter, it decreases its velocity due to the resistance of the air filter. This resistance is measured in inches of water column (IWC) at either a specific face velocity or airflow rate. The resistance to airflow of a brand new air filter is called the "initial pressure drop," whereas the resistance when the air filter is loaded with particulates is called the "final pressure drop." The contribution of the air filter to the total system pressure drop is typically 20 percent to 50 percent, depending on the system configuration, filter efficiency, and loading condition.[17] HVAC system designers should take the initial pressure drop of an air filter into account when determining how to size HVAC equipment and related ductwork for residential or commercial buildings. If HVAC designers have access to the initial pressure drop measurements of air filter models in the market, they can make precise, cost-effective system design decisions.

The resistance to airflow in a high static pressure system causes the controls of brushless permanent magnet (BPM) blower motors to increase speed and power draw to maintain system airflow, resulting in an increase in energy consumption. Permanent split capacitor (PSC) blower motors do not have airflow controls like BPM blower motors and thus, will not increase power and speed to maintain system airflow. Instead, since PSC blower motors cannot adjust speed or torque, they reduce power draw and airflow in response to increasing system pressures. This is known as "fall off," when the motor will stop pushing even though the fan continues to turn. As a result, the run time necessary to cool or heat the ambient air to the thermostat's set-point temperature is extended, which can lead to an overall increase in energy use. In addition, excessive pressure drop can damage furnaces due to overheating, can freeze condensing coils in air conditioning units, and can burn out blower motors. Consumers need to purchase air filters with the pressure drop performance that meets their HVAC system specifications to run their equipment efficiently and prevent damage.

Current Labeling

Currently, there are no federal energy efficiency labeling requirements for air filters. Residential HVAC air filters sold in the market do not disclose pressure drop, and if they disclose particle efficiency, they do so inconsistently. In addition to the MERV rating and AHRI 680 particle size efficiency, air filter manufacturers and retailers have their own rating systems for air filter particle capture. The manufacturer 3M uses "Microparticle Performance Rating" (MPR) to characterize its products. MPR measures the ability of an air filter to capture particles 0.3 to 1 μm in size. The Home Depot uses "Filter Performance Rating" (FPR) to characterize the

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17 Stephens, Novoselac and Siegel. "The Effects of Filtration on Pressure Drop and Energy Consumption in Residential HVAC Systems." May 2010. *HVAC&R Research*, Volume 16, Number 3, pgs 273-294.

products it sells. FPR ranges from 1 to 10 based on the weighted air filter performance of large particle capture (60 percent), small particle capture (30 percent), and weight gain/lifetime (10 percent).[18]

A market survey conducted in Northern California by the California investor-owned utilities (IOUs) in 2012 demonstrates the inconsistency of labeling in the market: 28 percent of air filters had no label, 25 percent were labeled only with MPR, 22 percent only with MERV, 12.5 percent with both FPR and MERV, 9.5 percent with both FPR and MPR, and 3 percent with only FPR.[19] Both the lack and inconsistency of particle-efficiency labeling are issues for consumers who are looking for the appropriate replacement air filter for their HVAC system.

As a general rule across the air filter market, as the MERV rating increases, so does the resistance to airflow. However, there are numerous exceptions. Different models of air filters with the same MERV rating can experience a different static pressure drop. As air filter depths increase, MERV rating can increase while maintaining the same pressure drop. Pressure drop information is necessary, and a MERV rating alone is not enough information for consumers and HVAC professionals to make cost-effective purchase decisions.

Title 24 Requirements

The language of the 2013 California Energy Code (California Code of Regulations, Title 24, Part 6, Section 150.0(m)12[20]) establishes requirements for air filter labeling:

12. **Air filtration**. Mechanical systems that supply air to an occupiable space through ductwork exceeding 10 ft (3 m) in length and through a thermal conditioning component, except evaporative coolers, shall be provided with air filter devices in accordance with the following:

    A. **System design and installation**.

18 The Home Depot, Air Filters Buying Guide. Retrieved February 11, 2014 from http://www.homedepot.com/c/Air_Filters.

19 California Investor-Owned Utilities, 2012 Northern California Air Filter Survey. Published in the California Energy Commission Appliance Efficiency Docket on May 10, 2013. Retrieved from http://www.energy.ca.gov/appliances/2013rulemaking/documents/responses/Air_Filter_Labeling_12-AAER-2E/California_IOUs_Response_to_the_Invitation_to_Participate_for_Air_Filter_Labeling_2013-05-09_TN-70821.pdf .

20 2013 California Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Title 24, Part 6-2013, Section 150.0(m) 12. Retrieved from http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf.

i. The system shall be designed to ensure that all recirculated air and all outdoor air supplied to the occupiable space is filtered before passing through the system's thermal conditioning components.
ii. The system shall be designed to accommodate the clean-filter pressure drop imposed by the system air filter device(s). The design airflow rate and maximum allowable clean-filter pressure drop at the design airflow rate applicable to each air filter device shall be determined.
iii. All system air filter devices shall be located and installed in such a manner as to allow access and regular service by the system owner.
iv. All system air filter device locations shall be labeled to disclose the applicable design airflow rate and the maximum allowable clean-filter pressure drop as determined according to Subsection ii above. The labels shall be permanently affixed to the air filter device readily legible, and visible to a person replacing the air filter media.

B. **Air filter media efficiency**. The system shall be provided with air filter media having a designated efficiency equal to or greater than MERV 6 when tested in accordance with ASHRAE Standard 52.2, or a particle size efficiency rating equal to or greater than 50 percent in the 3.0–10 μm range when tested in accordance with AHRI Standard 680.

C. **Air filter media pressure drop**. The system shall be provided with air-filter media that conforms to the maximum allowable clean-filter pressure drop determined according to Section 150.0(m)12Aii, as rated using AHRI Standard 680, for the applicable design airflow rate(s) for the system air filter device(s). If the alternative to 150.0(m)13B is utilized for compliance, the design clean-filter pressure drop for the system air filter media shall conform to the requirements given in Table 150.0-C or 150.0-D.

D. **Air filter media product labeling**. The system shall be provided with air filter media that has been labeled by the manufacturer to disclose the efficiency and pressure drop ratings that demonstrate conformance with Sections 150.0(m)12B and 150.0(m)12C.

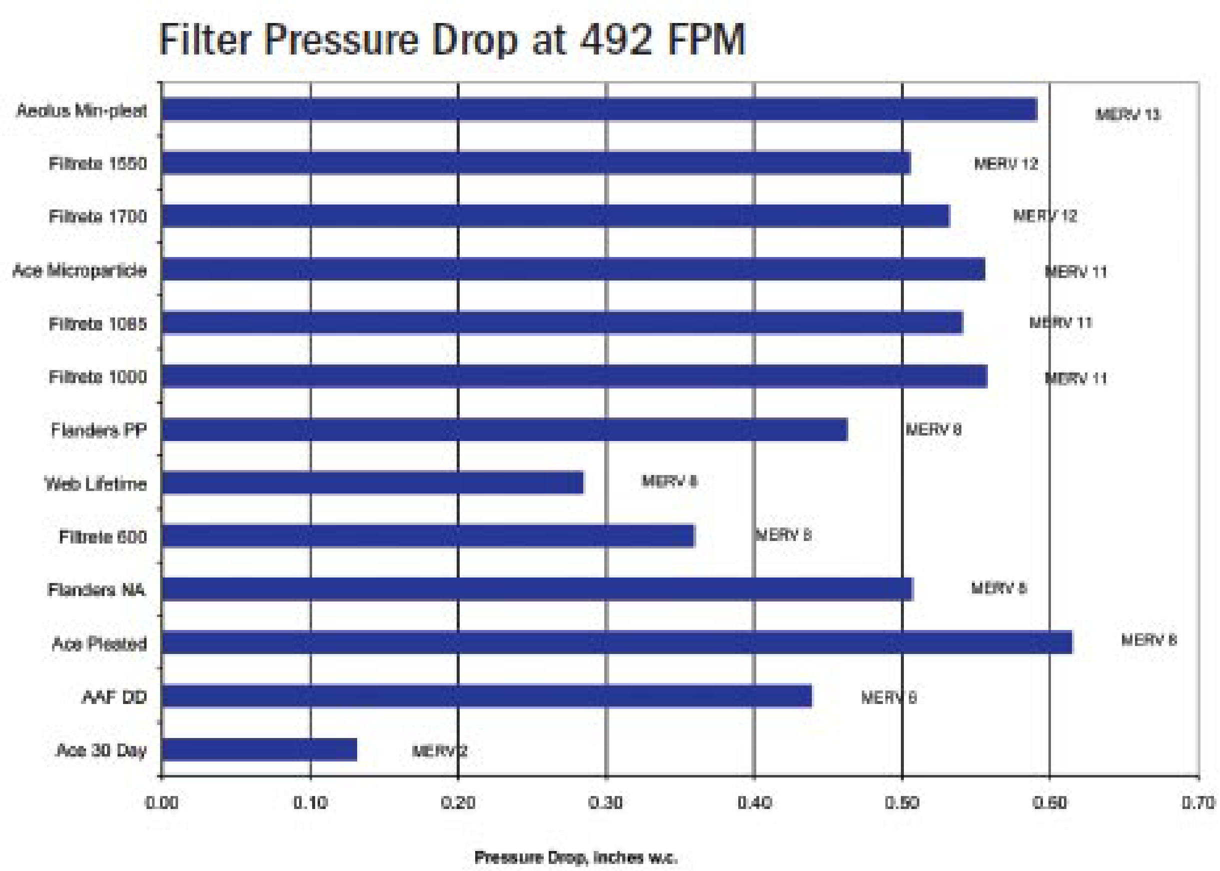
This provision applies to residential forced-air HVAC equipment, which must have filtered air entering the heating and cooling heat exchangers.

The appropriate pressure drop for the air filter is determined by the HVAC system designer's selection of the blower, ducts, and other devices (including the air filter) that have friction losses. Duct systems must be designed for a minimum 350 cfm/ton nominal cooling capacity and a maximum 0.58 watts/cfm, as well as accommodate the clean-filter pressure drop (otherwise known as the *initial pressure drop*) of the air filter.[21] Since HVAC designers do not have access to information on air filter initial pressure drop, they use a rule of thumb of 0.1 IWC

21 Cal. Code Regs., tit. 24, pt. 6, § 150.0(m)13, 15.

at the standard 492 feet-per-minute face velocity, as recommended in the *Air Conditioning Contractors of America (ACCA) Residential Duct Systems, Manual D*. This rule of thumb underestimates the initial pressure drop of the air filter, as demonstrated by the test results of a study[22] investigating the initial pressure drop of 13 popular air filter models at a face velocity of 492 feet-per-minute.

Figure 1: Clean Filter Pressure Drop of 13 Common Air Filter Models



Source: Springer, David. "Is There a Downside to High-MERV Filters?" *Home Energy Magazine.* November 2, 2009.

Since the location of the air filter in the HVAC system must have a label to disclose the designed airflow rate of the system and the pressure drop of the air filter, consumers should be able to easily match the appropriate air filter to their system specifications.

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22 Springer, David. "Is There a Downside to High-MERV Filters?" *Home Energy Magazine.* November 2, 2009.

Figure 2: Example of a Return Grille Label for Air Filter Performance

Airflow Rate (cfm)	Initial Resistance (in. w.c.)	
400	0.03	Use Only Replacement Filters With an Initial Resistance Less Than 0.032 in. w.c. at 400 cfm Airflow Rate

Source: Proctor, John. Residential AC Filters. ASHRAE Journal. October 2012. Pages 92-93.

While Title 24 requires manufacturers to label air filters with pressure drop and particle efficiency, it applies only to new installations that require permits. Therefore, the standards would apply to the HVAC system when installed, but not to subsequent consumer air filter replacements, which do not require a permit. While consumers will be able to find the air filter pressure drop information for their HVAC systems at or near an air filter's installed location (typically, the return grille), they would be unable to identify the appropriate replacement air filter for their HVAC system because of the lack and inconsistency of labeling. Similarly, HVAC system designers may have difficulty determining which air filter models sold in California meet their design specifications or Title 24 requirements.

The proposed labeling requirement for air filters is aimed at providing consumers with the ability to purchase the air filter model appropriate for their HVAC system at the point of sale through air filter labeling. By purchasing the appropriate air filter, consumers will save energy and prevent damage to their HVAC equipment. Furthermore, by labeling air filters and providing a list of performance data for air filter models through a certification process, HVAC system designers can find the air filters that meet their system specifications. In addition, building inspectors can use the information on the label to determine whether the installed air filter complies with the Title 24 regulations. This labeling initiative helps to fulfill Title 24's energy-saving potential in residential buildings.

Regulatory Approaches

Objectives of Labeling

There are two common scenarios that call for labeling. The first is when the market does not supply enough information to allow consumers to make choices mirroring their preferences (asymmetric[23] or missing information). The second is when individual consumption decisions affect social welfare differently than they affect the individual consumer's welfare (externality problems). Air filter labeling empowers consumers to purchase the air filter model that meets their HVAC system specifications, allowing them to run their equipment efficiently and prevent damage to their system. As more consumers purchase the appropriate air filters for their HVAC systems, demand for energy decreases, energy supply remains stable, and greenhouse gases are prevented from entering the atmosphere. Air filter labeling addresses both the asymmetric information and externality problem in the air filter market.

The objective of air filter labeling is to provide the necessary information to consumers, building inspectors, and HVAC system designers to make appropriate purchase, compliance, and design decisions for HVAC systems. This means the label should include the measurements and ratings that align with the pressure drop information provided on the HVAC system and in Title 24's air filter requirements. The information on the label should be easy for consumers and building inspectors to find and large enough to read. It should be clear, concise, and understandable so consumers do not feel overwhelmed and disregard it.

Label location should be consistent, making it easy to find the label at the point of sale. It should make it simple for consumers to compare two products at the same time. Furthermore, the label should provide a level playing field for industry. It should be consistent across all manufacturers, brands, and models.

Proposals

3M

The manufacturer 3M proposed that the Energy Commission adopt an air filter label with the particle efficiency metric "PM2.5" and pressure drop metric "average lifetime resistance." The PM2.5 metric is focused on the capture of fine particulate matter. As proposed by 3M, it's an equal weighting of eight ASHRAE 52.2 particle efficiency channels, encompassing all of "E1" (0.3-1 μm) and "E2" (1.0-3.0 μm) from the ASHRAE 52.2 test method. Average lifetime resistance would be based on a combination of the initial pressure drop and how an air filter is expected to load throughout its lifetime, based on data measured through the ASHRAE 52.2 test method.

23 Manufacturer or retailer knows relevant information about a product that the consumer does not know

The proposal assumes "zero or very little" incremental cost to consumers for labeling. It cites an ASHRAE research project indicating that proper air filter selection can lead to a 2-7 percent improvement in HVAC system energy efficiency ratio (EER).[24]

The Energy Commission considered 3M's proposal as a potential model for California air filter labeling requirements, and although the proposal may be cost-effective due to the low incremental cost and significant potential improvement in EER, it does not meet the Energy Commission's other energy-efficiency-focused objectives. First, the PM 2.5 metric does not align with the air filtration requirements of Title 24. Rather, it is a better indicator of the potential indoor air quality performance of air filters. Second, average lifetime resistance does not align with the air filtration requirements of Title 24. As a result, consumers and contractors would not be able to use this metric to purchase an air filter meeting the reported HVAC system specifications, and building inspectors would not be able to determine Title 24 compliance.

California IOUs and Natural Resources Defense Council

The California IOUs and the Natural Resources Defense Council (NRDC) proposed that the Energy Commission adopt an air filter labeling requirement with the particle efficiency metric MERV (measured by the ASHRAE 52.2-2010 test method) and the pressure drop in inches of water column (in. w.c.) at two face velocities, 300 and 500 feet-per-minute (fpm) (measured by the AHRI 680-2009 test method). The proposal calls for the label to be printed or affixed onto the air filter. In addition, air filter models sold or offered for sale would need test results certified to the Energy Commission for listing in the online Appliance Efficiency Database.

Figure 3: IOU Label Proposal

MERV	Face Velocity (fpm)	Static Pressure Drop (IWC, inches of water column)
(reported value)	300	(reported value)
	500	(reported value)

Source: California IOUs. "Air Filter Testing, Listing and Labeling", Codes and Standards Enhancement (CASE) Initiative for PY 2013: Title 20 Standards Development. July 29, 2013.

The IOU proposal assumes a label cost of \$0.02 per filter for manufacturers, potentially marked up to \$0.10 per filter for consumers. It assumes no incremental cost for the test and list

24 Stephens, Brent; A. Novoselac; and J. Siegel. "The Effects of Filtration on Pressure Drop and Energy Consumption in Residential HVAC Systems (RP-1299)." *HVAC&R Research* Vol. 16 No. 3 (May 2010): 273-294.

requirement since major manufacturers are presumed to be testing their products to the ASHRAE 52.2 and/or AHRI 680 test methods in compliance with Title 24.

The proposal assumes HVAC designers will improve system sizing as a result of having air filter pressure drop information, reportedly saving consumers first costs of $200 per dwelling on ductwork. It assumes HVAC system designers and consumers will purchase air filters appropriate for their HVAC system specifications (initial pressure drop), which will reduce an unspecified amount of energy through lower resistance of air flow in the HVAC system.

The Energy Commission considered the IOUs' proposal as a potential model for California air filter labeling requirements. Certain elements of the proposal are incorporated into the Energy Commission's proposal. However, the Energy Commission did not align with this proposal fully.

The MERV rating requirement is expressly recognized in the Energy Commission's existing Title 24 regulations. The Title 24 standards require a MERV rating of 6 or greater. By requiring MERV rating on the label, building inspectors can quickly determine if air filters are in compliance. In addition, MERV rating is widely used and simple and can be determined by directly applying the ASHRAE Standard 52.2 test results or by converting the AHRI 680 test results.

The Energy Commission sees the benefit in certifying air filter models in the Appliance Efficiency Database. This supports Title 24 compliance efforts and provides HVAC system designers with a repository of air filter performance data.

The Energy Commission agrees that affixing the label to air filter itself is beneficial. Building inspectors can determine whether an installed air filter meets the HVAC system's specifications. It also makes it easy for consumers to replace their air filter at the point of sale and to compare two air filter models at the same time.

The Energy Commission concluded that the proposed initial pressure drop metrics were not optimal for consumer and building inspector purposes. Per Title 24, the location of the air filter in the HVAC system must have a label to disclose the design airflow rate of the system and the pressure drop of the air filter. This design airflow rate is calculated at the volumetric rate cubic-feet-per-minute (cfm) to determine inches of water column. The IOU proposal calls for pressure drop to be calculated at face velocities of 300 fpm and 500 fpm. Thus, consumers and building inspectors would have to convert fpm to cfm to receive the information they need to determine Title 24 compliance or purchase the air filter meeting the HVAC system's labeled specifications. This is a more burdensome and less efficacious approach to meeting the purpose of the label.

AHRI 680 Standard − Format for Published Rating

The Energy Commission also considered requiring the AHRI 680 Standard Format for Published Rating as an air filter label. Some components of this rating format were incorporated into the Energy Commission's proposal, but other components, which did not meet the Energy Commission's labeling objectives, were not included.

Figure 4: AHRI 680 Standard Format for Published Rating − Example

AHRI 680 Standard Rating						
Airflow Rate (CFM)	Initial Resistance ("wc)	Final Resistance** ("wc)	Dust Holding Capacity** (g)	Particle Size Efficiency** (0.30 - 1.0 µm)%	Particle Size Efficiency** (1.0 - 3.0 µm)%	Particle Size Efficiency** (3.0 - 10 µm)%
400	0.05					
800	0.10					
1200	0.17					
1600	0.25					
2000*	0.32	0.50	45	17	53	87
* Maximum Rated Airflow Rate as published by the manufacturer.						
** Standard Rating requires that these shall be tested at Maximum Rated Airflow Rate as published by manufacturer.						

Source: ANSI/AHRI Standard 680 (I-P). 2009 Standard for Performance Rating of Residential Air Filter Equipment. August 2, 2010.

The Energy Commission recognizes the value of the air flow rates used in the AHRI 680 Standard Rating. Measuring inches of water column using the volumetric flow rate cubic-feet-per-minute matches the pressure drop information required on the HVAC system by Title 24. Building inspectors and consumers can use this to determine compliance or the appropriate air filter replacement. This specific aspect fulfills the Energy Commission's objective of making the label easy to use and understand.

The AHRI 680 Standard Rating is advantageous to HVAC system designers who understand the air filter performance metrics of the rating. However, it is overly complex for consumers who are trying to replace their spent air filter with the appropriate model. These consumers will receive more information than is necessary at the point of sale and may feel overwhelmed. In addition, this label is relatively large and may need resizing to fit onto the common one-inch-thick air filter. This resizing would make the label difficult for consumers and building inspectors to read.

Savings and Cost Analysis

The proposed air filter labeling requirements represent a significant energy and cost savings opportunity for California households.

Incremental Cost

The costs of implementing an air filter label include initial design, printing plates, production line adjustments, ink, and adhesive labels. Spreading these costs across the large number of air filters manufactured and sold each year, the manufacturer 3M characterized the incremental cost of air filter labeling as zero or near zero in its proposal.[25] The California IOUs characterized the incremental cost as $0.02 per filter in its proposal[26] with the use of manufacturer information submitted during the Invitation to Participate. Assuming a 50 percent markup for a commoditized label, the Energy Commission used $0.03 as the incremental cost per filter for its analysis.

Air filter replacement depends on the rate and amount of particulates that build up on the filter. Some households replace their air filters four times per year, as recommended, while others don't replace them at all (and don't even know where the air filter is located). For its analysis the Energy Commission assumes air filters are replaced twice per year. A study funded by the Energy Commission indicates there are 1.25 filter locations per HVAC system.[27] Accounting for air filter replacement and filters-per-system results in a total annual incremental cost of $0.08 per household, rounded to the nearest penny.

Energy Savings

The energy savings achieved by moving from a higher-resistance air filter to one designed for the pressure drop of the system depends on a number of variables, notably climate, equipment selection, system design, and performance condition.

Higher-resistance filtration causes a larger energy penalty in cooling-dominated climates versus heating-dominated climates. In climates dominated by either heating or cooling, a PSC-driven blower will decrease power and airflow in response to higher static pressure, but the furnace and air conditioner will increase their loads, typically resulting in a net energy penalty.

A BPM-driven blower operates best in a heating-dominated climate with a low pressure drop system and filter. As climate becomes cooling-dominated and system pressure drop increases, a BPM-driven blower will operate less efficiently since it increases power to maintain the airflow rate of the system.

In mixed heating and cooling climates, an energy penalty for higher-resistance filters typically is incurred regardless of blower motor type. For climates with both low heating and cooling loads, the energy impact of higher-resistance filters is small. The net average impact across all

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25 3M response to Invitation to Submit Proposals, July 29, 2013. Retrieved from http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2E_Air_Filter_Labeling/3M_Comments_re_Air_Filter_Labeling_2013-08-02_TN-71785.pdf.

26 California IOUs. *Air Filter Testing, Listing and Labeling: Codes and Standards Enhancement (CASE) Initiative for PY 2013: Title 20 Standards Development.* July 29, 2013.

27 Proctor, John, Rick Chitwood, and Bruce A. Wilcox. 2011. *Efficiency Characteristics and Opportunities for New California Homes*. California Energy Commission. Publication Number: CEC-500-2012-062.

California climate types, heating and cooling loads, blower motor types, duct leakage scenarios, and filter loading scenarios is a savings of 1 percent.[28]

The 2009 California Residential Appliance Saturation Survey[29] provides average heating and cooling energy consumption across household type and HVAC equipment. An average HVAC system energy savings of 1 percent corresponds to an average household energy savings of 3.78 kilowatt hours (kWh) and 0.7 therms per year.[30] These are the expected energy savings per year per household of the proposed regulations.

Cost-Effectiveness

Assuming two filter changes per year and an average of 1.25 filters per residential HVAC system[31], a consumer's annual incremental cost per air filter for labeling is $0.08. The average energy benefit to a consumer for selecting the appropriate filter for his or her HVAC system is 3.78 kWh and 0.7 therms per year. This amounts to $1.32 in annual monetary savings. The net benefit to the household is $1.24 per year.

The net benefit does not account for avoided equipment failure or decreased maintenance costs due to the prevention of overheated furnaces, frozen air conditioner condensing coils, or burnt out blowers. The Energy Information Administration's *2009 Residential Energy Consumption Survey* (RECS) indicates that 3 million California households[32] do not have routine maintenance performed on their central air conditioning units and 7.3 million households[33] do not have routine maintenance performed on their heating equipment. RECS also reports that 1 million central air conditioners and 3.6 million primary heating systems in California households are 20 years old or older.[34] Maintenance costs are likely a significant consumer cost despite the difficulty in estimating them. The proposed regulations could save household significantly more money than shown in the analysis.

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28 Walker, Dickeroff, Faulkner and Turner (Lawrence Berkeley National Laboratory). *Energy Implications of In-Line Filtration in California*. LBNL-6143E. October 2012.

29 KEMA, Inc. 2010. *2009 California Residential Appliance Saturation Study*. California Energy Commission. Publication Number: CEC-200-2010-004.

30 Calculations are presented in Appendix B.

31 Proctor, John, Rick Chitwood, and Bruce A. Wilcox. 2011. *Efficiency Characteristics and Opportunities for New California Homes*. California Energy Commission. Publication Number: CEC-500-2012-062.

32 Energy Information Administration, *2009 Residential Energy Consumption Survey*, Table HC7.11 Air Conditioning in Homes in West Region, Divisions, and States. Final release of April 2013.

33 Energy Information Administration, *2009 Residential Energy Consumption Survey*, Table HC6.11 Space Heating in U.S. Homes in West Region, Divisions, and States. Final release of April 2013.

34 Ibid.

Statewide Impact

The Energy Commission used data from the *2009 Residential Appliance Saturation Survey* (*RASS*) and 2010 Census to determine the number of residential HVAC systems that use filters and the energy consumption attributed to those systems. The percentage of HVAC systems using air filters with excessive pressure drop is estimated as high as 85 percent in one study.[35] However, given the degree of uncertainty, the Energy Commission assumed 50 percent of HVAC systems are using filters with excessive pressure drop.

Using data provided in the *2009 RASS*, an estimated 7,926,465 HVAC systems use air filters in California. Given an overall average of 1 percent energy savings due to excessive filter pressure drop, this corresponds to an estimated statewide savings of 29,994,466 kWh and 5,565,660 therms per year, amounting to $10,456,924 annually.[36] Factoring in the estimated unit costs of labels, the net benefit is $9,862,439 annually.

Air Filter Labeling: Technological Feasibility

The application of a label to an air filter is technologically feasible. Sticker labels require initial design, printing plates, production line adjustments, ink, and adhesive labels. These are all capabilities that air filter manufacturers possess. Air filter manufacturers may also choose to use molding or other approaches to labeling that still comply with the proposed regulations if they find cheaper, lower-cost labeling methods.

The Energy Commission assumes that the majority of air filter manufacturers are already testing their air filter products according to ASHRAE 52.2 and AHRI Standard 680. These test methods are technologically feasible for those manufacturers who are not conducting these tests. Manufacturers who only test for particle efficiency per AHRI Standard 680 can convert resulting data into a MERV rating.

Safety and Environmental Issues

Excessive pressure drop can damage furnaces due to overheating and can freeze condensing coils in air-conditioning units. This damage decreases the lifetime of HVAC equipment and increases maintenance costs. In addition, an overheated furnace can become a fire hazard in certain circumstances.

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35 Proctor, John, Rick Chitwood, and Bruce A. Wilcox. 2011. *Efficiency Characteristics and Opportunities for New California Homes*. California Energy Commission. Publication Number: CEC-500-2012-062.
36 Calculations and methodology in Appendix B.

An annual state energy savings of nearly 30 gigawatt-hours and 5.5 million therms amounts to preventing more than 85.7 million pounds[37] of carbon dioxide from entering the atmosphere per year. This is the equivalent of removing more than 8,100 cars from the road annually.[38]

The proposal would not result in negative environmental impacts, as it would not increase or change the purchase or disposal requirements for air filters, and it would not alter their composition.

Proposal for Air Filters

The Energy Commission analyzed the regulatory approaches proposed by 3M, California IOUs, and NRDC, along with the *AHRI Standard 680 Format for Published Rating*. It evaluated the cost-effectiveness and feasibility of implementing the proposed regulations in California and determined that the monetary savings from reduced energy consumption are greater than the costs. It also determined that compliance with the regulations is technologically feasible.

In addition to a label on the air filter, the proposed regulations require certification of product performance according to the AHRI 680-2009 test method for pressure drop and either the AHRI 680-2009 or ASHRAE 52.2-2012 test method for MERV, Particle Size Efficiency and Dust Holding Capacity. The proposed certification process is consistent with what is used for other appliances and requires that manufacturers submit data specified in Title 20, Section 1606, Table X for each model. Certification also requires that manufacturers sign a declaration that the products under certification comply with all applicable provisions of the *Appliance Efficiency Regulations*.

The Energy Commission is proposing the following changes and additions to the *Appliance Efficiency Regulations*. All language below would be new to the appliance efficiency regulations, with the exception of section headers.

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37 California Energy Commission. *Energy Aware Planning Guide*, CEC-600-2009-013, February 2011, Section II: Overview, page 5.

38 U.S. Environmental Protection Agency. "Calculations and References." Retrieved March 24, 2014, from http://www.epa.gov/cleanenergy/energy-resources/refs.html.

Regulatory Language

Section 1601. Scope.

(x) Air filters for use in forced-air heating or cooling equipment

Section 1602. Definitions. (x)

"Air filter equipment" means an air-cleaning device installed in forced-air heating or cooling equipment and used for removing particulate matter from the air.

"Air filter media" means the part of the air filter equipment that conducts the actual removal of particulates.

"Airflow rate" means the actual volume of test air passing through the device per unit of time, expressed in cubic-feet-per-minute, to three significant figures.

"Dust holding capacity" means the total amount of dust captured on the air filter equipment. Dust holding capacity shall be established at the maximum rated airflow rate, as published by the manufacturer.

"Final resistance" means the resistance of the air filter equipment operating at its maximum rated airflow rate at which the test is terminated and results determined.

"Forced air" means a HVAC system that uses air as its heat transfer medium.

"HVAC system" means a space-conditioning system or a ventilation system.

"Initial resistance" means the resistance of the air filter equipment operating at its rated airflow rate, as published by the manufacturer, with no dust load.

"Maximum rated airflow rate" means the highest airflow rate at which the air filter equipment is operated, as published by the manufacturer.

"Minimum efficiency reporting value (MERV)" means the composite particle efficiency metric defined in ASHRAE 52.2-2012.

"Particle size" means the polystyrene latex (PSL) light-scattering equivalent size of particulate matter as expressed as a diameter in micrometers (μm).

"Particle size efficiency" means the fraction (percentage) of particles that are captured on air filter equipment. Particle size efficiency is measured in three particle size ranges: 0.3-1.0, 1.0-3.0, 3.0-10 micrometers (μm).

“Pressure drop” means the drop in HVAC system static pressure versus air flow rate across air filter media.

Section 1604. Test Methods for Specific Appliances.

(x) Air Filters.

The test methods for air filters are shown in Table X.

Table X: Air Filter Test Methods

Appliance	Appliance Performance Criteria	Test Method
Air Filters	Air Filter Pressure Drop	AHRI 680-2009
	Air Filter Particle Size Efficiency and MERV	AHRI 680-2009 or ASHRAE 52.2-2012
	Dust Holding Capacity	AHRI 680-2009 or ASHRAE 52.2-2012

The following documents are incorporated by reference in Section 1604.

AIR-CONDITIONING, HEATING, AND REFRIGERATION INSTITUTE (AHRI)

AHRI 680-2009 2009 Standard for Performance Rating of Residential Air Filter Equipment

ASHRAE

ASHRAE 52.2-2012 Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size

Section 1606. Filing by Manufacturers; Listing of Appliances in Database.

Table X:
Data Submittal Requirements

	Appliance	Required Information	Permissible Answers
X	Air Filters	MERV	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20
		Particle Size Efficiency for 0.3 to 1.0 µm particle size	Test results in multiples of 1%. When the Particle Size Efficiency is greater than 99%, it shall be reported as “99%<”.
		Particle Size Efficiency for 1.0 to 3.0 µm particle size	Test results in multiples of 1%. When the Particle Size Efficiency is greater than 99%, it shall be reported as “99%<”.
		Particle Size Efficiency for 3.0 to 10.0 µm particle size	Test results in multiples of 1%. When the Particle Size Efficiency is greater than 99%, it shall be reported as “99%<”.
		Test Procedure used to determine air filter efficiency performance	AHRI 680-2009, or ASHRAE 52.2-2012
		Maximum Rated Airflow Rate	Test results in cubic-feet-per-minute, in multiples of 1
		Initial Resistance at 400 cubic-feet-per-minute (cfm)	Test results to one-hundredths of an Inch of Water Column
		Initial Resistance at 800 cubic-feet-per-minute (cfm)	Test results to one-hundredths of an Inch of Water Column
		Initial Resistance at 1,200 cubic-feet-per-minute (cfm) unless maximum rated airflow rate (as published by the manufacturer) is less than 1,200 cfm	Test results to one-hundredths of an Inch of Water Column
		Initial Resistance at 1,600 cubic-feet-per-minute (cfm) unless maximum rated airflow rate (as published by the manufacturer) is less than 1,600 cfm	Test results to one-hundredths of an Inch of Water Column
		Initial Resistance at 2,000 cubic-feet-per-minute (cfm) or the maximum rated airflow rate as published by the manufacturer	Test results to one-hundredths of an Inch of Water Column
		Final Resistance at 2,000 cubic-feet-per-minute (cfm) or the maximum rated airflow rate as published by the manufacturer	Test results to one-hundredths of an Inch of Water Column
		Dust Holding Capacity	Test results in multiples of one gram.
		Test Procedure used to determine air filter dust holding capacity	AHRI 680-2009, or ASHRAE 52.2-2012

Section 1607. Marking of Appliances.

(d) Energy Performance Information.

(14) ***Air Filters.***

Each unit shall be marked, permanently and legibly, on an accessible and conspicuous place on the edge of the filter itself, in characters of font size 12, with the following information, as applicable to the air filter model: the MERV rating of the unit and initial resistance at 400 cfm, 800 cfm, 1200 cfm, 1600 cfm, and either 2000 cfm or maximum rated airflow rate, as published by the manufacturer.

The information shall be disclosed in the format in Table Z.

Table Z

MERV	**Airflow Rate (CFM)**	**400**	**800**	**1200**	**1600**	**2000***	*Max Rated Airflow
[value]	**Initial Resistance (IWC)**	[value]	[value]	[value]	[value]	[value]	

If the marking on the air filter is not legible through its retail packaging, then the packaging shall also be labeled with the same information and in the same format as Table Z.

Dimming Fluorescent Ballasts

Background

Product Description

Fluorescent ballasts are used to start and power fluorescent lamps, such as a common 4-foot linear T8 lamp. A dimming fluorescent ballast has the additional ability to vary the output of attached lamps. To make use of this additional functionality, these ballasts are almost always connected to lighting controls beyond an on/off switch or relay such as day lighting controls and dimmer switches. This report focuses specifically on dimmable ballasts that are capable of dimming to or below 50 percent of the ballast's maximum output and that are currently not regulated by the U.S. Department of Energy (DOE).

There are three common types of control signals used to communicate desired light levels to a dimming ballast: digital, low-voltage DC, and phase chopping controls. A digital control signal sends data packets to the ballast directing operation. A low-voltage DC control typically uses between 0 and 10 volts to indicate ballast output between 0 percent (off), 100 percent, and anywhere in between. A phase-chopping control signal will alter the utility sinusoidal waveform, which is interpreted by the ballast as a command to increase or decrease output.

Some ballasts dim through continuous ranges, while others are designed to dim to predesigned levels, called "step dimming" because their outputs follow discrete "steps" rather than continuous curves. The controls for step-dimming ballasts can be translations of the above-mentioned signals, or they can consist of a series of on/off control inputs. Multilamp ballasts may also achieve dimming by simply switching off some of the connected lamps. Ballasts that have this functionality have connectors to fluorescent lamps that are individually controlled by the ballast. For example, a four-lamp ballast can achieve a 50 percent lighting level by simply turning off two of the four attached lamps.

Dimming ballasts are inherently energy-saving devices and can significantly reduce energy consumption by precisely lighting spaces instead of over lighting them (as is more common), and by incorporating feedback to lighting systems, such as levels of daylight, to further reinforce proper lighting. However, at full output, dimming ballasts can and often do perform worse than fixed-output ballasts that are designed and optimized for a single point of operation.

Dimming fluorescent ballasts generally have two inputs and one output. *Dimming ballast inputs* are the grid power used to power the device, referred to in this report as "input power" and a control signal. The output of a dimming ballast is the "arc power," which is a high-voltage, typically high-frequency supply of power to a fluorescent lamp. Sometimes as part of the arc power, a DC offset signal provides constant heating in the cathodes of a fluorescent lamp. This can extend the life of a lamp by reducing the stress of rapid heating on the cathode during lamp starting and/or to maintain stable and functional modes of operation in dimmed states.

Current Regulations

No current state or federal efficiency standards, test procedures, or labeling requirements exist for deep-dimming fluorescent ballasts. The U.S. Department of Energy (DOE) has set efficiency standards for other types of fluorescent lamp ballasts, but due to special exemptions from preemption in Sections 327(b) and 327(c) of EPCA,[39] the Energy Commission is not preempted from setting efficiency standards for fluorescent ballasts that do not have federal standards. Ballasts that dim below 50 percent of full output are not included in the federal standards, and a new rulemaking has not been planned to cover these products.

The Energy Commission's *2013 Building Energy Efficiency Standards,* effective July 1, 2014, require that new nonresidential, high-rise residential, and hotel/motel buildings that install dimming fluorescent ballasts,use ballasts that are able to dim to at least one step in each the following ranges:[40]

Figure 5: Table 130.1-A of Title 24

Luminaire Type	**Minimum Required Control Steps (percent of full rated power)**				**Uniform level of illuminance shall be achieved by:**
Linear fluorescent and U-bent fluorescent > 13 watts	Minimum one step in each range:				Stepped dimming; or continuous dimming; or switching alternate lamps in each luminaire, having a minimum of 4 lamps per luminaire, illuminating the same area and in the same manner
	20-40%	50-70%	80-85%	100%	

Source: Cal. Code Regs., tit. 24, pt. 6, § 130.1 and Table 130.1-A

Dimming ballasts have historically served a very small segment of the ballast market, estimated to be around 1 percent in 2005.[41] However, the above requirement in the *2013 Building Energy Efficiency Standards* is expected to greatly expand the use of multilevel lighting and, therefore,

39 42 U.S.C. § 6297(b) and (c).

40 Cal. Code Regs., tit. 24, pt. 6, § 130.1 and Table 130.1-A (multi-level lighting controls and uniformity requirements).

41 DOE Technical Support Document for Fluorescent Ballast Final Rule, November 2011, page 3-14. http://www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0016-0067.

the use of dimming ballasts, including deep-dimming ballasts, in commercial lighting applications.

This large expansion of the dimming ballast market increases the importance of the energy efficiency of the product to California's grid. Currently, only an estimated 225 GWh/yr of energy are used in dimmable fluorescent ballasts and their attached lamps. However, this is estimated to reach nearly 3,600 GWh/yr by 2020 by displacing fixed output ballasts. Of that energy, 20 percent on average is wasted in the ballast itself before ever reaching the fluorescent lamp. The market expansion will also put pressure on supply and price, encouraging the potential introduction of less efficient and cheaper dimming ballast solutions than are available.

Regulatory Approaches

Test Procedure

The test procedure used to evaluate the energy consumption of ballasts in all the approaches described below was a modified version of the current DOE test procedure for fluorescent ballasts: 10 C.F.R. Section 430.23(q) (Appendix Q1 to Subpart B of part 430). This test method measures only ballast performance at full arc and standby power; so to measure energy performance at deeper dimming levels (80 percent, 50 percent arc power), the Energy Commission proposes a modified test procedure to provide the additional measurements. The additional steps required are to tune the arc power to a set percentage of the measured full arc power for each measurement. The California investor-owned utilities (IOUs), as part of their Codes and Standards Enhancement (CASE) report, tested 34 ballasts using this altered version of the DOE test method and found the measurements to be repeatable and reliable.

Tuning the ballast to the required measurements is straightforward for continuously dimming ballasts but is less obvious for stepped dimming ballasts or ballasts that control individual lamps. Staff proposes substitute measurement for 80 percent and 50 percent arc power for those ballasts that are not precisely tunable. Specifically, staff proposes that the closest measurement above 65 percent and at or below 90 percent full arc power be used for a substitute for the 80 percent arc power measurement provided that 80 percent is not achievable. The dimming state that is between 35 percent and 65 percent full arc power and is closest to 50 percent can be used as a substitute measurement for 50 percent dimming where 50 percent full arc power is not achievable. If a dimming ballast cannot achieve dimming at 80 percent or 50 percent arc power, or dimming within the alternative ranges, then staff proposes that no measurement be taken as substitutes.

Staff also modified the DOE test procedure by elaborating on lighting control selection. The proposed selection method creates preference for controls manufactured by the ballast manufacturer, followed by the ballast manufacturer's recommendation, followed by laboratory expertise in finding an appropriate control.

The proposed test method includes an alteration to the standby mode method. The altered method sets a defined steady state of the control system for 90 minutes to allow a ballast to potentially "go to sleep," a function potentially used in digitally controlled ballasts with microcontrollers that have two-way communication. In addition, staff proposes that standby mode power be measured as the average of power measurements taken over a 5-minute period to avoid any cyclical problems or varying standby power.

The proposed test method also contains a method for converting measurements into annual energy use for comparison to the performance standard. The following equation is provided using the four input power measurements required by the proposed test procedure and four time constants.

$$Annual\ Energy\ Use = \frac{(P_{100} \times t_{100} + P_{80} \times t_{80} + P_{50} \times t_{50} + P_0 \times t_0)}{1000}$$

P_{100} represents the ballast input power at 100 percent arc power. P_{80} represents the ballast input power at 80 percent arc power. P_{50} represents the ballast input power at 50 percent arc power. P_0 represents the standby power of the ballast. The associated "t" variables represent the expected amount of time a ballast will operate at the associated arc power. The equation is divided by 1000 to convert the numerator units of watt-hours per year into kilowatt-hours per year.

The time constants are provided in a table and are based upon the duty cycle suggested in the IOU CASE report (See figure 6.) Staff proposed alternative duty cycles based upon the primary duty cycle for ballasts that cannot be tested at 80 percent, 50 percent, or either arc powers.

Expanding the DOE Standard

DOE adopted a final rule for fluorescent dimming ballast standards on November 11, 2011 for fixed output and dimming ballasts that do not dim below 50 percent full output.[42] The new DOE standards for these ballasts will take effect in November 14, 2014.

Energy Commission staff evaluated applying the requirements for commercial programmed-start ballasts covered by DOE to dimming ballasts that are not covered. DOE requires that those ballasts have a ballast luminous efficacy (BLE) that meets or exceeds the following equation:

$$Measured\ BLE\ \geq \frac{A}{1 + B \times arc\ power^{-C}}$$

42 76 Fed. Reg. 70548 (Nov. 11, 2011).

where A=0.993, B=0.51, and C=0.37. This standard applies only at full output power of a ballast (not dimmed state) and generally requires a BLE of 0.85 to 0.91, depending on the arc power.

The Energy Commission evaluated this standard against IOU test data of 34 dimming ballasts. Of those, only 9 (26.5 percent) complied with the DOE standard. In other words, 73.5 percent of the products tested are less efficient at full output than ballasts that are covered by DOE. Applying this standard would save energy by requiring the noncompliant ballasts to improve their full output efficiency. The use of better components would also likely yield energy savings at dimmed states as well.

This approach is technically feasible, as there are dimming ballasts on the market that already exceed the DOE standard level across manufacturers, control types, and arc powers. But staff is not proposing to align with the DOE standard because it does not save as much energy as staff's proposed regulatory approach.

IOU CASE Report

The California IOUs submitted a CASE report proposal for dimming ballast standards that would set requirements for BLE at 50 percent, 80 percent, and 100 percent output, as well as standby mode and flicker.[43] The Natural Resources Defense Council (NRDC) supported the standard levels proposed by the IOUs.[44] Compliance with BLE standards would be determined using the following formula:

$$BLE \geq \frac{ArcPower_{test\ point}}{ArcPower_{test\ point} \times A + ArcPower_{full\ output} \times B + C}$$

where A=0.84, B=0.235, and C=3.85 and $ArcPower_{test\ point}$ is measured at 50 percent, 80 percent, and 100 percent output. The proposal also would require that ballasts draw no more than 1 watt in standby mode and that lamps do not vary in amplitude by more than 30 percent for frequencies below 200 Hz to address flicker. Again, the Energy Commission evaluated this standard against IOU test data of 34 dimming ballasts. Staff found that there are products on the market today that comply with the proposed BLE levels with different controls and various arc powers.

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43 *Dimming Fluorescent Ballasts Codes and Standards Enhancement Initiative,* August 5, 2014, PGE SCE SDGE SCG, pp. 27-28, http://energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOU_Standards_Proposal_Ballasts_Updated_2013-08-06_TN-71809.pdf .

44 http://energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/NRDCs_Proposals_on_Lighting_Standards_2013-07-29_TN-71731.pdf .

Although the majority of tested products meet the standby power proposal, several do not. All ballasts that did not comply with the standby standard use digital control signals, such as DALI. These products all used fewer than 2 watts in standby but could save as much as 5 kWh a year by reducing that to 1 watt or fewer.

While the IOUs proposed a flicker standard, they did not propose a test method nor provide feasibility or current market status of products relative to flicker. Products that would most likely see flicker would be ballasts using phase-chopping controls and continuous dimming ballasts at very low dimming levels. This made evaluation of this aspect of the proposal difficult and in need of supporting test methodology and data.

Staff does not propose this IOU approach because it would not save as much energy as staff's proposed approach.

Cathode Cut-Out Design Standard

Staff also evaluated a design standard that would require dimming ballasts to reduce or eliminate cathode heating at dimming levels greater than 60 percent. Cathode heating is required to coax electrons to excite mercury in a stable manner while reducing overall arc power. However, cathode heat is not needed for all modes of operation and is often unnecessary at arc powers closer to full output. Cathode heat cut-out technology turns off this heating functionality where it is no longer needed and is wasteful. While several manufacturers on the market already implement this feature in one way or another, many models do not use this feature. The reduction in ballast power is around 3 watts per lamp when operated at higher lamp output, roughly halving the power associated with the ballast.

Requiring cathode cut-out at arc power close to full output would provide a single, clear path to compliance by setting a design standard and would take advantage of a cost-effective market opportunity to save significant energy. But this proposed approach would not allow for innovation in compliance through alternative ballast technologies that would equally reduce energy consumption. Because performance standards are statutorily favored over design standards, and because staff's proposal is for a performance standard that would be equally effective at reducing significant energy consumption, staff does not propose this design standard approach.

Annual Energy Use Performance Standard

Staff evaluated an alternative annual energy use standard that would require the estimated energy consumption attributed to the ballast to be less than the following equation in kilowatt-hours per year:

$$Annual\ Energy\ Use_{Ballast} \leq 0.22 \times Full\ Arc\ Power + 18$$

The annual energy use of the ballast would be established using a combination of an assumed duty cycle and four measurement points: 100 percent, 80 percent, 50 percent, and 0 percent (lamp off/standby) arc power. Annual energy use of the ballast would be calculated from test data using the following formula:

$$Annual\ Energy\ Use_{ballast\ measured} = (T_{100} \times (P_{input100} - P_{arc\ 100}) + T_{80} \times (P_{input80} - P_{arc\ 80}) + T_{50} \times (P_{input50} - P_{arc\ 50}) + T_0 \times P_0)/1000$$

The calculation is essentially the various power consumption measurements of the ballast (P_{input} – P_{arc}) multiplied by how many hours it is expected to operate at that power level. Figure 6 shows values for annual hours of use per year used to evaluate this regulatory approach.

Figure 6: Duty Cycle of Continuous Dimming Ballasts

Operational State	Hours of Use
100% arc power	$T_{100} = 637$
80% arc power	$T_{80} = 1592$
50% arc power	$T_{50} = 955$
0% arc power	$T_0 = 5576$[45]

Source: *Dimming Fluorescent Ballasts Codes and Standards Enhancement Initiative*. August 5, 2014, PG&E SCE SDG&E SCG, Table 4.1, pp 13.

Tested ballasts meet this standard across multiple manufacturers, maximum arc powers, and control types. This approach allows for design tradeoffs among any of the four measured points, with weights given to each mode of operation. This proposal has the highest calculated energy savings of the performance approaches evaluated and is therefore what staff chose as the basis for its proposal in this report.

Staff Proposal

Staff's proposal is the result of analysis of four potential approaches weighed against a baseline consisting of current product performance. A more detailed discussion of method, assumptions, and analysis is contained in Appendix C. Figure 7 shows the resulting estimated energy savings in 2030 and how many of the 34 ballasts tested by the IOUs would already meet the standard.

45 Remaining hours in the year after considering T100, T80, and T50.

Figure 7: Comparison of Regulatory Approaches

Approach	Standard Type	Estimated energy savings for the year 2029 (GWh)	Number of Products that comply out of 34 tested
Expanding DOE standards	Performance	181	9
IOU CASE Report	Performance	214	9
Cathode cut-out design standard	Design	142	8
Annual energy use performance standard	Performance	388	10

Source: California Energy Commission.

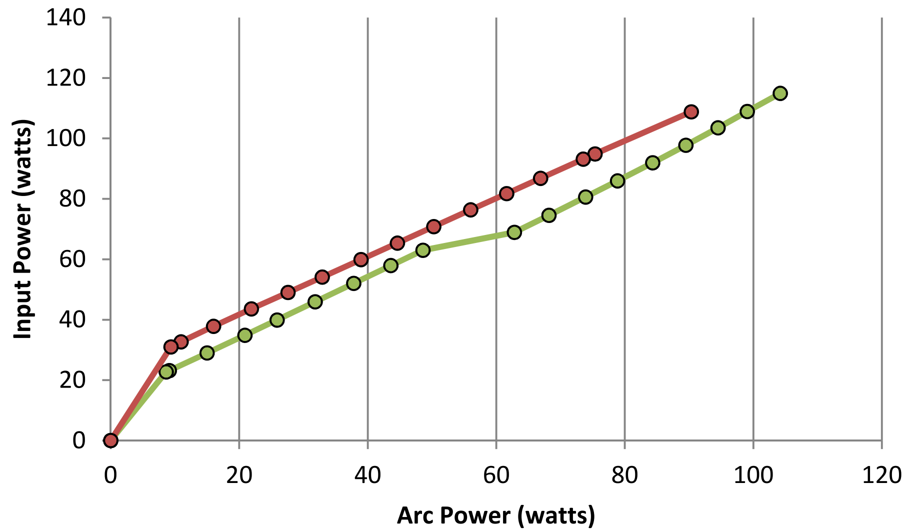
Staff chose to propose the Annual energy use standard as it was a performance standard with the greatest energy savings. Staff proposes that the standard take effect for deep-dimming fluorescent ballasts manufactured on or after January 1, 2016.

Technical Feasibility

There are a number of technology and design approaches that can improve the efficiency of ballasts generally, as well as the efficiency of dimming ballasts specifically. There are multiple products available in the market that meet the standards that would not need to be redesigned; therefore, the standard is technically feasible. The existence of compliant products in the market also speaks to the viability of the technologies in commercialized production and to meet the needs of the end user.

Figure 8 compares a three-lamp ballast that complies with the proposed regulation (bottom, green line) with a three-lamp ballast that is far less efficient (top, red line). The figure shows the existing opportunity and feasibility contained within the market of commercially available products.

Figure 8: Comparison of Input Power Versus Arc Power of Two Three-Lamp Dimmable Ballasts



Source: California Energy Commission analysis of IOU ballast test data.
Dots on the graph represent measured performance points of each ballast. The apparent "bend" in the bottom line between 50 and 60 arc power illustrates cathode cut-off. The gap at 62 arc power is nearly 13 watts.

Products that do not comply with the proposed standards will need to improve performance in one or in a combination of measured arc powers. The technically feasible, screened, generic improvements identified by the U.S. DOE for fixed output ballasts can also be incorporated into dimming ballasts.[46] These opportunities include improved components, such as diodes, transformers, transistors, and capacitors, which transfer power from main utility power to the lamp.

In addition, large energy savings potential exists in implementing cathode heat cutout. Nearly all of the dimming ballasts identified by staff in the market use cathode heating to maintain lamp operation at lower dimming states, the exception being ballasts that turn off/on individual connected lamps to obtain fixture dimming. This cut-out reduces consumption by about 3 watts per lamp without any significant effect on lamp output when operating at higher output levels. The level of control can range from simple on/off to variable cathode heating.

Most ballasts can comply with the proposed standard simply by incorporating cathode cut-out. Because dimming ballasts are electronic ballasts and already have control circuitry

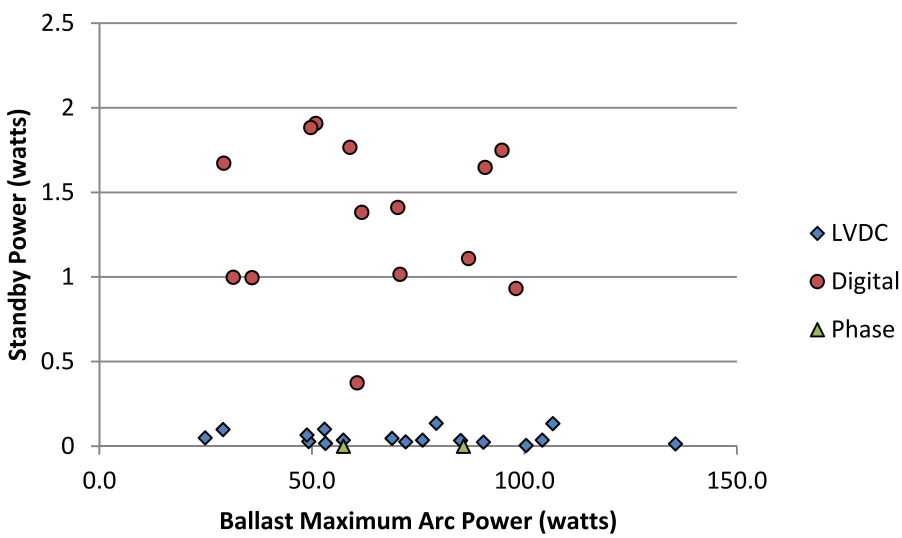
46 U.S. DOE. *TSD for Final Rule on Fluorescent Ballasts*, November 2011, pages 3-31 through 3-33. See also IOU CASE Report, August 5, 2013, pp. 15-16.

incorporated, there is only relatively minor additional circuitry, if any, needed to accomplish cathode cutout. In fact, the microcontrollers incorporated in these products already likely have the spare capacity to handle this functionality.

Products can also improve annual energy use by reducing the amount of power consumed at or near zero arc power. This power is attributable to transformer and power conversion components and to control circuitry awaiting dimming or other commands. While traditionally many lighting systems are controlled by a hard on/off switch that completely disconnects the ballasts from power, there are cases where dimming ballasts are not disconnected.

Standby power consumption is primarily an issue in digital-controlled ballasts. (See Figure 9.) Those digital controls are intentionally left powered so that the ballast can communicate with the building system. While this system certainly has expanded utility compared to other ballasts, test data show that using minimal power by implementing power saving modes in the microcontroller will significantly reduce standby power consumption without sacrificing that expanded utility. The most consumptive digital products tested by the IOUs consume fewer than 2 watts in standby-mode. However, there are certainly less consumptive implementations of digital controllers, showing opportunity and feasibility in reducing this standby load.

Figure 9: Standby-Mode Power Consumption by Control Technology



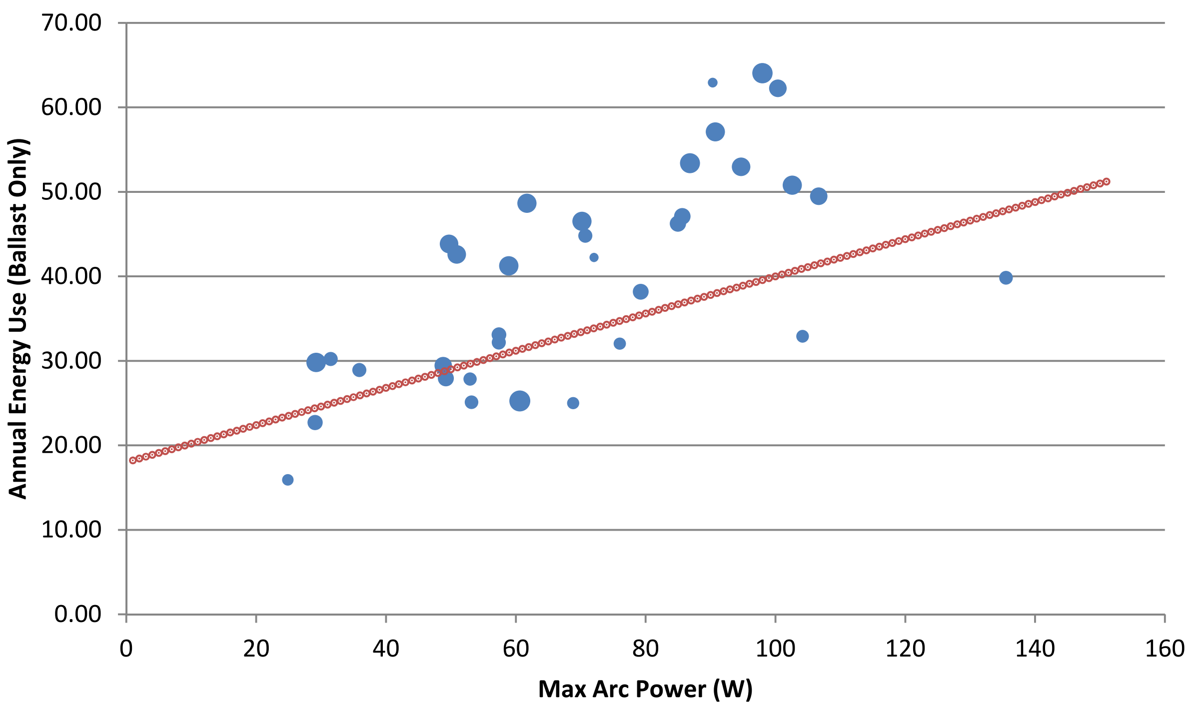
Source: California Energy Commission analysis of IOU test data.
LVDC stands for low-voltage direct-current.

Savings and Cost Analysis

Incremental Cost

Staff investigated the incremental costs of the regulations by looking at the prices of products that would comply versus those that would not and by looking at the cost to improve a noncompliant product to make it compliant. When investigating the price of products that complied versus those that did not in the IOU test results, there was no clear trend of price versus efficiency. Figure 10visually demonstrates this fact.

Figure 10: Annual Energy Use of Ballasts Versus Max Arc Power



The red straight line in this figure shows the proposed standard level. Blue dots that fall on or below the red line would comply. The size of the dot correlates with the price of the ballast – the larger the dot, the more expensive that ballast is. The smallest dots are around $25 and the largest are around $110.

Source: California Energy Commission

The average cost of a dimming ballast is significantly higher than that of a typical fixed-output ballast since dimming ballasts are viewed as a niche product and don't possess the economies of scale of fixed-output ballasts. This may change as Title 24 drives both the demand and supply of dimming ballasts to increase. Analysis of current market prices strictly for dimming ballasts did not yield any obvious incremental cost to the proposed regulation, meaning that there was no apparent price premium for an efficient versus an inefficient dimming ballast.

Staff also considered the upgrades needed to bring a non-compliant ballast into compliance with the standard. Staff characterized the incremental costs based on the execution of two opportunities as discussed in the technical feasibility section: implementing cathode cut-out and generally improving ballast efficiency using better components. While these are the analyzed approaches, manufacturers may find other approaches to improve their products to comply.

The cost of compliance will vary depending on how far from compliance a ballast currently is from the proposed regulation. However, as stated in the technical feasibility section, the majority of tested ballasts could comply just by incorporating cathode cut-out. While there is no clear cost difference for this feature in the retail prices researched by staff and those provided by the IOUs, DOE identified a price differential of $0.89 in its evaluation of 2-lamp program-start ballasts.[47]

Because of the additional existing control infrastructure and likely existence of microcontrollers in dimming ballasts that do not typically exist in non-dimming program-start ballasts, this is most likely an overstatement of cost. In addition, the cost is likely to increase with the number of lamps controlled by the ballast because of the need to use higher-power components. To adjust for this, staff used $0.10 per lamp adjusted from DOE's base of $0.89 for a two-lamp ballast. The results are incorporated in Figure 11.

Figure 11: Incremental Cost of Improved Dimming Ballasts

Number of lamps	Incremental Cost
1	$0.79
2	$0.89
3	$0.99
4	$1.09

Source: California Energy Commission

Energy Savings

Staff calculated energy savings by adjusting products that do not comply with the proposed standard to a point where they would just barely meet the standard. This forms a conservative estimate of the savings from improvements because, in reality, those products would most likely improve at least slightly beyond compliance. Staff evaluated energy savings by the number of lamps that the ballasts could power. For more detailed information about assumptions and calculations used to determine energy savings, see Appendix C of this report. The savings results are summarized in Figure 12.

47 DOE Fluorescent Ballast Final Rule TSD, November 2011, page 5-45, table 5.41. The price difference from ballasts that do not have cathode cut-out (baseline) to those that do (ESL2) is $0.89.

Figure 12: Unit Energy Savings

Number of Lamps	Design Life (years)[1]	Annual Energy Savings (kWh/yr)	Annual Dollar Savings ($)[2]	Lifetime Dollar Savings ($)[3]
1	13	4.6	$0.67	$8.71
2	13	9.3	$1.36	$17.68
3	13	13.4	$1.96	$25.48
4	13	18.2	$2.66	$34.58

Based on IOU proposal information
2 Assumes a commercial electricity rate of $0.146 average per kWh
3 Does not incorporate discount rate at this point in analysis

Source: California Energy Commission

Cost-Effectiveness

According to staff analysis the proposed standards are very cost-effective, as the energy savings greatly outweigh both the incremental cost of improvements ($0.79-$1.09, depending on the number of lamps) and the price premium on a compliant product ($0), often with payback in less than a year. The cost-benefit ratios of simple lifetime dollar savings (without discount rate) range from 1:11 to 1:31, with the measure being particularly cost-effective for four lamp ballasts.

Statewide Impact

Staff evaluated the statewide impacts by extending unit energy savings to the total number of units shipped in California. Staff assumed that each model had an equal share of sales: 1/34. The average energy consumption of one, , two, three, and four lamps ballasts was developed from test data, and those performance levels were used as the baseline case. Then new average performance levels were calculated by adjusting noncompliant products to a point where they just complied. The shipments are assumed to be fully compliant after the implementation date of staff's proposed regulation: January 1, 2016.

The number of fluorescent dimming ballast shipments year-to-year will vary because of the introduction of Title 24 requirements that strongly encourage their use. Because fluorescent lighting is perhaps the most popular form of lighting in commercial buildings this leads to a very rapid and large increase in dimming ballast shipments that in 2005 were estimated to be approximately 1% of the market. For more specific details about shipment assumptions see Appendix C of this report. Figure 12 shows the results of staff's statewide impact analysis.

Figure 13: Statewide Net Impacts

Number Of Lamps	Average Energy Consumption Baseline (kWh/yr)	Average Energy Consumption Standard (kWh/yr)	Annual Shipments 2016 (Thousand)	One year of shipment savings (GWh/yr)	Savings in the year 2029 (GWh/yr)
1	98.3	95.6	240	0.7	13
2	177.2	171.0	1,233	7.7	146
3	263.3	252.5	407	4.4	83
4	317.3	303.7	558	7.6	146
TOTAL	-	-	**2,438**	**20.4**	**388**

Source: California Energy Commission

Safety and Environmental Issues

Staff could not identify any safety or negative environmental impacts of improving dimming ballast efficiency. While the technical feasibility section acknowledges the use of different, more efficient components, and perhaps some additional control circuitry, those improvements would not create a particular waste hazard.

The proposed standards will, however, lead to improved environmental quality in California. Saved energy translates to fewer power plants built and less pressure on the limited energy resources, land, and water use associated with it. Saved energy also relieves pressure on transmission infrastructure, thereby enhancing grid reliability, which ultimately translates to improved health and safety to the people who depend on it. In addition, lower electricity consumption results in reduced greenhouse gas and criteria pollutant emissions, primarily from lower generation in hydrocarbon burning power plants, such as natural gas power plants. The energy saved by this proposal would reduce greenhouse gas emissions by 0.13 $MMTCO_2e$.[48]

48 Million metric tons of carbon dioxide equivalents. Conversion of 690 pounds per MWh to metric scale, using the rate estimated by the *Energy Aware Planning Guide*, CEC-600-2009-013, February 2011, Section II: Overview, page 5.

Regulatory Language

All language below would be new to the appliance efficiency regulations, with the exception of section headers.

Section 1602. Definitions.

(j)

"Arc power" means the power delivered to attached lamps, the output power of the ballast.

"Deep-dimming fluorescent ballast" means a fluorescent ballast that is capable of operating lamps in dimmed operating modes at any number of levels at or below 50 percent of full output.

"Input power" means the power provided to the ballast, typically line alternating-current power.

"Maximum arc power" means the maximum amount of power a dimming ballast will provide to lamps under normal operating conditions. It is the same power as the measured power at 100 percent arc power.

Section 1604. Test Method for Specific Appliances.

(j)

(3) Deep-dimming fluorescent ballasts shall be tested using 10 C.F.R. Section 430.23(q) (Appendix Q1 to Subpart B of part 430) (referred to as the "federal test method" in the following subsections), modified as follows:

(A) The control signal to the ballast shall indicate full output. The arc power of all connected lamps shall be measured and then added together. This result will be referred to as "max arc power." An appropriate lighting control shall be selected to achieve the control signal used to determine the max arc power and to tune the ballast to the appropriate dimming levels. The controls shall be selected by using the following methodology:

(i) If the ballast manufacturer also manufactures a lighting control designed to be operated with the ballast, the test shall be conducted using the ballast manufacturer's lighting control. Or;

(ii) If the manufacturer does not manufacture a compatible lighting control, but recommends the use of specific manufacturer and/or model of lighting control, such as in its product documentation, select from the recommended lighting controls. Or;

(iii) If the manufacturer does not manufacture a compatible lighting control, and does not recommend any specific lighting controls, the lab technician shall select a lighting control that sufficiently controls the ballast to complete the test.

(iv) If multiple control options are available, use the lighting control that is capable of using all of the features of a ballast and with the minimum amount of other features. The lighting control manufacturer and model number shall appear on the test report.

(B) Three sets of input power and arc power shall be measured using the federal test procedure with the total arc power tuned to 100, 80, and 50 percent of the measured max arc power. If a step dimming ballast or a ballast that can only turn connected lamps on or off has dimming steps other than 80 and 50 percent, then the closest step that is between 90 and including 65 percent shall be used for 80 percent testing, and the closest step that is between 65 and including 35 percent shall be used for 50 percent testing. If no step exists in the above prescribed ranges, then no result shall be recorded for that percentage dimming test. The resulting input powers shall be recorded and referred to as P_{100}, P_{80}, and P_{50}.

(C) The ballast shall also be tested with a control input set to the lowest dimming state possible up to and including no light output. The input power to the ballast shall be measured and recorded as P_0. The measurement must be taken 90 minutes after entering this state. P_0 shall be recorded as the mean value of measurements taken at 5 second intervals over a 5-minute period.

(D) The annual energy use shall be calculated, with the results in kWh/yr, using the following formula:

$$Annual\ Energy\ Use = \frac{(P_{100} \times t_{100} + P_{80} \times t_{80} + P_{50} \times t_{50} + P_0 \times t_0)}{1000}$$

Where power is in watts and time values (t_{100}, t_{80}, t_{50}, t_0) are taken from the appropriate tables below:

Standard Time Usage Table

Time Variable	Measurements taken			
	P80, P50	P80, no P50	No P80, P50	No P80, No P50
t_{100}	637	876	1592	2388
t_{80}	1592	1890	0	0
t_{50}	955	0	1592	0
t_0	5576	5576	5576	5576

Section 1605.3 State Standards for Non-Federally Regulated Appliances.

(j)

(1) See Section 1605.1(j) for energy efficiency standards for fluorescent lamp ballasts that are federally regulated consumer products.

(2) Deep-Dimming Fluorescent Ballasts

Effective January 1, 2016, deep-dimming fluorescent ballasts shall meet the following energy conservation standard:

$$Annual\ Energy\ Use \leq 0.22 \times maximum\ arc\ power + 18$$

Section 1606 Filing by Manufacturers; Listing of Appliances in Database

Table X Continued − Data Submittal Requirements

	Appliance	Required Information	Permissible
J	Deep-Dimming Fluorescent Ballasts	*Ballast Input Voltage	120, 277, other (specify)
		*Number of Lamps	
		*Lamp type	T5, T8, other (specify)
		*Dimming Type	Continuous, stepped, individual lamp control, other (specify)
		*Control Type	3-wire, 0-10 volts, digital communication, phase, other (specify)
		*Start Type	Instant start, rapid start, program start, other (specify)
		P100	
		Arc Power 100	
		P80	(answer NA if not applicable)
		Arc Power 80	(answer NA if not applicable)
		P50	(answer NA if not applicable)
		Arc Power 50	(answer NA if not applicable)
		P0	
		Annual Energy Use	
		Power Factor	

* “Identifier” information as described in Section 1602(a).
1 = Voluntary for federally regulated appliances
2 = Voluntary for state-regulated appliances

Heat-Pump Water Chilling Packages

Background

Heat-pump water chilling packages are not regulated for energy efficiency but represent an opportunity for efficiency that is hard to quantify due to a lack of available, credible, and verifiable data. These products are among key equipment that can contribute to reaching cost-effective, zero-net-energy buildings. These products can chill water for space cooling as well as heat water for space heating and domestic hot water use. Some packages can provide both space cooling and domestic hot water while in cooling mode.

The California Energy Code sets efficiency standards for new buildings and alterations.[49] These standards are verified through field inspection and through building energy efficiency compliance software. The Energy Commission's Building Energy Efficiency Standards Compliance Software is built around key metrics provided from standardized test procedures. Most large and consumptive appliances are covered under regulations that specify minimum efficiency and test standards. As a result, those appliance have publicly available, published performance characteristics that are input into the compliance software to determine compliance and compliance credit accurately. Heat-pump, water-chilling packages do not have minimum efficiency standards or test procedures, making it challenging for builders and installers to verify that these appliances comply with the California Energy Code. Therefore, the Energy Commission staff proposes to set mandatory testing and reporting requirements that will provide data to the building community and track the efficiency of these products for the appliance efficiency program.

Staff Proposal

Staff proposes a test and list requirement for heat-pump, water-chilling packages. The definition for this product and test method are based on ANSI/AHRI 550-590 (I-P) -2011. The data collected from testing the equipment are the minimum necessary for modeling in building efficiency software. Additional data requirements related to power draw and capacity are collected to distinguish whether units are likely to be used in residential buildings versus commercial buildings. The reporting requirements are harmonized with the certification requirements in existence through the Energy Commission's Building Energy Efficiency Program.[50] The collected data include heating coefficient of performance (COP) and cooling energy efficiency ratio (EER).

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49 Cal. Code Regs., tit. 24, pt. 6 (2013) (additional administrative requirements in pt. 1).

50 For more information visit http://www.energy.ca.gov/title24/equipment_cert/

All language below would be new to the appliance efficiency regulations, with the exception of section headers.

Regulatory Language

Section 1602(e) Definitions

"Heat-pump water-chilling package" means a factory-made package of one or more compressors, condensers, and evaporators designed for the purpose of heating water. Where such equipment is provided in one or more than one assembly, the separate assemblies are designed to be used together. The package is specifically designed to make use of the refrigerant cycle to remove heat from an air or water source and to reject the heat to water for heating use. This unit may include valves to allow for reverse-cycle (cooling) operation.

Section 1604(e) – Test Procedures

(4) Heat-pump water-chilling packages

Heat-pump water-chilling packages shall be tested using ANSI/AHRI 550-590 (I-P) 2011. The heating capacity tests shall be conducted at ambient temperature of each 47 and 17 degrees Fahrenheit and a leaving water temperature of 120 degrees Fahrenheit. If the package is capable of cooling, it shall be tested at an ambient temperature of 95 degrees Fahrenheit and a leaving water temperature of 44 degrees Fahrenheit.

Section 1605.1(e) – Federal Standards

(6) There is no energy efficiency standard or energy design standard for heat-pump water-chilling packages.

Section 1605.3(e) – State Standards

(5) There is no energy efficiency standard or energy design standard for heat-pump, water-chilling packages.

Section 1606(e) – Reporting Requirements

Table X

	Appliance	*Required Information*	*Permissible Answers*
E	Heat-pump water-chilling package	Voltage*	
		Phase*	1, 3
		Refrigerant Type*	Ozone-depleting, non-ozone-depleting
		Compressor Motor Design*	Single-speed, dual-speed, multiple-speed, variable-speed

		OD Fan Motor Design*	Single-speed, dual-speed, multiple-speed, variable-speed
		Model number includes all components?	Yes, no
		Is the model designed for space cooling?	Yes, no
		Cooling Capacity (BTU per hour) if applicable	
		Cooling power input (watts) if applicable	
		Energy Efficiency Ratio (EER) if applicable	
		Integrated part load value (IPLV)	
		Heating Capacity (BTU per hour) at 47 degrees F	
		Heating power input (watts) at 47 degrees F	
		Coefficient of Performance (COP) at 47 degrees F	
		Heating Capacity (BTU per hour) at 17 degrees F	
		Heating power input (watts) 17 degrees F	
		Coefficient of Performance (COP) at 17 degrees F	
		Heat Capacity (BTU per hour) of heat reclaim[2]	
		COPR of heat reclaim[2]	

* “Identifier” information as described in Section 1602(a).
1 = Voluntary for federally regulated appliances
2 = Voluntary for state-regulated appliance

APPENDIX A:
Particle Efficiency and MERV Ratings

Table A-1: Particle Efficiency Equivalents for MERV Ratings

	Composite Average Particle Size Efficiency (%) in Size Range (μm)		
Standard 52.2 MERV	**Range 1: 0.3 – 1.0 μm**	**Range 2: 1.0 – 3.0 μm**	**Range 3: 3.0 – 10.0 μm**
1	n/a	n/a	$E_3 < 20$
2	n/a	n/a	$E_3 < 20$
3	n/a	n/a	$E_3 < 20$
4	n/a	n/a	$E_3 < 20$
5	n/a	n/a	$20 \leq E_3 < 35$
6	n/a	n/a	$35 \leq E_3 < 50$
7	n/a	n/a	$50 \leq E_3 < 70$
8	n/a	n/a	$70 \leq E_3$
9	n/a	$E_2 < 50$	$85 \leq E_3$
10	n/a	$50 \leq E_2 < 65$	$85 \leq E_3$
11	n/a	$65 \leq E_2 < 80$	$85 \leq E_3$
12	n/a	$80 \leq E_2$	$90 \leq E_3$
13	$E_1 < 75$	$90 \leq E_2$	$90 \leq E_3$
14	$75 \leq E_1 < 85$	$90 \leq E_2$	$90 \leq E_3$
15	$85 \leq E_1 < 95$	$90 \leq E_2$	$90 \leq E_3$
16	$95 \leq E_1$	$95 \leq E_2$	$95 \leq E_3$

APPENDIX B: Model for Air Filter Labeling

Appendix B discusses the information and calculations used to characterize air filters in California, the current energy use impact of air filters, and potential energy savings.

Energy Use

The California Energy Commission's *2009 Residential Appliance Saturation Survey (RASS)* provided the average energy use and household saturation of central air conditioners, air-source heat pumps, furnace fans, and furnaces across the single-family, townhome, 2-4 unit apartment, 5+ unit apartment, and mobile home housing types. The 2010 Census and *2010 American Community Survey* provided the total number of state households and the household breakdown for single family, townhouse, 2-4 unit, 5+ unit, and mobile home households.

The Energy Commission determined the annual statewide energy consumption of home HVAC systems using air filters. As the first step, the annual energy consumption of each filtered HVAC system type per household type was determined using the formula:

$$Total\ Annual\ Energy_{Household\ Type} = N_{households} \times S_{HVAC\ per\ HH} \times E_{avg\ HVAC\ per\ HH}$$

N = number of households
S = household saturation of HVAC type per household type
E = average energy consumption per HVAC type per household type

The energy use across all HVAC system types per each household type is summed to determine total annual filtered HVAC energy use per household type. Then, the energy consumption of each household type is summed into a state total for home filtered HVAC systems.

Table B-1: Annual State Energy Consumption of Residential HVAC Systems with Filters

	# of HHs	Central ACs		Heat Pumps		Furance Fans		Furnaces		Total Energy Consumption	
Household Type		kWh/yr	Saturation	kWh/yr	Saturation	kWh/yr	Saturation	Therms/yr	Saturation	kWh/yr	Therms/yr
Single Family	7,269,794	894	56%	994	1%	216	73%	183	73%	4,858,112,434	971,171,760
Townhouse	905,580	483	41%	320	1%	91	61%	58	61%	232,498,572	32,039,415
2-4 hh Apartment	1,031,355	494	33%	324	1%	80	42%	66	42%	206,126,578	28,589,156
5+ hh Apartment	2,829,937	324	36%	522	3%	64	40%	32	40%	446,847,060	36,223,194
Mobile Home	477,945	876	48%	504	2%	157	66%	143	66%	255,308,620	45,108,442
Total										**5,998,893,264**	**1,113,131,967**

Energy Savings

The 2013 California average residential electric rate of $0.164 per kilowatt-hour was provided by the U.S. Energy Information Administration's Electric Power Monthly for December 2013 (released February 21, 2014), *Table 5.6B. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, By State, Year-to-Date through December 2013.* The 2013 California average residential gas rate of $0.995 per therm was developed using data provided by the U.S. Energy Information Administration's Natural Gas Monthly Data, California Price of Natural Gas Delivered to Residential Consumers (retrieved March 3, 2014).

The net average energy impact across California climate types, heating and cooling loads, blower motor types, duct leakage scenarios, and filter-loading scenarios is a savings of 1 percent.[51] The percentage of HVAC systems using air filters with excessive pressure drop is estimated as high as 85 percent, according to data in one study.[52] However, given the degree of uncertainty, the Energy Commission made the conservative assumption that 50 percent of HVAC systems are using filters with excessive pressure drop.

51 Walker, Dickeroff, Faulkner and Turner (Lawrence Berkeley National Laboratory). *Energy Implications of In-Line Filtration in California.* LBNL-6143E. October 2012.

52 Proctor, John, Rick Chitwood, and Bruce A. Wilcox. 2011. *Efficiency Characteristics and Opportunities for New California Homes*. California Energy Commission. Publication Number: CEC-500-2012-062.

Total energy consumption for residential filtered HVAC systems (E_{total}) is multiplied by the percentage of households using air filters with excessive pressure drop (P_{non}) and percentage of energy savings per household ($P_{savings}$) to determine annual energy savings ($E_{savings}$), as demonstrated in the formula:

$$E_{savings} = E_{total} * P_{non} * P_{savings}$$

Annual energy savings ($E_{savings}$) are multiplied by the monetary rate per energy unit (R_{energy}) to determine monetary savings per energy type (M_{energy}):

$$M_{energy} = E_{savings} * R_{energy}$$

The total annual state monetary savings (M_{total}) are the sum of the monetary savings per each energy type, electric ($M_{electric}$) and gas (M_{gas}):

$$M_{total} = M_{electric} + M_{gas}$$

Table B-2: Annual State Savings

	Electric kWh/yr	**Gas** Therms/yr	**Total Monetary Savings**
Total Energy Consumption	5,998,893,264	1,113,131,967	
Non-Compliance %	50%	50%	
Energy Savings %	1%	1%	
Total Energy Savings	29,994,466	5,565,660	
$/kWh	$0.164		
$/Therm		$0.995	
Total	$4,919,092	$5,537,832	**$10,456,924**

Costs of Compliance

The *2009 RASS* provided household saturation of central air conditioners, air-source heat pumps, furnace fans, and furnaces across the singe-family, townhome, 2-4 unit apartment, 5+ unit apartment, and mobile home housing types. The 2010 Census and *2010 American Community Survey* provided the state households and household break down for single family, townhouse, 2-4 unit, 5+ unit, and mobile home households.

The Energy Commission projected the number of filtered HVAC systems in the residential sector. The number of households for each household type (N_{hh}) was multiplied by the saturation of each HVAC system type ($S_{cac\ per\ hh}$, $S_{hp\ per\ hh}$, $S_{f\ per\ hh}$) to determine the number of filtered HVAC systems per household type as demonstrated in the formula:

$$F_{hh} = (N_{hh} * S_{cac\ per\ hh}) + (N_{hh} * S_{hp\ per\ hh}) + (N_{hh} * S_{f\ per\ hh})$$

The sum of all filtered HVAC systems per household type determined the total number of filtered HVAC systems in the residential sector (F_{total}).

The manufacturer 3M characterized the incremental cost of air filter labeling as zero or near zero when spread across all air filter shipments. The California IOUs characterized the incremental cost as $0.02 per filter in their proposal with the use of manufacturer information. Assuming a 50 percent markup for a commoditized label, the Energy Commission considers $0.03 as the incremental cost per filter. The Energy Commission assumed two filter changes per year and an average of 1.25 filters per home HVAC system.[53] This results in an annual incremental cost (C_i) per air filter of $0.08 to the consumer for labeling. The total cost of labeling (C_{total}) is the number of filtered HVAC systems (F_{total}) multiplied by the annual incremental cost (C_i) to the consumer.

$$C_{total} = F_{total} * C_i$$

53 Proctor, John, Rick Chitwood, and Bruce A. Wilcox. 2011. *Efficiency Characteristics and Opportunities for New California Homes*. California Energy Commission. Publication Number: CEC-500-2012-062.

Table B-3: Annual State Costs

Household Type	Number of HHs	Central AC Saturation	Heat Pumps Saturation	Furnace Fan Heating Only	Total
Single Family Avg	7,269,794	56%	1%	17%	5,379,647
Townhouse Avg	905,580	41%	1%	20%	561,460
2-4 hh apartment avg	1,031,355	33%	1%	9%	443,483
5+ hh apartment avg	2,829,937	36%	3%	4%	1,216,873
Mobile home avg	477,945	48%	2%	18%	325,003
Total Number of HVAC Systems with Filters					**7,926,465**
Filters per HVAC System					1.25
Filter replacements per year					2
Cost per Filter Label					$0.03
Total Annual Cost per Filter Label					**$0.08**
Annual Monetary Cost					**$594,485**

Net Benefit

The Energy Commission determined the total net benefit (NB_{total}) to California by subtracting the annual state monetary cost (C_{total}) from the annual state monetary savings (M_{total}).

$$NB_{total} = M_{total} - C_{total}$$

The Energy Commission determined net benefit per household (NB_{hh}) by dividing the annual state monetary savings (M_{total}) by the number of filtered HVAC systems (F_{total}).

$$NB_{hh} = M_{total} \div F_{total}$$

Table B-4: Annual Net Benefit

	Per Household	State
HVAC Systems with Filters	-	7,926,465
Annual kWh Savings	3.78	29,994,466
Annual Therm Savings	0.70	5,565,660
Annual State Monetary Savings	$1.32	$10,456,924
Annual State Monetary Costs	$0.08	$594,485
Net Benefit	$1.24	$9,862,439

Carbon Dioxide Savings

The carbon dioxide emissions conversion factor of 690 pounds per MWh for California electricity generation came from the *Energy Aware Planning Guide*, CEC-600-2009-013, February 2011, Section II: Overview. The U.S. Environmental Protection Agency's Clean Energy Calculations and References Web page provided the carbon dioxide emissions conversion factor per therm of natural gas, as well as per passenger car per year.

The Energy Commission determined the carbon dioxide emissions avoided ($S_{c\ per\ source}$) for each power source by multiplying the carbon dioxide emissions conversion factor (R_{carbon}) by the annual energy savings ($E_{savings}$).

$$S_{c\ per\ source} = R_{carbon} * E_{savings}$$

The sum of carbon dioxide emissions avoided from electric and gas results in total carbon dioxide emissions avoided (S_{carbon}). Total carbon dioxide emissions avoided is divided by the carbon dioxide emissions per passenger car per year (CO_{2car}) to determine the equivalent number of cars removed from the road annually (S_{car}).

$$S_{car} = S_{carbon} \div CO2_{car}$$

Table B-5: Annual State Carbon Dioxide Savings

	Electric	Gas	Total CO2 Savings
Total Energy Savings	29,994,466	5,565,660	
Pounds of CO2 per kWh	0.69		
Pounds of CO2 per Therm		11.6889	
Total Pounds of CO2	20,696,182	65,056,441	**85,752,623**
Pounds of CO2 per Car per yr			10,472
Cars removed from the road			8,189

Appendix C

Shipments and Stock

The number of shipments of dimming ballasts is calibrated around the DOE finding that 1% of ballasts were dimming ballasts in 2005, as referenced in the "current regulations" subsection of the dimming ballast section of the report. A market growth rate of 3% was assumed between 2005 and 2015, associated with very slow growth. This slow growth rate is consistent with the high price and specialty market of dimming ballasts today. In 2015 the shipment number is expected to suddenly and rapidly increase from 0.1 million to 2.3 million units per year in reaction to Title 24 building efficiency regulations. From that point onwards growth was set to 6% to incorporate alterations affecting fixed output ballasts and building stock growth on top of the original 3% growth rate. Shipments were then projected out to 2030.

Table C-1: Estimated Shipments by Year (thousand units)

Ballast Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1 Lamp	8	8	8	8	8	9	9	9	10	10	226	240	254
2 Lamp	39	40	41	42	44	45	46	48	49	51	1,163	1,233	1,307
3 Lamp	13	13	14	14	14	15	15	16	16	17	384	407	432
4 Lamp	18	18	19	19	20	20	21	22	22	23	527	558	592
Total	77	79	81	84	86	89	91	94	97	100	2,300	2,438	2,584

Ballast Type	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1 Lamp	269	285	302	321	340	360	382	405	429	455	482	511	542
2 Lamp	1,386	1,469	1,557	1,650	1,749	1,854	1,965	2,083	2,208	2,341	2,481	2,630	2,788
3 Lamp	458	485	514	545	578	612	649	688	729	773	819	869	921
4 Lamp	627	665	705	747	792	839	890	943	1,000	1,059	1,123	1,190	1,262
Total	2,739	2,904	3,078	3,263	3,458	3,666	3,886	4,119	4,366	4,628	4,906	5,200	5,512

The shipments in Figure C-1 and associated growth rate, in combination with an assumed ballast lifetime of 13 years, was used to develop estimates of the stock of dimming ballasts in California from 2005 through 2030. Figure C-2 summarizes the result of those estimates. The methodology used to estimate stock added that year's shipments, and subtracted the shipments from 13 years prior as old ballasts retire.

Table C-2: Estimated Stock of Dimming Ballasts by Year (thousand units)

Ballast Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1 Lamp	77	80	82	85	87	90	93	96	99	102	321	554	800
2 Lamp	397	410	423	436	450	464	479	494	510	526	1,654	2,851	4,120
3 Lamp	131	135	140	144	149	153	158	163	168	174	546	941	1,361
4 Lamp	180	185	191	197	204	210	217	224	231	238	749	1,290	1,865
Total	785	810	836	862	890	918	947	977	1,008	1,040	3,270	5,636	8,146

Ballast Type	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1 Lamp	1,062	1,339	1,634	1,946	2,277	2,629	3,002	3,397	3,816	4,261	4,517	4,788	5,076
2 Lamp	5,467	6,896	8,411	10,019	11,725	13,534	15,453	17,489	19,648	21,939	23,257	24,654	26,135
3 Lamp	1,806	2,277	2,778	3,309	3,872	4,470	5,104	5,776	6,489	7,246	7,681	8,142	8,631
4 Lamp	2,474	3,121	3,807	4,535	5,307	6,126	6,994	7,916	8,893	9,930	10,526	11,159	11,829
Total	10,809	13,634	16,630	19,809	23,182	26,759	30,553	34,578	38,847	43,375	45,981	48,743	51,671

The division proportion of 1 lamp, 2 lamp, 3 lamp, and 4 lamp ballasts were developed using overall proportions of those lamps in the fixed output market and assuming that the same proportions would persist when builders move to implement the 2013 building standards. These proportions were 9.8%, 50.6%, 16.7%, and 22.9% respectively.

Energy Consumption and Savings

Energy savings were calculated by taking the difference of energy consumption in a base-case and energy consumption in an improved efficiency case. Improvements to efficiency were made to product performance such that they would exactly meet the minimum requirement. Improvements to comply with the DOE or IOU regulations often only required improvement at a single dimming level. However, when that dimming level was improved, staff assumed some lesser energy savings at other dimming points as well. To find the improvement of implementing cathode cut-out, the input power was reduced by 3 watts per lamp at full output. Products that already comply with a proposed standard did not change in performance and did not contribute to energy savings. The compliance rate in the market was assumed to be the same proportion of products that meet or did not meet a proposed standard in the test data. Figure C-3 shows the average energy consumption in the base case and each proposed standard case.

Table C-3: Average Annual Energy Consumption of Ballasts (including energy consumption in associated lamps) in the Base Case and Various Regulatory Cases (average kWh/yr for all ballasts sold)

Ballast Type	Base Case	Expanding the DOE Standards	IOU Case Report	Cathode Cut-out Design Standard	Annual Energy Use Performance Standard
1 Lamp	98.3	92.7	97.1	96.8	95.6
2 Lamp	177.2	173.3	173.5	174.1	171.0
3 Lamp	263.3	259.1	256.6	260.4	252.5
4 Lamp	317.3	314.3	310.8	313.5	303.7

These averages were used in conjunction with shipment and stock data to determine statewide energy savings of each approach.